Wadden Sea Quality Status Report 2009

WADDEN SEA ECOSYSTEM No. 25 - 2009

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The Wadden Sea – Protection and Management

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1.1 General Description

Figure 1:
The Wadden Sea (Landsat TM satellite images from the period 2000–2002) (CWSS, Brockmann Consult).

The Wadden Sea, stretching over 500 km along the North Sea coast of The Netherlands, Germany and Denmark, has evolved over the last 8,000 years and is a very young ecosystem in geomorphological and evolutionary terms.

It represents an outstanding example of the Holocene development of a temperate-climate sandy barrier coast under conditions of rising sea level. The Wadden Sea is unique in that it consists entirely of a sandy-muddy tidal system with only minor river influences on morphodynamics. The Wadden Sea ecosystem is characterized as tidal flats and barrier island system with extensive salt marshes. The Wadden Sea differs from other systems of this type in that it is the only tidal flat and barrier island depositional system of this scale and diversity in the world. There are no systems in the world that compare to the Wadden Sea.

The Wadden Sea contains very fine examples of post-glacial coastal geomorphology and the dynamic interaction of physical and biological processes on a scale that is not found within one unified system anywhere else in the world. Despite man-made interventions, the continuing presence of these dynamic natural processes ensures the development and rejuvenation of landforms including the whole range of habitats, and secures the maintenance of ecosystem functions. The Wadden Sea ecosystem will thus continue to serve as an important bio-physical reference for the study of the effect of sea level rise and it will be important to consider this function as a legitimate part of the World Heritage concept.

The Wadden Sea is a unique coastal ecosystem with enormously productive marine biota and with linkages far beyond its narrow geographical boundaries. It is one of the last remaining natural large-scale inter-tidal ecosystems in Europe where natural processes continue to function in an undisturbed manner. Excellent and broad scale examples of biogeomorphological processes can be found in the coastal dunes, the salt marshes, and on the tidal flats on mussel beds and sea grass meadows. This transitional environment between land and sea is characterized by the constant change of flood and ebb tides, great fluctuations in salinity, high temperatures during summer and occasional ice cover in winter. These circumstances have created numerous ecological niches, colonized by species that are adapted to the extreme environmental conditions.

The Wadden Sea is an ecological transition zone between land and ocean. With its estuaries, marshes and particularly its wide intertidal zone intersected by deep gullies, the Wadden Sea functions as a gigantic coastal filter system. Freshwater and marine waters are mixed and flushed to and fro with the tides, transporting huge amounts of sediments, organic matter and nutrients. These riverine and marine imports of materials form the basis of the trophic system. Imported organic material is mineralized in the marshes, tidal flats sediment and shallow waters. The release of nutrients from this spacious purification plant, together with those nutrients supplied from the catchment area and the Atlantic waters, fuels outstanding primary production. Due to the active biota, this filter never clogs but is continuously renewed.

The tidal flats in the Wadden Sea form the largest unbroken stretch of sand and mudflats worldwide, accounting for 60% of all tidal areas in Europe and North Africa. As such it is 'the only one of its kind' and many textbooks refer to the Wadden Sea when describing inter-tidal habitats and the rich and diverse flora and fauna they sustain. The tidal flats and the salt marshes form the largest coherent habitat of this type in Europe and constitute an essential element of the Wadden Sea ecosystem.

The Wadden ecosystem represents one of the internationally most important wetlands. It is internationally recognized as a biologically highly productive ecosystem of great natural, scientific, economic and social importance.

The Wadden Sea is extremely rich in environmental gradients and transitional zones, yielding many different (micro) habitats that form the basis for ecological specialization under extreme conditions. The salt marshes host about 2,300 species of flora and fauna. The marine and brackish areas support a further 2,700 species. In total it is estimated that the Wadden Sea Area provides habitats for up to 10,000 species of unicellular organisms, plants, fungi and animals.

The large size of the Wadden Sea allows the diverse species to survive by spreading over several habitats, or by adopting a series of niches over the course of time. This constantly opens up territory for use by other individuals or species, and accounts for a high capacity to accommodate migratory species.

The rich and diverse habitats are of outstanding international importance for birds as staging, moulting and wintering areas. According to the 1% criterion of the Ramsar-Convention, which is an internationally recognized measure to identify wetlands of international importance, the Wadden Sea is of outstanding international importance

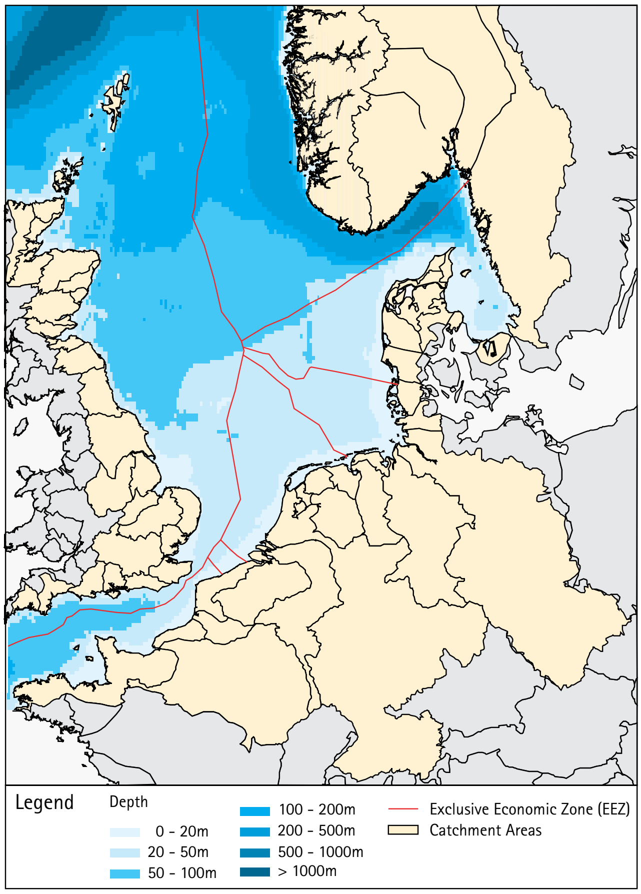


Figure 2: Water depth and catchment areas of the Greater North Sea (Source: OSPAR Commission)

as a staging, moulting and wintering area for at least 52 populations of 41 migratory waterbird species that use the East Atlantic flyway and originate from breeding populations as far away as northern Siberia or Northeast Canada. Numbers of 44 populations of 34 species are so high that the Wadden Sea is indispensable and often the main stepping stone during migration, or as their primary wintering or moulting habitat. Therefore the Wadden Sea is essential for the existence of these bird species. A severe deterioration of the Wadden Sea implies a biodiversity loss on a worldwide scale.

A detailed description of the Wadden Sea physical environment (geography, hydrology, climate), geology, morphodynamics, soils and sediment is given in the nomination dossier for the inscription of the Dutch-German Wadden Sea into the UNESCO World Heritage List (Common Wadden Sea Secretariat, World Heritage Nomination Project Group, 2008).

The Wadden Sea is an open system and there are many interactions with the adjacent North Sea. The quality of water, sediment and marine habitats is, to an important degree, influenced by the North Sea and activities in the catchment area of the debouching rivers (Figure 2)

The OSPAR Quality Status Report for the North Sea gives a comprehensive overview about geography, hydrography and climate of the North Sea and numerous influences from land-based as well as sea-based human activities (OSPAR Commission 2000).

The Wadden Sea region (Figure 3) is also an area where people live, work and spend their leisure time. About 3.7 million people live along the Wadden Sea coast, of which about 75,000 live inside the Wadden Sea Area. The Trilateral Wadden Sea Plan (1997) acknowledges this by stating that economic and social values should also be maintained and enhanced.

With the establishment of a Wadden Sea Forum (WSF) as an independent stakeholder forum, the inhabitants of the Wadden Sea region have been given an opportunity to get actively involved in the activities of the Trilateral Wadden Sea Cooperation. Based on the WSF report "Breaking the Ice" (2005) and new developments in the region, the Forum approved a wide-ranging work program, which is under implementation.

An emphasis is laid on Integrated Coastal Zone Management, including off-shore spatial planning and the enhanced interaction between land and sea. This has become more relevant recently by

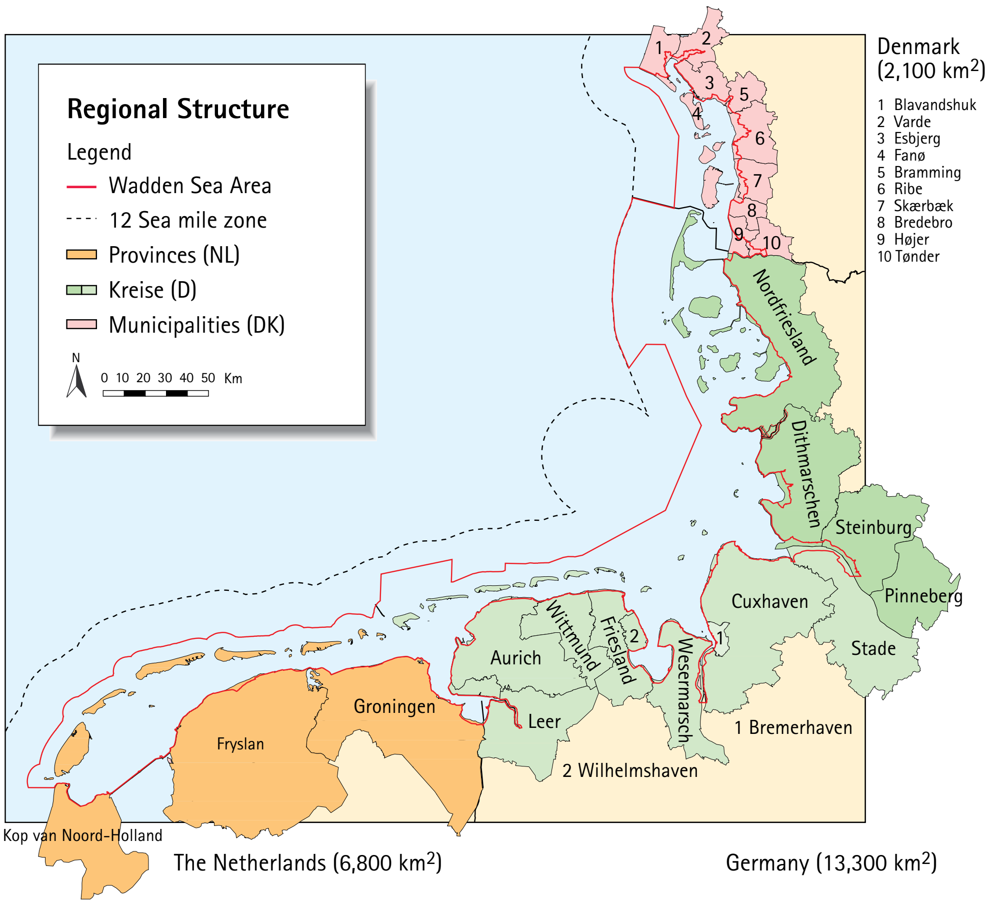


Figure 1.3: The Wadden Sea and its regional structure (from Prognos, 2004). Regional Structure: 3.7 million inhabitants; 6 regional centers (Bremerhaven, Wilhelmshaven, Emden, Groningen, Leeuwarden, Esbjerg); 22,000 km² area (60% Germany, 31% Netherlands, 9% Denmark); mainly rural structure with low population density (141 inhabitants per km²).

incorporating date on increased container shipping and grid connections to off-shore windmill parks.

With regard to national energy production policies, the WSF investigates the effects on the economy and different sectors in the Wadden Sea Region. The different working groups are prepared to work on most relevant topical issues to find a balance between different interests in the Wadden Sea region.

A step forward to a healthy and sustainable Wadden Sea Region was also the adoption of an Memorandum of Understanding between the Trilateral Wadden Sea Cooperation and the WSF as well as the establishment of the WSF's own secretariat in 2008.

1.1 General Description

1.2.1 Trilateral Cooperation

The first Governmental Conference on the Protection of the Wadden Sea was held in 1978 in The Hague, The Netherlands. In 1982, at the third conference in Copenhagen, the "Joint Declaration on the Protection of the Wadden Sea" was signed. Within the Wadden Sea Cooperation, conferences are held every 3-4 years. The 10th Wadden Sea Conference was held in 2005 at the island of Schiermonnikoog. The 11th Ministerial Conference will be held on the German island of Sylt on 18 March 2010.

The formal basis of the Cooperation is the "Joint Declaration on the Protection of the Wadden Sea" signed at the Third Wadden Sea Conference in Copenhagen in 1982. In this declaration, the governments recognize their responsibilities for the conservation of the ecosystem and declare their intention to coordinate their activities and measures to implement a number of international legal instruments in the field of natural environmental protection, amongst others the Ramsar Convention and the EC Birds Directive, for the comprehensive protection of the Wadden Sea region as a whole, including its flora and fauna. Since 1982, seven Governmental Wadden Sea Conferences have been held and the trilateral cooperation has been strengthened and intensified.

The Common Wadden Sea Secretariat was established in 1987 following a decision at the 4th Wadden Sea Conference in The Hague in 1985. The basis for the secretariat is the Administrative Agreement concluded in 1987 between the competent ministries of the three countries. The Administrative Agreement stipulates the tasks and the financing of the secretariat and its staff. The secretariat has been located in Wilhelmshaven since its establishment in 1987.

The three countries also concluded the "Agreement on the Conservation of Seals in the Wadden Sea" which was enacted in October 1991, as the first agreement, as defined in Article 4 of the Convention on the Conservation of Migratory Species of Wild Animals (CMS, Bonn Convention). The Seal Agreement was concluded between the Wadden Sea countries with the aim of cooperating closely in achieving and maintaining a favorable conservation status for the common seal population of the Wadden Sea.

The Declarations Trilateral Conferences on the Protection of the Wadden Sea, 1978 – 2005 issued on the occasions of the Wadden Sea Conferences are political declarations, in which agreements are made between the governments. They cover all areas of the cooperation such as management, monitoring, international cooperation, etc. The declarations are therefore an integrated part of the total protection and management of the nominated property to which the governments have committed themselves.

Wadden Sea Plan, Shared Principles and Targets

The Guiding Principle of the Trilateral Wadden Sea policy, as agreed upon at the 6th Conference in Esbjerg, 1991, is "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way". The Wadden Sea Plan, the policy and management plan for the Wadden Sea Area, which includes the central objectives and principles of the Wadden Sea Cooperation, is also an agreement made at the 8th Conference in Stade, 1997. The Trilateral Monitoring and Assessment Program (TMAP), associated with the implementation of the Wadden Sea Plan, was launched on the same occasion.

The trilateral conservation policy and management is directed towards achieving the full spectrum of habitat types which belong to a natural and dynamic Wadden Sea. Each of these habitats needs a certain quality (natural dynamics, absence of disturbance, absence of pollution), which can be reached by proper conservation and management. The quality of the habitats is to be maintained or improved by working towards achieving targets agreed upon for six habitat types: Salt Marshes, Tidal Area, Beaches and Dunes, Estuaries, Offshore Area and Rural Area. Targets for the quality of water and sediment are valid for all habitats. In addition, supplementary targets on birds and marine mammals were adopted, as well as targets for landscape and cultural aspects (Trilateral Wadden Sea Plan, 1997).

For each target category, trilateral policy and management and proposals for trilateral projects and actions necessary for the implementation of the targets are included in the Trilateral Wadden Sea Plan. The trilateral policy and management is the core of the agreements on the common protection and management of all relevant uses and activities.

The arrangements of the Wadden Sea Cooperation have been embedded in the framework of the Trilateral Wadden Sea Plan, which entails policies, measures, projects and actions agreed upon by the three countries (Trilateral Wadden Sea Plan, 1997).

The Trilateral Wadden Sea Plan was adopted at the 8th Wadden Sea Conference in Stade, Germany in 1997. The Wadden Sea Plan (WSP) constitutes the common trans-boundary policy and management plan for the Wadden Sea Area. It is important to acknowledge that the WSP is a policy and management plan adopted by governments for a trans-boundary area and therefore has a wider perspective than a traditional management plan for a site in the sense that the WSP encompasses also the vision, principles, policies and measures and is a framework for the integrated protection and management of the Wadden Sea. The Plan is an agreement of how the countries envisage the coordination and integration of management of the Wadden Sea Area and of the projects and actions that must be carried out to achieve the commonly agreed targets.

The WSP is a coherent approach to the protection and management of the Wadden Sea in a trans-boundary context. In essence, it is an ecosystem approach and directed towards achieving and, hence, also maintaining the geomorphological and biological processes and the full scale of habitat types which belong to a natural and dynamic Wadden Sea in order to maintain biological diversity.

It includes the vision, shared principles, targets and policies and management measures combined with actions. The vision of the WSP is

- A healthy environment which maintains the diversity of habitats and species, its ecological integrity and resilience as a global responsibility;
- Sustainable use;
- Maintenance and enhancement of values of ecological, economic, historical-cultural, social and coastal protection character, providing aspirations and enjoyment for the inhabitants and users;
- Integrated management of human activities which takes into account the socio-economic and ecological relationship between the Wadden Sea Area and the adjacent areas;
- An informed, involved and committed community.

The shared principles include the already central Guiding Principle as referred to above "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way". The associated management principles are fundamental for the common management of the Wadden Sea:

- The Principle of Careful Decision Making, i.e. to take decisions on the basis of the best available information;
- The Principle of Avoidance, i.e. activities which are potentially damaging to the Wadden Sea should be avoided;
- The Precautionary Principle, i.e. to take action to avoid activities which are assumed to have significant damaging impact on the environment, even where there is no sufficient scientific evidence to prove a causal link between activities and their impact;
- The Principle of Translocation, i.e. to translocate activities which are harmful to the Wadden Sea environment to areas where they will cause less environmental impact;
- The Principle of Compensation, i.e. that the harmful effect of unavoidable activities must be balanced by compensatory measures; in those parts of the Wadden Sea, where the Principle has not yet been implemented, compensatory measures will be aimed for;
- The Principle of Restoration, i.e. that, where possible, parts of the Wadden Sea should be restored if it can be demonstrated by reference studies that the actual situation is not optimal, and that the original state is likely to be re-established;
- The Principles of Best Available Techniques and Best Environmental Practice, as defined by the Paris Commission.

An essential principle is that unreasonable impairments of the interests of the local population and of traditional human uses of the Wadden Sea Area have to be avoided. Any user interests have to be weighed on a fair and equitable basis in the light of the purpose of protection in general, and the particular case concerned.

As emphasized above, the trilateral conservation policy and management is directed towards achieving the full scale of habitat types which belong to a natural and dynamic Wadden Sea. Each of these habitats needs a certain level of quality, which can be reached by proper management of

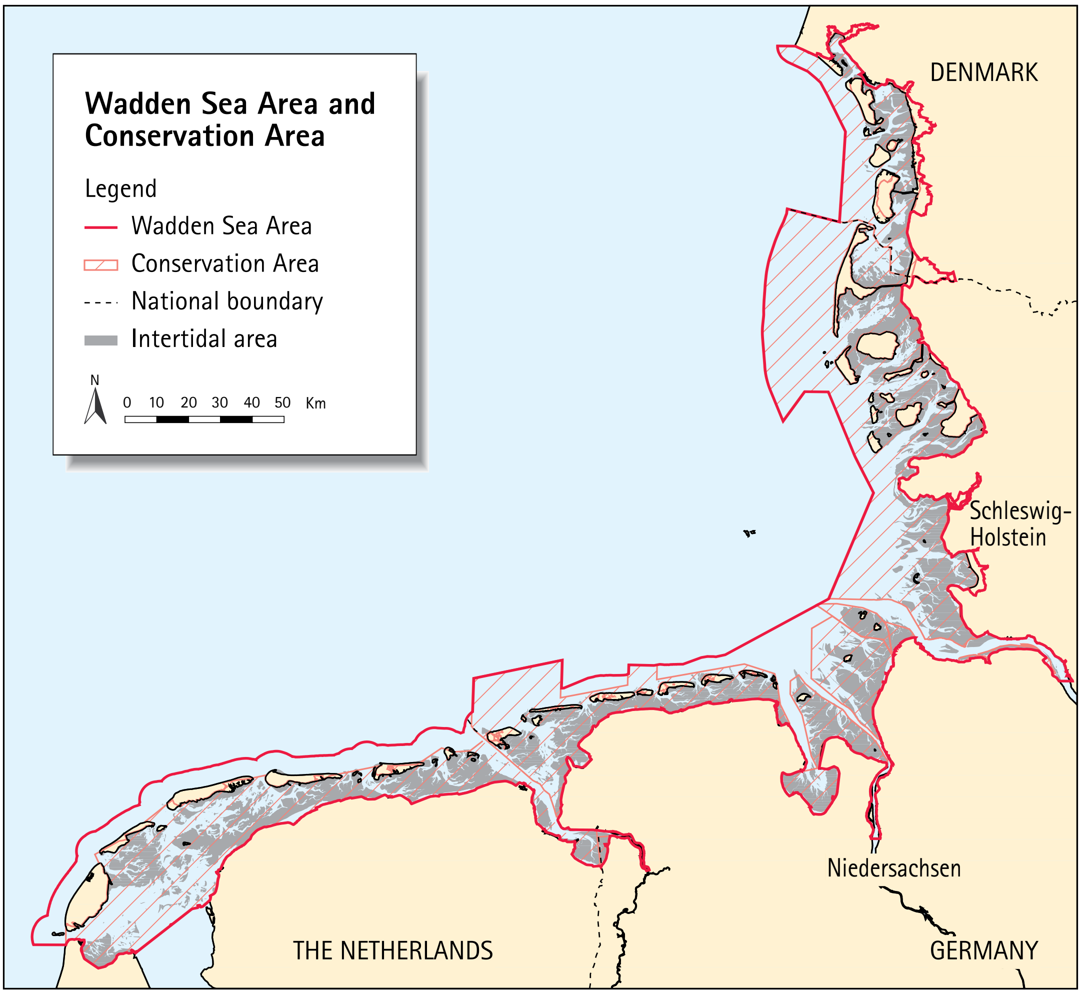


Figure 4: Map of the Wadden Sea Area and Conservation Area

the area. This quality level can be described by certain characteristic structures, the presence of certain organisms, the absence of disturbance and toxic effects and by the chemical condition of the habitat.

For the common management six habitat types are distinguished:

- The offshore zone;
- The beaches and dunes;
- The tidal area;
- The salt marshes;
- The estuaries;
- The rural area.

For the first five of these habitats, ecological targets were adopted with the objective of maintaining and enhancing the area which is natural, dynamic and undisturbed, including targets for birds and marine mammals.

Size and delimitation

The Wadden Sea Area is, in general terms, the area seaward of the main dike (or, where the main dike is absent, the spring-high-tide-water line, and in the rivers, the brackish-water limit) up to 3 nautical miles from the baseline or the offshore boundaries of the Conservation Area. Additionally, some adjacent inland marsh areas of Denmark and Schleswig-Holstein are part of the Wadden Sea Area (Figure 4) After the extensions of the Danish Wadden Sea Wildlife and Nature Reserve in 1998, the Schleswig-Holstein Wadden Sea National Park in 1999, and the Hamburg Wadden Sea National Park and Niedersachsen Wadden Sea National Park in 2001, the delimitation of the Trilateral Cooperation Area and the Conservation Area was adapted in 2001 (Esbjerg Declaration, 2001) because parts of the national parks of Schleswig-Holstein and Niedersachsen exceeded the three nautical mile line. The Conservation Area consists of the Dutch Key Planning Decision area, the three German National Parks and the Danish Wildlife and Nature Reserve.

Table 1:
Size of the Conservation Area and Wadden Sea Area (km²)
***Because of the disputed area in the Ems estuary, the figures for NL and FRG are approximate.**

	Conservation Area km²	Wadden Sea Area km²
Denmark	1,250	1,500
Germany*		9,050
Schleswig-Holstein NP	4,410	
Hamburg NP	137.5	
Niedersachsen NP	2,777	
Nds: NSG Ems, Elbe	34	
Netherlands*	2,600	3,900
Disputed Area (NL, FRG)		250
Trilateral	**11,208.5**	**14,700**

Targets - Trilateral Wadden Sea Plan (1997)

Landscape and Culture

Identity – to preserve, restore and develop the elements that contribute to the character, or identity, of the landscape.
Variety – to maintain the full variety of cultural landscapes typical for the Wadden Sea landscape.
History – to conserve the cultural-historic heritage.
Scenery – to pay special attention to the environmental perception of the landscape and the cultural-historic contributions in the context of management and planning.

Water and Sediment

A Wadden Sea which can be regarded as a eutrophication non-problem area.
Background concentrations of natural micropollutants in water, sediment and indicator species.
Concentrations of man-made substances as resulting from zero discharges.

Salt marshes

An increased area of natural salt marshes.
An increased natural morphology and dynamics, including natural drainage patterns, of artificial salt marshes, under the condition that the present surface is not reduced.
An improved natural vegetation structure, including the pioneer zone, of artificial salt marshes.

Tidal Area

A natural dynamic situation in the Tidal Area.
An increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas.
An increased area of, and a more natural distribution and development of natural mussel beds, Sabellaria reefs and Zostera fields.
A favorable food availability for migrating and breeding birds.

Beaches and Dunes

Increased natural dynamics of beaches, primary dunes, beach plains and primary dune valleys in connection with the Offshore Zone.
An increased presence of a complete natural vegetation succession.

Estuaries

Valuable parts of estuaries will be protected and river banks will remain in and, as far as possible, be restored to their natural state.

Offshore Area

An increased natural morphology, including the outer deltas between the islands.
A favorable food availability for birds.
Viable stocks and a natural reproduction capacity of the common seal, grey seal and harbor porpoise.

Rural Area

Favorable conditions for flora and fauna, especially migrating and breeding birds.

Birds

Favorable conditions for migrating and breeding birds:
- a favorable food availability;
- a natural breeding success;
- sufficiently large undisturbed roosting and molting area;
- natural flight distances.

Marine Mammals

Viable stocks and a natural reproduction capacity of the common seal, grey seal and harbor porpoise in the tidal areas and the offshore zone.

The Wadden Sea Area covers an area of about 14,700 km²; the Conservation Area is about 11,200 km² (Table 1).

Trilateral Monitoring and Assessment Program

The Trilateral Monitoring and Assessment Program (TMAP) is the common monitoring program for the Wadden Sea carried out by The Netherlands, Germany and Denmark in the framework of the Trilateral Wadden Sea Cooperation. The aim of the TMAP is to provide a scientific assessment of the status and development of the Wadden Sea ecosystem and to assess the status of implementation of the trilateral targets of the Wadden Sea Plan. After a pilot phase which started in 1994, a common package of monitoring parameters, including the associated data management, has been implemented since 1997 (Stade Declaration, 1997).

Joint monitoring programs for breeding and migratory birds and seals had already been trilaterally implemented since 1989 and 1992 respectively, and are also part of the TMAP.

In 2008, the TMAP has been further elaborated (TMAP Revision) in order to meet the requirements of the EC Directives to the largest extents possible (Schiermonnikoog Declaration, 2005). The revised guidelines are available at:

http://www.waddensea-secretariat.org/TMAP/Monitoring.html

1.2.2. International Protection Regimes

UNESCO World Heritage Site

On 26 June 2009 the World Heritage Committee at its 33rd session, Seville, inscribed the Dutch-German Wadden Sea on the World Heritage List under natural criteria (viii) geomorphology, (ix) ecological and biological processes, and (x) biological diversity.The Committee also adopted a Statement of Outstanding Universal Value which according to the Operational Guidelines forms the basis for the future protection and management of the property (UNESCO, 2009).

The Statement is in accord with the nomination and the supplementary information submitted by The Netherlands and Germany in 2008 and 2009. The Committee also decided to encourage Denmark to nominate its part of the Wadden Sea as soon as feasible to complement the existing property, to request the elaboration and implementation of a tourism development strategy, to implement a strict monitoring programme to control invasive species associated with bal-

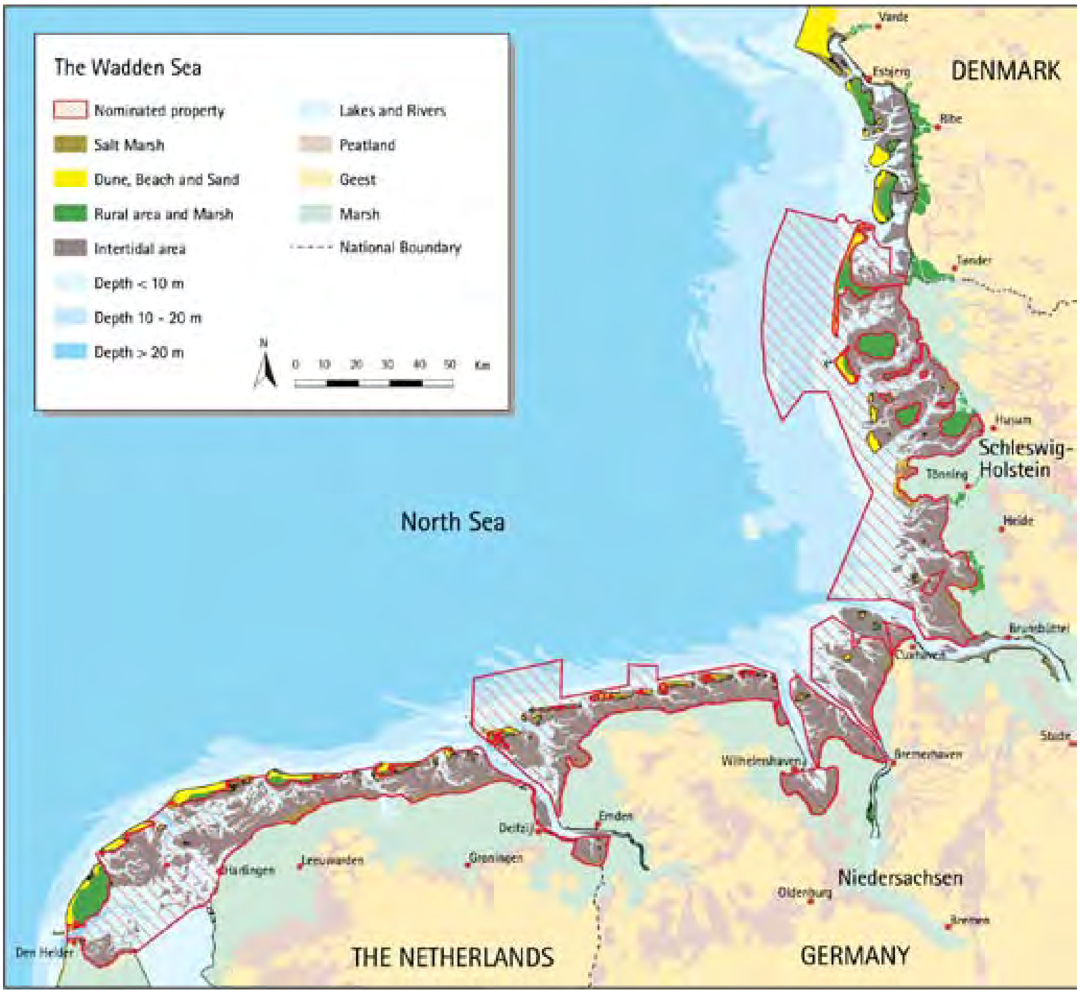


Figure 5: Map of the Wadden Sea World Heritage Site (CWSS, 2009)

last waters and aquaculture in the property, and finally to request Germany and The Netherlands to strengthen cooperation on management and research activities with States Parties on the African Eurasian Flyways.

The "Wadden Sea World Heritage Site" encompasses the Dutch and German parts of the Wadden Sea (Figure 1.5a). It covers an area of almost 10,000 km2 along a coastal strip about 400 km long. The Wadden Sea has had a protected status for more than 20 years, in Germany, as national parks and in the Netherlands, as nature reserves. The designation as World Heritage Site has neither influence on the protection status of the area nor does it cause any new regulations.

Particularly Sensitive Sea Area

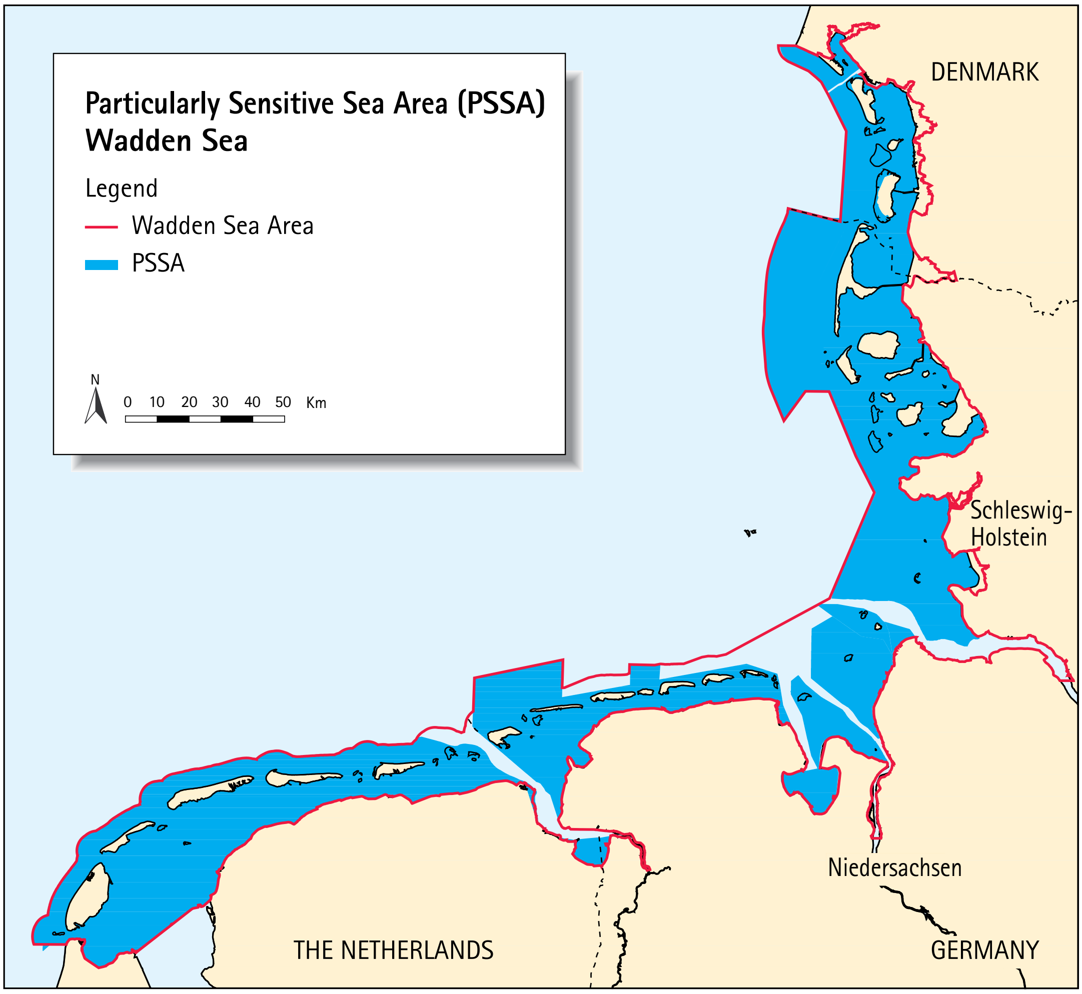
In 2002, the Wadden Sea was designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO) (Figure 6). The area designated as a PSSA is the marine area of the Wadden Sea. The PSSA covers an area of approximately 13,000 km^2; the major shipping routes have been excluded from the designation. The PSSA does not limit shipping in the area nor the use of the Wadden Sea harbors.

The designation of the PSSA Wadden Sea is seen as a recognition of the extensive regime of the national and international protective measures already in place in the Wadden Sea and the adjacent the North Sea. Examples are the MARPOL Special Areas prohibiting discharges of oil and garbage, routing systems making certain routes compulsory for ships carrying hazardous goods and compulsory reporting for ships. An evaluation of the PSSA is agreed before the 2010 Wadden Sea Conference.

EC Directives

The European Union legislation in the field of environment is of specific significance for the Wadden Sea and has increased in importance during the past two decades. The European Union legislation is trans-boundary and, increasingly, covers all environmental policy areas. The legislation also has direct implications for Member

Figure 6: Map of the Particularly Sensitive Sea Area (PSSA) Wadden Sea as designated by the International Maritime Organization (IMO) in 2002.



States' legislation. Of the comprehensive list of environmental legislation, the Habitats, Birds and the Water Framework Directives are the most relevant pieces of legislation for the protection and sustainable use of the nominated property. The Marine Strategy Framework Directive is currently being implemented and will also be important for Wadden Sea policy.

Birds and Habitats Directive

The Council Directive 79/409/EEC on the conservation of wild birds (Birds Directive) was adopted in 1979 and aims at the protection of all species of naturally occurring birds in the territory of the member states. According to the Birds Directive, member states must classify the most suitable territories for the conservation of the species listed in the Annex 1 of the Directive, as 'Special Protection Areas' (SPAs). Basically, the entire Wadden Sea Area has been designated as SPA (Figure 1.6). Exceptions are the main shipping lanes and some adjacent offshore areas.

The Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive), adopted in 1992, complements the 1979 Birds Directive. It has the aim of ensuring that biodiversity is maintained through conservation of important, rare or threatened habitats and the habitats of certain species. In the framework of the Habitats Directive a coherent ecological network called NATURA 2000 is being established. NATURA 2000 will consist of Special Areas of Conservation (SACs) designated according to the Habitats Directive (Figure 8) and the SPAs of the Birds Directive (Figure 7.).

The Wadden Sea is part of NATURA 2000 and subject to the provisions of the Habitats Directive, of which Article 6 is a crucial one. Article 6 stipulates that for SACs, member states shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans. Member states shall also

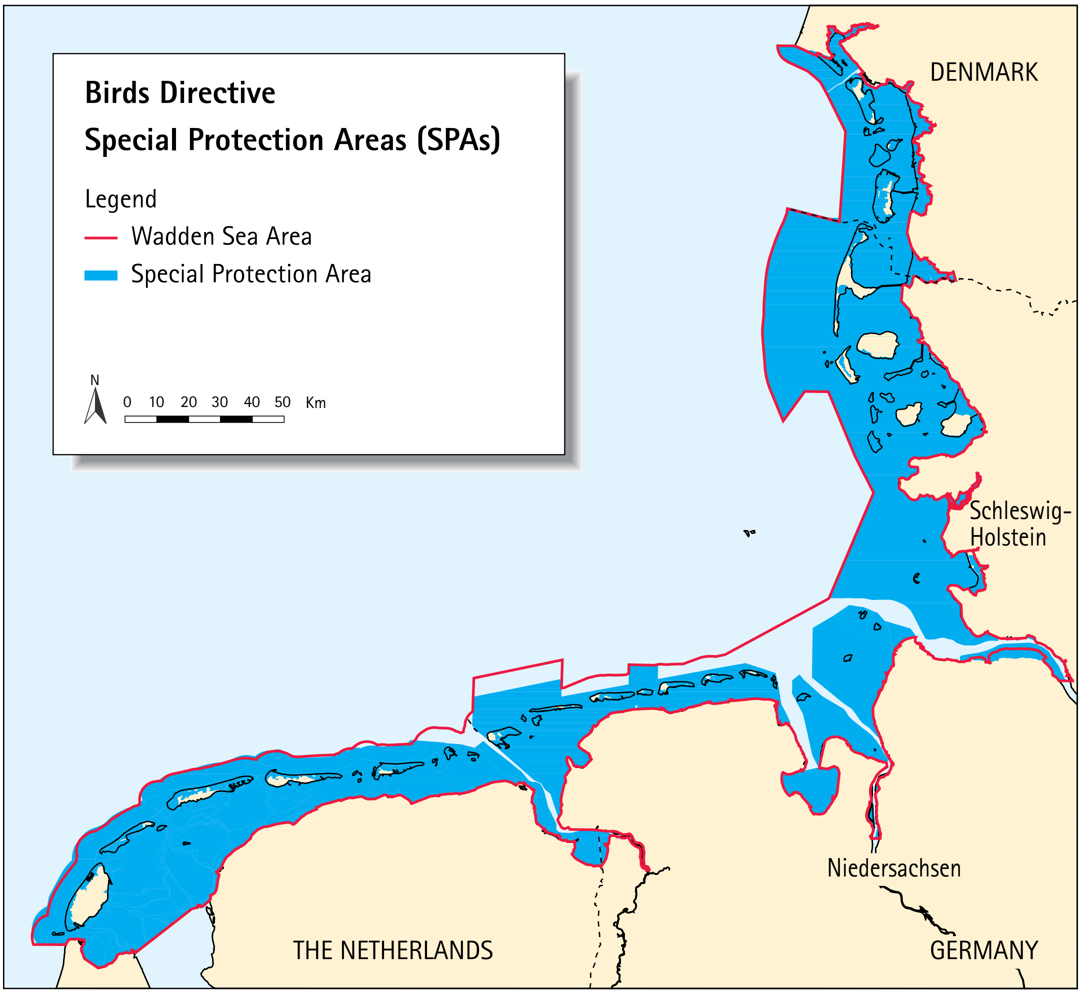


Figure 7: Special Protection Areas (SPAs) under the EC Birds Directive in the Wadden Sea Area

take appropriate steps to avoid, in the SACs, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this directive. A report on the ecological status of NATURA 2000 areas has to be delivered to the European Commission every six years.

A plan or a project likely to have a significant effect on the areas shall be subject to an appropriate assessment of its implications for the site. Only if it will not adversely affect the designated conservation area shall a competent authority agree to the plan or project. If a project or plan must nevertheless be carried out for imperative reasons of overriding public interest, in the absence of alternatives it must be compensated to ensure the overall coherence of the NATURA 2000 network. These provisions are legally enforceable by the European Court of Justice.

Water Framework Directive

The Council Directive 2000/60/EC on establishing a framework for community action in the field of water policy (Water Framework Directive, WFD) was enacted in December 2000. It aims at a coordination of all water-related measures on a European level. The key elements of the WFD include the protection of all waters, surface and ground waters in a holistic way and achieving good quality ('good status') by 2015. A first analysis of pressure and impacts was reported by the member states in 2005.

River Basin Management Plans have been prepared in 2009 based on the results of an operational monitoring program (established by 2006). River management plans are to be reviewed every 6 years.

The Wadden Sea has been assigned to 6 different River Basin Districts (RBDs) differentiated in coastal and transitional waters. These RBDs are the main management units of the WFD and cover all

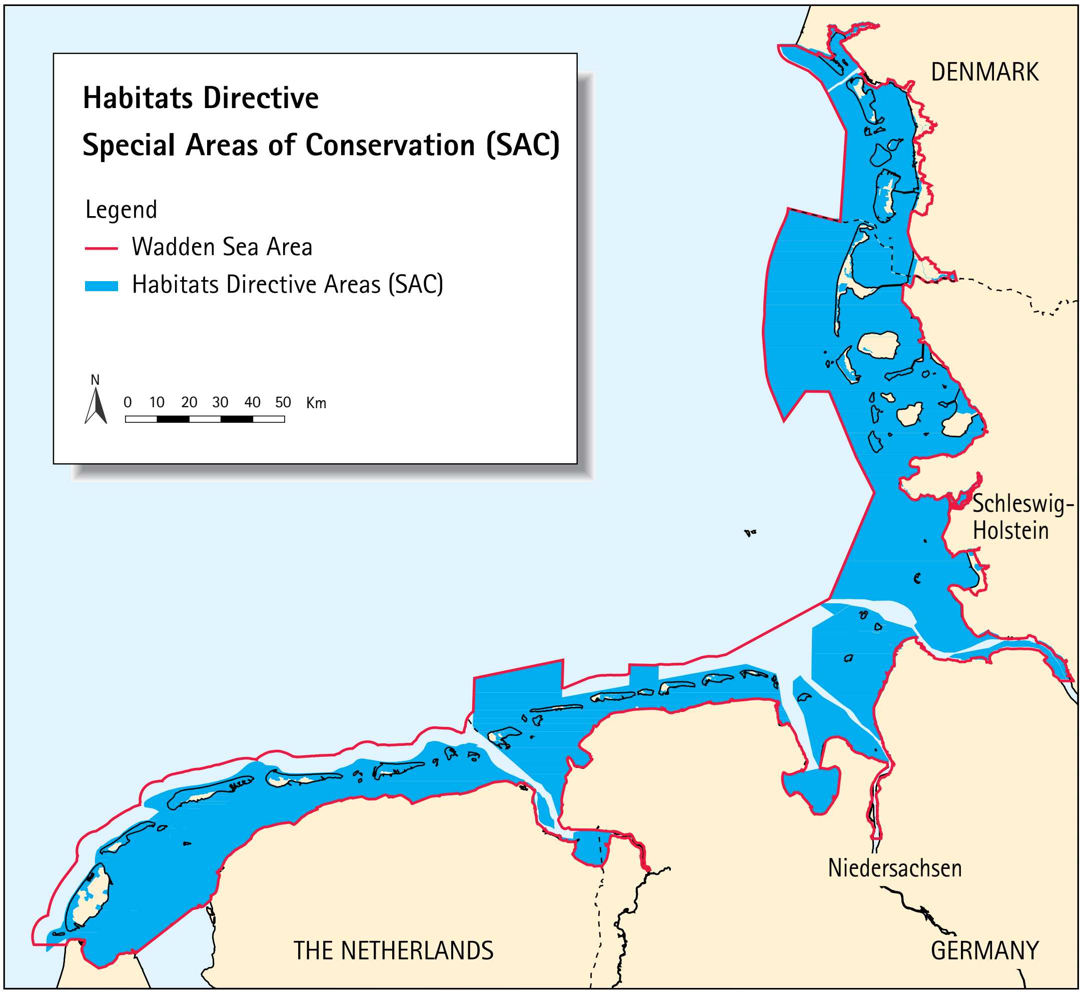


Figure 8: Special Areas of Conservation (SAC) under the EC Habitats Directive in the Wadden Sea Area.

types of surface and ground waters. Coastal waters covers the areas up to 1 sm from the baseline and with regard to the chemical status also the territorial waters (up to 12 sm) (Figure 9).

Regarding the Habitats, Birds and Water Framework Directives, the Schiermonnikoog Declaration (2005) reaffirmed that a coordinated and consistent implementation will continue to be a central aim. The Wadden Sea Plan will be further developed into a management plan in accordance with the stipulations of the mentioned directives.

Other European Union legislation

Other relevant European Union legislation includes the Environmental Impact Assessment Directive and the Strategic Environmental Assessment Directive, which are of central importance for the assessment of the environmental impacts of policies, plans and concrete projects. Also, the recommendation of the European Parliament and the Council on Integrated Coastal Zone Management is of particular importance for the Wadden Sea, it being a site located at the interface between land and sea and to be managed according to this specific characteristic.

Other International Conventions and Programs

The Wadden Sea countries are contractual parties to a number of international agreements, conventions and treaties, in particular, the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention) (Figure 1.9), the Convention on Biological Diversity (CBD), Convention on the Conservation of Migratory Species of Wild Animals (CMS, Bonn Convention) also covering the Agreement on the Conservation of Seals in the Wadden Sea (Seal Agreement), the Agreement on the Conservation of African-Eurasian Waterbirds (AEWA) and the Agreement on the Conservation of Small Ceta-

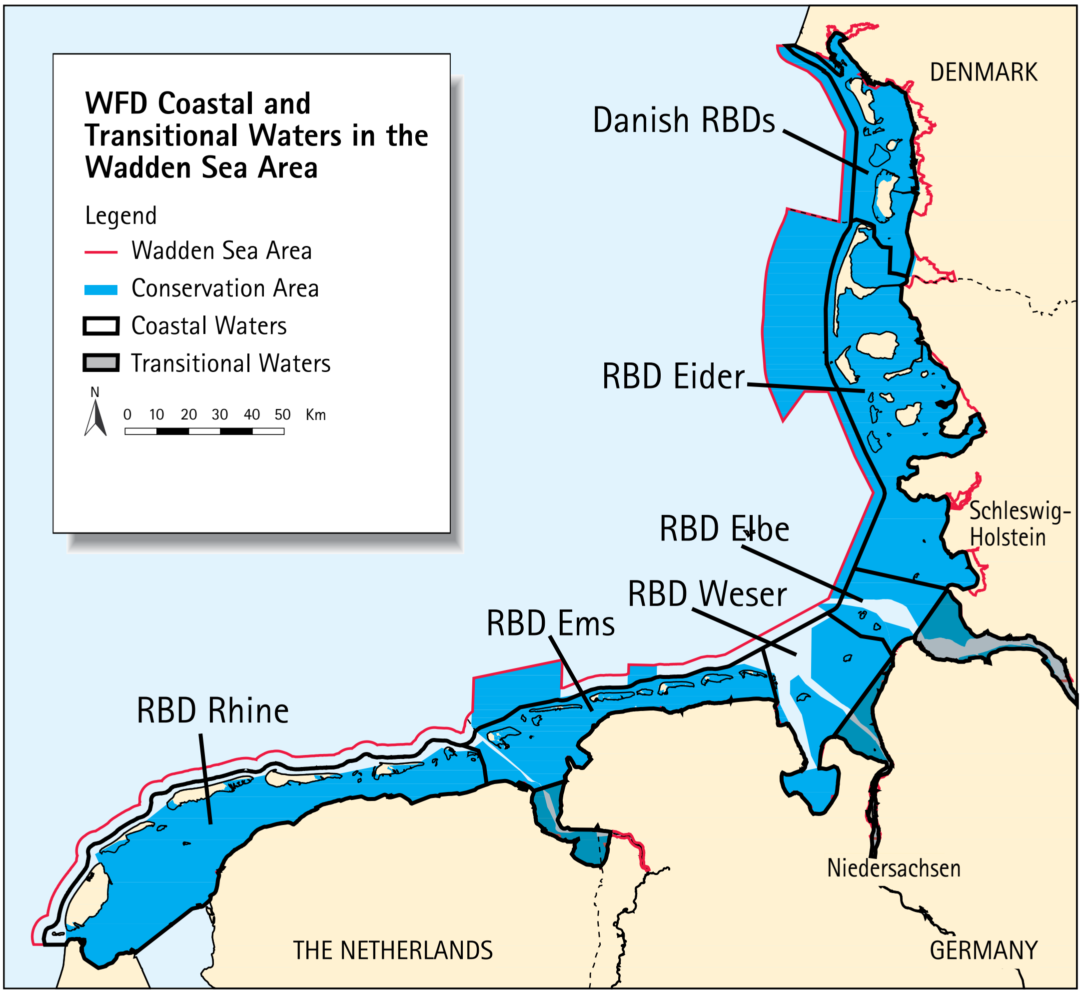


Figure 9: Coastal and transitional waters of the River Basin Districts (RBDs) of the Water Framework Directive in the Wadden Sea Area (only seaward parts of the RBDs are shown).

ceans of the Baltic and North Seas (ASCOBANS), the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) and the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention).

The German and Dutch parts of the Wadden Sea have been designated as Man and Biosphere (MAB) Reserves under the United Nations Educational, Scientific and Cultural Organization (UNESCO). Whereas the MAB-Reserve in the Dutch, Niedersachsen and Hamburg part is nearly identical with the conservation area, the MAB Reserve in Schleswig-Holstein also includes five Halligen as development zone adjacent to the nominated property.

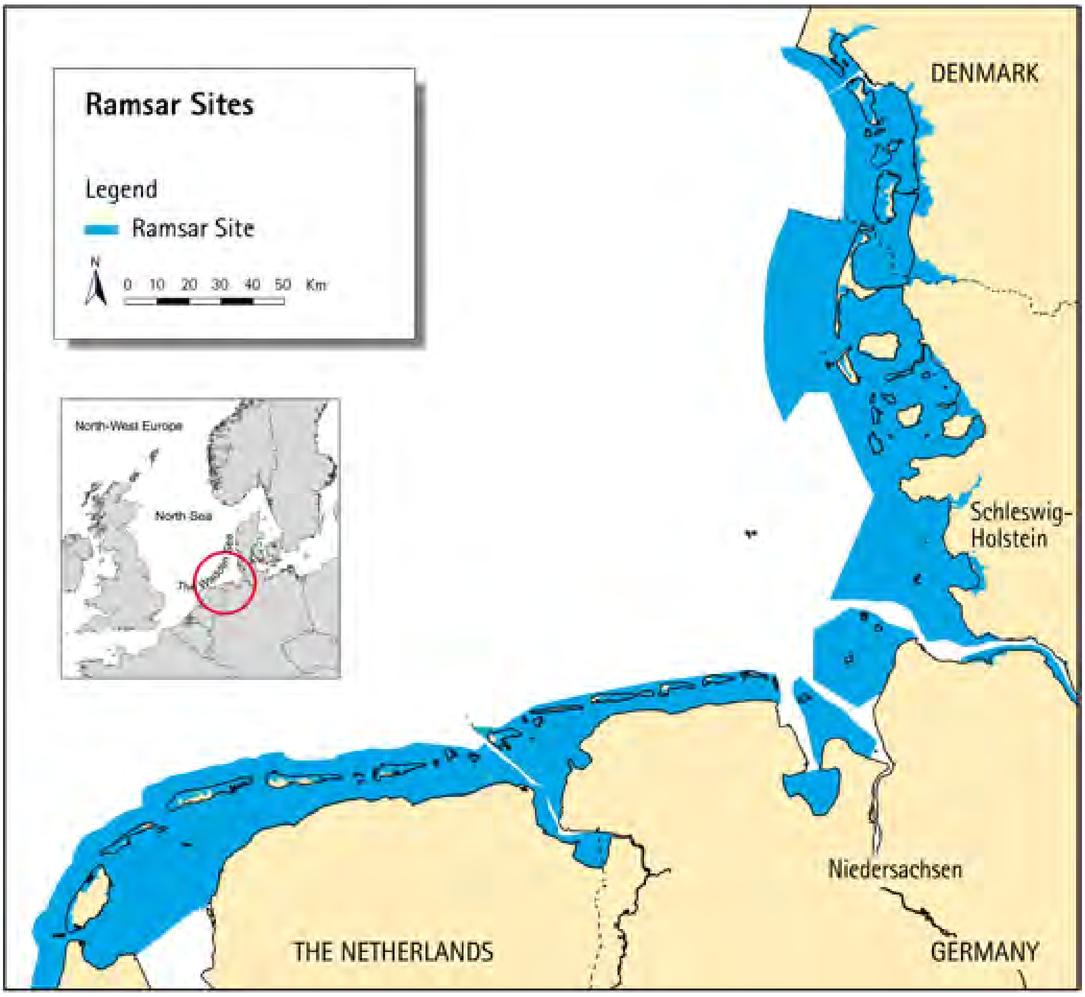
Due to the strong interactions between the Wadden Sea and the adjacent North Sea, the trilateral policy and management regarding pollution is closely related to the OSPAR and the North Sea Conferences.

At the 5th North Sea Conference in Bergen 2002, the North Sea ministers agreed to implement an ecosystem approach to management which was to be guided by a conceptual framework (Bergen Declaration, 2002). Part of this framework is ecological quality objectives (EcoQOs), to be used as a tool for setting clear operational environmental objectives directed towards specific management and serving as indicators for the ecosystem health.

The EcoQOs cover many parts of the ecosystem, including plankton, benthic organisms, fish, sea birds and marine mammals. Most objectives can be linked to specific human activities, such as shipping (oil at sea), litter, fishing and pollution by chemicals and nutrients.

The development of a coherent and integrated set of EcoQOs is undertaken by OSPAR and the International Council for the Exploration of the Sea (ICES), in coordination with the development of marine indicators in the European Environment

Figure 10:
Wetlands of International Importance according to the Ramsar Convention in the Wadden Sea Area.



Agency (EEA) and environmental objectives in the EU Water Framework Directive. For the North Sea, a pilot project on the development of EcoQOs for a selected set of ecological quality elements was formulated (Bergen Declaration, 2002). A first set of EcoQOs that have been delivered has been tested in practice by North Sea countries.

EcoQOs relevant for the Wadden Sea relate to the proportion of oiled common guillemots among those found washed ashore, the level of imposex in female dog whelks, phytoplankton indicator species for eutrophication and winter nutrient concentrations (dissolved inorganic nitrogen and phosphorus).

1.2.3. National regimes

In the 1999 QSR, a comprehensive overview of the national protection and management regimes was given. In the following sections, the focus has been placed on the main developments since then.

The Netherlands

The protection of the Dutch part of the Wadden Sea combines a unique national physical planning approach (the Key Planning Decision Wadden Sea (PKB) with a designation of the nominated property under the Nature Conservation Act, 1998 supported by additional designations.

1. Key Planning Decision Wadden Sea, 2007 (3rd Policy Document Wadden Sea)

Since 1980 The Netherlands Wadden Sea has been protected according to the PKB Third Policy Document of the Wadden Sea (Annex 16), which is a national physical planning decree defining the overall objectives of conservation, management and use of the Wadden Sea. The PKB is a specific integrated physical planning instrument of the Spatial Planning Act and its objectives and conditions are binding for all state, regional and local authorities. The PKB document is valid for the whole Dutch part of the nominated property. The PKB is subject to amendment on a regular basis. The latest amendment was issued in 2007 after adoption by Parliament.

2. Nature Conservation Area

Through the Nature Conservation Act (1998), nature areas designated as SACs according to the Habitat Directive, and as SPAs under the Birds Directive are protected under the aforementioned Act as nature reserves. The conservation objectives for these Natura 2000 areas are stipulated in a ministerial order together with the delimitation of the area. Management plans outlining the required measures will be drawn up for each area. Arrangements will be made with provincial authorities to implement them. According to legislation it is prohibited without permission to undertake activities which destroy and damage the protected area including its flora and fauna or its scenic importance. The guiding principle is that human activities are allowed as long as they are consistent with the major goal of the policy given in the PKB document. Therefore, the actual legislation includes an assessment frame to be used when the acceptability of proposed new activities has to be determined.

3. Act on the Wadden Sea Council, 2002

The Act establishes the Wadden Sea Council. The Council is to be considered a continuation of the Advisory Board established in 1982. The Wadden Sea Council is an independent advisory board and advises the governments and the parliament on issues of general importance for the Wadden Sea region such as policies (regional, national, trilateral) with regard to, for example, fishery, recreation, the development of management plans and the improvement of the governing structure for the area and with regard to the development of a sustainable development perspective. Its members are designated on the basis of their technical knowledge and do not represent specific sector interests.

4. Ecological Main Structure

The Dutch part of the nominated property is also designated part of the Ecological Main Structure (EMS), which is the coherent national ecological network of nature areas. The aim of the EMS is to prevent plants and animals from extinction in isolated areas and the devaluation of nature areas. For each of the areas of the EMS, a specific 'nature goal' is defined. This is a testable objective for a nature area. At the national borders the EMS connects with other areas of the Pan European Ecological Network (PEEN).

5. National Parks

Parts of the islands of Schiermonnikoog and Texel, also within the nominated property, are designated national parks in accordance with national legislation.

6. Environmental Protection Area

Areas that have a special conservation status based on the Nature Conservation Act 1998 or the Ramsar Convention are designated as Environmental Protection Areas in accordance with the Environmental Management Act. This means that the Environmental Decree issued by the provincial government includes at least regulations concerning the protection of the quality of groundwater and the prevention and restriction of nuisance by noise.

The PKB has the status of a law and its objectives and conditions are binding upon all state, regional and local authorities. The main objective of the PKB is a sustainable protection and development of the Wadden Sea as a nature area and conservation of the open landscape. This explicitly includes the conservation of landscape qualities, in particular the quietness, the openness and the naturalness. This objective, as indicated in the PKB, closely relates to the targets in the Wadden Sea Plan. The PKB must hence be implemented in regional and local spatial plans, taking into account that the Wadden Sea is municipalized amongst the adjacent three provinces and municipalities. The municipalization was done in the 1980s to ensure that the PKB would be implemented within the framework of spatial planning and hence guarantee that the objectives and policies of the PKB would be also binding upon the lower government levels. The local plans are binding legal documents with direct implications for the individual citizen or company. This approach was also opted for to engage and commit the regional and local authorities.

The designation of the Wadden Sea as a nature conservation area is to ensure that the Nature Conservation Act 1998 and its stipulations can be applied. The PKB, in combination with the Nature Conservation Act 1998, guarantees special protection. According to this legislation it is prohibited without permission to undertake activities which destroy and damage the protected area, including its flora and fauna or its scenic importance. The guiding principle is that human activities are allowed as long as they are consistent with the major goal of the policy given in the PKB document. Therefore, the actual legislation includes an assessment frame to be used when the acceptability of proposed new activities has to be determined.

The PKB, in combination with the Nature Conservation Act 1998 (article 20) or the Criminal

Code (article 461), allows for closing of zones in the area for public admittance for the whole or part of the year. The delimitation of these zones can be updated each year. It concerns mainly zones that are important for seals and breeding birds. About a quarter of the tidal flats has been closed for cockle and mussel fishery. Based on the trilateral agreement laid down in the PKB document and the Policy Decision on Shellfish Fisheries (2004) in the eastern part of the Dutch Wadden Sea, a reference area is designated. This area is about 7,400 ha, which is about 3% of Dutch Wadden Sea, and it includes all the important ecological features. It has been closed for shellfish fisheries since 1993. In the reference area, exploitation of biotic and abiotic resources and other disturbing activities is not allowed. The area serves comparative monitoring and research in the Wadden Sea.

Germany

In Germany the coastal federal states are responsible for the implementation of the Federal Nature Conservation Act. This is a federal framework act for nature conservation which includes provisions for the establishment of nature reserves and national parks. According to §24 of the Federal Nature Conservation Act (2002), national parks are larger areas of national importance of which the major part is undisturbed and qualify to be designated as a nature conservation area. The aim is to safeguard, in the greater part of the area concerned, undisturbed ecosystem interactions and their natural dynamic processes to the extent possible.

Schleswig-Holstein, Niedersachsen and Hamburg established national parks for the Wadden Sea in 1985, 1986 and 1990, respectively. The objectives of the national parks are to protect the Wadden Sea and to allow natural process to take place with a minimum degree of disturbance and other detrimental effects of human activities. The national parks have been divided into two or three zones of which the zone I includes the ecologically most valuable areas. Therefore, strict regulations apply to the zone I, including extensive restrictions to public admittance. In zone II, utilization and activities are allowed under such conditions that the overall protection objectives are not impaired. Each national park is managed by an administrative authority, the national park authority, which is responsible for the implementation of the provisions of the national park instruments.

The marine area of the German Wadden Sea Area is federal waterways. Navigation is hence to be regulated by Order of the Federal Minister for Traffic. An order was issued in 1992 and amended in 1995 and 1997. The order establishes speed limits for navigation in the National Parks and closed areas comprising of seal haul out sites, and breeding and moulting areas for birds.

Niedersachsen

The Niedersachsen Wadden Sea National Park was designated in 1986 by state statutory order, which was given the status of state act in 1999. The act was amended in 2001 and the National Park was extended seawards partly beyond the three nautical mile line off the islands of Borkum and Baltrum, it includes areas previously outside the National Park in the Ems-Dollard estuary (Rysumer Nacken), the nature reserve in the Dollard and a transition zone between the salt marsh and the geest south of Cuxhaven. The National Park also covers the large majority of the islands.

Compared to the previous National Park area, well defined parts on the islands consisting of built-up and intensively used areas have been excluded and the boundaries redefined.

The zoning scheme within the National Park has been partly revised. Zone 1 was extended on most of the islands to also include the primary dune areas on the eastern parts of the islands. Also in the tidal area, zone 1 was extended. The recreational zone was partly extended. Some intensively used parts of the recreational zone were excluded from the National Park.

The area of the National Park has, as a result of the amendment of the act, increased with about 400 km² up to 2,777 km² (277,000 ha).

The Niedersachsen National Park, which includes the uninhabited part of the East Frisian Islands, is divided into three zones. Zone 1 – the core zone – covers 61 % of the total area and includes the ecologically most valuable areas. All activities which destroy, damage or change the National Park or its components are prohibited. Public admittance is prohibited with the exception of assigned paths and routes. Some human activities (farming, hunting on parts of the islands and fishing) are still possible, but only under restricted conditions. Zone 2 – the intermediate zone – covers 38.5 % of the total area. All activities which change the character of the Wadden Sea, including the islands, in particular the scenic value or nature impression, are prohibited. A list of specifically prohibited activities is annexed to the act. Admittance is allowed to this zone, with the exception of the salt marshes during the breeding season for birds, from 1 April until 31 July. Zone 3 – the recreational zone – covers about 0.5 % of the total area. Only recreational activities and health resort activities are allowed there. Paragraph 17 of the Niedersachsen National Park Act regulates possible exemptions and exclusions.

Resource use and activities that are not prohibited, coastal defence activities or those of a traditional nature according to the above mentioned national park acts are subject to licensing. Prior to issuing permits and exemptions the activity or project must be made subject to an assessment in accordance with the Habitats Directive.

Hamburg

The Hamburg Wadden Sea National Park was established in April 1990 by state law and amended in 2001. The amendment led to a seaward extension of the National Park up to the 3 mile line. The extension has increased the area of the national park by approximately 2,050 ha up to now 13,750 ha. The amendment entails both a harmonization between the National Park law and the Habitats Directive and new specifications for fishing regulations within the National Park resulting in the extension of the already existing zero-use zone up to more than 75 % of the National Park area.

The Hamburg National Park is divided into two zones. Zone 1 is reserved for the establishment and succession of natural dynamics covering about 92% of the National Park. Public access is prohibited with the exception of (mainly tidal flat) walking routes, and the tidal flats north of the island Neuwerk ("Kleiner Vogelsand"). Zone II (about 8 %) is reserved for recreation, sustainable tourism and nature experience activities which are in line with the National Park targets. There are also some farming activities supporting the maintenance of the some hundred years old historically small scale structured landscape of the island of Neuwerk. Neuwerk bears the oldest secular building at the Wadden Sea coast, the old 30 m high tower from 1300-1310, used as a lighthouse since 1814. The tower called "Nige Wark" (= new building) is an impressive remnant of the Hanseatic era during the Middle Ages in the Wadden Sea. Commercial fishery is forbidden with the exception of shrimp fishery along three narrow shipping routes (less than 1% of the area). Hunting is prohibited within the entire National Park.

Schleswig Holstein

The Schleswig-Holstein Wadden Sea National Park was established in 1985 by state law, which was amended in October 1999. The amended national park law entails a further specification of objectives, extension of the area under protection, and a new zoning scheme. In comparison with the 1985 law, the amended law entails in particular a seaward extension of the National Park, including the designation of a cetacean conservation area off the islands of Sylt and Amrum, a new definition of the protection objective and the introduction of a new zoning system, including a zero use area.

The National Park covers about 4,410 km² (441,000 ha) which is an extension of about 1,700 km². The whale protection area is approximately 1,240 km².

Two statutory boards of trustees represent the local authorities and the most important stakeholder interests on county level. They advise the national park authority on basic issues and long-term planning.

The Schleswig-Holstein National Park is divided into two zones, in which different activities are allowed. The core zone, zone 1, comprises coherent tidal basins and covers about 36% of the National Park. Public access is prohibited, with the exception of e.g. tidal areas adjacent to the coastline, tidal flat walking routes, and commercial fishery as stipulated in Section 6 (2) of the act. Within the core zone, an area south of the Hindenburg causeway of 12,500 ha has been designated as a zone in which all resource use has been fully prohibited. Navigation is only allowed in the zero use zone on the marked shipping lanes. The area covers about 3% of the National Park area. Any activity which could cause destruction, damage or change to the protected area or any part thereof or that could lead to lasting disturbance, is prohibited. Permitted activities are explicitly stated in Section 6 of the National Park Law. The kind and location of activities is primarily determined by the zoning concept. Additionally, hunting and cockle fishery, which prior to the new amendment were largely phased out, are now completely prohibited within the National Park. The same holds for wind turbines.

Denmark

The revised Statutory Order for the Danish Nature and Wildlife Reserve (the Danish section of the Conservation Area) was enacted in 1998 (for details see 1999 QSR) implementing the Stade Declaration (1997) and Wadden Sea Plan (1997).

In 2008, the Danish parliament formally agreed to establish the Danish Wadden Sea National Park which is basically similar delimited as the Danish Wadden Sea Area and hence incorporates the islands, adjacent marsh areas and the Varde Å estuary. The national park covers an area of almost 146,000 ha. The national park is planned to be inaugurated in autumn 2010, together with the enactment of the Statutory Order.

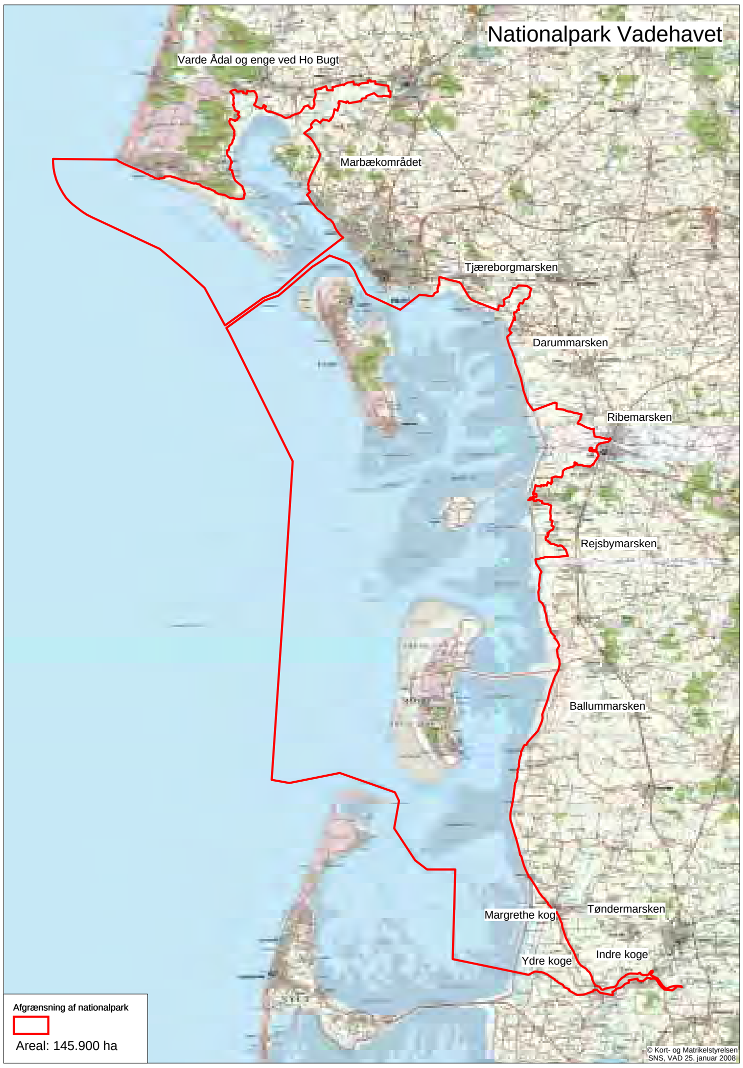


Figure 11: Map of the Danish Wadden Sea National Park (source: http://nationalparker.skovognatur.dk/Vadehavet/Udgivelser_kort/)

The national park will be governed by a national park board. The members of the board will be appointed by the minister and represent central and local governments, the Danish Association for Nature Conservation and the Outdoor Council, the Countryside Association and "Visit Denmark". The Council has no legal authority and its primary task is to develop and oversee a national park plan which will guide the protection, management and sustainable use of the park. Focus will be on access and outdoor activities, information and awareness and nature restoration projects and extensive farming with local involvement.

The National park will be funded by the central government based on the plan but will have the possibility to acquire additional funds from local governments, partnerships etc. The existing Advisory Board will constitute the future Advisory Board for the national park.

1.3 Reference Areas

1.3.1 Introduction

The term 'reference area' is commonly used for sites representing certain conditions for purposes of monitoring or research. In the framework of the Trilateral Cooperation, they are first mentioned in context of initiating the Trilateral Monitoring and Assessment Program (TMAP) in the Esbjerg Declaration of 1991. There, it was agreed to designate "sufficiently large areas, spread evenly over the Wadden Sea, where all exploitation and all disturbing activities are banned and which can serve as reference areas for scientific purposes" (Esbjerg Declaration, 1991, § 33.3). At the Esbjerg Conference 2001, the ministers recalled 'the decision taken at the 6th Wadden Sea Conference to designate reference areas, and in this respect, to welcome the designation of a reference area without resource exploitation in the Schleswig-Holstein Wadden Sea 1999 in addition to the Danish zero use reference area designated in 1982, and the Hamburg zero-use area designated in 1990, and the anticipated designation of a reference area in the Dutch Wadden Sea' (Esbjerg Declaration, 2001; §11).

1.3.2 Definition

Reference areas represent certain standards (e.g. for libraries), conditions (e.g. for medical purposes), states or stages (e.g. ecological stages). By definition, they are designed to serve monitoring and research. Thus, their inventory is thought to be representative for larger units.

According to the Ministerial Declaration of the TGC in Esbjerg 1991, areas serving as reference areas for scientific purposes must

- have a sufficiently large size;
- be spread evenly over the Wadden Sea;
- be free of exploitation and disturbances

("zero-use zone").It is obvious that reference areas were to be established to serve monitoring and research in the Wadden Sea. The relation has been further specified by the Trilateral Monitoring and Expert Group (TMEG), installed to develop the conceptual framework of the Trilateral Monitoring and Assessment Program (TMAP) in 1992.

The 1999 QSR (chapter 6.4.7) stated that reference areas meet the requirements of scientific research and monitoring as a basic instrument for nature protection management and politics. A precondition for measurement and assessment of the effects of anthropogenic influence on natural ecosystem structures and processes is the comparison of areas with and without human resource utilization. The proper assessment of data and results of the TMAP depends on the existence of reference areas (TMEG, 1993). The necessity of reference areas – the only sites where 'undisturbed' ecosystem processes can be studied - has also been stressed by Colijn *et al.* (1995), especially for the description and understanding of changes in the abundance of species and the assessment of sustainable development.

The QSR 1999 concluded that the above listed features are only represented by entire tidal basins, stretching from the salt marshes to the ebb delta opening out into the adjacent North Sea. Reise (1992, 1994) proposed a concept for such 'core areas' or 'ecological priority areas' distributed over the Wadden Sea.

1.3.3 Recent Status

The Netherlands

Based on the trilateral agreement laid down in the PKB document and the Policy Decision on Shellfish Fisheries (2004) in the eastern part of the Dutch Wadden Sea, a reference area is designated. This area is about 7,400 ha, which is about 3% of the Dutch Wadden Sea, and it includes all the important ecological features. It has been closed for shellfish fisheries since 1993. In the reference area, exploitation of biotic and abiotic resources and other disturbing activities is not allowed. The area serves comparative monitoring and research in the Wadden Sea.

Germany

Within the core zone of the National Park of Schleswig-Holstein, an area of 12,500 ha called 'Hörnum Tief' south of the Hindenburg dam has been designated as a zone in which all resource use including fishery has been fully prohibited in 1999.

Navigation is only allowed in the zero use zone on the marked shipping lanes. The area covers about 3% of the National Park area. Any activity which could cause destruction, damage or change to the protected area or any part thereof or that could lead to lasting disturbance is prohibited.

In the 'Hörnum Tief' area, regular surveys of seals, roosting and breeding birds, blue mussel beds, eelgrass and macroalgae are carried out as part of the TMAP. Since 2001, pelagic fish monitoring has been carried out at three stations in the reference area in addition to the three stations in the Meldorf Bight where fish monitoring has been carried out since 1991. Since 2002, an automatic recording device has been installed in the reference area during the period May – November to collect data on weather, water level, hydrology and turbidity. Also in 2002, a benthos mapping was carried out in the Wadden Sea similar to the survey in 1987-1993 also covering the zero-use-area.

Within the National Park of Hamburg, an area of about 10,400 ha has been protected as a 'zero-use zone' mainly since 1990. In this area, all resource use has been fully prohibited. Navigation is only allowed in the zero-use zone on the marked shipping lanes. Fishery is prohibited with the exception of shrimp fishery in these shipping lanes (100 m width). The area covers about 76% of the National Park area (Figure 1.10). An integrated monitoring program has been established in the Hamburg National Park according to the reporting requirements for the TMAP, the EU Habitats and Birds Directives. It consists of monitoring breeding and migratory birds, common seals, macrozoobenthos, salt marsh and dune vegetation (Umweltbehörde Hamburg, 2001).

In Niedersachsen, large areas within the National Park, e.g. the islands Memmert and Mellung, and tidal flats, the 'Hohe Knechtsand' are without any resource use and disturbances by recreational activities. However, these zero-use areas have not officially been designated as reference areas for scientific purpose.

Denmark

In 1982, a reference area was designated around the island of Langli which is free of exploitation and disturbances and fulfills the definition of a reference area. It covers the tidal flat (about 800 ha, about 1% of the Danish Wadden Sea) between Langli and the Skallingen peninsula. In addition, the island of Langli (80 ha) and a zone 300 m north, east and south of the island are closed to the public for most of the year (16 September – 15 July). The area represents typical tidal and island habitats covering one tidal basin (Figure 11).

Since 1983, regular monitoring of breeding and migratory birds has been carried out on Langli and is included in the TMAP (breeding birds since 1991, spring tide counts of migratory birds since 1994). The field station was run 1983–2002, manned by 1-2 persons over the whole year. Since 2002, monitoring has been carried out during

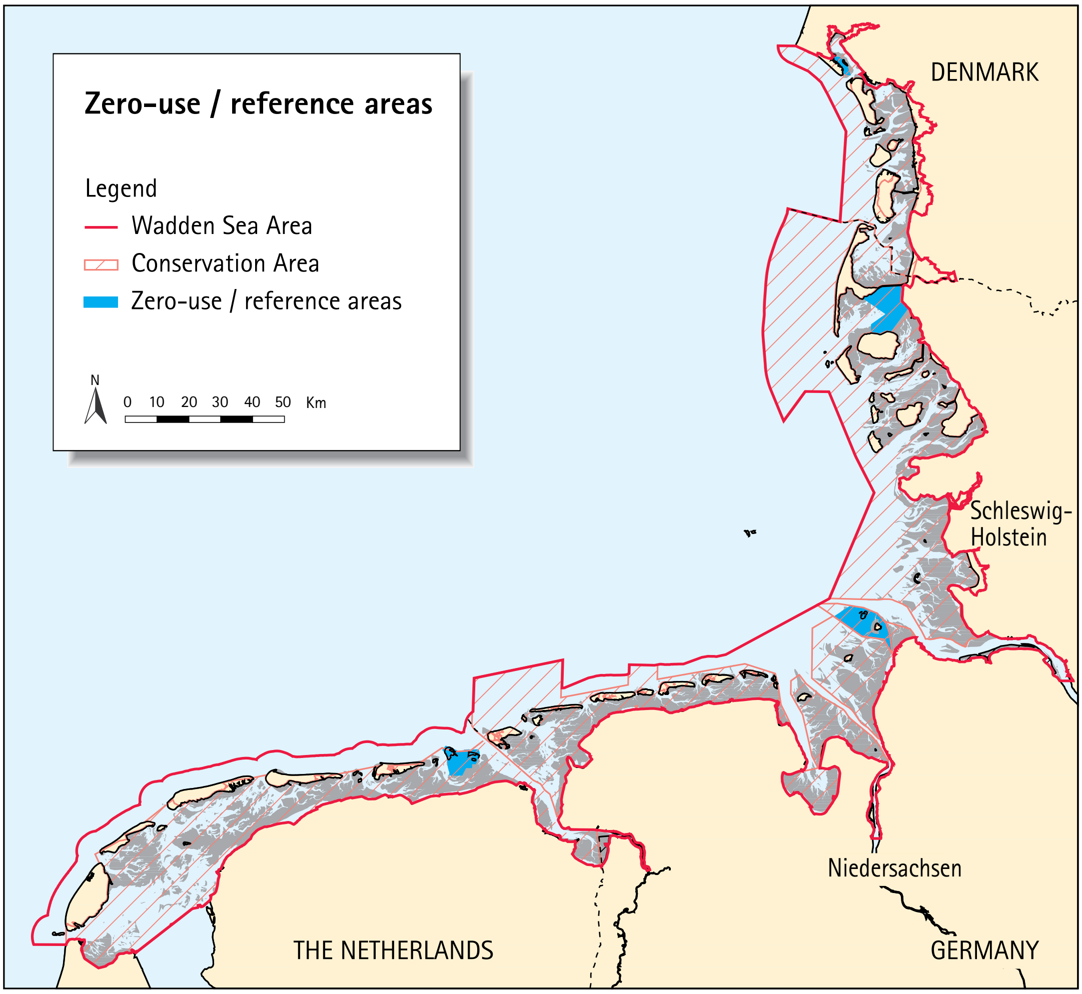


Figure 12: Map of zero-use / reference areas in the Wadden Sea (source QSR 2004).

	Langli (Denmark)	Hörnum Tief (Germany – Schleswig-Holstein)	Hamburgisches Wattenmeer (Germany–Hamburg)	Rottumeroog / Rottumerplaat The Netherlands
Size and area	800 ha Entire tidal basin	12,500 ha Approx. 50% of the tidal basin	10,400 ha	6,500 ha Part of tidal basin
Typology	Tidal flats and island habitats	Back-barrier tidal flats	Open Wadden Sea area	Back-barrier tidal flats
Sub-ecosystems included	Tidal basin with silt, mixed, sandy flats, creeks and deep; island with dunes and salt marsh and mainland salt marsh	Inner tidal basin with silt, mixed, sandy tidal flats and tidal creek systems, island and mainland salt marshes and primary dunes	Estuary flats with silt, mixed, sandy tidal flats and tidal creek systems; island salt marshes and primary, white and grey dunes	Small uninhabited islands, primary dunes, salt marsh, tidal basin with sandy flats.
Legal basis	Wildlife Reserve Act 1998 (Art. 7)	National Parks Act (Art. 4)	National Parks Act (enacted 1990, amended 2001): Art. 2 to 5	Proposed for designation in PKB 2005-2015
Year of designation	1982	1999	1990	Planned in 2005
Reasons for designation	Safeguard the dynamics of flora and fauna, natural processes and structural diversity	Safeguarding development free of human intervention, as well as natural structural diversity and the dynamics of processes	Safeguarding the dynamics of natural processes and structural diversity	Safeguarding the natural dynamic development of habitats and species diversity
Resource uses	None	None	None	None
Zero-use area	Conform ED 1991	Conform ED 1991	Conform ED 1991	Conform ED 1991
Public access, shipping, fishing	Closed to the public from September to July	Shipping only along navigational routes, entry near coastlines	Shipping and shrimp fishing only along navigational routes; in some cases, entry close to islands (e.g. Kleiner Vogelsand) or navigation on two marked routes	Shipping: Already closed for shellfish fisheries and shrimp fisheries
Monitoring program and parameters	TMAP Birds, blue mussel bed	TMAP Fish fauna, measuring pole, theme-based mapping	TMAP Macrofauna, seals, seabirds	TMAP blue mussels, fish birds, seals
Reference area and purpose	Yes Undisturbed development of a tidal basin, which represents a typical 'small scale' Wadden Sea ecosystem	Yes Purpose under discussion	Yes Undisturbed development of high tidal flats and semi-natural dune islands including their biological communities	Yes Undisturbed development of a tidal basin, which represents a typical 'small scale' Wadden Sea ecosystem
Representative for	Tidal flats, island habitats	Back-barrier tidal flats	Mesohaline estuary flats and partly tidal creeks, salt marshes	Back-barrier tidal flats

Table 2: Overview of zero-use-areas in the Wadden Sea and their status in the light of Esbjerg Declaration 1991 and 2001 (QSR 2004). For Niedersachsen, the zero-use areas are not listed because they have not official designated as reference area

regular visits. In addition, biological and geological research studies have been carried out on Langli by universities and other institutes. The intertidal part of the reference area is also a site of the blue mussel monitoring program.

1.3.4 Conclusion and recommendations

The precondition for reference areas in the sense of the Esbjerg Declarations 1991 and 2001 is the designation of zero-use-areas. This has been done in Denmark, Schleswig-Holstein and Hamburg by legislation as shown above. In line with the 1999 QSR, it has to be concluded that existing zero-use-areas do not yet meet the scientific approach in which entire tidal basins serve as reference areas.

To fulfill the obligations of the Esbjerg Declarations 1991 and 2001, more zero-use-areas are recommended. These areas should stretch from the salt marshes to the ebb delta and have to be spread over the whole Wadden Sea. Then, and only then, can these areas serve as reference areas for monitoring and research.

Furthermore it is obvious that there is a necessity to control the zero-use in these areas in addition to the parameter set of the TMAP Common Package.

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Landsape and Cultural Heritage

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1. Historic Development and Characterization

1. Historic development and characteristics of the cultural heritage in the Wadden Sea Region

1.1 Development and cultural history of the tidal Wadden Sea area

The Wadden Sea is the most dynamic natural landscape of Western Europe. The sea, its islands and coastal surroundings together form an ever shifting 'monument' of topographical changes. As a consequence, the history of the Wadden Sea is a fine example of man coping with his environment, by trial and error as well as by expansion and contraction. Socio-economically it is a good example of a society based both on agriculture and maritime activities (sailing, fishing, salvage and reclamation). Large parts of what is now land were sea about 1,000 years ago and vice versa. The Marne-estuary (south of Harlingen), the Middelsea-inlet with It Bildt, the inlets and former estuaries of rivers like the Lauwers, the Hunze and the Fivel were all part of the Wadden Sea and have since been reclaimed. The same goes for the bays and gulfs of Campen, Sielmönken, Harle and Maade in East-Frisia and Oldenburg (both in Lower Saxony).

Prehistoric and Medieval Times

At the end of the last Ice Age, the Wadden Sea area was dryland, with the coast located to the west of the present Dogger Bank. Finds recovered during dredging or fishing in this marine environment have established that the area hosted large herds of animals and bands of hunter-gatherers. However, as sea-levels rose the inhabitants must have retreated back to the current shoreline. There are undoubtedly Palaeolithic and Mesolithic sites under the present Wadden Sea, buried beneath many metres of sediment.

There is more information for the Neolithic period. For example, many finds have been recovered from the Wadden Sea Area between the Eiderstedt peninsula and the island of Föhr, including late Neolithic and early Bronze Age flint daggers and flint sickles. These, prove the presence of people in this area in the late 3rd and early 2nd millennium BC, and probably even human settlement. Some undisturbed sites have also provided information about the surface level of the marsh 4,000 years ago. Middle Neolithic finds are often recovered on the coasts of Fanø. The finds must originate from submerged hunting camps and are washed ashore. The most outstanding find is a stylised bear made of amber. Today the level is 1.50 m below sea level (NN), but the spatially varying subsidence of glacial sediments must be taken into account. So far, there are no artefacts from the following periods, the late Bronze Age and the pre-Roman Iron Age, from the northern coastal marshes. Finds of the 2nd to 5th century AD have been recovered from an area between the Japsand west of the Hallig island of Hooge and the island of Pellworm demonstrating that by the 2nd century A. D. people had returned to the southern parts of the Wadden Sea Area of North Frisia. In Roman times a large part of the Wadden Sea south of an imaginary line between Texel and Zurich (Friesland) were in fact raised bogs fringed by a rather narrow belt of marshland.

There appears to have been a general abandonment of settlements across the region during the late Roman Iron Age and the Migration period, probably due to rising sea-levels and storm-tides in the 4th century. Settlement recommences in the 7th or 8th centuries, often in areas that had been previously favoured as settlement sites in the Roman Iron Age. However, these settlements were always vulnerable to storm-tides, of which the most famous and best recorded is probably the Grote Mandränke or 'Great Drowning' of 1362 which devastated the entire Wadden Sea region, submerging villages and islands and re-modelling the entire coastline.

As a remnant of a partly drowned landscape, archaeological traces of former settlements can be found or are historically documented throughout the Wadden Sea. Visible fragments of human occupation like the remnants of drowned villages, houses and farms may be found in the Jadebusen, but also off the mainland coast near Neuharlingersiel (Otzum, Ostbensum), off the Westermarsch (Itzendorf) and off Land Wursten (Rintzeln and Reminzeln).

Other remains, although mostly washed away or submerged, may be assumed elsewhere, especially off Texel and Wieringen (Balgzand), near the small island of Griend, off the north-coast of Fryslân (villages like Biniathorp and Dikesherne are historically documented near Harlingen) and most of all in the Dollard. Reclamation has led to the excavation of traces of occupation on the mainland around former coastlines. They all need to be documented and protected.

Large areas of peat, and the salt deposits found in it, had been extracted systematically since the High Middle Ages. There is archaeological evidence of the extraction of salt peat in a narrow strip reaching west-east, from the Hallig islands of Hooge, Langeneß, Oland, Gröde and Habel to the mainland marshes and north to the southern periphery of the Wiedingharde. Many traces of salt peat extraction have already been eroded by the North Sea, others have been covered by mainland marshes, Hallig islands and mudflats. Extensive erosion south of the Hallig island of Langeneß has led to the temporary exposure of peat extraction sites enclosed by former inland dykes

Salt was a much sought after commodity as the town charters of Ribe, Flensburg and Schleswig document and the extraction and trade of salt brought some temporary prosperity to the coast dwellers involved. This is mirrored in the distribution of sandstone sarcophagi imported from the Rhineland and Weser area and the correspondence between the distribution patterns of sarcophagi and extraction areas of salt peat were surely not accidental. The great flood of 1362 (Mandränke) caused the collapse of this flourishing salt-extraction industry. After 1362 the extraction of salt from previously untouched areas shows the lack of interest in the restoration of protective dykes destroyed by the Mandränke. The boom years of salt trade in North Frisia, however, were over.

Early Modern Times

The Wadden Sea area in early modern times is characterised by three great themes; reclamation, international maritime conflict and international trade.

In the southern part of the Wadden Sea the remnants of the old dam to Ameland can be seen (the relict of a failed attempt in 1871-1882 to connect this island to the mainland as a first step in reclaiming this part of the Wadden Sea). It is still visible during the ebb tide and is worth protecting from a cultural-historical point of view. Other dams like the Geise Leitdamm (opposite Emden), the Pollendam (near Harlingen), the Nieuwe Dam (West-Terschelling), and the dams alongside the river Weser by Ludwig Franzius, were built and function as training walls to influence the current. Minsener Oog was the result of an early 20th century attempt to deepen the Jade channel.

On the mud-flats bordering the salt marshes, ditches and warping dams are witnesses of recent land reclamation. The most famous dam is the Afsluitdijk. This barrier dam, which is almost 30

Figure 1: The Wadden Sea Region with the defined cultural entities.

km long was completed in 1927-1932 and joins the coasts of the former island of Wieringen and Friesland. The Zuyder Zee was enclosed and shut off from its northern part with this great enclosure dike. The former mouth of the Zuyder Zee is now the subtidal western part of the Dutch Wadden Sea.

In the northern half of the Wadden Sea, the coastal dwellers of Dithmarschen proved to be as successful in the reclamation of new polders during early modern times as they had been in the Middle Ages. In North Frisia, however, it proved impossible to reclaim all the coastal land that had been cultivated during the Middle Ages. Archaeological finds show that during the 16th and early 17th century those areas which succeeded in empoldering at least parts of the coastal marshes gained in prosperity. The increase in affluence was, however, short-lived and as early as the 1st half of the 17th century storm-floods wreaked havoc again and caused significant losses of land. In particular the central part of the densely populated island of Strand was permanently lost and nothing but the islands of Pellworm and Nordstrand as well as the Hallig island of Nordstrandischmoor remained (see also the cultural entity descriptions of the Islands and Hallig islands).

The extent of land loss cannot only be traced through archaeological remains of settlements, dykes and cultivated land which are still found in the Wadden Sea, but also through the comparison of comparatively detailed maps of the late 16th and especially of the 1st half of the 17th century (J. Mejer, P. Sax, Q. C. Indervelden, J. Behrends, J. Wittemak) with modern topography.

The mobile evidence for human activities, such as maritime conflict and trade, in the form of ship-wrecks, have been found near the entrances to the Wadden Sea. Medieval and Early Modern water routes and harbour sites deserve special attention. The greatest number of historical wrecks has been recorded alongside the sailing routes in the west, to historical ports around the former Zuyder Zee like Amsterdam, Kampen, Enkhuizen, Hoorn, Stavoren and Harlingen. Some areas are especially promising e.g. the Texel Roads and the Vlie Roads (Vlieree). Because of the number of shipwrecks that have been traced (of Dutch East-Indiamen, medieval cogs and other merchantmen) the western part of the Dutch Wadden Sea was put on the Tentative List of World Heritage Sites. Apart from light-houses, buoyage and other maritime marks which derive their existence from daily sailing practices are mostly short-lived. The same applies to fishing-gear and fishing-grounds which are usually movable (e.g. hooks, bow-nets) and more or less constantly shifting (e.g. mussel-beds, eelgrass). Old fishermen's houses, harbours, museums, monuments and fishing-boats however can be found everywhere along the mainland and island coasts of the Wadden Sea. The same applies to maritime activities like pilotage and salvage. The buoyage-shed (tonnenloods) at the harbour in West-Terschelling, which is a centre of pilotage and used to be a salvage station (e.g. museum tugboat Holland) is a good example of the strong ties between the inhabitants of the area and the sea.

1.2 Development of the cultural landscape and heritage of the mainland and islands in the Wadden Sea Region

The landscape of the Wadden Sea region has developed since the end of the last Ice Age due to the repeated erosion of moraines and sand deposits and subsequent sedimentation by the rising sea. This created repeatedly flooded bog and marsh areas, intersected by tidal inlets and repeatedly flooded. The islands of the Wadden Sea off the coast of Denmark and Schleswig-Holstein in part owe their origins to these glacial deposits against which sand dunes have formed, whereas the Dutch and East Frisian islands are essentially a dissected sand barrier. The dunes are extensive and can reach considerable heights. The highest dune top, on Vlieland, is 40m above sea level. The prevailing pattern of winds and currents generally lead to erosion on the western sides and deposition on the eastern side. In a number of instances this has lead to a general tendency for the islands to shift eastward. At the same time there is some shift in the direction of the mainland coast, due to erosion at the North Sea side and sedimentation at the Wadden Sea side. An overview of the geomorphological changes during the last 2000 years is given in the QSR 2009 thematic report on geomorphology.

For thousands of years the Wadden Sea itself has played a central role in the life of the people of the region. Changing sea levels mean that areas that were once dry land are now within the intertidal zone, and erosion may reveal ship wrecks and remains of human occupation from the Neolithic onwards. They are often particularly well preserved.

Whilst there are a number of finds of Palaeolithic flint tools from the region, these are largely in secondary contexts having been redeposited by movement of ice sheets. The earliest substantial

Figure 2: Ockholmer Koog and Sönke-Nissen-Koog (Photo: Archäologisches Landesamt Schleswig-Holstein)

indications of human habitation in the Wadden Sea date from the Mesolithic. In the Danish area of the Wadden Sea, Mesolithic settlement, of more than 8,000 years ago, consists of campsites along streams, with more permanent settlements located at the former coastline, now submerged by the sea. There is widespread evidence of Neolithic settlement. For instance, de Kop van Noord Holland has particularly significant Neolithic settlement remains. In a number of locations, monuments were built on the higher moraine islands like Texel that always remained dry. There are megalithic tombs at a number of locations in Schleswig-Holstein. Similar tombs existed in Lower Saxony Most of them have been destroyed but a few examples have survived for example at Tannenhausen in Auricherland. A move to expand the useable land seems to have occurred during the later Neolithic. For instance in Lower Saxony, finds from this period have been made in areas which had not been previously exploited, such as the edges of the marshes, river valleys and fenland. A bog track leads from Tannenhausen in the direction of the Ewiges Meer in the district of Wittmund. Numerous remains of wagons provide evidence for vehicle traffic at that time.

Parts of the Danish area of the Wadden Sea region appear to have been permanently occupied from the Neolithic period on with scattered single farms on the Geest. In this area the combination of cattle farming in the marshlands and grain-growing on the Geest can be dated back to the Bronze Age 3,000 years ago. There are dense concentrations of settlements following the Geest edges, and numerous burial mounds from this period. Iron Age settlements are also widespread. It is perhaps in this Danish area that the nature of prehistoric settlement may be most easily appreciated by visitors. In Marbæk Plantage (plantation) there are two protected Iron Age dwellings where remains of the houses and paving can still be seen, and large protected field systems, called Celtic fields, from the same period. In a small heath land area north of Hjerting is a group of more than 15 protected burial mounds. Around Esbjerg a range of historic dwellings have been excavated, which show the whole development of settlements from the Neolithic to the Middle Ages.

Elsewhere, continuity of settlement can also be demonstrated, for instance on the island of Texel. Occupation appears to have been continuous there since the Middle Bronze Age, but in a number of other places there are clear discontinuities in settlement patterns. For instance on Sylt there is a multitude of extant single mounds and mound cemeteries dating from the Bronze Age to Viking Age. However, settlement seemed to cease for a while in the 5th and 6th century AD, an absence usually ascribed to migration to Britain. During the Viking Age, the island was inhabited again, presumably by Frisians from the western Wadden Sea This period is represented by cemeteries with large numbers of mounds as at Morsum Kliff. To the south in Halligen settlement is demonstrated by a number of finds dating to the late Neolithic, around 2300 BC. Hhowever, continuity of settlement on the islands can only be demonstrated from the Viking Age.

In the Carolingian and Viking periods the Dutch Frisian islands saw significant settlement. Den Burg on Texel may be a fortress of Viking origin and a Viking Age trading centre or emporium existed on Wieringen. Similarly, there are a number of significant fortifications such as the circular earthen rampart of the Tinnumburg, a fortified Viking Age settlement on Sylt, and the Bökelnburg in Süderdithmarschen which is a circular embankment on the very fringe of the high Geest. It was designed as a fortification for the northern part of the Dithmarschen in the 9th century, when it was part of the empire of Charlemagne. In the Danish area, until the 11th century AD the villages were often moved, but from the beginning of the Middle Ages most of the villages settled at a permanent location.

The fertile marshlands were important to the economic prosperity of the Wadden Sea, and sea born contacts to the west European area can be traced back to the early Iron Age. A settlement at Dankirke near Vester Vedsted probably played a central role in the trading of luxury goods from first the Roman and later the Frankish area. In burials of the 7th and 8th centuries AD, objects imported from the Saxon-Frisian and Anglo-Saxon area have been recovered.

Human occupation and the need for protection against flooding have always been closely linked in the Wadden Sea, and the need to manage flood risk has strongly influenced the form and nature of settlement. The earliest settlements were on the relatively high Geest, in areas protected by dunes and on the highest salt marshes. Settlement of the marshland began in some places during the Iron Age, but much later in other areas for instance during the Roman Iron Age in Norderdithmarschen. Dwelling mounds are one of the most characteristic settlement forms of the Wadden Sea and occur very widely. There are many examples in the Netherlands, including the well known excavated example at Ezinge. However, during the later 19th and early 20th century, the mounds in the Netherlands suffered severely from systematic removal of their fertile soil for the improvement of poor soils elswhere. Dwelling mounds are also widespread in Lower Saxony, of which the most famous one is the excavated mound of Feddersen Wierde.

The first settlements on the high salt marshes were without mounds, but rising sea levels made such locations and other low-lying areas vulnerable to flooding. Mounds were to be constructed as a response to the increased threat of flooding. In some places these mounds began to be constructed at the end of the 1st millennium BC and continued through the Roman Iron Age and into the early medieval period. The dwelling mounds, often constructed along tidal inlets or on higher marshes, vary considerably in size from single farms to entire villages. They are characteristic of the marshland and their distribution is often highly distinctive. For example in Wangerland, the mounds are aligned along the oldest areas of firm marsh land marking the fringes of the oldest settlement areas. In Schleswig-Holstein, dwelling mounds are again a highly characteristic feature. They are rather later in origin than those in the Netherlands and Lower Saxony, often occuring in rows of medieval dwelling mounds with adjacent elongated strips of land, intersected by parallel drainage ditches. In Lower Saxony and Schleswig Holstein, the mounds have not suffered the same degree of systematic destruction as in the Netherlands. Dwelling mounds also occur in the Danish part of the Wadden Sea, and include the very large mound village of Ubjerg, the most northerly Frisian settlement in the Wadden Sea.

Mound construction was essentially a means of avoiding flooding driven by rising sea levels. The construction of dykes, also driven by the need to manage flood risk, and often closely related to mound construction, began on a small scale during the Roman period in the Netherlands. Large scale dike construction began in the 11th century AD. In the Netherlands and elsewhere, the first examples were ring dikes. Such dikes are particularly numerous in Westergo. Later linear dikes, such as the long dike parallel to the coast in Süderdithmarschen, were built along the until then unprotected coast, or as extensions of the already existing ring dikes, until they linked up, as in the case of Altdeich which enclosed the whole of Wangerland. Dikes and former dikes are common and distinctive features of the Wadden Sea, the old dikes sometimes now being used as tracks and roads. The progressive construction of dikes made dwelling mounds less essential. Settlement migrated or new settlements were constructed, focussed on the dikes, or outfall sluices where a number of harbours developed. This resulted in distinctive forms of settlement; examples include the landscape of right-angle roads and drainage systems, linear villages and embankment-hedges, of Overledingen, the well preserved Aufstreck-settlements (farms, strung together, one after the other, on the flat embankments used for settlement) which were intended to secure the edge of the moorland in Brookmeland, and linear settlements, starting in the 12th/13th century on the north and east edge of the Ahlenmoor, from which the moor was cultivated by turf-cutting.

In general, the fields are closely related to settlements and often reflect changes in flood defence and land reclamation. On Texel, Terschelling and Ameland, early fields tended to be small and irregular. In a number of instances such as on Wieringen and the higher parts of Texel, where water filled ditches were not practical, field boundaries were constructed of sod banks. Similarly, there are often clear differences in settlement and land use between the higher Geest areas and lower marshland. In Wangerland, the Jever Geest with its fens, birch trees, bank hedges and tree-lined roads contrasts with the wide-open sparsely-wooded marsh landscape. Settlements often reflect successive changes in flood defence and land reclamation. Embankment hedges are characteristic features of Geest areas in Lower Saxony. In other areas, the distinction between Geest and marsh is equally distinct but quite different; in Overledinger, agriculture is concentrated on the marshes along the banks of the rivers Leda and Jümme, and the poorly drained, less fertile Geest-ridge with its bog-areas is mainly used for peat digging. This is just one example of a particular type of field system within the Wadden Sea region. The origins, history and purpose of fields and their boundaries are often complex and vary considerably throughout the region, but wherever they occur and in whatever form they are important elements of the cultural heritage and a critical part of the historic landscape character.

The successive changes in flood defence and land reclamation are often reflected in the fields. Within the marsh areas themselves there is often a clear distinction between the older marshland, which tends to have small irregular fields defined by drainage ditches oriented along irregular former tidal streams, and more modern polder constructions that were designed with an enhanced drainage system in mind, and often included the straightening of former tidal inlets and digging of new canals. Consequently the more recently reclaimed areas have more rectilinear field systems, such as the organised strip fields of the Grodenmarsch region, or the large rectilinear fields of the polders in Overledingen, and Rheiderland. This organised pattern of large rectilinear fields also characterises the extensive polders of the Dutch part of the Wadden Sea. For example polders were constructed at the islands of Texel, Terschelling, Ameland, Schiermonnikoog as well as along the mainland coast, and fields were larger and more rectilinear in form. In the first half of the 20th century, extensive reorganisation of the field systems and land re-allotment swept away much of the earlier pattern of fields on the Dutch Frisian islands and mainland and many of the traditional sod bank boundaries were destroyed in the process. Most areas of polders have different patterns of drainage ditches and other features reflecting the chronology of reclamation. For instance, there are differences in the Tønder Marshlands, in Denmark, between the outer and inner polders. The outer polders are divided by (former) sea dikes and dikes along the large streams (Vidåen) into polders of different ages. The regular pattern of dense drainage and watering ditches, divides the marsh into rectangular fenlands. The inner polders delimited by a sea dike of 1556, are characterised by embanked areas, and many medieval dwelling mounds and stream dikes are also important elements. During 1750-1850 a land reform movement was active in Denmark, part of which was the promotion of "Enclosure", which aimed to merge all plots into consolidated land holdings. This caused some damage to the old patterns of field divisions, but not to the same degree as in many other places in Denmark.

In Schleswig-Holstein, the more recent polders, like those in Nordergosharde are characterised by rectilinear and large-scale fields. In Wiedingharde, roads, drainage canals and fields are more rectilinear and large-scale in the south-east and have a totally straight and planned appearance in the far western polder. By contrast, fields in the old polders are irregular, small scale and intersected by sinuous ditches. Polders in Norderdithmarschen still reflect the original landscape with many irregular tidal inlets. In the 20th century agricultural changes have continued with the creation of larger fields driven by the Common Agricultural Policy and in Schleswig-Holstein, vast interventions in connection with the "Programm Nord" have taken place since the 1960s.

Woodland is not particularly characteristic of the Wadden Sea, but there are exceptions. In the Friesische Wehde, there were formally extensive forests. Hhowever, intensive exploitation for timber led to deforestation although some fragments still survive. In other places particularly the Dutch Wadden Sea islands, woodland has been planted for commercial exploitation and dune stabilisation. Planting took place on Ameland in the late 19th century, but most planting was undertaken in the early 20th century on the islands of Texel, Vlieland, Terschelling and Ameland.

A particularly characteristic feature of the Wadden Sea landscape, are duck decoy ponds used for the trapping of waterfowl. Such ponds are widespread in the Dutch part of the Wadden Sea. They were introduced there during the 16th century and subsequently spread to other North Sea countries. Today they are common in many parts of the Wadden Sea in the Netherlands and

Figure 3: Roter Haubarg (Photo: Archäologisches Landesamt Schleswig-Holstein)

Germany. In Denmark, they are scarce, and present on Fanø only.

The farms of the Wadden Sea region are often particularly distinctive, for instance, areas like Oldambt have many large farms with fine gardens. Many of the farms within the region are characterised by a variety of distinctive vernacular buildings. These include farmhouses with pyramid-shaped roofs, the so called 'cloche' farmhouses (*stolpboerderij*) in the Kop van Holland and Wieringen, the 'Gulf House' the "Kübbing"-houses of Krummhörn the Niederdeutsche Hallenhaus (lower German hall house) or Niedersachsenhaus (Lower Saxony house) of Land Wursten, and the four post halls of Land Würden.

Whilst the traditional economy of most of the Wadden Sea region was farming, the economic importance of the sea itself cannot be overestimated. On the islands fishing, whaling and other maritime activities were economically dominant during the 18th century. On the Dutch Frisian islands, the supply of ships with provisions and water as they waited in sheltered anchorages in the lee of the islands was a significant part of the economy. The importance of seafaring to the Wadden Sea and the treacherous nature of the sand flats and navigable channels means that structures relating to navigation are widespread. Lighthouses are a particular feature of the Frisian islands. Terschelling has the oldest surviving lighthouse in the Netherlands and the island has played a significant role in nautical history. As late as 1874 most of the mariners in the Dutch merchant navy came from Terschelling, a major naval college was established there in 1875 and institutions based on the island still have a significant role in ensuring safe navigation of the Wadden Sea.

Sea born trade was important from at least the middle of the 1st millennium AD, (and may well have been so from later prehistory). Such was the importance of water born trade and transport that harbours and wharfs were widespread. Many of the dwelling mounds had such facilities and harbours developed around sluices in sea dikes. In the Viking period, Ribe, the oldest town in Denmark, was one of the foremost trading centres in southern Scadinavia. During the medieval period, many towns including Tønder, Husum, and Meldorf were active trading ports. The Wadden Sea was a stronghold of the Hanseatic League with the Weser and the Elbe, providing access to the great trading towns of Bremen and Hamburg. The importance of ports in the region was not only linked to trade but also to military activity. The city of Den Helder lies at the southern most point of the Wadden Sea region, the town was a major naval base from the late 18th century and has a series of historic defenses from the Napoleonic period onward. Ports were developed at a number of coastal locations in the 19th century including Glückstadt, and Esbjerg, and a major naval base was created at Wilhelmshaven, now somewhat in decline and seeking opportunities for regeneration.

The mouths of the Weser and Elbe have been much altered particularly during the 19th and 20th centuries to facilitate their role as major transport routes. By contrast the Varde Stream Estuary in Denmark is the best example in the entire Wadden Sea region of a non-embanked river mouth where the marsh processes are still ongoing. Numerous watercourses both natural and manmade were for centuries the main means of transportation. Although water transport is now largely superseded by road transport, the road and rail network is not well developed by modern standards and the area is not particularly well served by major roads. Den Helder is served by two major roads, and a main railway line makes this area one of the better connected parts of the Dutch Wadden Sea area. The construction of the Kiel Canal at the end of the 19th century had a significant impact on the southern part of Schleswig-Holstein. In the 21st century it is likely that major infrastructure projects in some parts of the Wadden Sea may have similar effects. Historically wind power has been of significance throughout the Wadden Sea and historic windmills are features of many parts of the region. However, over the last 20 years or so large industrial scale wind power generators have become common in many parts of the area, and have had and will continue to have a significant impact.

Tourism began to develop in the late 18th and early 19th centuries as part of a wider European fashion for sea bathing. The development of spa and bathing facilities particularly affected the Wadden Sea islands. Later in the 19th century and in the early 20th century, mass tourism developed. For instance Norderney grew to become the most prominent seaside resort in the new German Empire, whilst on Sylt, the foundation of a spa in the village of Westerland in 1855, triggered a rapid and massive landscape change which has lasted until today. In the Danish part of the Wadden Sea, the Ribe tourist association was founded in 1899, aiming, through its work of preservation of the old houses, to promote the town as an important tourist attraction. Many recreational cottages are located north and west of Esbjerg and in the 1900s the dunes and beaches near Blåvand began to attract townspeople and tourists. During the 20th century tourism became a major activity in the Wadden Sea region and now, on the Dutch Frisian islands, more than 40% of employment is related to tourism. Tourism has historically been concentrated on the coast and particularly on the islands, and despite the development, particularly in the second half of the 20th century, of a broader interest in the marshland landscapes and towns of the mainland this remains the case. Sylt is probably still the place with the highest number of tourists in the Wadden Sea. However, the immense impact and importance of tourism in the region may be illustrated by the fact that Neuwerk, with a permanent population of about 40 people, caters for around 120,000 visitors per year.

2. Potentials and Vulnerabilities

The variety and diversity of the cultural heritage reflects the historical interaction of human activity and a changing natural environment. The cultural heritage is a central resource for modern life. It has a powerful influence on peoples' sense of identity and civic pride. Its enduring physical presence contributes significantly to the character and 'sense of place' of rural and urban environments. In the Wadden Sea, this resource is rich, complex and irreplaceable; it has great potential both with regard to its intrinsic worth and its role in economic development. As a critical aspect of the region's environmental infrastructure the cultural heritage has a major role to play in the future of the Wadden Sea.

The fundamental and most valuable potential is the variety of cultural landscapes and heritage. The individual monuments, sites and other cultural elements are each intrinsically significant, but added value is provided by their interrelationships and context in space and time. This creates cultural ensembles or cultural environments of greater value than a number of unrelated or poorly integrated individual sites or elements.

Conservation of biodiversity provides significant cultural and social benefits for the Wadden Sea Region. The maintenance of high biodiversity value will often require the maintenance of a rich diversity in the cultural landscape. Conservation and enhancement of the natural and cultural landscape can thus be a symbiotic process which can be used to enhance people's appreciation of the region as a place to live and work in or to visit. However, in order to achieve the full benefits of this potential and minimise conflicts of interest, it is necessary to have an integrated approach to the natural and cultural heritage.

A sound awareness among the local people, stakeholders and politicians about cultural heritage values in the region is vital for the preservation, development and sustainable use of the heritage. Awareness and understanding is a precondition for managing development in a sustainable fashion, which values the heritage, and which will create a strong sense of place for local people and visitors. Closely linked to this are access and cultural tourism. Easy and appropriate accessibility is a precondition for further development of cultural tourism, which is an important economic factor in the rural area of the Wadden Sea Region. Good accessibility to cultural environments and ensembles through foot paths or cycling routes, especially if these are historic route ways, can in itself enhance awareness. This could be further developed through education and training programs. Furthermore, accessibility which is sustainable maintains the cultural heritage and landscape, enhancing people's sense of place and making the area a desirable place to live. Cultural tourism, developed in respect to the assets and treasures of our cultural heritage, can and should be a major contribution to the conservation of the cultural heritage and the economic wellbeing of the region. The openness of the landscape, the significance of historic settlements and trade, characteristic agricultural features, the remains of the different ways people have coped with and defended themselves from the threat of flooding, together with other sites and activities traditional to the region, are all attractive to visitors.

However, the cultural heritage is sensitive to change, and in the Wadden Sea Region it is under pressure from structural changes, often driven by issues at national, European or even global level, leading to rapid transformation. The pressures are mainly caused by economic development across all relevant sectors but also by changes in the natural environment, notably sea-level rise and global warming. Careful consideration is required as change is planned in order to ensure that the cultural heritage can be part of a sustainable future for the Wadden Sea Region.

Farming in the EU has evolved into a high-tech industry employing less than 5% of the population. When the common agricultural policy (CAP) was introduced, the aim was to increase food production, and support schemes were established to achieve this. The aims of the CAP together with the resulting industrialisation of agriculture could threaten the diversity of cultural landscapes, the accessibility to valuable landscapes and the conservation of unique heritage elements. Whilst this is still a matter of concern, a recent trend to move from payments subsidising production to payment for environmental stewardship offers an opportunity to develop enhanced conservation of, and access, to cultural heritage and landscapes.

In order to maintain the area as a place that people wish to live in with a viable economy, modern facilities including housing and adequate transport infrastructure are necessary. This inevitably requires development in and around towns and villages leading to potentially adverse impacts on the cultural landscape and heritage. Impacts may affect particular sites and locations, but there may also be a cumulative affect on valuable ensembles and cultural environments. Only well informed and carefully considered spatial and physical planning can secure the cultural heritage values while meeting the needs of new settlement and industrial areas as well as of the related infrastructure. Accordingly spatial planning has a central role in balancing these competing claims and delivering necessary change in a sustainable manner.

Population change, although less obvious than physical change, is nonetheless important in its effects on the cultural heritage. Demography and other social parameters such as unemployment rates, housing markets and mobility and patterns of commuting have effects on the cultural heritage and its maintenance. Living conditions change due to migration to and from rural areas like the Wadden Sea Region and influence the need for infrastructure. A declining population level in the region could threaten the local quality of life (liveability), sense of belonging, awareness of, and care for, the cultural values.

Energy development plays an important role in the Wadden Sea Region. The strategy of developing the region as a hub for renewable energy production such as wind and solar generated energy in particular will tremendously effect the cultural landscape and its perception. Energy production parks are large scale constructions with effects on space, landscape structures, openness and the cultural heritage. As such, here again careful planning will be particularly important.

In many ways spatial planning is the most important instrument to conserve and enhance cultural heritage and landscape values. Planning is also a central instrument for a sustainable use of the heritage integrated with the various economic requirements for regional development. A vulnerability in this respect is that the valuable cultural issues are not deeply integrated on the legal and management level; a comprehensive consideration of the cultural landscape heritage in physical planning is not guaranteed. The cultural entities may prove particularly valuable in addressing this issue as a means of engagement with planners and others, and as a means of moving from a site-based to a character-based approach in strategic planning for the cultural heritage.

Future Directions

The cultural entities have been created and described primarily to serve as a tool to enhance understanding, conservation and management of the cultural heritage in general and landscapes in particular. They reveal the scale, diversity and value of the cultural heritage of the Wadden Sea region.

The characterisation provided by the cultural entities can provide the starting point for more effective incorporation of cultural heritage within spatial planning and for better integration of nature conservation and heritage conservation. The cultural entities will allow planners, with appropriate support and advice from specialists, to integrate the protection, promotion and management of the cultural heritage into spatial plans. In this regard their greatest advantage is that they enable a move away from a site-based approach to the cultural heritage. Given the complexity of the cultural heritage and the importance of cultural ensembles, a more holistic, character-based approach, can be more effective, particularly in highlighting the need for communication and co-ordination between appropriate services. In addition to use, by professionals, the cultural entities may provide a means of engaging the wider public with understanding and conserving the cultural heritage.

As a matter of principle, it may be suggested that environmental protection and enhancement, valuing natural and historic assets and ensuring change, is sustainable. The cultural entities can play a role in putting that principle into effect as they provide a strategic overview of the cultural heritage of the Wadden Sea region. Set out below are suggested general ways in which they could be used and developed.

3. Managing landscape and cultural heritage

Figure 4: Ballum Vesterende, DK (Photo: Svend Tougaard)

3. Managing the landscape and cultural heritage: the overarching approach

The management of the cultural and landscape heritage of the Wadden Sea Region is a complex issue. In the following section targets are identified for the preservation and conservation of the historic landscape and the primary management principles described. Vision 2020 which states the importance of the characteristics and cultural history of the Wadden See Region is restated. Following on from this, a range of strategies are presented and potential obstacles identified. Policies are also identified which will provide guidance on how the cultural heritage should be integrated into existing planning and conservation documents and strategies. Finally a number of projects are outlined which will address specific issues to promote the cultural heritage of the Wadden Sea area.

Managing our Cultural and Landscape Heritage

Spatial planning is the most important tool for the conservation and enhancement of cultural heritage and landscape values. Planning is also a central instrument for a sustainable use of the heritage integrated with the various economic requirements for regional development. A vulnerability in this respect is that the valuable cultural issues are not deeply integrated at the legal and management level, and a comprehensive consideration of the cultural landscape heritage in physical planning is therefore not guaranteed. The cultural entities may prove particularly valuable in addressing this issue as a means of engagement with planners and others, and as a means of moving from a site-based to a character-based approach in strategic planning for the cultural heritage.

Monitoring has become - in all environment relevant planning procedures - an important means of assessing the outcome and effectiveness of decided measures. The application of monitoring techniques on issues concerning the cultural landscape in the Wadden Sea Region is however still not widely spread, and therefore shortcomings in actual planning procedures are not sufficiently reflected, discussed and eliminated.

Points of Departure

Targets for the landscape and cultural heritage were adopted at the 7th Ministerial Conference on the Protection of the Wadden Sea held in Leeuwarden in 1994 (Leeuwarden Declaration) and implemented in common policies and projects within the Wadden Sea Plan adopted at the 1997 Stade Conference. These were complemented with management principles adopted at the 9th Ministerial Conference held in Esbjerg in 2001 (Esbjerg Declaration). These Targets and Management Principles remain the starting points for the trilateral approach on the landscape and cultural heritage of the Wadden Sea Region.

Targets Landscape and Culture (Leeuwarden 1994/Wadden Sea Plan 1997)

- To preserve, restore and develop the elements that contribute to the character, or identity, of the landscape. (*Identity*)
- To maintain the full variety of cultural landscapes, typical of the Wadden Sea landscape. (*Variety*)
- To conserve the cultural-historic heritage. (*History*)

- To pay special attention to the environmental perception of the landscape and the cultural-historic contributions in the context of management and planning. (*Scenery*)

Management Principles (Esbjerg 2001)

- Managed development of the heritage.
- Use of the landscape and cultural heritage as an opportunity.
- Involvement of stakeholders in the management.
- Integration of policy and management of the natural and cultural environment.
- Enhancement of the awareness of the landscape and cultural heritage.

3.1 Vision 2020

Within the Lancewad project a vision has been stated, in image-terms to inspire the long- term protection by development of the landscape and cultural heritage of the Wadden Sea Region:

"For more then 2000 years, the landscape and cultural heritage of the Wadden Sea Region has displayed the richness of the specific nature of the Wadden Sea and the unique interaction with man to its full extent. The overall landscape characteristics entail the wide open skies, the straight horizons, the clear transition between sea and land, the notion of being engulfed by nature on the seaside; and on the landside, the dwelling mounds, dykes and the settlements as green oases in the open fields. In the inhabited areas, the different characteristics of the landscape and cultural heritage of the several sub-regions can be clearly distinguished. The cultural heritage is well kept and (re)used. New developments show new faces into the "old portraits" enriching them and telling the continuing story of living in the Wadden Sea Region, a landscape of world-uniqueness.

The vision can be translated into the following process-terms:

(1) Preserve the identity, variety, history and the scenery of the landscape and cultural heritage of the Wadden Sea Region as a coherent heritage which will be reflected as a common responsibility of the appropriate authorities of the three countries.

(2) Manage and use the landscape and cultural heritage of the Wadden Sea Region in a sustainable way, as one coherent natural and cultural landscape heritage in a land-sea interface in respect of the specific facets of each of the landscape types by making it an integrated part of coastal management.

(3) Enhance the awareness of the unique landscape and cultural heritage of the Wadden Sea Region, supporting the targets of the trilateral Wadden Sea cooperation, and making use of the opportunities the heritage assets provides to strengthen the region through a single coherent awareness program.

3.2 Strategies for the near future

(1) To identify and evaluate the landscape and cultural heritage in a coherent way with a view to fully understand its outstanding international value.

(2) To apply the international and national legal instruments for the conservation, management and sustainable use of the heritage in a coordinated way for the coherent management of the heritage across the Region.

(3) To integrate the landscape and cultural heritage of the Wadden Sea Region within spatial planning on a national, regional and local level that corresponds to its unique

Figure 5: Megalith grave (Photo Jan-Joost Assendorp)

qualities. Using planning to strengthen the spatial qualities of the landscape and its cultural historic elements in order to support the regional development of the land-sea interface.

(4) To develop appropriate landscape assessment tools in order to better understand the various values of the landscape character and to provide support in decision making.

(5) To increase the awareness of the heritage and landscape assets among all relevant politicians, organizations, the regional and local public, also through the empowerment of the local communities and within an international context.

(6) To improve the work with the cultural heritage in the Wadden Sea Region on an international level. This includes trans-national cross border co-operation to work with cultural values and create awareness of the Wadden Sea Region. In this respect, the experience from nature protection can be used.

(7) To create added value for the Wadden Sea Region regarding ensuring and promoting the common cultural history, particularly with the support of public institutions.

(8) Exchanging information by the utilisation of modern communication techniques. Spatial planning, as well as the evaluation of potentials and assets e.g. by nature conservation and cultural heritage management, require the information stored in different databases and GIS-systems in order to produce results integrating all issues. Harmonisation, interfaces and mutual platforms and formats are therefore essential tools.

(9) Implementation of suitable financial instruments and adaptation of existing funds to the requirements of integrated landscape management.

4. Conclusions

Figure 6: Church on dwelling mound, Zetel, Lower Saxony (Photo Henning Haßmann)

There is no doubt that the Wadden Sea Region is a jewel with its unique character and quality of the cultural heritage and historic landscape. The adoption and implementation of the strategy will be a major step forward in the protection and management of this unique resource. As part of this implementation it will be essential to widen the understanding of the cultural heritage amongst people that live in or visit the region, whilst also making the strategy an integrated part of planning and conservation management at national, regional and local level.

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Coastal Defence

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and Sea Level Rise (CPSL)

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3.1 Coastal Defence

Coastal defence aims to safeguard coastal lowlands, their inhabitants and economic assets against the forces of the sea. It consists of coastal flood defence (protection against flooding) and coastal protection (protection against structural erosion and land loss).

This chapter concentrates on new developments in coastal defence since 2005. For a more compre-hensive overview of national responsibilities and measures, the reader is referred to the 1999 and 2005 Wadden Sea Quality Status Reports and to the fist report of the trilateral working group 'Coastal Protection and Sea Level Rise' (CPSL, 2001).

With respect to the organisation of coastal defence, the period since the last Quality Status Report was characterized by merging of national and regional responsible administrations. For example, a number of institutions and departments with coastal responsibilities merged into "Waterdienst" (water service) and "Deltares" in the Netherlands in 2007. In Schleswig-Holstein, the "Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz" (State Agency for Coastal Defence, National Park and Marine Conservation) was founded in 2008 by mergence of three coastal institutions. The responsibil-ity for coastal defence in the Danish Wadden Sea was transferred from the districts to the four newly grounded municipalities in the region. For coordination, the municipalities founded a common secretariat in 2008.

Major developments with relevance for coastal defence in the Wadden Sea since 2005 have been the publication of the fourth report on climate change by IPCC in 2007 (see Oost *et al.*, 2009), the adoption of a Directive on the Assessment and Management of Flood Risks (Flood Directive) by the European Un-ion in 2007 (see Oost *et al.*, 2009), and the continuing work of the trilateral working group on "Coastal Protection and Sea Level Rise" (CPSL).

The EU-Flood Directive prescribes the member states to conduct a number of actions with respect to (coastal and inland) flood risk management). Based upon a preliminary assessment of flood risks (in-cluding climate change aspects), the states shall define areas with a potential significant flood risk by the end of 2011. For these areas, flood hazard and flood risk maps shall be established by the end of 2013. Finally, by the end of 2015, flood risk management plans shall be established.

The hazard maps delineate the risk areas that could potentially be flooded with low, medium and high probability. Member States may decide that, for coastal areas where an adequate level of protection is in place, the preparation of flood hazard maps shall be limited to the scenario "floods with a low probability, or extreme event scenarios". The risk maps include vulnerability indicators like number of inhabitants and land utilization types. In the management plans, the EU member states shall establish appropriate objectives and measures for the management of flood risks. The plans shall take into account relevant aspects such as costs and benefits as well as the environmental objectives of the Water Framework Directive. Finally, the management plans shall address all aspects of flood risk management (Fig.ure 1), focusing on prevention, protection, preparedness, and taking into account the characteristics of the particular river basin or coastal stretch (*i.e.*, tailor-made solutions). In consequence, the Directive does not only focus on technical protective measures, but considers non-structural efforts to reduce the vulnerability against flooding (*i.e.*, prevention by spatial planning, see below) as well.

The trilateral expert group CPSL was established in 1999 as an output of the 8th Trilateral Governmental Conference on the protection of the Wadden Sea. The group was installed with the merit to investigate the possible effects of enhanced sea level rise and, on the basis of this study, develop proposals for sustainable coastal protection. The solutions should, in the long term, help maintaining the existing safety standards and anticipate the expected impacts of sea level rise. At the same time, they should, at least, not

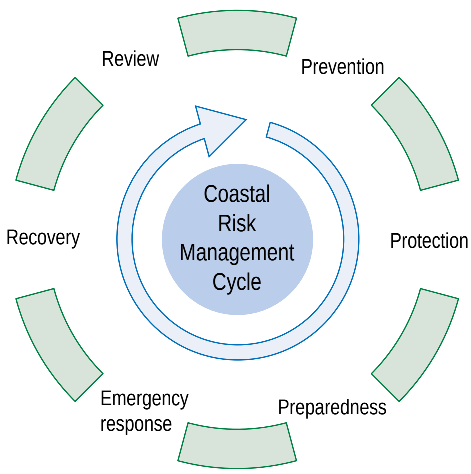

Figure 1: The coastal risk management cycle (adopted from Hofstede 2007)

be negative for natural assets, such as natural dynamics and habitat quality.

In a first phase (1998 – 2001), the CPSL established a common understanding of the Wadden Sea (geomorphology, biology and coastal protection). For three sea level rise scenarios, the impact upon physical, biological, and socio-economic parameters was investigated. Further, a first screening of possible coastal protection measures to secure present safety standards in the future was conducted. The results were published in a report (CPSL, 2001), and presented at the 9th Trilateral Governmental Conference in 2001. Recognizing the high topicality and exigency of sustainable strategies, the ministers decided to continue the work of CPSL.

In this second phase (2002 - 2005), the expert group conducted ad-hoc feasibility studies of seven promising and/or important options to reduce coastal risks: "spatial planning", "sand nourishment", "dune management", "salt marsh management", "mussel beds and sea grass fields", and "sea dikes". In its report (CPSL, 2005), the group established, amongst others, two recommendations on spatial planning and sand nourishment. At the 10th Trilateral Governmental Conference in 2005, the delegations as well as invited NGOs welcomed the report, and agreed to seriously consider the recommendations within the revision of the Wadden Sea Plan in the forthcoming period. Further, it was decided that competent authorities (coastal protection, nature conservation and spatial planning) will support the continuation of the CPSL work group with the following tasks: 1) to initiate a study on the feasibility of coastal spatial plans and measures that consider climate change, and 2) to investigate the possibilities of a study on the feasibility and effects of sand nourishment to balance the sediment deficit of the Wadden Sea tidal basins under increased sea level rise. These studies that may support the implementation of the Flood Directive in the Wadden Sea region are in progress. The results will be presented at the 11th Trilateral Governmental Conference in March 2010 (CPSL, 2010).

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Harbors and Shipping

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3.2 Harbors and Shipping

3.2.1 Introduction

The Wadden Sea is adjacent to several of the busiest shipping routes in the world, additionally both within and close to the Wadden Sea are some of Northern Europe's largest ports which have both an international significance and are of great economic importance for the region. Major ports within the Wadden Sea area are the ports of Hamburg and Bremen/Bremerhaven, both of which were listed in the top twenty of the world's busiest container ports in 2008 (UNCTAD, 2009), as well as the major oil refinery and port of Wilhelmshaven and the port of Esbjerg in Denmark. Furthermore the Wadden Sea has many smaller ports operating short sea shipping and ferry services to the fringing islands, as well as supplying the needs of the fast growing offshore energy industry in the region. Routes through and in the vicinity of the Wadden Sea are also used as an access point to the Baltic Sea, by vessels transiting coastwise or by those using the Kiel Canal.

Shipping is considered as one of the most beneficial and environmentally friendly forms of international transport when compared on a tonne/mile shipped basis with air, rail and road. However shipping still has impacts on the marine environment due to operational factors which include oil, sewage, garbage and air pollution, and potential risks from incidents such as collisions and grounding. Measures have been put in place by both the IMO and the European Union (EU) to limit the impact of pollution threats, for example by capping the levels of oxides of Sulphur (SOx) and Nitrogen (NOx) released within ships exhaust gases, to improve air quality through the adoption of Annex VI of the MARPOL 73/78 Convention.

3.2.2 Traffic density

Due to the high density of traffic in the German Bight the International Maritime Organisation (IMO) established, in cooperation with the German government, a traffic separation scheme in order to control the flow and direction of the transiting vessels. Furthermore a deep water route was established for vessels with deep draughts and vessels carrying dangerous goods, located approximately 27 nautical miles from the German coast, allowing for greater coastal protection in the event of an accident or incident. Over the past few years the number of commercial vessels within the area has increased, in line with the global trend where it can be said that "globalisation has caused maritime traffic to surge in the past years" (Hamburg Port Authority, 2008).

Figure 1 illustrates the density of shipping traffic in the North Sea, the highest volumes of traffic being depicted by the thicker red lines. From this can be seen that the Wadden Sea is adjacent to one of the most heavily transited areas of the North Sea, with high volumes of traffic also evident in the estuaries of the major rivers that flow into the Wadden Sea as well as the Kiel Canal

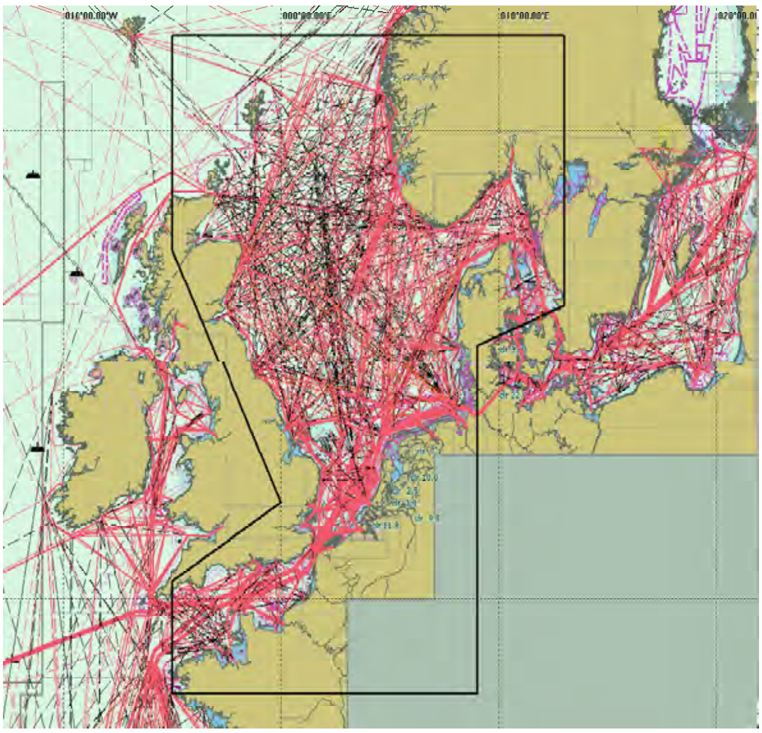


Figure 1: Shipping Traffic in the North Sea (OSPAR, 2010).

which links the North and Baltic Seas.

It is estimated that the North Sea has around 260,000 ship movements per year, which makes it one of the busiest sea basins in the world. Furthermore it is estimated that this figure will grow by between 14-31% over the coming years (North Sea Commission, 2009). Since the *Pallas* incident of 1998, shipping incident data for the Wadden Sea countries show no major pollution incidents within and immediately adjacent to Wadden Sea area. However, whilst not causing major pollution, several accidents and collisions have been reported in the area adjacent to the Wadden Sea, both within and adjacent to the Traffic Separation Schemes adjacent to the Wadden Sea.

3.2.3 The Wadden Sea PSSA

"A PSSA is an area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities" (Resolution A.982 (24)).

The International Maritime Organisation's (IMO) Marine Environment Protection Committee (MEPC) designated major parts of the Dutch, German and Danish Wadden Sea as a Particularly Sensitive Sea Area (PSSA) in October 2002 (MEPC, 2002). The PSSA consists of the marine area of the Wadden Sea Conservation Area, being the Wadden Sea National Parks in Germany and the Wadden Sea Nature Protection areas in Denmark and the Netherlands (Figure 2), which covers an area of approximately 12,000 km^2. The designation of the Wadden Sea PSSA was formally recognised at the Schiermonnikoog Conference in 2005, in which Ministers declared their determination to protect the Wadden Sea from negative impacts from shipping (§14 Schiermonnikoog Declaration).

The purpose of a PSSA is to protect an area which has *significance for recognized ecological, socio-economic, or scientific attributes* and which may be vulnerable to damage by international shipping. Protection for the area is through adoption of IMO recognised Associated Protective Measures (APMs), which should address the vulnerability in such a way as to protect, reduce or eliminate the risk posed by international shipping (IMO Resolution A.982 (24)).

The application for the Wadden Sea PSSA included two Associated Protective Measures (APMs), which were the German Bight Traffic Separation Scheme and the Deep Water Route, these are located outside but adjacent to the boundaries of the PSSA.

The PSSA concept is not supposed to limit international shipping but to increase awareness of the areas sensitivity and hence reduce the impact international shipping has on the area.

Since the Wadden Sea PSSA designation in

Figure 2: Boundaries of the Wadden Sea PSSA (Marencic & Essink, 2004).

2002, the International and European communities have introduced several important pieces of legislation aimed at protecting the environment from shipping activities. These policies have and will continue to improve both the standard and safety of shipping, thereby reducing their potential negative impact on the marine environment. For the Wadden Sea, amendments to existing legislation and the introduction of new legislation should also improve the quality of the marine environment. Furthermore the development of the EU Integrated Maritime Policy will assist with bringing countries coastal policies in line with each other, thus encouraging and enabling them to develop further policies together specifically aimed at protecting vulnerable areas such as the Wadden Sea.

Integrated Maritime Policy

In 2007 the EU Commission presented its vision for an Integrated Maritime Policy for Member States, two years on they have made progress with several projects under way. "In its strategic objectives for 2005-2009 the Commission declared the particular need for an all-embracing maritime policy aimed at developing a thriving maritime economy, in an environmental sustainable manner. Such a policy should be supported by excellence in marine scientific research, technology and innovation" (Van Houdt, 2008).

The Integrated Maritime Policy "will encompass all aspects of the oceans and seas in a holistic, integrated approach," where the Commission "will no longer look only at compartmentalised maritime activities, but... will tackle all economic and sustainable development aspects of the oceans and seas, including the marine environment, in an overarching fashion" (Commission of the European Communities, 2007). There is a further aim to "develop policies and legislative proposals that are coherent and mutually compatible" (Commission of the European Communities, 2007, p6), which would bring all Member States in line with one another. The establishment of united policies and inter-linking between industry (economic) and environment will strengthen the sustainability of Europe's maritime sector.

The European Commission have also established a European Maritime Day, which will inform and update stakeholders of progress that has been made amongst the maritime community, the first of these annual events to be held in 2010.

3.2.4 Ports in the Wadden Sea Region

The ports in the Wadden Sea area specialise in specific cargoes as well as having multi functional ports which have the capacity for all types of goods. The three major ports are Hamburg, Bremen/Bremerhaven and Wilhelmshaven including the new deep-water port project at the Jade Bay. Hamburg and Bremen/Bremerhaven are both in the top twenty for container transition amongst container ports worldwide and in 2008 were ranked 11th and 19th , there are only four European ports in the top twenty with the other two being Rotterdam ranked 9th and Antwerp ranked 13th (UNCTAD, 2009). Wilhelmshaven is one of the largest oil terminals importing crude oil into Europe. Smaller ports which are more specialised include Emden, Eemshaven, Delzijl, Harlingen and Brunsbüttel. Esbjerg is the only Danish port in the Wadden Sea. In 2007 it was recorded in the port of Hamburg that there were 40,000 shipping movements, (Hamburg Port Authority, 2007) this figure does not include any recreational or inland vessels.

The Northern Range ports, which include the main Wadden Sea ports, have generally seen the volumes of cargo handled increasing year on year, however the first three quarters of 2009 have seen a slight decrease in the amount of cargo handled,

Port	2004	2005	2006	2007	2008	2009 1st, 2nd & 3rd Quarters	Specialization Categories of Cargo
Hamburg[1]	114,484	125,743	134,861	140,381	140,375	82,774	Containers, food, ore, coal, chemical
Bremen / Bremerhaven[2]	52,319	54,190	64,556	69,095	74,525	45,462	Containers, cars, food/fish, steel
Wilhelmshaven[3]			44,470	41,590	40,512	18,373	Oil, coal, chemical
Esbjerg[4]	3,997	4,007	4,339	4,589			Containers, fish
Defzijl[5]	5,991	5,958	6,137	6,062	5,781		Coal, salt, food
Eemshaven[5]	617	1,143	1,584	1,743	2,187		Coal, salt, food
Harlingen[6]				3298	2582		Salt, potatoes, sand, gravel

Table 1: Total Cargo Handled 2004-2009 (in 1000 tons). Data from Hamburg Port Authority[1], Die Bremische Häfen[2], ISL Shipping Statistics Reports between 2007 -2009[3] (ISL, 2007a, ISL, 2009a, ISL, 2009b), Port of Esbjerg[4] (n.d.), Groningen Seaports[5] (n.d.), and Harlingen Seaport[6] (n.d.).

Table 2:
Total TEUs Handled 2004–2009. Data from Hamburg Port Authority 2008 report, ISL Shipping Statistics 2007 –2009 and Harlingen Seaport (n.d.).

Year	2004	2005	2006	2007	2008	2009 1st & 2nd Quarter
Port						
Hamburg	7,003,479	8,087,545	8,861,804	9,889,792	9,737,110	3,550,000
Bremen / Bremer-haven	3,469,253	3,735,574	4,444,389	4,444,389	5,529,159	2151000
Wilhelmshaven	43,032	2,681	--	--	--	--
Cuxhaven	32,000	37,660	68,354	63,808	63,271	--
Emden	1,000	426	204	51	--	--
Harlingen				14388	13864	

due to the economic downtown and reduced imports from the Far East. This decrease in cargo turnover started in the 4th quarter of 2008 as the "world economy experienced a sharp downward lurch in the course of the second half of 2008, caused in particular by the global financial crisis which also had a negative impact on turnover rates, in particular in the 4th quarter of 2008" (Hamburg Port Authority, 2008).

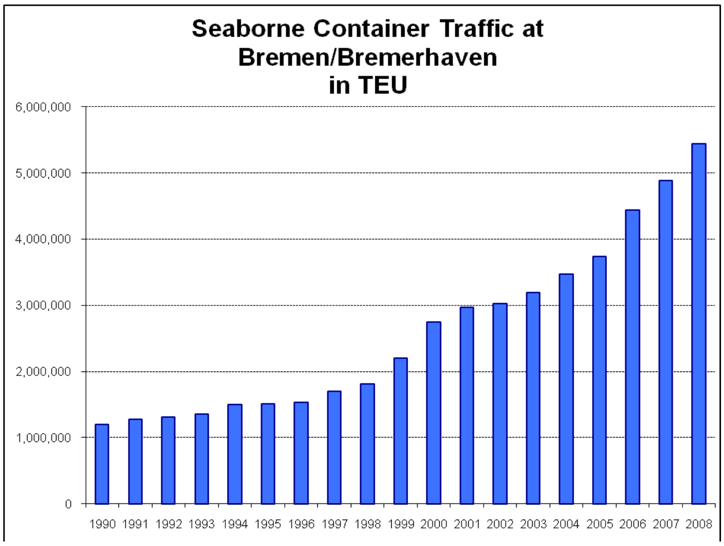
Table 1 shows a dramatic increase for cargo handled in Hamburg between 2006 and 2007, however all three ports have significantly reduced cargo handling figures for the first three quarters of 2009. Since 2006 there has been a small but steady decrease in volumes transported through Wilhelmshaven, which may be associated with operational changes at the refinery.

Table 2 shows a dramatic increase between 2006 and 2007 in the number of TEU's handled in the port of Hamburg, however in 2008 the number of TEU handled at Bremen/Bremerhaven ports increased whilst those in Hamburg decreased. The port of Hamburg has achieved high container handling figures in the past due to a high level of trade with Asia, however in the second half of 2008 this turned out to be a disadvantage, "as Hamburg was hit worse by Asia's economic weakness than the competing ports along the northern range" (Hamburg Port Authority, 2008). If 2009 follows the pattern of the first two quarters there will a decrease in the amount of cargo handled by both Hamburg and the Bremen ports.

Over recent years container ports across the global have seen an increase in the number of containers handled, this trend is reflected in the Wadden Sea container ports, figure 3 demonstrates the increase in container traffic experienced by the ports of Bremen over the past 19 years. This trend is set to increase with future developments of both ports within the area and the development of new container vessels.

The Dutch ports of Delfzijl and Eemshaven are located on the estuary of the River Ems and cater for both sea going and inland waterway traffic and

Figure 3:
Seaborne Container Traffic at Bremen/Bremerhaven in TEUs (The Ports of Bremen/ Bremerhaven, 2008).



a variety of cargos which includes bulk, ConRo and RoRo. In 2008 cargo throughput for the Groningen Seaports (Ewmshaven and Delfzijl) reached over 7.9 million tons (Groningen Seaports, n.d). The port of Eemshaven saw a major increase in amount of cargo handled between 2004 and 2005 and since then total volume of cargo has increased year on year; however there has been a slight decrease in cargo handled through Delfzijl since 2006.

Esbjerg is the only large Danish port located in the Wadden Sea area; this is a multi functional port, handling a wide variety of cargoes. Since 2004 there has been a steady yearly increase in the total amount of cargo handled. The two areas which have seen the most growth since 2004 are Fossil fuels and Container goods.

The maritime industry has a significant economic importance for the Wadden Sea area and Germany as a whole, in terms of both revenue and employment figures. The 2008 Hamburg Port Authority annual report shows that across the whole of Germany 267,000 jobs are either directly or indirectly dependent on the port, of which 167,000 jobs are in the Hamburg metropolitan region (Hamburg Port Authority Annual Report 2008).

3.2.5 Trends and developments of the Wadden Sea ports

In 2007 a maritime transport forecast carried out for the German Government states that the overall quantity of cargo handled is expected to rise from its 2004 figures of 793 million tonnes to 1,658 million tonnes in 2025; furthermore the highest growth rates are expected to be seen at Bremerhaven with an annual increase of 5.8% and Hamburg with an annual increase of 5.3% (PLANCO, 2007). This growth at Bremerhaven port will make it “Germany’s second largest seaport by 2025” (PLANCO, 2007) with Hamburg remaining the largest, disregarding unforseen peaks at the new Jade-Weser Port container port. Additionally, Hamburg is expected to grow at a faster rate than Rotterdam and it is suggested that by 2025 Hamburg will handle around 50% of Rotterdam’s annual handling figures. Container handling is also set to increase and will see a higher rate of growth than total volume of cargo handled, with Hamburg and Bremerhaven having growth rates of 6.7% and 6.0% respectively (PLANCO, 2007). Evidence would suggest that the trend of an overall increase in cargo throughput across all the major ports in the Wadden Sea area will continue particularly when taking account of major development projects.

The Jade-Weser container port at Wilhelmshaven is well under construction and set to be commissioned in the autumn of 2011. When completed this will be one of the thee ports in Germany that are capable of handling the Maersk ‘E’ class container vessels. The port and its approaches have been dredged to 18m, making it one of the deepest ports in the North-Range. The Jade-Weser Container port “will have at its first level of completion a capacity of 2.7 million TEU” (ISL, 2007b) and its 1.7 kilometre quay will be able to accommodate the largest of vessels at its four berths.

The Port of Hamburg has also planned several extensions to cope with its increased traffic, some of which are due for completion in 2010, these will increase Hamburg Port capacity to about 13 million TEUs (ISL, 2007b), according to the Hamburg Port Authority the handling capacity is expected to increase to 18 million TEU by 2015 (Hurtienne, n.d.). There is also a further terminal planned within the Port of Hamburg called Container Terminal Moorburg which will be located close to the existing Altenwerder terminal, “however this is envisaged as a long-term project to be realised after 2015” (ISL, 2007b). The Ports of Bremen and Bremerhaven have no planned extensions, primarily due to geographical location, as the last extension brought the port to the border of the Federal State of Bremen.

Recent developments for the Groningen seaports include the extension of the deep sea bulk quay and the completion of Beatrixhaven in Eemshaven which was built to serve the increase in short sea trade (Groningen Seaports 2010). In 2008 the port of Esbjerg received funding from the EU under the Trans European Transport Network Executive Agency (TEN-T) Motorway of the Seas programme to provide an intermodal alternative to truck transport between Esbjerg and the Benelux countries. The project is expected to double the capacity of the RoRo connection between Zeebrugge and Esbjerg. A further aim of the project is to further develop the Benelux-Scandinavia short sea bridge. (Esbjerg Ten-T, 2008). The project is due for completion by the end of 2012.

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Fisheries

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2009
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3.3.1 Introduction

The Wadden Sea Area harbours rich stocks of shellfish, and shrimps of marketable size are abundant in the subtidal areas. The main fisheries are for brown shrimps (*Crangon crangon*) and blue mussels (*Mytilus edulis*). Additionally, there is small scale fishery on cockles (*Cerastoderma edule*), and there is a local fishery with fixed nets and tow nets.

Aquaculture is carried out in two ways: There is one oyster culture (*Crassostrea gigas*) on the island of Sylt, and blue mussels are grown on a large number of culture lots in the Netherlands, Lower Saxony and Schleswig-Holstein.

The following chapters give an overview of recent developments of the national shellfish policies in the trilateral Wadden Sea since 2004 and an update of the landings of blue mussels and cockles, as well as shrimps (Facts and figures see Table 3.5.1).

A more detailed analysis of the fisheries' sector of the Wadden Sea region with emphasis on the economic aspects has been compiled by the Wadden Sea Forum Report (Prognos, 2004).

An overview of all (small scale) fisheries in the Dutch part of the Wadden Sea is given in a (Dutch) report from Wageningen IMARES (Overzee *et al.*, 2008).

An overview of fishing activities in the whole North Sea together with an assessment of fish stocks is given in the Quality Status Report by the OSPAR Commission (OSPAR, 2000) and ICES (2004). A new OSPAR QSR is under preparation for 2010.

The framework for the coastal fisheries (off the 3 sm line) is given by the Common Fishery Policy of the European Union.

3.3.2 Blue mussel fisheries

Fisheries of blue mussels have been regulated in all countries with regard to the amount of permits, size of culture lots, fishing periods and other regulations (see Figure 3.3.1 and Table 3.3.1). To protect intertidal mussel beds, considerable parts of the Wadden Sea Area have been closed for blue mussel fisheries. In The Netherlands, mussel fishery is restricted to subtidal beds outside areas that are permanently closed. In Niedersachsen, fishery for seed mussels is allowed in significant parts of the intertidal, in accordance with a management plan. In Schleswig-Holstein, mussel fishery is not allowed in the intertidal area, as well as, in most subtidal parts. In the Hamburg National Park, mussel fishery is not allowed. In the Danish part of the Wadden Sea, mussel fishery is allowed on a small scale, in intertidal and subtidal areas, but the quotas since 1992 have been fished in subtidal areas only. In Denmark, commercially sized mussels are fished from wild natural beds.

In The Netherlands and Germany, blue mussel fisheries are mainly carried out on seed mussels from natural beds. Traditionally, seed mussels of around 1 to 4 cm length are transferred from natural beds where they have settled to culture lots where they grow to marketable sizes (on-bottom culture). They are allotted to mussel farmers by the responsible authorities. After 1.5 to 2 years, the mussels on the culture lots are more than about 4.5 cm long, and ready for the market. Seeding of culture lots is usually done in autumn and spring. What remains is a depleted bed, until spatfall occurs again.

On 50 ha of culture lot, a standing stock of 5,000 to 8,000 t of blue mussels may develop,

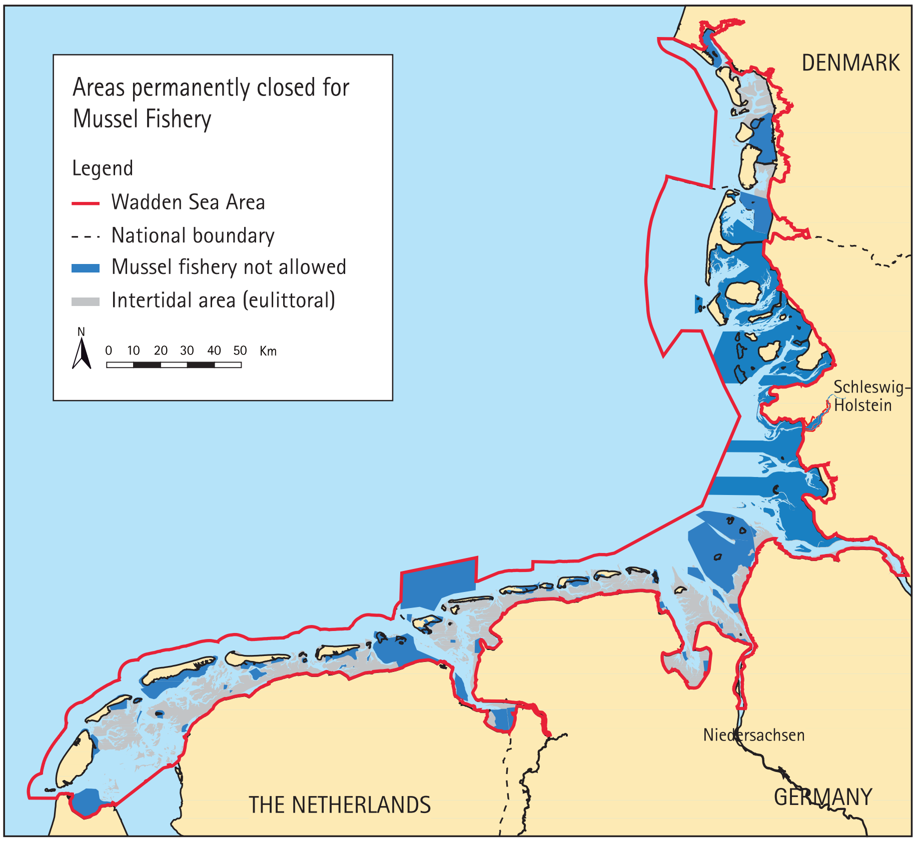


Figure 3.3.1: Areas in the Wadden Sea region permanently closed for mussel fishery in 2008.

while stocks at natural sites after surviving two years will reach 1,000 to 1,600 t at the most.

The total size of culture lots in the Wadden Sea is about 109 km^2 (see Table 3.3.1).

Culture lots are leading to an enhancement of blue mussel biomass in comparison with a situation without mussel culture (Bult *et al.*, 2004). Part of the seed and half-grown mussels from the Dutch Wadden Sea are exported to the southwest of The Netherlands for cultivation in the Eastern Scheldt.

No culture lots and exports of seed mussels are allowed in the Danish part of the Wadden Sea because, according to the Danish fishery regulation, no mussels below 5 cm in shell length may be fished, transported or landed. In landing, a by-catch of up to 10% weight of smaller mussels is allowed.

In Germany a research project (2000 - 2004) was developed in the Jade to investigate whether long-line culture could be used successfully as a supplementary source for seed mussels. The comparison of different tested long-line types has proved that single longtubes carrying net collectors are the most stable system. Artificial collectors were settled by a large number of mussel larvae. Important settling took place between May and July (11,000 to 64,000 ind./m collector). The shell length of suspended mussels increased in their first summer at an average of 1.2 mm per week. Between end of August until end of September a mean of 2 to 9 kg mussels per meter (4,500 to 20,300 ind./m) were harvested and then re-layed on-bottom cultures (Walter & de Leeuw, 2007).

Recently, further experiments are being carried out with new collector methods such as 'smart farms'. This on-growing system consists of several units, which are adapted to each site using PE pipe for buoyancy with a 2-3 meter deep mussel collector-net running the length.

The potential of seed collectors in the Wadden Sea is yet difficult to evaluate as only few attempts have been made so far to explore these techniques which have proven to be successful in other places. Thus, it is easy to foresee that mussel fisheries will still be reliant on conventional practices for the near future.

In The Netherlands several techniques were developed and tested for a number of years. Kamermans & Smaal (2009) describe the results of the experiments. Scholten *et al.* (2007) give an overview of the techniques, the resulting crop and policy related issues. They advocate extending the experiments and while monitoring possible impacts gradually replace fishery of natural beds by these seed collecting devices.

Amount and abundance of natural spatfall is always varying, thus, catches of mussels show strong fluctuations per year and region. In the last ten-year period, the years 1998 and 1999 allowed higher catches in Germany, while 2001 was a relatively good year in The Netherlands. Because of low seed availability, in the following years the lowest catches were reported, accompanied by a decreasing or failing spatfall and declined mussel beds.

In the period 1994-2007 the average annual landings of mussels were about 56,000 tons wet weight (including shells). Most of them (about 35,000 t) were landed in The Netherlands (Figure 3.3.2). On average about 70% of all Wadden Sea mussels are of Dutch origin.

A considerable part of the German landings are transported to The Netherlands where the majority of landings are traded.

Trilateral Policy and Management

WSP 4.1.16. The negative effects of cockle fishery are being limited by:

- Cockle fishery is not allowed in the German part of the Conservation Area;
- Cockle fishery is not allowed in the Danish part of the Wadden Sea Area, with the exception of some small areas along the Esbjerg shipping lane and in the Ho Bay;
- Cockle fishery is allowed in the Dutch part of the Wadden Sea Area, but has been limited by the permanent closure of considerable areas; there are possibilities for additional restrictions to safeguard food for birds. A co-management scheme with the fishing industry is in operation, in which the protection and enhancement of the growth of wild mussel beds and Zostera fields are central elements. (Identical with 9.1.3).

WSP 4.1.17. The negative effects of mussel fishery are limited by the permanent closure of considerable areas. In addition, the management of fishery on mussels aims at, inter alia, protecting and enhancing the growth of wild mussel beds and Zostera fields. (Identical with 9.1.4).

WSP 4.1.18. Mussel fishery will, in principle, be limited to the subtidal area. Based on national management plans, which are documented in the Progress Report, fishery on the tidal flats may be granted. The fishery sector is called upon to exchange information on the existing practices and to investigate possibilities for minimizing impacts of mussel fishery, in general and seed mussel fishery, in particular. (Identical with 9.1.5).

WSP 4.1.19. The current area of mussel culture lots will not be enlarged.

WSP 4.1.20. The existing permit for oyster culture will remain in force for traditional reasons. According to this permit, the imported oysters originate from hatcheries and are under veterinary control. New permits will not be granted.

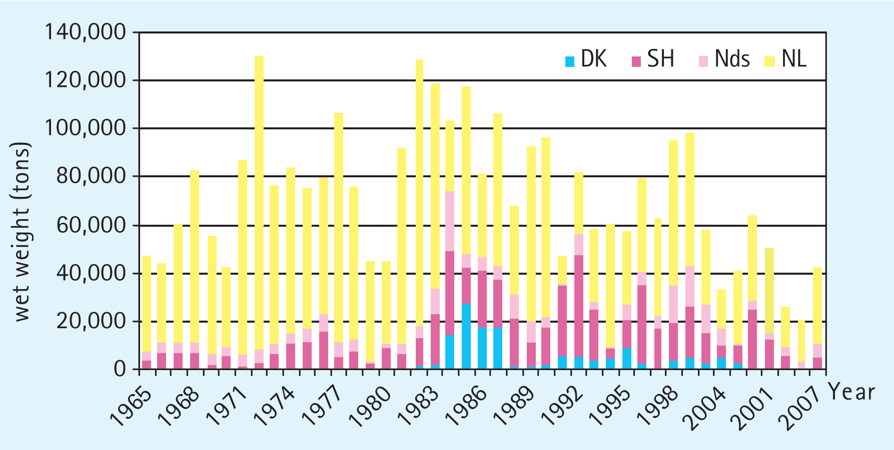


Figure 3.3.2: Landings of Blue Mussels in the Wadden Sea 1965-2007 (in tons wet weight). (sources: Trilateral Workshop on Blue Mussel Fishery Management 2008).

National developments

The Netherlands

In the Dutch part of the Wadden Sea Area, blue mussel fishery is mainly done for mussel seed. The subtidal seed fisheries occur both in autumn and spring and they remove between 60 and 80% of the spat. Figure 3.3.3 indicates the fished area over several years.

The seed mussels are transferred to culture lots. These occupy an area of 7,600 ha of which 3,300 ha are actually in use. The culture lots are situated in the subtidal of the western part of the Dutch Wadden Sea. The average annual landings of mussels from culture lots in the period 1994-2007 amounted to 35,166 tons of gross weight (including shells). An overview of facts and figures is given in Table 3.3.1.

The National Planning Decree (Planologische Kernbeslissing, PKB) for the Wadden Sea sets out the general policies for all human uses in the Wadden Sea conservation area, including shellfish fisheries. With regard to shellfish fisheries, the PKB refers to the Sea and Coastal Fisheries Policy Document (Structuurnota Zee- en Kustvisserij) which was published in 1993 and has long formed the basis for fisheries policy. The policy focused on three keystones: closed areas, food reservation for birds and co-management (CWSS, 2002). In 2005 it was replaced by a new policy.

In The Netherlands, mussel landings and mussel stocks on natural beds decreased in the eighties leading to an increase of the fishery and culture in Denmark and Germany (Figure 3.3.2). The intertidal stocks, fishery and culture crashed in the early nineties. This event, and a following mass mortality of mussel-eating birds, has lead to a strong controversy about mussel farming, which was considered to be a main cause of this collapse. On the basis of an interim report in 1998 and newer observations (1999 and 2000), it was decided to take additional measures in order to enhance the restoration of blue mussel beds in the Wadden Sea and to improve the food availability for birds, by additional closure of 5% of the intertidal area for cockle fishery (and 10% for mussel fishery) of areas with high potential for blue mussel beds and new measures to prevent food shortage for birds (CWSS, 2002; Ens *et al.*, 2004). This 2nd policy phase was accompanied by a comprehensive research program (EVA II) which began in 1999 and ran until 2004 (LNV, 2003; Ens *et al.*, 2004). The results of this research program were only partially used as a basis for the development of a new shellfish policy which was adopted by Parliament in October 2004 (LNV, 2004). The new policy holds for: re-opening of the closed 'best 5%-areas', termination of the mechanical cockle fishery, and, as a consequence, end of the food reservation policy, restriction of subtidal mussel

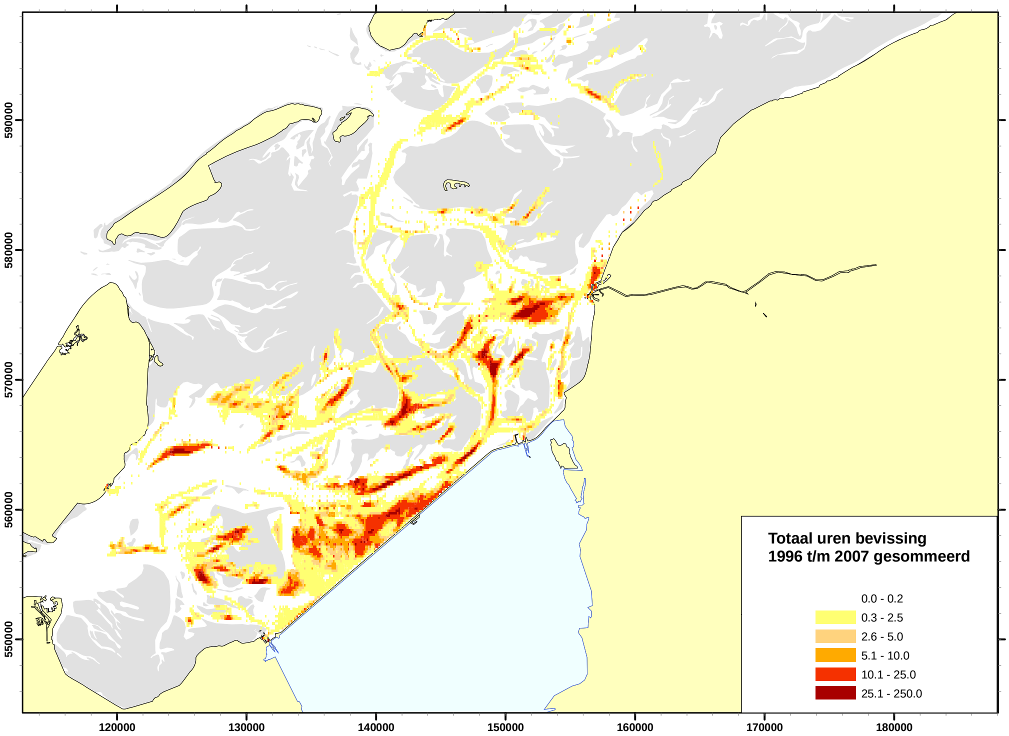


Figure 3.3.3: Mussel seed fishery in the Dutch Wadden Sea (between 1996 and 2007).

seed fishery on instable mussel beds in autumn leaving them for birds in winter and subsequent fishery in spring, experimental fishery on intertidal beds, experimental development of seed harvesting techniques and general transition to less damaging seed collection.

Mussel stocks of the intertidal part of the eastern Dutch Wadden Sea have recovered since the fishery in the intertidal areas was almost completely closed since 1995. The mussel landings based on subtidal spat, but partly also from import from other countries, increased again but have not reached former levels. The mussel stocks in the subtidal generally stayed at lower levels than in the years before 1990.

In October 2008, a framework agreement (covenant) has been signed by the mussel fisheries sector, green NGOs and the Dutch government about the transition towards sustainable fisheries, as well as nature recovery in the Wadden Sea. In March 2009, an implementation plan was adopted. In this plan it will be aimed to close 20% of the subtidal mussel beds each year cumulatively and replaced by artificial seed collectors. In 2009, about 150 ha seed bed will be left to develop undisturbed, and no fishery will be allowed on them, even if the mussels disappear and new beds develop afterwards. On the other hand the fishery will be allowed to develop methods for seed collection by artificial means (nets and ropes). Considerable areas, in future amounting to more than 600 ha, will be set aside for this development. When successful, an additional 20% of the new spatfall will be left undisturbed next year. In a bit over a decade the whole subtidal seed fishery should be replaced by seed collectors.

Germany: Niedersachsen

In Niedersachsen, blue mussel fishery is regulated according to the Niedersachsen Fishery Ordinance of 1992 by the State Fisheries Administration. The National Park Administration is consulted in the licensing procedure. According to the National Park Law seed mussel fishing is allowed in a number of explicitly specified parts of zone I (the most protected zone) and the whole of zone II (intermediate protection zone). The major parts are formed by an area between Weser and Elbe and the Borkum Riff ground (Figure 3.3.1).

Seed mussels are fished in the subtidal and certain parts of the intertidal area. Wild mussel for consumption may only be fished on sublittoral banks. Five licenses have been issued for mussel seed fishing. The area designated for culture lots has a maximum of 1,300 ha.

Seed mussel fishing is only allowed within the framework of a management plan (Bewirtschaftungsplan, 2004), issued jointly by the fisheries and nature protection authorities. The management plan takes account of the protection aims as laid down in §2 of the National Park Law. Currently, the management plan for mussel fishery is being renewed for a further period. According to the plan, 29 of the described 102 mussel bed sites have been excluded from seed mussel fisheries: 12 sites already excluded according to the National Park Law, 12 additional sites excluded according to the management plan and five additional sites which are voluntarily excluded from fishery to enable a long-term monitoring and a reliable calculation of the total blue mussel stock.

The average annual landings of mussels (from cultures and wild mussels) over the period 1994-2007 were 6,318 metric tons gross weight. Table 3.5.1. gives an overview about facts and figures.

Germany: Schleswig-Holstein

In the Schleswig-Holstein National Park, fishing for seed mussels is only allowed within the subtidal part of zone II and in the subtidal part of four defined areas in zone I (CWSS, 2002).

According to the National Park Law fishing for seed mussels is only permitted with a license according to §40 and 41 of the Schleswig-Holstein Fisheries Law. The areas where fishing is allowed have been fixed in the Schleswig-Holstein mussel fishing program, which has been issued in accordance with §40-1 of the Fisheries Law.

Since 1997 a mussel fishing program for the use of mussel resources in the National Park of Schleswig Holstein has been in force which was amended within the framework of the revision of the National Park Law in 2000. A Framework Agreement between the Ministry and the fisheries sector for the period until end of 2016 has been agreed upon. The main elements contained in the agreement are the specification of the conditions under which mussel seed fishery and mussel fishery may be carried out and the development of fishing and culture practices in the period under consideration (CWSS, 2002). A detailed overview of the recent monitoring and management is given by Nehls and Ruth (2004).

The average annual landings from culture lots in the period 1994-2007 were 12,454 metric tons gross weight. The total size of the culture lots in 2005 was 2,000 ha. The facts and figures have been summarized in Table 3.3.1.

Table 3.3.1: Shellfish fishing. Overview of facts (source QSR 2004, updated).

	NL	NDS	SH	DK
Size Tidal Area (ha) according to trilateral definition (see WSP)	250,000	183,400	222,000	68,500
Intertidal (ha)	124,000	144,000	141,000	55,400
% Intertidal	49.6	78.5	63.5	80.9
MUSSEL FISHERY				
Average annual Mussel landings (metric tons gross)	39,132 (94 – 03) 35,166 (94-07) (from culture lots)	7,278 (94 - 03) 6,318 (94-07) (culture + wild)	15,167 (94 - 03) 12,454 (94-07) (from culture lots)	4,507 (94 - 03) 2,507 (94-07) (wild mussels)
Mussel culture in use (ha)	7,600 usable: 3,300	1,300 (maximum)	2,000	none
Number of Licenses	89 (seed fishing vessels) 82 mussel culture	5 (vessels)	8	4
Quota	For seed mussels	None	None	On the basis of stock assessment. In recent years between 0 and 5.000 tons
Permanently closed area (ha)	42,540 (this area covers 18% of total intertidal stock)1	93,480 (this area covers about 10 % of total area of intertidal mussel beds)[2]	135,000 (this area covers 100% of intertidal mussel beds)	28,700
Additional restrictions	Intertidal: Seed fishery on unstable mussel beds only if at least 2000 ha of 1-year old mussel beds are left.	Additionally 17 sites closed in accordance with Management Plan (about 10% of intertidal mussel beds)[2] Min. size 50 mm (wild)	Min. size 40 mm	Min. size 50 mm After 2008 an annual Environmental Impact analysis has to be carried out before fishery can take place.
COCKLE FISHERY				
Average annual cockle landings (tons wet weight)	Mechanical: no landings since 2005 Non-mechanical: around 600 tons of meat yearly	No landings since 1999	No landings since 1989	1997-2007: 898 After 2008 an annual Environmental Impact analysis has to be carried out before fishery can take place.
Number of licenses/vessels for cockle fishery	Maximum of 31 licences for manual cockle fishery (30 actively used) 3)	None	None	1
Permanently closed area (ha)	42,540	100% of conservation area	100% of conservation area	99% of conservation area
Additional restrictions for cockle fishery	Min. size 15 mm. Maximum yearly catch: 5% of the cockle stock	Min. size 30 mm		Min. size 16 mm
SPISULA FISHERY				
Spisula landings, annual average in tons fresh weight (period)	34,630 (1996 - 1999) 36,160 t (1998 – 2003) Probably no Spisula fishery after 2001; last recorded permits ended 31/12-2001	No landings since 1996	No landings since 1995	1,978 (92-95) 1996 - 1998 no landings 2,846 (99 – 03)
Number of licenses	None	None	None	5 (1 active)
Restrictions	Min. size 30 mm	-	Min. size 30 mm	Min. size 35 mm
OYSTER CULTURE				
Oyster culture	Not practiced	Not practiced	1 oyster culture lot	1 license (not used)
Restrictions oyster			Min. size 50 gr	

1) Based upon average annual biomass in spring 1999-2001.
2) Average of 5 years (1999-2003): range 9.5-13.2 %. Additionally, about 10% of the mussel bed areas (average 1999-2003) is closed for fisheries (range: 8.4-12.5%) (Herlyn and Millat, 2004). The closed area covers 33.8% of the National Park area; not all parts of the closed area are suitable for fishing.
3) Mechanical cockle fishery in the Dutch Wadden Sea was closed on 1 January 2005. No cockle fishery in 2004 because of a legal procedure against the licensing procedure.
4) Re-opening of the "5%-areas from 2005 on due to discontinuation of mechanical cockle fishery.

Denmark

In the Danish part of the Conservation Area, commercially sized mussels are fished from wild natural beds because mussel culture is not allowed. There are three areas with a total size of 28,700 ha (42% of the Tidal Area; see Figure 3.3.1) where fishing for wild blue mussel is allowed. The minimum landing size is 50 mm in length. The annual landings of wild blue mussels were on average 2,500 metric tons gross weight in the period 1994-2004. Very limited landings have taken place since 2004. The data has been summarized in Table 3.3.1.

Because of overfishing and severe winters, which caused a decline in some mussel-eating bird species, and reduction of intertidal mussel beds, the number of licenses has been reduced from 40 to 5 and an annual quota of mussels with a maximum of 10,000 tons has been negotiated with the Ministry for Environment. From 2009 onwards the amount of mussels set aside to birds will be 37,000 tons. Currently, there are only four licenses for mussel fisheries.

In 2002, the Danish Directorate for Fisheries has given permission to a nature restoration project for blue mussel beds in parts of the Danish Wadden Sea. Up to 1,000 tons of blue mussel seed have been fished in 2002 in the Horns Reef area, more than 10 km west of the Wadden Sea conservation area, and then re-laid on the seabed in the Wadden Sea Area. The time period for the project was three years.

3.3.3 Cockles

Fisheries of cockles have been regulated in all three countries with regard to the amount of permits, size of culture lots, fishing periods and other regulations (Table 3.3.1).

The Wadden Sea Area is closed for mechanical cockle fisheries in the Dutch and German conservation area. In Denmark, 99% of the Wadden Sea Area is closed for cockle fisheries with the exception of some small areas in Grey Deep along the Esbjerg shipping lane. In the period 1994-2003 average annual cockle landings were about 22,000 tons (wet weight) with lower amounts at the end of the period (Figure 3.3.4). Most of them were landed in The Netherlands. In January 2005, mechanical cockle fishery was stopped in the Dutch Wadden Sea.

The Netherlands

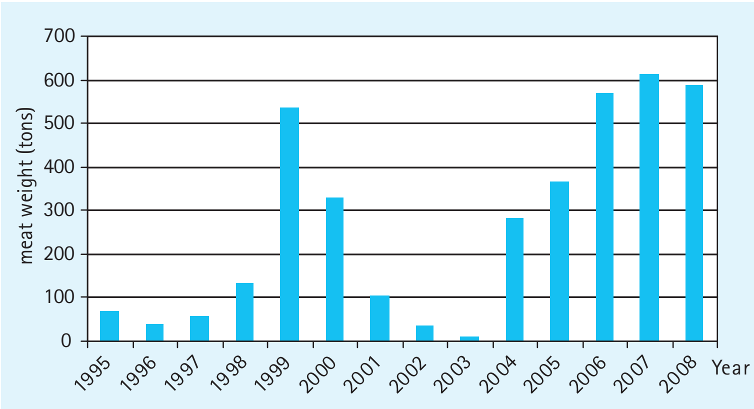
Since January 2005 mechanical cockle fishery in the Dutch part of the Wadden Sea is not allowed any longer. Only a manual cockle fishery is still allowed with a maximum yearly catch of 5% of the cockle stock. A maximum of 31 licenses for manual cockle fishery have been granted. The fished amounts were between 0.1 and 1.5 % of the stock. The amount fished (in tons of meat, 15% of fresh weight) is given in Figure 3.3.5.

Germany

Cockle fishery in the Schleswig-Holstein was stopped in 1989 and in the Niedersachsen National Park in 1992 and is not allowed in the Hamburg National Park.

Figure 3.3.4: Landings of cockles in the Wadden Sea 1977-2007 (in tons wet weight) (sources: DTU Aqua, Fischerblatt, RIVO, PVIS).

Figure 3.3.5: Cockle catch (meat weight) by hand rakers in the Dutch Wadden Sea (information from Rakers Association, OHV, presented by Bert Keus).



Denmark

There is one license for cockle fishing in the Danish part of the Wadden Sea. Cockle fishing is restricted to three small areas in the Grådyb, of which one may be fished per year.

In the period 1997-2007 an average annual amount of about 898 tons wet weight of cockles was fished (Figure 3.3.4).

3.3.4 Other Shellfish Fisheries

The Netherlands

The average annual landings of Spisula subtruncata in the period 1996-2001, taken from the coastal zone north of the Wadden Sea islands, were about 36,160 tons of fresh weight (about 3,600 t meat). Since 2001, no fishery has taken place because of lack of *Spisula* and food requirement of ducks. Currently, a comprehensive policy for the fishery of Spisula (and other shellfish species) is under preparation.

Germany

In Niedersachsen, there has not been any fishing of Spisula species or other shellfish species in the Wadden Sea Area since 1995.

In Schleswig-Holstein, fishing of razor clam (*Ensis* spp.) is not allowed in the Conservation Area. *Spisula solida* fishing may only be carried out outside the 3-mile zone. Since 1996, there has not been any Spisula fishing.

Table 3.3.2: Landings of Spisula (1992-2007) (information from Per Sand Kristensen).

			Danish landings	
	Spisula solida		Value in euro	pr. kg
	DK-landings tons	Other EU-countries tons	x 1000	euro
1992	484	-	113	0,23
1993	1.651	-	382	0,23
1994	2.716	-	373	0,14
1995	2.877	260	445	0,15
1996				
1997				
1998				
1999	The stock was not fishable due to fishing gear limitations			
2000	55	3.914	9	0,17
2001	214	2.267	56	0,26
2002	1.709	2.656	300	0,18
2003	566	5	110	0,19
2004	1.018	3	198	0,19
2005	31	-	6	0,19
2006	6	-	1	0,19
2007	-	-	-	-
SUM	**11.327**	**9.105**	**1.993**	**0,19**
Annual	**1.030**		**249**	

There is one license for oyster (*Crassostrea gigas*) culture in Schleswig-Holstein. The culture area has a size of 30 ha.

In the Hamburg National Park, shellfish fishing is forbidden in the whole area.

Denmark

In Denmark, there are five licenses for *Spisula* fishing, but only one has been used. After the whole *S. solida* stock in the two fishing sites has disappeared in 1996, *Spisula* fishing started again in 1999 with an annual average of 2,846 t/yr (1999-2003). There has been no fishery on *Spisula* within the last 3 years.

One license for oyster culture has been issued, which is currently not in use.

3.5.5 Shrimp Fishery

In all three Wadden Sea countries, fisheries on brown shrimps (*Crangon crangon*) are carried out in the offshore belt and within the Wadden Sea in all gullies and channels.

Part of the larger vessels (>15 meters) are equipped with VMS (Vessel Monitoring by Satellite). Figure 3.3.6 indicates the fishing pressure. It should be noted that the smaller vessels which can not be traced mainly fish within the islands.

Only in the Danish part of the Conservation Area and in 95% of the area of the Hamburg National Park in Germany shrimp fishery is not allowed. Generally, there are no substantial differences in policies and practices within the Trilateral Cooperation Area, except for Denmark where shrimp fishery is not allowed within the line of barrier islands.

Landings are recorded by country and kept separately. The Working Group on Crangon Fisheries and Life History (WGCRAN) of the International Council for the Exploration of the Sea (ICES), which compiles biological and statistical data on brown shrimp, has met in IJmuiden end of May 2006 and found new record landings in 2005 for all three Wadden Sea countries (Neudecker and Damm, 2006). However, German landings declined in 2006 and the question arose, whether effort reductions or a reduced stock caused this development (Neudecker *et al.*, 2007).

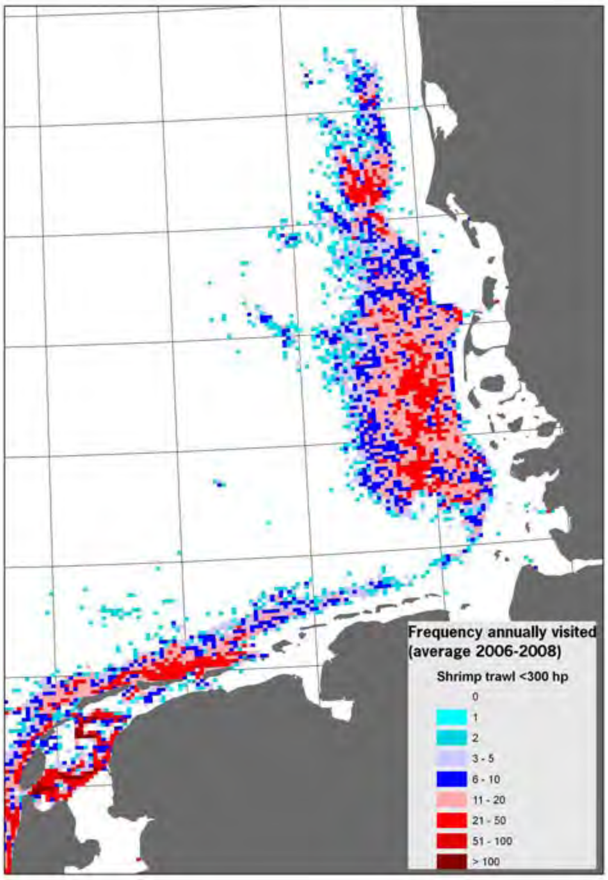
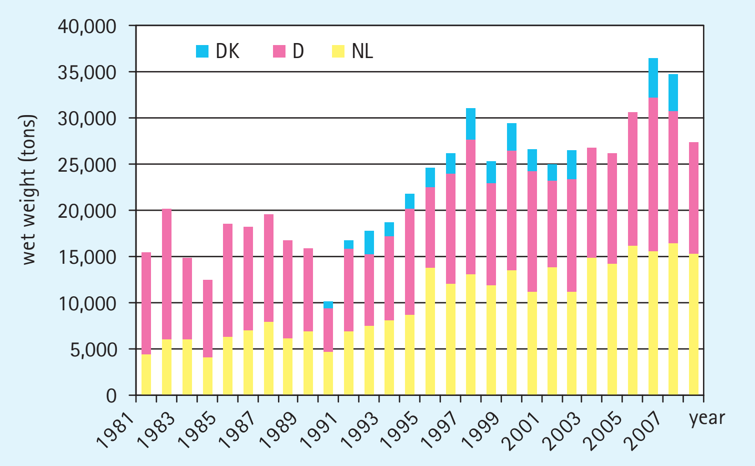


Fig. 3.3.6: Intensity of Shrimp fishery by Dutch vessels in and around the Wadden Sea. The legend indicates the number of visits in an area of 1 square nautical mile (based on VMS information). It should be noted that only around 30% of the fleet is equipped with a vessel monitoring system. Especially the small vessels operating largely within the Wadden Sea do not have such equipment (use of figure by permission of the fishermen association).

Figure 3.3.7: Landings of brown shrimps in 1981-2007 (in tons wet weight) (sources: DTU AQUA, Fischerblatt, PVIS) (DK: data for 1991 – 2002 for Danish vessels).



The Netherlands

In the Dutch part, shrimp fishery is carried out by 204 licensed vessels. Of these, 90 vessels are operating in the Wadden Sea, with 60 exclusively fishing on shrimps. The total average annual catch in The Netherlands (including that from vessels outside the Wadden Sea) was about 15,000 t in most recent years (Figure 3.3.7). According to fishermen, roughly estimated, about half of these landings are fished in the Wadden Sea.

Germany

In Germany, the shrimp catch has been on average 12,000 t/yr (1994-2007). Fishery on small sized shrimp for animal consumption and fish meal is still carried out in Niedersachsen in the second half of the year. The landings are around 600-1,200 t/yr which is about 13% of the amount landed for human consumption in Niedersachsen.

Since the establishment of the National Park of the Hamburg Wadden Sea in April 1990, fishing of shellfish and shrimp in the core zone of the National Park, which is nearly the entire Conservation and Wadden Sea Area, has been prohibited. According to the National Park Law there are exceptions for fishing shrimp for human consumption in three tidal inlets within the core zone, which are also the only designated and marked navigable waters in the Conservation Area. All other areas outside the Conservation Area and inside the Hamburg Wadden Sea Area are not suitable for shrimp fishing.

Denmark

In the last fifteen years, between 21 and 28 licensed vessels have fished for shrimps in Danish waters west of the 'Shrimp Line' (SL) drawn between the Wadden Sea islands from the peninsula of Skallingen to Rømø. Between 100 and 150 vessels (mainly German, Dutch and a few Belgian) fish for shrimps periodically or more permanently in the Danish Economical zone in the North Sea. The SL has been enforced since 1977. In the last fifteen years, the Danish landings have been on average around 2,900 t (only Danish vessels) and about 3,400 t annually (including vessels from other EU countries) (in Figure 3.3.7, Danish data are total landings including foreign vessels). The main landing harbors are Havneby and Esbjerg.

3.5.6 Other Fisheries

The Netherlands

In the Dutch part of the Wadden Sea several other fisheries are carried out, described in more detail in Overzee *et al.* (2008). Gill nets and seines are used to target (mainly) bass and mullet from May-November. There are 13 gill net permits for the Wadden Sea of which 5-6 are actively used. About 4-5 Dutch fishers use seines in the Wadden Sea. Fikes are used in the Wadden Sea for fishing eel, flounder, smelt and Chinese mitten crab. Fyke nets are used all year long, but a peak is observed from August-November. There are 24 fishers with permits for fykes in the Dutch Wadden Sea.

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Tourism and Recreation

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3.4.1 Introduction

3.4.1.1 Economic factor tourism

Tourism has continued to play a very important role in the economy. The total revenue in Denmark is 8.9 billion Euros per year, accounting for 2.8% of the national income and around 100,000 jobs, which corresponds to approximately 5.2% of the employed (VisitDenmark 2007, see also the German/Danish economic portal: www.GrenzNet.com).

According to the German Tourism Association (2008) the tourism sector accounts for yearly revenues of around 150 billion Euros, and the total proportion of jobs dependent on tourism in Germany is around 8% (Deutscher Tourismusverband DTV e.V. 2008). On the average, it accounts for about 6% of the gross national product.

In the Netherlands, tourism generates around 35 billion Euro in revenue. It accounts for 3% of the national income (Centraal Bureau voor de Statistiek 2008) and employs 7.2% of the population (Instituut Service Management 2008).

The total revenue in Denmark is 8.9 billion Euros per year, accounting for 2.8% of the national income and around 100,000 jobs, which corresponds to approximately 5.2% of the employed (VisitDenmark 2007, see also the German/Danish economic portal: www.GrenzNet.com).

The statistics on overnight stays in the Wadden Sea states show that tourism plays a very important role, particularly in the coastal regions.

The umbrella organization for tourism marketing in Denmark estimates a total of 37.6 million overnight stays along Denmark's coasts. The German-Danish economic portal assesses tourism there to have an importance similar to neighboring Germany. For southern Jutland alone a figure of 9.5 million overnight stays is given for the year 2006. The immediate vicinity of the coast is estimated to account for around 6.6 million overnight stays in the Wadden Sea region (personal communication T. H. Christensen, 31 October 2008).

The Nordseetouristik Service GmbH estimates the number of overnight stays in the North Sea coastal area to be around 15 million annually (Höfinghoff 2008), which is about one third of the total volume of overnight stays in Schleswig-Holstein. In Lower Saxony, the North Sea coast and the East Frisian Islands account together for around 13,4 million overnight stays, which also amounts to around one third of the total volume (IHK Ostfriesland and Papenburg,).

In the Netherlands, 88 million overnight stays were estimated in 2007 of which 13.5 million were estimated for the provinces of Friesland and Groningen (13.7 million in 2008) (Instituut Service Management, 2008 and 2009). 4.4 million of these overnight stays were counted on the Wadden Sea islands of Friesland. On the island of Texel (Provice of North-Holland), the number of overnight stays amounted to 3.9 million in 2006 and 2007, and 4.1 million in 2008 (pers. comm. VVV Texel)

A look at the indicator for "tourism intensity" (the ratio of overnight stays to inhabitants) reveals the significant role of tourism, particularly for the – mainly rural – coastal areas bordering the Wadden Sea.

In Germany, the national average for tourism intensity is around 4 overnight stays per inhabitant. In the recreational areas at the North Sea coast in Schleswig-Holstein, an average of 67 overnight stays per inhabitant is documented. This means that 37.5% of the aggregate income on the west coast is coming from tourism. For the year 2005, it is estimated that 41,600 of the 110,900 inhabitants in the North Sea recreational area earned their livings from tourism, generating total annual revenues of 1.5 billion Euros. Two thirds of this came from overnight tourism and one third from day trips (Wirtschaftsförderungsgesellschaft Nordfriesland 2006).

Due to the structural similarities between Germany and Denmark, it can be assumed that Danish tourism intensity is of a comparable order of magnitude. For the Netherlands, which has the highest population density in Europe, a lower tourism density can be expected. The corresponding value added to the gross domestic product will thus be lower there.

3.4.1.2 Resource Nature

The fact that nature is the main resource which can be marketed by tourism is underlined each year with the new publication of the travel analysis by the research council "Vacation and Travel" (Forschungsgemeinschaft Urlaub und Reisen, F.U.R. Kiel). Also, the study "Vacation trips and the environment", by the "Study group for tourism and development" (SfTE), has documented for years the fact that nature is the central element determining the appeal of the area for tourists (DTV 2005). An intact natural environment is an important factor for vacation satisfaction for 84% of the German populace (SfTE 2005). In its travel analysis for the year 2006, the research council "Vacation and Travel" found that 36% of the German populace

Best Practice example: Socio-Economic-Monitoring

Since 1999 the Schleswig-Holstein Wadden Sea National Park Bureau has been carrying out a so-called Socio-Economic Monitoring (SEM). The monitoring entails counts of Wadden Sea guided walks as well as surveys of inhabitants and guests, addressing running topics and current issues in the national park. The SEM in 2008 showed among other things that North Sea tourists in Schleswig-Holstein place value on recreation (89%), nature (29%), health (16%) and sports (14%) (multiple answers were possible) (Institut für Bäderforschung in Nordeuropa (N.I.T.), 2006/2007 nach Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer (Hrsg.), 2008B (http://www.wattenmeer-nationalpark.de/themen/SOEM_Bericht_2008.pdf))

consider a "nature vacation" to be a form that they would either consider or are actually planning for the near future (F.U.R. 2006). Of those interested in a vacation at the North Sea coast, the proportion is, with 45%, even higher (Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer 2008a). The chance to visit a nature preserve or national park is important for 33% of the German populace (SfTE 2005).

Surveys in Denmark also document the fact that nature is a significant factor determining the choice of a travel destination. In Danish studies 82% per cent of the visitors named nature as the motivation for their trip, followed by the tidiness of the countryside (64%) as well as the safeness and child-friendliness (60% each) (VisitDenmark 2007).

In a representative study carried out in 2006 by the Emnid Institute on behalf of Europarc, it became evident that vacationers also regard the protective status of a national park to count towards "vacation quality" and to at least have a positive influence on the choice of destination. Seventy-one per cent of the questioned answered in the affirmative when asked whether they prefer to spend their vacation in an area where nature is protected as a national park (Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer 2008a).

3.4.2 Update of tourism data

The update of information for this Quality Status Report on tourism and recreational activities has been carried out on the basis of the parameters used for 2004. This continued consideration allows comparisons, at least in some areas, and makes it possible to recognize trends in the development. The structure was changed slightly for the QSR 2009. In the following, the parameters will be divided into those which describe the general tourism market and those related to activities. As in the previous years, the latter are separated into land-based and water-based uses of the Wadden Sea.

Particularly the numbers of guest arrivals and overnight stays are useful for describing tourism demand. Setting them in relation to each other, an average stay duration can be derived. This

Trilateral Policy and Management

It is the aim to reduce disturbance caused by recreation and tourism by introducing and applying information systems and/or temporal and spatial zoning. (WSP § 3.1.12, identical with 5.1.8).
Speed limits within the tidal area have been, or will be, imposed where such is deemed necessary. (WSP § 4.1.9)
The recreational values of the Wadden Sea will be maintained and to this end,
- in the ecologically most sensitive areas, zones have been or will be established where no recreational activities, including excursion ships and recreational boating, is allowed;
- the use of jet skis, water skis and similar motorized equipment has been, or will be, prohibited, or limited, to small designated areas;
- within the Conservation Area, new marinas will be avoided and the extension of the existing marina capacity will only be allowed within the approved levels;
- wind surfing has been, or will be, limited.

(WSP § 4.1.21)
Speed limits for ships have been, or will be, imposed, if this is deemed necessary, taking into account safety, environmental and recreational factors. (WSP § 4.1.22)
The negative effects of hovercraft and hydrofoil craft and other high-speed craft are minimized by the following strategies:
- In The Netherlands and Germany, hovercraft and hydrofoil craft are forbidden in the tidal area of the Conservation Area; new, other high speed craft are forbidden outside the designated shipping routes in the area;
- In Denmark, applications for new, high-speed craft can only be granted on the basis of an Environmental Impact Assessment and if it is not in conflict with the nature protection targets for the area.

(WSP § 4.1.23)
It is the aim to reduce disturbance caused by recreation and tourism by introducing and applying information systems and/or temporal and spatial zoning. (WSP § 5.1.8, identical with 3.1.12 and 4.1.24).
Ground water extraction will be managed in such a way that no negative effects on wet dune valleys occur. (WSP § 5.1.10)
Disturbance in significant breeding areas will be reduced and access to these areas will be made more predictable for birds, i.e. using only certain footpaths on salt marshes, beaches and dunes (information system for visitors). (WSP § 9.1.6)
Driving cars in breeding areas on beaches and in dunes is prohibited. (WSP § 9.1.8)
(Trilateral Wadden Sea Plan (WSP), 1997)

	Denmark		Germany				The Netherlands	
			Lower Saxony		Schleswig-Holstein			
Tourism-related Parameter	QSR 04	QSR 09	QSR 04	QSR 09	QSR 04	QSR 09	QSR 04	QSR 09
Arrivals				x		x		x
Overnight stays >9	x	x	x	x	x	x	x	x
Average duration of stay in days			x	x	x	x	x	x
Number of beds	x		x - total value for Germany	x	x - total value for Germany	x	x	
Bed capacity utilization		x		x		x		
Foreign visitors in %		x		x		x		x
Daily spending (commercial operations)		x	General value and Weser-Ems Region	x				x
Revenues from overnight visitors		x		x		x		x
Day trips				x		x		x
Total revenues	x	x		x	x	x	x	x
Number of employees		x		x				
Gray accomodations market			x		x	x		
SÖM Report					x	x		

Table 1: Overview of tourism related parameter available for the QSR 2004 and 2009.

is especially important for the development of products and marketing, since it indicates the marketability of potential offerings.

The number of beds, set into relation with the number of overnight stays, gives information about the capacity utilization of the accommodations, and an insight into the economic status of the hospitality industry of a region. Together with knowledge about the daily spending of visitors to the region, it is possible to calculate the tourism-related revenues of the first and second chains of economic value added (DWIF 2005).

The following table gives an overview of the data which were shown in the QSR 2004 compared with those which are available for the QSR 2009. Updates have not been made available by the bureaus of statistics and/or tourism organizations for all parameters in the different countries. In these cases attempts were made to complete the data by personal communication with the experts in each country.

Due to the high degree of variability in the survey methods, particularly of the tourism parameters in the individual Wadden Sea states, the descriptions of the development in tourism will first be given separately for the different countries and then summarized in order to point out trends and draw conclusions.

A comparison of the tourism data compiled for the QSR 2004 with the recent data were not be carried out because the statistical methods have been modified in some of the regions which considerably limits the conclusions that can be drawn from these data

3.4.2.2 Basic data on tourism demand

Denmark

The number given for overnight stays in commercial operations in the Danish Wadden Sea (excluding camping) was 3.1 million for the year 2007 (dwif-Consulting GmbH, 2008, Lecture by Mathias Feige, Tourismustag Schleswig-Holstein, 19 November 2008). The average capacity utilization of beds was 33.1% (SGVSH, 2008b).

The average amount of money spent by tourists in the Danish Wadden Sea region was 54Euro per day (personal communication Christensen, 31 October 2008).

In the year 2007, 2.3 million overnight stays were registered for hotels, holiday resorts, camping resorts, hostels and marinas. Multiplying this

Specific features of the data collection for tourism parameters in Denmark

The Danish statistics are based mainly on larger accommodations with more than 40 beds and camping resorts with more than 75 sites. The statistics for overnight stays include summer bungalows, hotels, holiday resorts, camping resorts, hostels and marinas (personal communication Christensen, 31 October 2008). Since the renting structure in the Danish Wadden Sea area is of a similarly small scale as in Germany, it can be assumed that the actual number of beds and accommodations is much higher than the statistics show.

figure by the average daily expenditures yields revenues of 125.3 million Euros.

In the year 2006, the number of overnight stays registered in the counties of Ribe and South Jutland was 4,315,200 for summer bungalows alone. For the year 2007 there are no data available for summer bungalow guests (personal communication Christensen, 31 October 2008).

The revenue generated by the renting out of summer bungalows was 233 million Euros in 2006. Taken together this would yield a calculated revenue of around 358.3 million Euros.

In the houses covered by the statistics, the beds were distributed in the municipalities of Varde, Esbjerg, Fanø and Tønder over 27 hotels, 15 holiday resorts, 34 camping resorts as well as 12 Hostels and Marinas. Together, the hotels and holiday resorts generated 95.2% of the revenue in the branch and the camping resorts 96.4%. In 2007, the 88 operations surveyed, registered a total of 2,319,900 overnight stays, of which 56.3% were at camping grounds, 42.1% in hotels and holiday resorts, as well as 1.4% in hostels and marinas (personal communication Christensen, 31 October 2008) (Table 2).

The revenues calculated for 2007 in the regions Varde, Esbjerg, Fanø, Tønder and Vejen are thus 241.4 million Euros. In total, around 10,000 persons are employed in the tourist industry in this region. It is assumed that this would amount to a total of around 3,500 full-time jobs (personal communication Christensen, 31 October 2008).

Germany

The German states Lower Saxony and Schleswig-Holstein are considered individually in the following, since the surveys are carried out separately in the two states.

For Lower Saxony, the tourism organization "Tourismusverband Nordsee e.V." published for the first time its "Concept for the future of North Sea tourism 2015" in the year 2008. This makes it possible to present the tourism industry of the region in great detail for the year 2007. The data on tourism in Schleswig-Holstein are based on the surveys of the "Savings Bank Tourism Barometer", supplemented by the regional collections of annual tourism statistics by the North Sea coastal resort association (Nordseebäderverband Schleswig-Holstein e.V., NBV), which also covers the "gray accommodations market".

Specific features of the data collection for tourism parameters in Germany:

The official tourism statistics from the Bureaus of Statistics in Germany include all operations with more than eight beds. Operations with less than nine beds are thus not represented in their figures. However, in rurally structured regions like the North Sea coast of Schleswig-Holstein the percentage of vacation accommodations rented out by small operations can be up to 80%. These belong to the so-called "gray accommodations market" and are not accounted for in the official statistics.

Lower Saxony

The number of beds available in the coastal areas of the Lower Saxony Wadden Sea was 75,958 for the year 2007 (17,283 of which were hotel beds) (Tourismusverband Nordsee e.V., 2008). In 2007

Table 2: Tourism on the Danish North Sea coast

	No. of enterprises				No. of overnight stays			
	2004	2005	2006	2007	2004	2005	2006	2007
Hotels*	28	28	27	27	396,200	388,300	418,800	412,700
Holiday resorts	15	13	14	15	366,200	302,900	288,400	564,100
Camping resorts	36	35	35	34	1,368,500	1,321,900	1,392,200	1,311,100
Hostels & marinas**	12	12	12	12	36,200	35,400	35,300	32,000
TOTAL	91	88	88	88	2,167,100	2,048,500	2,134,700	2,319,900
* Data include hostels for Esbjerg Municipality								
** Data only cover marinas for Esbjerg Municipality								
Data are limited to information from hotels and holiday resorts with 40 beds or more and camping resorts with 75 units or more. These are known to account for 95.2% and 96.4% of the market turnover respectively.								
Source: Newsletter for Service enterprises from Statistics Denmark (http://www.dst.dk/HomeUK.aspx) 2007:16 and 2008:11, (personal communication Christensen, 31 October 2008, 7 November 2008).								

Table 3:
Tourism at the North Sea coast of Lower Saxony in the year 2006

Region North Sea	Duration of stay in days	Ø Daily expenditures per person* (Euro)	Revenues (Euro)
Commercial operations	11,614,000	67.42	783,036,000
Operations with < 9 Beds	9,109,000	47.70	434,483,000
Tourist camping	1,807,000	25.60	46,251,000
Long-term camping	3,626,000	16.90	60,386,000
Recreational vehicles	412,000	37.20	15,332,000
Vacation bungalows	2,832,000	25.10	71,075,000
Visits to friends and relatives	7,570,000	19.50	147,799,000
Day trips	32,555,000		824,767,000
TOTAL	69,525,000		2,383,129,000
* from dwif data			
Source: Tourismusverband Nordsee e.V., 2008			

Lower Saxony had more than 1.86 million visitors to the coastal regions and islands and 13.4 million overnight stays. At the seaside resorts 4.7 million overnight stays and 698,128 visitors were registered. The number of overnight stays on the East Frisian Islands was 9.1 with a total of 1.16 visitors (overnight stays: 65.8% on the islands and 34.2% on the mainland; visitors: 62.5% on the islands and 37.5% on the mainland). This corresponds to a duration of stay of 7.8 days on the islands and 6.8 days on the mainland (IHK Ostfriesland and Papenburg, 2008). In comparison to the year 1985 this means a reduction in the duration of stays by half, which is in agreement with general vacationing trends.

In recent years, overnight stays in accommodation enterprises with more than nine beds have decreased in the region. Between 2000 and 2007 operations with more than nine beds in the East Frisian Islands lost more than ten per cent, and on the coast (including Bremerhaven) there was a decrease of more than 5%. In contrast, operations with less than nine beds have shown a light upsurge in the number of overnight stays (calculated from research results). As a result, the total number of overnight stays remain on a same level. (Tourismusverband Nordsee e.V., 2008).

The bed capacity utilization in 2007 was 35.2% on the islands and.31.3% on the mainland. The proportion of foreign guests staying overnight was 0.5% on the islands and 2% in the coastal mainland (SGVSH, 2008a).

In the year 2006 there were a total of 69.5 million days of stay, and revenues of 2.38 Euros were generated (see Tab. 3). After subtracting the value-added tax, this amounts to tourism-generated net revenues of 2.12 billion Euros for the North Sea coast of Lower Saxony. 38% of these revenues can be allotted to gastronomy, 20% to accommodations, 25% to retail sales, 8% to services, 7% to maintenance and 2% to transportation. For the region, a job equivalent of 40,383 full-time jobs in tourism is calculated (Tourismusverband Nordsee e.V., 2008).

Schleswig-Holstein

In the year 2007 there were 7.867.300 overnight stays in operations with more than nine beds on the North Sea coast of Schleswig-Holstein. The number of beds is declining slightly (Tab. 4). In 2007, there were almost 65,000 beds available on the North Sea coast, and the utilization of this capacity was around 33.2%. The proportion of foreign guests was 1.1% in 2007 (SGVSH, 2008a, 2007).

In the so-called "gray accommodations market" around 36,000 beds were available in vacation rentals during 2007. In that year there were around 3.5 million overnight stays in these rentals

Table 4:
Tourism at the North Sea coast of Schleswig-Holstein

	2007	2006	2005	2004
Overnight stays > 8 Beds	7,867,300	7,530,900	7,393,100	7,440,200
Number of beds > 8 Beds	64,973	64,911	65,290	63,378
Bed capacity utilization	33.20%	31.80%	31.10%	30.90%
Day trips	n.s.	15 Mio	13.8 Mio.	14 Mio.
Source: SGVSH (2008, 2007, 2005)				

along the North Sea coast of Schleswig-Holstein. With a capacity utilization of 25.5%, these operations lie below those with more than nine beds (SGVSH, 2008a, 2007).

In the tourism statistics of the North Sea coastal resort association (Nordseebäderverband Schleswig-Holstein e.V., NBV), the official and the "gray" accommodations markets are presented together. This results in a total bed capacity of 115,865 beds for the year 2007, for which 15.7 million overnight stays were recorded, 12.5 million of which were in vacation rentals and hotels. A total of 1,932,872 guests were registered, and the average stay was seven days (NBV, 2007).

Day trips to the North Sea coast of Schleswig-Holstein play a prominent role. In the year 2006 there were 15 million day trips, of which 83.2% were recreational and 16.6% for business purposes. The expenditures were 33.10 Euro/day for recreational day guests and 16 Euro/day for business travelers. This results in revenues of 453.7 million Euros for day trips, of which 413.7 million Euros were spent by recreational visitors and 40 million Euros by business travelers (SGVSH, 2008a, 2007).

In order to determine the revenue from tourism in the Wadden Sea region of Schleswig-Holstein for the year 2005, expenditures of 73.30 Euros per overnight guest and 33.10 Euros per day guest were assumed (NBV Schleswig-Holstein, 2006). The number of overnight stays in the year 2007 was 15.7 million. If these figures are multiplied, this yields a total revenue of 1.15 billion Euros for overnight stays.

For the year 2007 there are no data on day trips, so the 12.5 recreational day guests from the year 2006 are taken as a basis for calculations, which yield additional revenues of 413.7 million Euros. Taken together, this amounts to approximate revenues of 1.5 billion Euros for the North Sea coast of Schleswig-Holstein.

The Netherlands

The basis for the description of the tourism market in the Netherlands is the study "Toerisme in Cijfers 2003 – 2007" and "Tourisme in Cijfers 2009" published by the "Instituut Service Management" and „Toerisme en recreatie in cijfers 2008" published by the „Centraal Bureau voor de Statistiek".

The region of the tourism analysis for which statistical data are published covers the entire provinces of Frisland and Groningen and the island of Texel (Province of Noord-Holland) (the so-called "Wadden Sea Region"9. The same area was chosen for the QSR 2004 and in the NetForum project (2000) although not all tourism is entirely related to the Wadden Sea. A more specific analysis of the Wadden Sea related tourism to was outside the scope of the QSR but is recommended for future analyses.

In the year 2007 1,362 operations on the Wadden Sea islands and at the North Sea seaside offered a total of 263,859 beds (personal communication Hilkhuijsen, 26 November 2008). Amongst other, 250 hotels and 462 camping grounds offer accomodation in the Provinces of Groningen and Friesland, In total over 1880 enterprises were recorded.

Specific features of the data collection for tourism parameters in the Netherlands

The statistics for Studie "Toerisme en recreatie in cijfers 2008" covers operations, hotels, holiday bungalows and campgrounds with more than five beds.
The report "Toerisme in Cijfers 2003 – 2007" and the update "Toerisme in Cijfers 2009" published by the "Instituut Service Management" is a best practice example compiling tourism data for North Netherlands. Amongst other, detailed overnight statistic and expensed are compiled for various sectors (hotels, accommodations with breakfast, camping grounds, holiday homes, group accommodation and marinas). All data are statistically harmonized and published in the reports which ensures a comparison of the data.

Table 5: Number of enterprises in the provinces of Groningen and Friesland in 2007, Source: Instituut Service Management, 2008.

	Groningen	Friesland	Total
Hotels	74	176	250
Accomodation with breakfast (Logies en ontbijt)	140	286	426
Erfgoedlogies	44	47	91
Camping	113	349	462
Recreation parks	22	153	175
Group accommodations	28	186	214
Marinas	45	218	263
Total	466	1415	1881

Accomodation categories	2005			2006			2007			2008		
	Groningen	Friesland	Total	Groningen	Friesland	Total	Groningen	Friesland	Total	Groningen	Friesland	Total
Hotels / pensions	523	1,195	1,718	528	1,251	1,779	498	1,231	1,729	503	1,191	1,694
Accomodation	35	88	123	33	97	130	40	103	143	40	121	161
Camping (tourism)	404	1,623	2,027	429	1,686	2,115	410	1,548	1,958	439	1,492	1,931
Camping (permanent)	494	2,388	2,882	522	2,392	2,914	491	2,380	2,871	476	2,351	2,827
Group accomodation	65	979	1,044	58	987	1,045	58	948	1,006	55	950	1,005
Holidy home	466	2,881	3,347	488	2,968	3,456	481	3,194	3,675	457	3,396	3,853
Second home	118	282	400	121	280	401	126	297	423	120	315	435
Water sports	156	1,576	1,732	160	1,570	1,730	164	1,554	1,718	158	1,601	1,759
Total	2261	11,012	13,273	2,339	11,231	13,570	2,268	11,255	13,523	2,248	11,417	13,665

Table 6: Overnight stays differentiated between the various sectors in the provinces of Groningen and Friesland 2005 – 2008) Source: Instituut Service Management, 2009.

In addition, on the island of Texel, number of beds is about calculated to 44,000 (no specification of type of accommodation)

In 2007, 13.5 million overnight stays were estimated for the provinces of Friesland and Groningen (13.7 million in 2008) (Instituut Service Management, 2008 and 2009). 4.4 million of these overnight stays were counted on the Wadden Sea islands of Friesland. On the island of Texel (Provice of North-Holland), the number of overnight stays amounted to 3.9 million in 2006 and 2007, and 4.1 million in 2008 (pers. comm. VVV Texel)

In addition, over 60 million day trippers were estimated in the provinces of Groningen (31.7 million) and Friesland (31,4 milion) in 2007 (Instituut Service Management, 2008).

On the Dutch Wadden Sea island, the number of overnight stays amounted to 8.5 million in 2008 (4.1 million Texel, 4.4 on the Frisian Wadden Sea islands) (Instituut Service Management, 2009, and pers. Comm., Texel VVV).

In Figure 1, the overnight stays in the provinces of Groningen and Friesland in 2008 are differentiated into various sectors, the largest amount (28 %) covers holiday homes (Instituut Service Management, 2009). No detailed information is available for the Wadden Sea islands.

The average expenditures of day trippers were calculated with 14.02 Euro (Instituut Service Management, 2008). In total, 63.1 million day trippers were estimated which results in a total of 884 million Euro revenues in the provinces of Groningen and Friesland. Together with the income from overnight stays (530 million Euro), the total revenue of 1.4 billion Euro was gained from the tourism sector in the provinces of Groningen and Friesland in 2007 (Instituut Service Management, 2008). No data are available for the island of Texel.

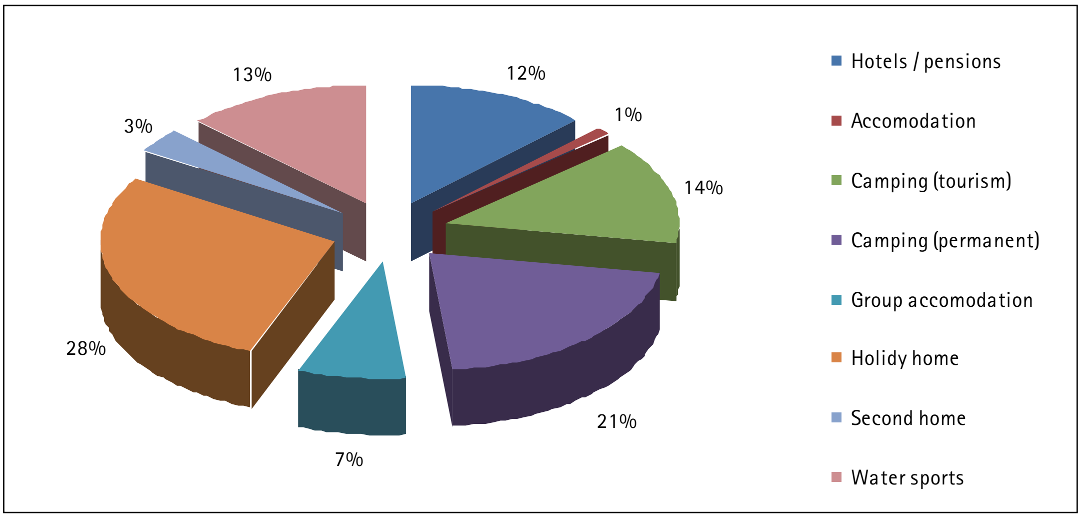


Figure 1: Distribution of overnight stays in the provinces of Groningen and Friesland in 2008. Source: Instituut Service Management, 2009.

Table 7:
Expenditure for each accomodation category in Euro and % in the provinces of Groningen and Friesland. Source: Instituut Service Management, 2008.

	2005						2006						2007					
	Groningen		Friesland		Total		Groningen		Friesland		Total		Groningen		Friesland		Total	
	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%
Hotels / pension	32	36%	73	17%	105	20.8%	33	36%	77	18%	110	21.1%	31	35%	77	18%	108	20.4%
Accomodation with breakfast (Logies en ontbijt)	2	2%	4	1%	6	1.2%	2	2%	5	1%	7	1.3%	2	2%	5	1%	7	1.3%
Camping (tourism)	11	12%	42	10%	53	10.5%	11	12%	44	10%	55	10.5%	11	12%	41	9%	52	9.8%
Camping (permanent)	13	15%	62	15%	75	14.9%	14	15%	63	15%	77	14.8%	13	15%	64	15%	77	14.5%
Group accomodation	2	2%	30	7%	32	6.3%	2	2%	31	7%	33	6.3%	2	2%	30	7%	32	6.0%
Holiday homes	16	18%	101	24%	117	23.2%	17	19%	105	24%	122	23.4%	17	19%	115	26%	132	24.9%
Second home	3	4%	8	2%	11	2.2%	4	4%	8	2%	12	2.3%	4	4%	9	2%	13	2.5%
Water sports	10	11%	96	23%	106	19.8%	10	11%	97	23%	107	20.5%	10	11%	98	22%	108	20.4%
Total	88	100%	417	100%	505	100%	92	100%	430	100%	522	100%	91	100%	439	100%	530	100%

Table 8:
Revenues from day trippers and overnight stays in the provinces of Groningen and Friesland in 2007. Source: Instituut Service Management, 2008.

	Day trippers (Mio. Euro)	Overnight stays (Mio. Euro)	Total (Mio. Euro)
Groningen	444	91	535
Friesland	440	439	879
Total	884	530	1414

3.4.2.3 Evaluation of the basic data on tourism demand in an overall context

Tourism has considerable economic importance in the Wadden Sea region. Cumulating all the available data on overnight stays in the Wadden Sea region yields a total of approximately 49,2 million overnight stays for 2007. However, the number of overnight stays is probably much higher in all regions because many small enterprises are not covered by the official statistics.

Nature is the dominating factor which is increasingly determining the attractiveness of the region for tourism. This is partly due to the desire of most of the visitors to experience "intact nature and environment" described above. In addition, it is most probably also the result of an increased willingness for cooperation on the part of the national parks, protection areas and the regions, as well as more professionalism in the marketing of the natural environments together with regional and local stakeholders (Maschewski 2008).

Taken together, the day guests visiting the Wadden Sea states generate revenues of 2.1 billion Euros. The reason for this increase in comparison to earlier surveys of day trippers has most probably only to a certain degree to do with the developments described above, although they, of course play a role. Surely more important, however, is the fact that the role of this market has only begun to become known in the regions during the past few years, and targeted surveys and comprehensive analyses of this market are thus relatively young.

The daily expenditures given for the different regions vary to a high degree, ranging from 26,60Euro in the Netherlands over 54Euro in Denmark and up to 67.42Euro in Lower Saxony and 73.30Euro in Schleswig-Holstein. This amounts to an average daily expenditure for a tourist in the Wadden Sea region of 55,33Euro.

In the year 2007, the revenues generated by overnight stays in the Wadden Sea region amounted to 3.5 million Euros, whereby the value for Lower Saxony is based on calculations from the year 2006. The revenues in Germany, with 1.5 billion Euros for Lower Saxony and 2.2 billion Euros for Schleswig-Holstein, are markedly above those in Denmark, with 358.3 million Euros, or in the Netherlands, with 530 million Euros. For the

Table 9:
Summary of basic tourism data in the Wadden Sea regions in 2007.

	Denmark	Germany		Netherlands	TOTAL 2007
		Lower Saxony	Schleswig-Holstein		
Arrivals	n.s.	1.86 million	1.9 million	4.8 million*	n.s.
Overnight stays	6.6 million	13.4 million	15.7 million	13.5 million**	49,.2 million
Average duration of stays in days	n.s.	7.2	7	5.4*	n.s.
Number of beds	n.s.	75,958 beds	115,865 beds	263,859 beds*	n.s.
Bed capacity utilization	33.1% South Denmark	31.3% mainland, 35.2% islands	33.20%	n.s.	n.s.
Foreign guests %	88.1% in summer bungalows	0.5% islands, 2% mainland	1.10%	27.5% *	n.s.
Daily expenditures (commercial operations)	54 Euro	67.42 Euro	73.30Euro.	39,19 Euro overnight stay, 14,02 Euro daytrippers***	n.s.
Revenues from overnight stays	358.3 million Euro	1.5 billion Euro ***	1.15 billion Euro	530 million Euro**	3.5 billion Euro
Day trips	n.s.	32.5 million ***	12.5 million ***	63.1 million **	n.s.
Revenues from day trips	n.s.	824.7 million Euro ***	413.7 million Euro ***	884 million Euro**	2.1 billion Euro
Total revenues	358.3 million Euro	2.38 billion Euro ***	1.5 billion Euro	1.4 billion Euro**	5.6 billion Euro
Jobs	3,500	40,383	n.s.	38.138**	n.s.

* Data refer to Wadden Sea islands and North Sea seaside locations in operations with more than 5 beds, including camping sites for the entire Dutch coastal region

** Data refer to the Provinces of Groningen and Friesland. (Number of ovenight stays for the Frisian Wadden Sea islands is 4.1 million and the island of Texel (Province of Noord Holland) is 4.4 million.

*** Value from 2006

Sources:
Denmark: SGVSH, 2008, Lecture at tourism conference. Overnight stays and revenues refer to hotel data from 2007 and summer bungalow data from 2006.
Lower Saxony: IHK East Frisia and Papenburg 2008, SGVSH, 2008, Tourismusverband Nordsee e.V., 2008.
Schleswig-Holstein: SGVSH, 2008, Nordseebäderverband 2007.
The Netherlands: Central Bureau voor de Statistiek, 2008, Instituut Service Management, 2008, 2009

year 2007, this calculation, based on the data described above, yields a higher value of 5,6 billion Euros.

The average length of stay has declined markedly for all regions in recent years, which corresponds to the general trend in travel toward more and shorter trips. This is also the case for tourism in the Wadden Sea region. The utilization of bed capacity is around 33% for all countries, which is an average value for rurally structured areas.

The numbers of foreign guests vary, which lies is the nature of the very heterogeneous structure of the available facilities in the different countries. Denmark, with 88.1% in summer bungalows, lies markedly higher than the Netherlands, with 27.5%, and Germany stands out extremely with only 1.0%. Even though there is certainly potential for growth in the German market, at the moment no strong growth in the foreign sector is to be expected. The focus in marketing of the German Tourism Center (Deutsche Zentrale für Tourismus, DZT) for foreign tourism is in the segment of city and cultural travel.

The designation of the Wadden Sea area as World Heritage would surely present new chances for marketing, since this decision would bring with it a number of new platforms in the global competition. This would have positive consequences for the economics of the region and should therefore be considered in future marketing strategies.

3.4.3 Land based tourism and recreation

3.4.3.1 Tidal flat walking

The land-based activities related to tourism and recreation will be evaluated in the following according to the number of guided tidal flat walks in the individual countries. The counts of tidal flat walks are carried out using different methods in the various countries:

In Lower Saxony five aerial surveys were carried out during the period from 2000 to 2007 at "times of maximum tourist density" (= good weather, weekend, season). During the aerial surveys, all people observed in the coastal area between the mouths of the Ems and Elbe rivers were counted. The counts differentiated between groups hiking in the tidal flats, individual hikers in the flats, hikers at the beach and hikers starting at boats. It can be assumed that the groups hiking in the tidal flats were in practically all cases accompanied by guides (Frank, 2007). In the year 2008, the aerial surveys were discontinued.

In Schleswig-Holstein, the National Park guides and the nature conservation NGOs are obliged to report the number of guided tours (flat walking) and number participants to the National Park Administration. Tours by non-certified tidal flat guides and private tours are reported on a voluntary basis. Therefore, a complete registration of all guided tours cannot by guaranteed by this method.

In the Netherlands, the Stuurgroep Waddenprovincies surveys and publishes the annual numbers of guided tidal flat walks. The walks are grouped into three categories. In the first category, the Type A excursions, tours are offered by seven organizations for groups of 50 to 70 participants. Type B excursions are organized for smaller groups of at most 12 persons. Type C-licenses are individual hikers (no participants are allowed) and excursions.

Around half of the tours are carried out by individual guides, the other half by License Type A guides. The number of participants in excursions of the types A and B are limited to 50,000 per year. The number of Type C excursions is not recorded.

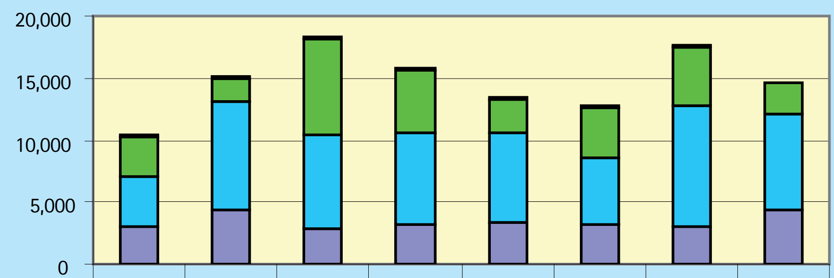
For Denmark no new data have become available since the Quality Status Report 2004.

Monitoring Results

In the Wadden Sea area of Lower Saxony, the quantitative results on the tidal flat hiking groups vary to a great degree from year to year, which points to a low reliability of the survey methods. The distribution of the categories surveyed is, however, similar over the years. The greatest proportion is made up by the individual hikers, followed by the groups and the hikers at the beach. For the year 2007 the results show that 52% were in the category individual hikers, 29.7% were hikers in groups, 17.6% were hikers at the beach and 0.5% were persons at boats (Frank, 2007, unpublished) (Figure 2).

The values from Schleswig-Holstein present a much more consistent picture. A total of 6,204 hikes with almost 125,000 participants were carried out in the year 2007 (Table 10). There was a marked increase of around 50% in the number of guided tours in the Wadden Sea between the years 1999 and 2007. The size of the groups walking the tidal flats decreased during this period. In the year 1999, the average group consisted of 27 participants; in 2007 the number had decreased to 20. The majority of the tours (69%) were carried out by members of NGOs (Schutzstation Wattenmeer), 23% by National Park guides, 3% by members of „Öömrang Ferian“ and 2% each by employees of the National Park Service, independent guides and employees of the NABU (Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer, 2008c, unpublished).

In the Netherlands the majority of walking tours are carried out in the "Groninger Wad" and in the eastern part of the "Frisian Wad". The number



	2000	2001	2002	2003	2004	2005	2006	2007
Persons at boats	81	115	240	144	121	158	147	79
Hikers at the beach	3,193	1,987	7,751	5,095	2,721	4,121	4,635	2,580
Individual hikers	4,121	8,677	7,552	7,262	7,229	5,445	9,742	7,662
Hikers in groups	3,000	4,364	2,835	3,247	3,325	3,110	3,081	4,363

Figure 2: Results of aerial counts in summer in the Wadden Sea of Lower Saxony in the period 2000-2007 (sum of five flights, respectively). Source: Frank, 2007.

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Participants	114,719	108,281	113,681	115,951	112,905	111,039	106,052	105,750	124,904
Number of guided tours	4,123	4,467	4,682	4,924	4,934	4,847	4,515	4,637	6,204
Average size of groups (number of participants)	27.8	24.2	24.2	23.5	22.8	22.9	23.5	22.8	20.1

Table 10: Number of guided tours (tidal flat walking) and numbers of participants in the Schleswig-Holstein Wadden Sea region for the period 1999-2007. Source: Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer, 2008c, unpublished.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Type A excursions	32,071	30,598	33,999	32,430	27,227	30,253	26,182	26,182	21,088	22,458	24,964
Type B excursions	4,376	4,582	5,694	5,700	5,682	4,981	5,268	4,933	2,604*	7,107	5,244
Excursions for environ. education	33,000	34,928	37,575	38,822	46,230	35,963	50,851	51,524	30,132*	53,847	44,033
Total	69,447	70,108	77,268	76,952	79,139	71,197	82,301	82,639	53,824	83,412	74,241

Table 11: Participants in guided tours in the Dutch Wadden Sea. *incomplete data. Source: QSR 2004, Stuurgroep Waddenprovincies, 2008, unpublished.

of participants in excursions of the types A and B was 30,208 for the year 2007. The limit of 50,500 participants set for this type of excursion was thus not reached in 2007 (Table 11).

Conclusions

The number of tidal flat tours in the countries bordering the Wadden Sea appears to remain at a continuously high level and in some cases to show an increase. Particularly the Schleswig-Holstein Wadden Sea National Park has shown significant growth in this respect. Since the numbers of tours and participants are assessed with widely varying methods in the different countries, the available data do not seem to be a sufficient basis for deriving reliable trends for all countries. Against the background of growing numbers of visitors in all countries bordering the Wadden Sea, in can however be assumed that the total numbers of tidal flat walks (e.g. individual hikers or unregistered tours) is much greater than represented here. Since, as can be seen for example in Schleswig-Holstein, large numbers of visitors are involved, it is urgently recommended that consistent methods of data collection should be applied. Only on the basis of sound data the needs for protection and utilization can be balanced.

3.4.4 Water-based tourism and recreation

3.4.4.1 Recreational boating

Regulations

Since the last Quality Status Report 2004 there have been no changes in regulations for boating in any of the countries.

Methods

Various indicators are used to depict the development of recreational boating. In the Netherlands the number of sluice passages are counted; in the other areas of the Wadden Sea data are generated by aerial surveys.

Sluice passages

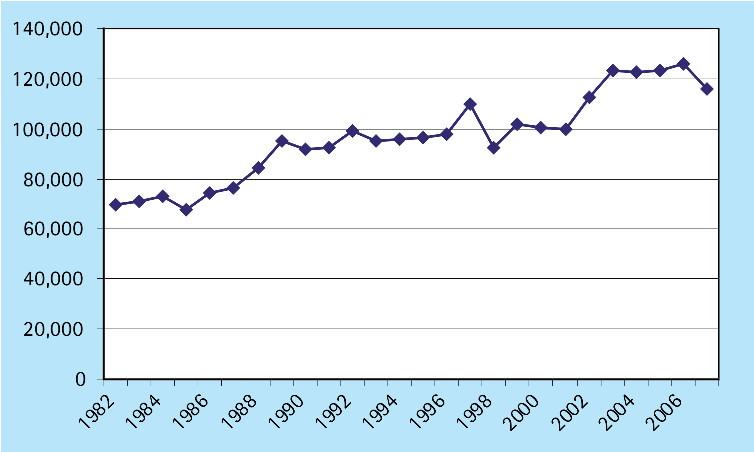
The Wadden Sea coast of the Netherlands can only be reached from the open sea and from the German Wadden Sea by way of sluice passages. There are eight localities on the North Sea coast which have sluices: Den Helder, Den Oever, Kornwerderszand, Harlingen, Lauwersoog, Delfzijl, Termuntenzijl and Nieuw Statenzijl. The number of passengers on the boats passing through have been recorded since 1982.

Aerial surveys

In Denmark data have been collected since 1980 on recreational boating and other outdoor activities in the Wadden Sea people on the beach, beach sailing, windsurfing, recreational fishing, people outside the beach/dune areas, recreational boating, horseback riding, and hunting. The National Environmental Research Institute (NERI) and the Ribe Environmental Center have aerial counts carried out over the region. The last survey was in 2004. In comparison to 1980, the number of flights was reduced by 25 - 33%. Since 2003, only shipping as a whole has been monitored and not individual types of leisure boats and ships (personal communication Christensen, 31 October 2008, 07 November 2008).

In the Schleswig-Holstein Wadden Sea the „Wasser und Schifffahrtsamt" (WSA) had the number of watercraft surveyed by plane. The aerial surveys are carried out in connection with the monitoring responsibilities of the National Park Office. The objective of the surveys is to count all seabirds, seals and watercraft. In 2007 twenty aerial counts were carried out from March to September in the Wadden Sea areas of North Frisia and Dithmarschen.

Figure 3: Development of the number of sluice passages of recreational boats in Dutch harbors connecting to the Wadden Sea, period 1982 – 2007 (Den Helder, Den Oever, Kornwerderzand, Harlingen, Lauwerssoog, Delfzijl). Source: http://www.interwad.nl/Feiten_en_Figuren.1901.0.html#c7999



In Lower Saxony aerial surveys were carried out in the Wadden Sea area in the months May to August from 1988 to 1998 by the "Wasser- und Schifffahrtsdirektion" (WSD) Nordwest. These surveys were discontinued in 1998.

In the Netherlands aerial surveys were carried out in the years 1980, 1982, 1988, 1995, 2000 and 2005. Since 1995 the Stuurgroep Waddenprovincies has carried out surveys every five years. In the year 2005 four flights were carried out in the period from May to August. All four were on weekends, three at high tide and one at low tide.

3.4.4.2 Monitoring Results

Sluice passages and marinas

In the year 2007, a total of 115.651 sluice passages were recorded in the Dutch Wadden Sea. Since the year 1982 the number of sluice passages has increased continuously. With 126,002 passages in 2006, the highest number was recorded since 1982 (69,808 passages). In recent years the number of passages has been consistently over 115,000 (Figure 3).

Aerial surveys

In the Danish Wadden Sea the distribution of the different outdoor activities hardly changed over the period 1980 to 2004 (Table 12). The largest proportion (85%) was represented by people on the beaches followed by people outside the beaches and dunes. Wind surfing and beach sailing are underrepresented in the counts, because they were carried out on days with little wind. Hunters were also underrepresented, since the counts were carried out during full daylight. On the average, ten wind surfers were counted in 1980 and 2004. The number of beach sailors/kite buggies increased from 1-2 in 1980 to 2-91 in 2004. The number of boats anchored in the Wadden Sea area and in the harbors behind the dikes was 900 in 2004 (personal communication Christensen, 31 October 2008, 07 November 2008; data provided by Laursen / Frikke).

The aerial surveys of 2005 show that the western Wadden Sea of Lower Saxony is the area with the highest density of shipping traffic (in

Table 12: Comparison between 1980 and 2004 data on distribution between different outdoor activities.

Activity	1980*	2004**
People on the beach	86.4%	85.4%
Beach sailing	0.1%	1.0%
Windsurfing	0.9%	0.5%
Recreational fishing	1.4%	0.1%
People outside the beach/dune areas	8.5%	10.8%
Recreational boating	1.9%	0.9%
Horseback riding	0.0%	0.5%
Hunting	0.9%	0.2%
* Aerial surveys by NERI on days with light wind in the period July-November		
** Number of flights reduced to 25-33% compared to the 1980 surveys		
Source: John Frikke, Environmental Centre, Ribe and Karsten Laursen, National Environmental Research Institute (NERI) personal communication Christensen, 30 October 2008, 7 November 2008		

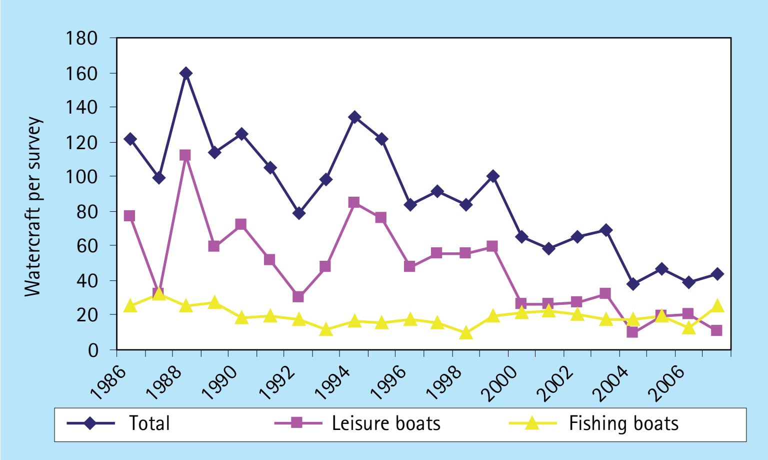


Figure 4: Average number of boats per flight in the Schleswig-Holstein Wadden Sea National Park in the period 1986-2007. Source: Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer, 2008d, unpublished.

1995: 78%, and in 2000: 69%). The highest shipping density of 8.4% was observed in the Frisian Wadden Sea. In previous surveys this value was rather stable and around 10%. In the vicinity of the Engelsmanplaat 10.6% of the boats were counted, which is in good agreement with the value from 2000 of 11%. In the area of the Groninger Wad and the Ems-Dollar around 10% were registered as well. In the year 2005 a total of 1,516 ships were counted during the flights. In the Wadden Sea of Schleswig-Holstein, counts in the North Sea during the years 1986 to 2007 yielded between 38 and 159 ships (Nationalparkverwaltung Schleswig-Holsteinisches Wattenmeer, 2008d) (Figure 4). The number of boats was normally highest in the North Frisian region between the islands of Föhr and Amrum and the mainland.

General Trends

In the Netherlands, the number of sluice passages has increased since 1982. In Schleswig-Holstein the numbers of ships counted has declined since 1986, even though there was a slight increase in 2007 compared to 2006. The available data may not be really sufficient for a quantitative comparison of recreational boating in the entire Wadden Sea region, but indicated general trends in the single Wadden Sea region. In order to incorporate this TMAP parameter into the data base for future QSRs, a more uniform method of data acquisition is recommended.

3.4.5 Conclusion and recommendations

Tourism represents an important and ever growing market in the Wadden Sea region, as the 49,2 million total overnight stays, the over 6 billion Euro total revenue and the presentation of the other key data on tourism demand has shown clearly. For the people living in the predominantly rurally structured regions of the countries bordering the Wadden Sea, there is in most cases no alternative to tourism. It therefore appears to be of utmost importance to harmonize the existing surveys and find reliable parameters for quantitative monitoring of the activities and impacts of the visitors to the Wadden Sea region. The parameters determined at present and, especially, their interpretation is not suitable to indicate reliable trends for the entire Wadden Sea. A prerequisite for assessing the effects of recreational activities is the use of uniform parameters and – in particular – reliable survey methods, which is the only way the actual impacts on the Wadden Sea area can be assessed. The indicators regarding the tourism market in the countries allow a reliable estimation of the developmental trends, even though they differ in definitions and survey methods. However, the presently used approaches for recording land-based and water-based activities in the various are not adequate for a trilateral assessment. In this respect there is great heterogeneity of methods and approaches During the process of defining uniform impact parameters, it would therefore appear reasonable to carry out surveys on vacationers in the region and to analyze their main activities in order to be able to react to changes in human activities in a timely fashion. A good example can already be found in the Schleswig-Holstein Wadden Sea National Park. The objective should be a multi-dimensional market research instrument with which demand as well as changes in utilization behavior, as well as the impacts on nature and the environment can be monitored. It should also form the basis for coordinated regional development concepts in the Wadden Sea region, which are clear in direction but allow for flexible and just solutions to the many challenges posed by nature protection, tourism and recreation.

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Military Activities

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3.5 Military Activities

3.5.1 Introduction

The military activities in the Wadden Sea Area and adjacent areas involve exercise and shooting ranges for ground forces and aircraft, testing areas for military equipment, low altitude flight and air target areas for military aircraft, and associated flights of aircraft and helicopters.

The main centre of the activities is situated in the western Dutch section of the Wadden Sea Area. The 1999 QSR stated that, in general, military activities and exercise areas have been reduced during the last decade in all of the area. Since then, no major new developments have been reported. In The Netherlands, the regulations for military activities are laid down in the 'Structuurschema Militaire Terreinen' which was adopted by Parliament in December 2004.

The PKB (Derde Nota Waddenzee, January 2007) contains the policy with regard to military activities for next ten years and several decisions have been taken to reduce effects on the environment. The general minimum flight height was raised from 300 to 450 m (with an exception for military helicopters and the approach of the shooting range Vliehoors) and the low-altitude flight route was closed. The cavalry range on Vlieland was closed in 2004, and the anti-aircraft artillery range at Den Helder was closed in 2005.

A map of the localities of the exercise areas and the activities in the Wadden Sea Area is in Figure 3.5.1

3.5.2 Military exercise areas

The Netherlands

There are two military exercise areas in The Netherlands, the "Vliehors" and the "Mokbaai". Both are partly within the PKB area.

Vliehors

In use since 1960, the "Vliehors" is a shooting range for NATO-military aircraft on a large sandbank on the west side of the island of Vlieland, partly in the PKB area. Normally it is used on work days for firing guns and rockets and bomb dropping. Explosive bombs are only used outside the breeding season. Practices with bombs, rockets and gunning from fighter planes occur on average 180 days per year. On average, about 3,000 aircraft movements are registered annually. This activity is now being subject to an assessment of their possible effects on the natural values, required for the Nature Conservation Act licensing procedure.

The security zone of this shooting range is located north of the island off the coast in the Wadden Sea Area. The danger zone, which primarily stretches out into the Wadden Sea (to a width of 12 km), has a total surface area of 105 km². The target area, including the standing points for shooting, covers a surface area of 1.5 km².

In order to limit disturbance, the dropping of explosive bombs is excluded in the period from 15 April to 1 September. Furthermore, the flight route has been situated off the coast to limit the disturbance of the neighboring island Texel.

Mokbai

The "Mokbaai" has been an amphibious exercise ground since 1917, with a military barrack and 100 persons permanently stationed. Annually, about 50 exercises involving zodiaks, landing crafts and helicopters of the naval forces are executed, confined to work days. By planning the exercises, the breeding and moulting periods of birds are taken into account. During the exercises, specific nature-respecting rules of conduct have to be followed.

Both areas have been assessed to qualify according to the Natura 2000 criteria and have been assigned accordingly. Currently, in the light of the development of the required management plans for Natura 2000 areas, investigations are ongoing to make detailed inventories of all the activities, including the possible significant effects on the natural values. Preliminary results as well as former investigations indicate that there are reasons to believe, especially at the Mokbaai, that the presence of the military zone might even have a positive effect upon the natural values. There is no impact on the overall integrity of the area.

Based on the investigations referred to above, and bearing in mind that the actually used exercise-area in the 'Mokbaai' only concerns a very small area of the nominated property, which also holds true for the 'Vliehors', consultations have started with the Ministry of Defense in The Netherlands to explore the possibilities to zone the area in time and space to reflect the activity within the Wadden Sea.

Trilateral Policy and Management

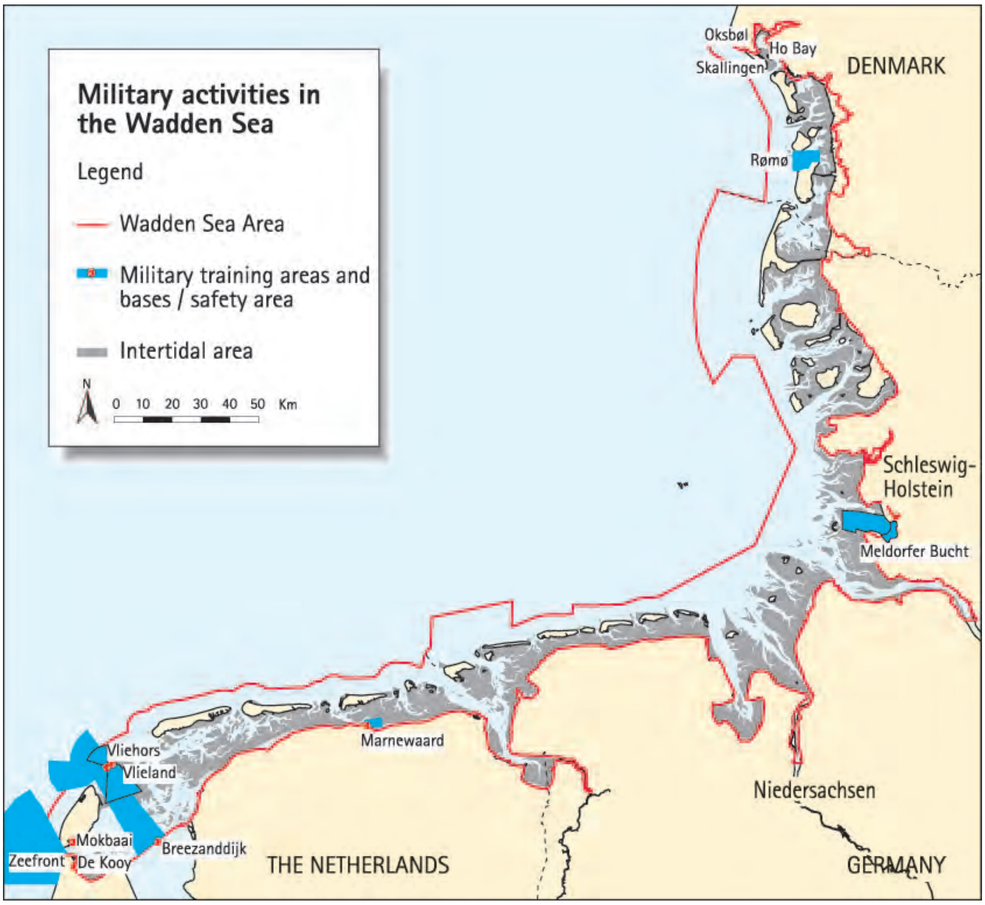
WSP 9.1.21 Disturbance caused by military activities has been, or will be, reduced and the possibilities for further concentrating and/or phasing out military activities will be regularly examined.

WSP 9.1.22 The negative effects of low altitude flight routes of military aircraft have been, or will be, reduced by reducing the number of flights and the maximum speed.

WSP 9.1.23 Action to minimize disturbance caused by military air traffic in the Wadden Sea area will be taken on a coordinated basis.

WSP 9.1.24 High priority will be given to the assignment of redundant shooting ranges as nature protection areas.

Figure 3.5.1: Military activities in the Wadden Sea Area.



Areas partly inside or adjacent to the Wadden Sea Area

Zeefront consists of relatively small shooting exercise ranges near Den Helder outside the Wadden Sea Area. Part of the security zone is located within the Wadden Sea Area.

Breezanddijk is a test shooting range in the IJsselmeer from a position on the Afsluitdijk, used about to a maximum of 85 days per year. The activity does not take place inside the Wadden Sea Area and only limited noise disturbance results from the tests.

The location on Vleiland has been used for tank firing. In order to limit the disturbance, the shooting period was confined to 1 September to 15 April. The security zone is situated south of the island. In 2003, the location was used for 13 weeks in total. Since May 2004, the shooting range has been out of order. Since 2005, there has been no firing at the location, but the shooting range is not officially abandoned.

Marnewaard is a shooting range for machine guns situated directly adjacent to the Wadden Sea Area northeast of the embanked Lauwersmeer and encompasses an area of 2,500 ha. The security zone is situated in the Wadden Sea Area. The shooting range is used to a maximum of 42 days per year (14 weeks per year, three day per week).

Germany

Meldorfer Bucht

The Meldorfer Bucht location in Germany has been a ballistic testing site for new weapons of the German Ministry of Defence since the early 1980s. However, over the last ten years the range has been used on average on 0.5 days per year only. In several years there were no tests at all. Tests are undertaken from platforms on the seawall outside the nominated property and the target area stretches into the nominated property in the Meldorfer Bucht. If tests are carried out, timing is tuned with the national park administration to avoid, as far as possible, sensitive times and disturbances of birds and mammals. Strictly no tests are undertaken during the moulting season for shelduck, which gather in the region in large flocks. Prior to any tests, helicopters fly over the area, to ensure that the security zone is safe. The remains of the projectiles are recovered from the Wadden Sea also by use of helicopters.

An impact assessment study conducted in 2001 has shown that the overall impact on birds, seals and macrobenthos was very small. Disturbances of birds due to the helicopter flights have since then been further minimized. Thus in combination with the very low frequency of testing activities it can be stated that the testing site has no negative effects on the biological values and the integrity of the Meldorfer Bucht area.

Denmark

Rømø

The northern part of the island of Rømø is a shooting range for NATO-military aircraft for gun and rocket shooting at low altitudes. The security zone covers the northern part of the island and part of the tidal inlet between Mandø and Rømø. A larger area is restricted for air traffic during exercise time. The activities are primarily carried out during summer but, normally, not in July.

Ho Bay, Skallingen and Oksbøl

Ground forces are allowed to carry out landing exercise operations in the Ho Bay and at the coast of Skallingen north of the 55°38´ latitude. The large exercise and shooting range Oksbøl is located north of the Wadden Sea Area. In connection with exercises on the exercise and shooting range, flights are undertaken on 1-2 days in August to September in the northern Danish Wadden Sea Area in flight corridors.

3.5.3 Other military activities

Other military activities concern the air traffic and associated traffic connected with the use of the exercise areas. In the Dutch Wadden Sea Area, helicopters are, e.g., used as stand-by during exercises on the locations. Specific helicopter routes have been designated to limit the disturbance, for example, off the coast of the islands and the minimum flight altitude is 500-600 feet under normal weather conditions.

In the Dutch Wadden Sea, the recently adopted management plan ('Structuurschema Militaire Terreinen') entails the ultimate closing of the low-altitude-flight route (which crosses area between the island of Schiermonnikoog and Ameland, see Figure 2.7.1), an increase of the minimum flight altitude of military aircraft over the Wadden Sea to 300-400 m and a shift of the approach corridor to the shooting range Vliehors from the Wadden Sea to the open North Sea (Interwad ,2008).

In Germany, the minimum flying-altitude for military aircraft was changed in 2002. For major parts of the German Wadden Sea, due to its status as national park, military aircraft must adhere to a minimum flying altitude of 3,000 feet (915 m) for jet aircraft and 2,000 feet (610 m) for all other aircraft, including helicopters, unless specific operations or weather conditions dictate otherwise.

The Leybucht, the Außenweser and the Jade, including the Jadebusen, belong to a low altitude flying-area with a minimum flying-altitude of 500 feet (152 m).

There are several military airports in the vicinity of the Wadden Sea Area (De Kooy and Leeuwarden in The Netherlands; Jever, Wittmund, Nordholz, Eggebek/Tarp and Kropp in Germany; Skrydstrup, Denmark) but there is no direct relationship with the use of the Area.

3.5.4 Abandoned exercise areas

In addition to the reductions indicated above, three exercise areas have been abandoned:

- Den Helder/Lutjewaard shooting exercise range in the Conservation Area;
- Noordvaarder on the island of Terschelling since 1 July 1995; the exercises have been transferred to the Vliehors; the former exercise area has been cleaned of ammunition remainders; the designation of the area as a nature reserve will be considered in the framework of the overall conservation regime of the islands;
- Königshafen exercise area on the island of Sylt has been abandoned since October 1992; the exercise area was situated outside the Conservation Area.

3.5.5 Historical ammunition dumping sites

Since the end of the First World War, dumping of conventional and chemical weapons at sea was a fairly common international practice and has been reportedly carried out in every ocean. The sea disposal of the huge no-longer-required ammunition stocks was regarded as efficient and – from a security related point of view – as unproblematic.

In the years immediately following the Second World War, there was extensive sea dumping of ammunition, especially in the North and Baltic Sea (OSPAR, 2005).

Trends indicate that the biggest part of conventional ammunition were dumped in the German coastal waters within the 12-nautical-miles zone, while the two biggest dumping sites for chemical weapons are located in the Skagerrak and the Bornholm Basin (OSPAR, 2005).

In Lower Saxony, a first systematic study about dumping sites and possible risk potentials of dumped ammunition for humans and environment started in 1990 (Rapsch and Fischer, 2000).

Extensive reviewing of papers and documents in archives showed that, according to British sources, a total of 750,000 to 1.5 million tons of conventional ammunition was dumped over the side along the German North Sea coast. About 75% of the total amount was dumped at the Lower Saxonian coast. Chemical weapons were also dumped in low quantities at the German North Sea coast (e.g. mustard bombs in the Jade and tabun shells near Helgoland) whereby definite information about actual hazards are not available up to now (Rapsch and Fischer, 2000; Liebezeit, 2002).

The 1990s survey at the Lower Saxon coast showed that the sediment loading with ammunition varied between the investigated sites from <1 t/km^2 to about 500 t/km^2. It was estimated that today a total of about 10,000 tons of ammunition is still to be found on these dumping grounds (Rapsch and Fischer, 2000).

The total amount is higher because two specific Lower Saxonian dumping grounds (in the Jade and in front of Wangerooge, on which up to 1 million tons of ammunition was dumped) and all dumping grounds along the coast of Schleswig-Holstein were not investigated. A recent study revealed that there is still at least 400,000 tons and up to 1.3 million tons of conventional ammunition and at least 90 tons of chemical weapons in the German Bight (Nehring, 2005).

Information about the occurrence of ammunition in the Dutch and Danish Wadden Sea are scarce.

3.5.6 Summary

Several exercise areas have been abandoned in the early 1990s. Since then, the activities at the existing sites in all three countries have been reduced and the cooperation of nature conservation and military authorities has been extended in order to minimize the negative effects on the Wadden Sea Area.

The possible impacts of dumped ammunition along the North Sea coast on the Wadden Sea Area cannot be assessed yet.

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Energy

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Sophia Witte

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Common Wadden Sea Secretariat
Trilateral Monitoring and Assessment Group

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3.6 Energy

3.6.1 Introduction

The demand for energy is increasing year after year. To meet this demand, various sources of energy are available, with fossil energy resources probably predominating in the coming decades. However, at the same time, the use of renewable energy sources, especially offshore windfarming, is recently discussed Wadden Sea wide.

3.6.2 Gas and oil

All exploration and exploitation activities are subject to strict regulations, probably world wide. They will be carried out in accordance with binding international and national mining and nature protection legislation, and in compliance with the Wadden Sea Plan (Stade Declaration, 1997) and international regulations, for example PSSA, OSPAR, AEWA, MARPOL, and the Ramsar and Bonn Conventions. Germany and The Netherlands confirmed their commitment not to explore and extract oil and gas at locations within the boundaries of the World Heritage Site (WHS), in line with law in force (CWSS, 2008, 2009).

The 1999 and 2005 QSR gave a detailed overview on the exploration and exploitation of gas and oil in the Wadden Sea Area. This chapter gives a short overview about the present status and focuses on major new developments since 2003.

An overview of oil and gas production sites and pipelines in the Wadden Sea Area is given in Figure 3.6.1.

The Netherlands

In The Netherlands, gas is currently being produced from five fields that are either fully or partially located underneath the Wadden Sea Area (Figure 3.6.1). These fields are: Zuidwal, Ameland, Blija, Moddergat and Groningen.

'Zuidwal' is an unmanned gas exploitation platform in the western part of the Dutch Conservation Area (PKB) between Harlingen and Vlieland. The natural gas is transported to Harlingen via a pipeline. All discharges from the exploitation site are deposited on land and the produced water is returned to the reservoir. An extensive study, carried out in 1999, and a report published by the Ministry of Transport and Water Management in 2004 showed that the effects of gas extraction from the Zuidwal site were most likely very minimal. The production facility is a 'zero emission

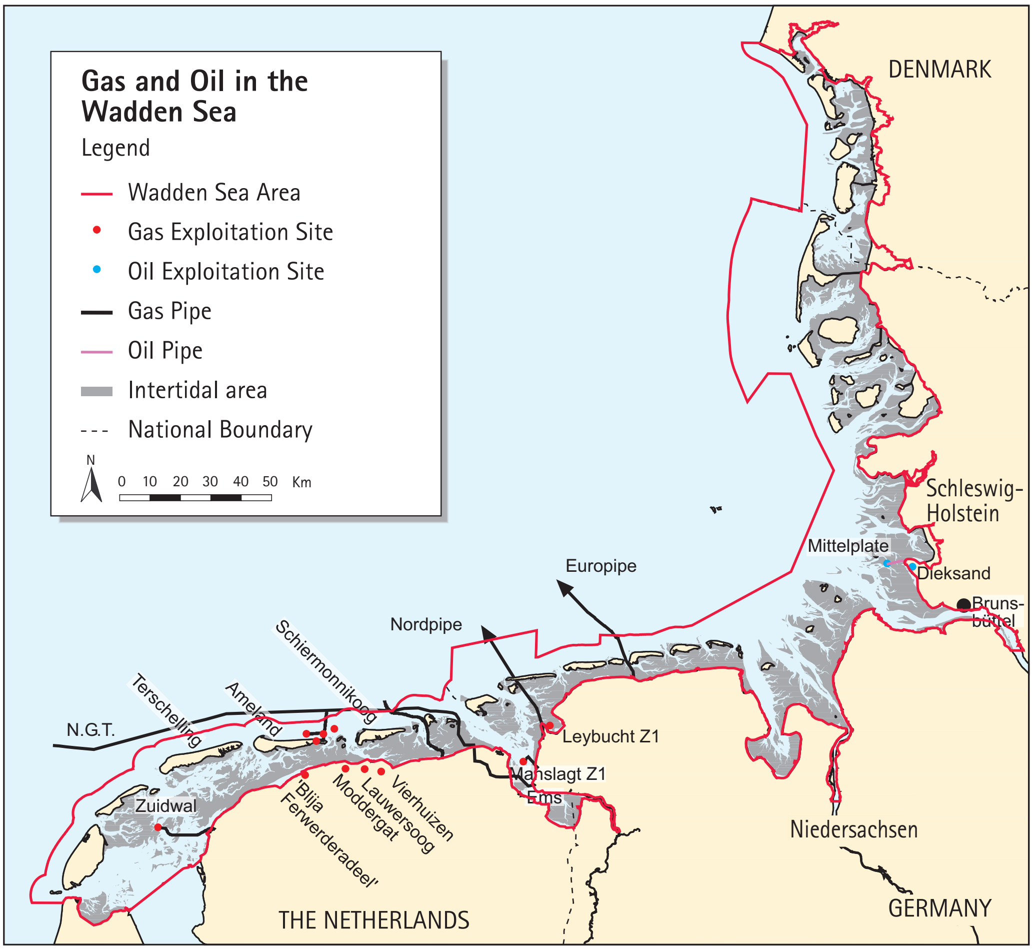


Figure 3.6.1: Gas and exploitation sites and pipelines in the Wadden Sea (source: CWSS 2008. Nomination of the Dutch-German Wadden Sea as World Heritage Site).

unit'. The area excluded from the World Heritage Site encompasses a circle around the platform with a radius of 500 meters.

The other production sites are all located outside the Wadden Sea, but their wells or reservoir may extend under it. Permits for two additional gas exploitation sites adjacent to the Wadden Sea - Vierhuizen and Lauwersoog - were granted. Production is allowed within the limits of the resilience of the Wadden Sea to compensate for sea level rise by natural sedimentation. Both subsidence and the ecological development will be followed by a strict monitoring program.

The production site "Blija Ferwerderadeel' is located on the mainland coast in the eastern part of the province of Fryslân.

The Groningen gas field extends slightly under the Wadden Sea and the Ems estuary. All production sites are on the mainland, and no production wells were drilled under the Wadden Sea.

On the island of Ameland, three sites were constructed with only one producing. The production site is situated on the east cape of the island and is connected to two offshore platforms.

The proven total gas reserve in the Dutch Conservation Area has been estimated by the "Nederlandse Aardolie Maatschappij BV" (NAM) at about 45-60 billion m^3. These gas resources underneath the Wadden Sea include the existing production locations, the proven reserves in Nes, Lauwersoog, Ternaard and Vierhuizen.

Not all gas reserves are yet explored or in production. However, it is agreed that new exploration drilling and new production installations within the Dutch part of the Wadden Sea Area will not be permitted in the future. New exploration and exploitation of gas is only permitted from sites on land and from existing platforms in the North Sea coastal zone. Thus, new production from under the Wadden Sea will have to be developed from the mainland, the islands or the North Sea coastal zone.

Germany

In Germany all exploration and exploitation activities are subject to the Federal Mining Act and are carried out in accordance with the relevant mining regulations procedure. In the context of this licensing procedure, standard authorization preconditions are required to be fulfilled. The relevant nature protection regulations of the National Park Acts, the State and Federal Nature Protection Acts, relevant EU directives and international regulations are to be complied with and followed.

An area around "Mittelplate A", within which the oil exploitation occurs, is excluded from the World Heritage Site, together with two smaller boundary adjustments in the Elbe estuary and the Knechtsand area. In these excluded areas, oil exploration drillings will take place pending licensing under the legal regime, in particular assessment and permission according to Article 6 of the EC Habitats Directive and national laws. In case resources are found, it is agreed that exploitation will only take place from outside the World Heritage Site or the existing platform respectively.

Concessions cover most of the German part of the Wadden Sea. To date, zero-discharges are applied at all installations in the German Wadden Sea Area.

Niedersachsen

There are two sites where natural gas is exploited in the Niedersachsen Wadden Sea Area. 'Leybucht Z 1' in the exploitation field 'Juist-Leybucht I"' of the concession area 'Juist' is an unmanned gas exploitation site situated in the Conservation Area:

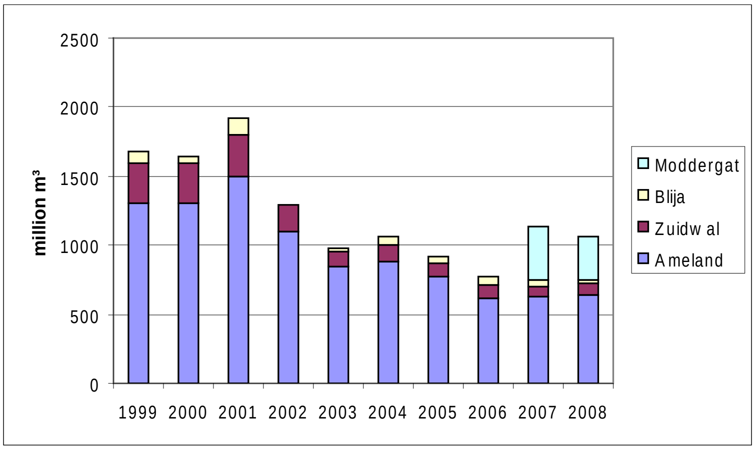


Figure 3.6.2: Gas production in the Dutch Wadden Sea (in million m^3) (1999-2007) (data source: 2008 WaddenInzicht).

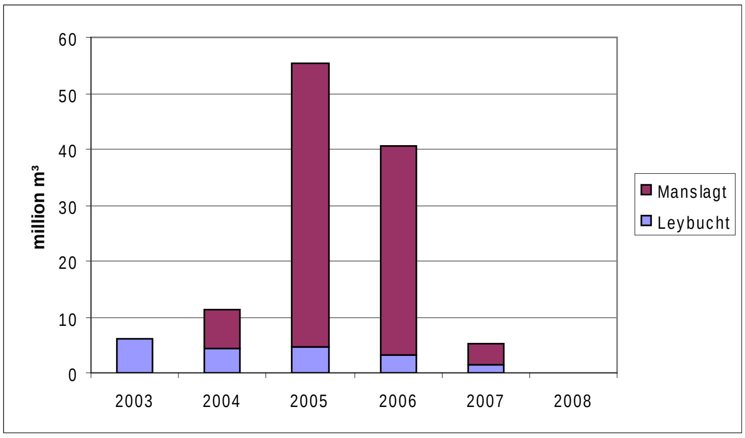


Figure 3.6.3: Gas production in the Niedersachsen Wadden Sea (in million m³) (2003-2008) (source: WEG Jahresberichte 2005-2008).

production started in 1977. The area excluded from the World Heritage Site encompasses the gas production installation. 'Manslagt Z 1', in the exploitation field 'Groothusen II' of the concession area 'Groothusen', is situated in the Ems estuary outside the Conservation Area. The production started in 1993 and stopped in October 2000 because of an occlusion of the drill-hole. In 2004 production started again.

Gas is transported from the Norwegian continental shelf of the North Sea via the Nordpipe pipeline to the Phillips Petroleum treatment plant 'Rysumer Nacken' west of Emden and the 'Europipe I+II' which has been in operation since October 1995 (see Figure 3.6.1).

Hamburg

According to the Act on the Hamburg Wadden Sea National Park, the exploitation of energy resources in the Hamburg Wadden Sea Area is not allowed.

Schleswig-Holstein

In Schleswig-Holstein, the exploitation of natural oil reserves is only permitted in the region of the Mittelplate and the Hakensand south of Trischen, situated in the southern part of the

Trilateral Policy and Management

Discharges from oil and gas exploration and exploitation activities

The exploration and exploitation of the energy resources in the North Sea, as well as in the Wadden Sea Area, has to comply, at least, with the international agreements in the appropriate fora. This results *i.a.*, in a prohibition to discharge oil-based muds and cuttings. Dumping or discharge of water based muds and/or cuttings is only allowed in line with relevant PARCOM agreements. (WSP § 2.1.8)

The leaching of toxic substances from protective coatings of pipelines and other installations will be avoided by the use of appropriate materials. (WSP § 2.1.9)

In the Conservation Area, offshore activities that have an adverse impact on the Wadden Sea environment will be limited and zero-discharges will be applied. In the Wadden Sea Area outside the Conservation Area, discharges of water-based muds and cuttings will be reduced as far as possible by applying Best Available Techniques and by prohibiting the discharge of production water from production platforms.
(WSP § 2.1.10)

Infrastructural works

New infrastructural works which have a permanent or long-lasting impact should not be established in salt marshes.
(WSP § 3.1.14)

New licenses for the construction of pipelines in the salt marshes for the transport of gas and oil shall not be issued unless such measures are necessary for imperative reasons of overriding public interest. In that case, the method of construction and the planning of the location line shall be such that the environmental impact on the Wadden Sea ecosystem is kept to a minimum and permanent, or long lasting, negative impacts are avoided. (WSP § 3.1.16; Reference to 4.1.13)

Mineral extraction and infrastructure

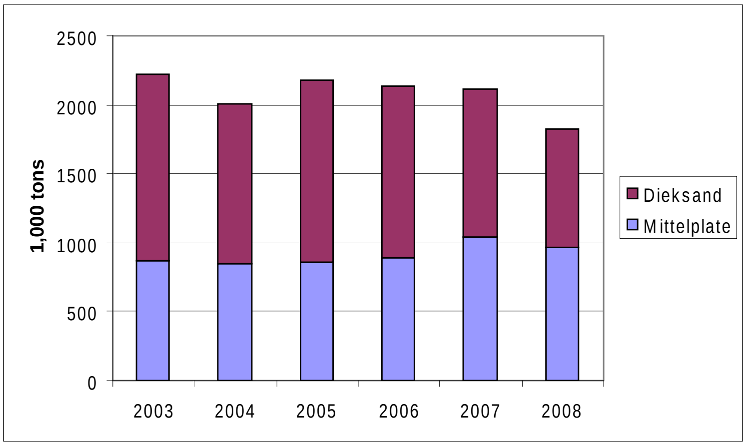
In the Conservation Area, new exploitation installations for oil and gas will not be permitted. Exploration activities are permitted within the Conservation Area if it is reasonably plausible that deposits can be exploited from outside the Conservation Area. Net loss of nature value must be prevented. Therefore, exploration activities will be regulated in space and time.

Associated studies, mitigation and compensation measures should be carried out where appropriate. (WSP § 4.1.10)

The construction and planning of pipelines shall be such that the environmental impact on the Wadden Sea ecosystem is kept to a minimum and permanent, or long lasting, negative impacts are avoided, and if this is not possible, compensated. In the Conservation Area, new licenses for the construction of pipelines in the tidal area for the transport of gas and oil shall not be issued unless such measures are necessary for imperative reasons of overriding public interest and if no alternative can be found. (WSP § 4.1.13; Reference to 3.1.16)

In order to prevent a further loss of dune areas, the existing infrastructure will, in principle, not be extended and new constructions will, in principle, not be allowed.
(WSP § 5.1.4)
(Wadden Sea Plan 1997)

Figure 3.6.4: Oil production Mittelplate (in tons) (source: WEG Jahresberichte 2005-2008).



Schleswig-Holstein Conservation Area (National Park), according to the Act on the National Park Schleswig-Holstein Wadden Sea. This requires specific approval by the responsible ministry. The consortium 'Mittelplate' initiated the construction of the exploitation site 'Mittelplate A' in 1985 and oil production was started two years later. An area around 'Mittelplate A', within which the oil exploitation occurs, is excluded from the World Heritage Site.

According to current estimates by the consortium running Mittelplate (RWE Dea and Wintershall), there are still more than 100 million tons of crude in several layers of oil-bearing sandstone at depths between 2,000 and 3,000 meters. Around 60 million t are considered to be recoverable.

In 1998, drilling operations started to exploit part of the oil from the eastern section of the 'Mittelplate' field from the mainland. Onshore production started at the Dieksand land station in Friedrichskoog in 2000, in order to speed up the exploitation and to limit the impact of the existing drilling site in the area.

Formerly, the crude oil was transported daily from the platform Mittelplate to Brunsbüttel by three special double hull tankers and from here pumped to the refinery near Hemmingstedt. Thus, oil production was restricted by transport capacity and tidal regime. In 2003, the State Mining Authority approved plans for a pipeline link between the Mittelplate production site and the Dieksand land station in Friedrichskoog (Mittelplate Konsortium, 2004). The pipeline construction in the Wadden Sea went into operation in 2005. As a result, disturbance of moulting shelduck has been minimized and potential risks of oil spills have been virtually excluded. Until now, no negative effects at the locality and its surroundings have been found.

Denmark

The Danish part of the Wadden Sea is part of the concession area of the North Sea but licenses are not issued and, according to the Statutory Order on the Nature Reserve Wadden Sea, exploitation of gas and oil in the Danish part of the Conservation Area is prohibited.

3.6.3 Wind energy

The construction of wind turbines is prohibited in the whole Wadden Sea Conservation Area according to the Danish Statutory Order, the German National Park Acts and the Dutch Conservation Area (PKB Area).

On the islands and the adjacent mainland outside the Wadden Sea Conservation Area, the construction of wind turbines and wind farms is only allowed if important ecological and landscape values are not negatively affected.

Policies are in force regarding the construction of wind turbines outside the Wadden Sea Area - along the coast and offshore - considering ecological and landscape criteria.

The following chapters focus on development in the Wadden Sea Area and the adjacent offshore area.

The Netherlands

According to the Dutch Wadden Sea Policy Plan ('pkb Waddenzee'), construction of wind turbines is not allowed in the PKB core area. The licensing of wind turbines on the mainland outside the core area is a responsibility of the provincial authorities. The Natura 2000 protection regime for the Wadden Sea is applicable to this licensing policy.

The territorial sea north or west of the Wadden Sea has been closed for wind turbines according the National spatial policy plan ('Nota Ruimte').

Currently, there are two offshore projects, which are located at the west coast (off Egmond aan Zee) (Figure 3.6.5).

In the Exclusive Economic Zone (EEZ) north of the Dutch Wadden islands, three offshore wind energy projects have been submitted for a license. These projects are situated just north of the territorial border (Riffgrond area) and will probably be approved end of 2009 (see table 3.6.1). These projects are not yet feasible financially.

Currently in the framework of the National Water Policy Plan, an area for wind energy production is to be delimitated in the EEZ North of the Wadden Islands. The three planned projects of Table 3.6.1 are situated within this area. A final decision on this area will be taken in the course of 2010.

Trilateral Policy and Management

1.1.4 The construction of wind turbines in the Conservation Area is prohibited. (Identical with 9.1.9).
1.1.5 The construction of wind turbine, in the Wadden Sea Area outside the Conservation Area is only allowed if important ecological and landscape values are not negatively affected. (Identical with 9.1.10).

Germany

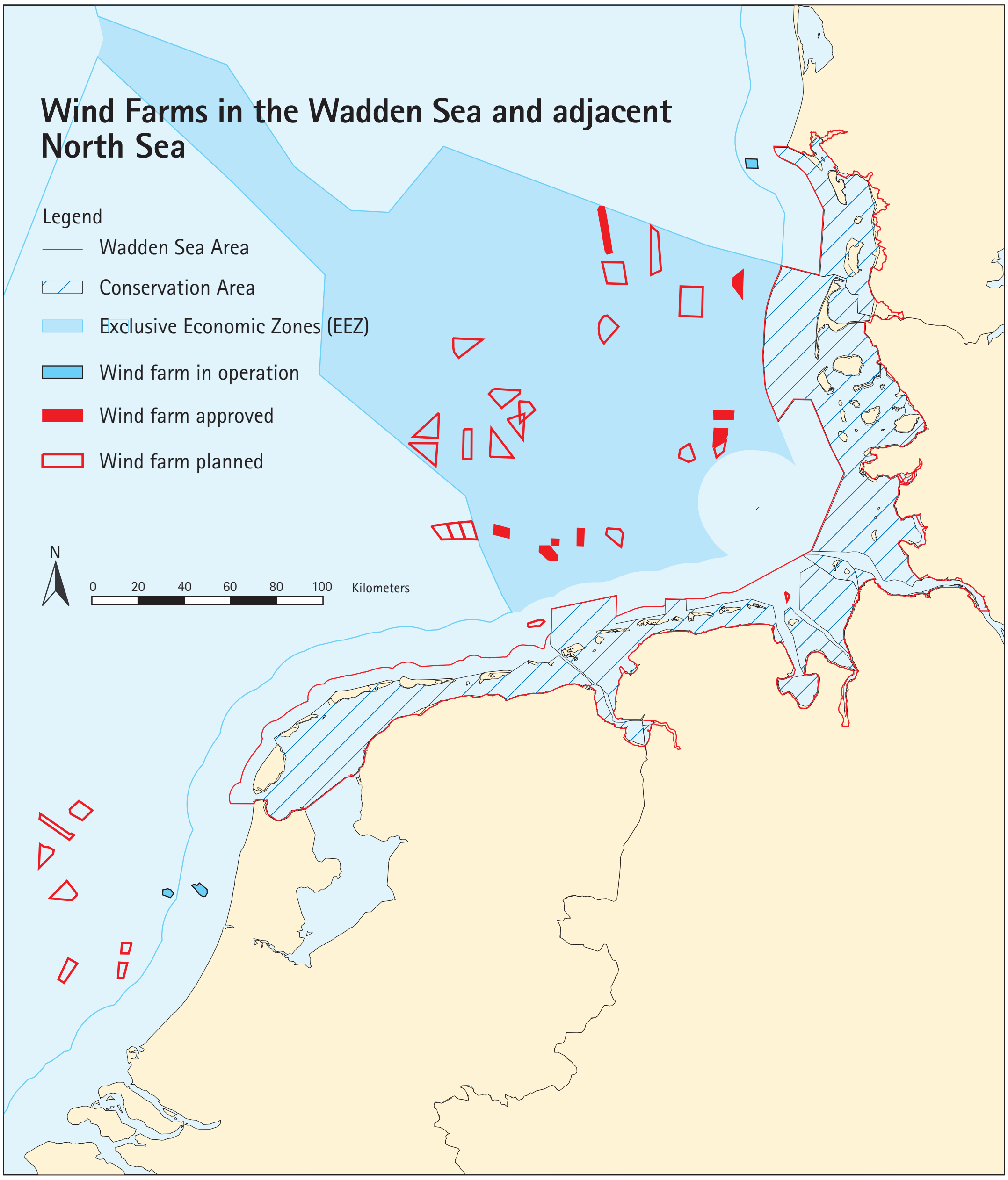
In February 2002, a political aim was set to build offshore wind turbines with an installed capacity of around 20,000-25,000 MW by the year 2030. The aim was to increase the share of electricity consumption generated by wind power on- and offshore to at least 25% within the next 30 years (BMU, 2002). The government estimated that about 500 MW of offshore capacity could be achieved in an initial phase until 2006 and about 3,000 MW in the mid term (up to 2010). In the long term (up to 2015 or 2030) 20,000 to 25,000 MW of installed capacity were thought to be realistic (see 2005 QSR). However, current projections for offshore wind energy predict a capacity of about 1500 MW by 2011 and about 3,000 MW by 2015 and about 10,000 MW in the long term.

At the moment, more than 40 offshore windparks are planned for the German North and Baltic Seas. 33 of them have already been approved by the Federal Maritime and Hydrographic Agency (BSH). An overview of offshore wind farm projects in Germany is given separately for territorial waters (up to 12 nautical miles [nm]) and the German EEZ, because the competences for the licensing procedure of offshore wind farms and their cables vary in the EEZ and the 12 nm zone. In the EEZ, the Federal Government is responsible and

Name (company)	Capacity (MW)	Location	Characteristics	Status
Princess Amalia Wind Farm (outside 12 nm)	120	23 km west of Egmond aan Zee	60 turbines	In operation since 2008
Egmond aan Zee (inside 12 nm)	108	10-18 km of Egmond aan Zee	36 turbines	In operation since 2007
BARD Offshore NL1 (Bard Engineering)	300	EEZ north of Riffground area	60 turbines	In procedure for license and subsidy
EP Offshore NL1 (Eolic Power)	275	EEZ north of Riffground area	55 turbines	In procedure for license and subsidy
GWS Offshore NL1 (Global Wind Support)	300	EEZ north of Riffground area	60 turbines	In procedure for license and subsidy

Table 3.6.1: Offshore wind farm projects in The Netherlands in 2009.

Figure 3.6.5: Offshore Wind Farms in the Wadden Sea and adjacent North Sea (status November 2009). Only approved pilot projects and wind farms in operation are shown.



the licensing procedure falls under the Offshore Installations Ordinance ('Seeanlagenverordnung') whereas in the 12 nm zone the German 'Länder' are responsible and carry out regional planning procedures. The construction of wind turbines along the coastline is also subject to the national building regulations ('BauGB'). Thorough Environmental Impact Assessments are carried out both in the EEZ and in the 12 nm zone. The German Renewable Energy Sources Act (EEG), which is also applicable for EEZ and 12 nm zone, contains a regulation that electricity from offshore wind farms will only be eligible for payment if sited outside of nature and bird conservation areas to discourage intervention in these protected Natura 2000 areas.

The routing of cables from offshore wind farms to the mainland power grid network is under discussion. Presently, four cable connections have been approved by the Federal Maritime and Hydrographic Agency (BSH): 'Windnet' (Borkum West), 'Multikabel' (Nördlicher Grund), 'Sandbank 24', 'OTP' (Amrumbank West, Nordsee Ost).

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) aspires to accelerate the offshore wind energy development. For this purpose, it supports a comprehensive research project at the offshore test site "Alpha Ventus", around 45 km north of the island of Borkum. The project, called RAVE ("Research at Alpha Ventus"), includes wind measurements, technological upgrading of turbines, grid integration and ecological accompanying research. An important prerequisite is the BMU's offshore research platform FINO 1, which started collecting data in 2003. No projects have been undertaken anywhere in the world with the construction and operation of offshore wind parks at a comparable depth and at such a great distance from the mainland. Thus, the results of the project and the lessons learned through the construction of Alpha Ventus will be of prime importance for the technical and environmental assessment of offshore wind technology in Germany. At completion, the Alpha Ventus wind farm will comprise a total of twelve wind turbines; six of them have already been constructed and have been in operation since August 2009. All are expected to be in operation by the end of this year. Already in August 2007 preparatory work for the connection to the German grid has been ongoing on Norderney and around Hilgenriedersiel. To protect the sensitive ecosystem of the Wadden Sea National Park from disturbances, hollow pipes have been laid and lines drilled horizontally through dunes and other points critical for coastal protection. In the spring of 2008, a hollow ducting structure was completed across Norderney. Simultaneously, the new substation at Hager Marsch was erected to which Alpha Ventus was connected. At the end of May 2008, the cable system was laid for the connection from Alpha Ventus to the hollow ducting construction. In summer 2008, both onshore and offshore cables were laid. With the construction of the offshore transformer station in September 2008, the operator DOTI (Deutsche Offshore-Testfeld und Infrastruktur GmbH) created the necessary prerequisites for the transmission of the generated wind power ashore (http://www.alpha-ventus.de/).

In 2008 another research platform, FINO 3, was build 80 kilometers west of the island of Sylt, at the edge of the potentially suitable area for wind farms. As with research platform FINO 1 and FINO 2 in the Baltic Sea, meteorological and hydrological data will be collected and bird migration monitored (http://www.fino3.de).

Niedersachsen

In the Conservation Area, the construction of wind turbines is not allowed but exemptions are possible, for example, on the islands (see 1999 QSR).

Within the regional planning program, a proposal for two offshore wind energy areas within the 12 mile zone was endorsed in December 2003 by the Government concerning the areas 'Nordergründe' and 'Riffgatt' (Table 3.6.2, Figure 3.6.5).

With regard to cable routing, a decision was taken in September 2004 to connect the wind farm 'Nordergründe' to the mainland power grid in Wilhelmshaven.

Schleswig-Holstein

The construction of wind turbines is not allowed in the Wadden Sea Conservation Area. The same is valid for all Halligen, the geest parts of the islands Amrum, Föhr and Sylt, geological formations under protection, as well as the areas seaward of the dikes in the Wadden Sea Area. Wind energy installations are not allowed in, or close to, feeding and roosting areas for birds. Generally, distances of 50-1,000 m from these areas have to be respected.

At the moment, there are wind energy installations on the islands of Föhr (twelve wind turbines), Pellworm (six) and Nordstrand (seven).

Hamburg

According to, the construction of wind turbines is prohibited in the entire Hamburg Wadden Sea Area.

German North Sea EEZ

Outside the 12 nm zone in the German EEZ, the Federal Maritime and Hydrographic Agency (BSH) is in charge of licensing offshore wind farm projects. In September 2008, about 18 projects were in some kind of planning stage for sites in the North Sea (BSH 2008, Figure 3.6.5). In Table 3.6.3, an overview is given of the pilot projects which have been approved by the BSH until September 2009.

Table 3.6.2: Offshore wind farm demonstration projects within 12 sm zone in Niedersachsen.

Name (company)	Capacity (MW)	Location	Characteristics	Status
Nordergründe (Energiekontor AG)	125	15 km northeast of Wangerooge	25 turbines	Approved November 2007
Riffgat (Enova GmbH)	264	15 km northwest of Borkum	44 turbines	EIA in preparation

Table 3.6.3: Overview of approved offshore wind farm pilot projects in the German North Sea EEZ (outside territorial waters > 12 sm) (BSH 2009, status September 2009) .

Name (company)	Capacity (MW)	Location	Characteristics	Status
Alpha Ventus (Prokon Nord)	60	43 km north of Borkum	12 turbines in pilot phase (planned 208)	Approved November 2001
Borkum Riffgrund-West (Energiekontor)	280	50 km northwest of Borkum	80 turbines in pilot phase (planned 458)	Approved February 2004
Borkum Riffgrund (PNE2 Riff I GmbH)	231	34 km north of Borkum	77 turbines in pilot phase (planned 180)	Approved February 2004
Amrumbank West (Amrumbank West GmbH)	400	36 km southwest of Amrum	80 turbines	Approved June 2004
Nordsee Ost (Winkra mbH)	400	30 km northwest of Helgoland	80 turbines in pilot phase (planned 250)	Approved June 2004
Butendieck (Butendieck GmbH)	240	37 km west of Sylt	80 turbinen	Approved December 2002
Sandbank 24 (Sandbank 24 GmbH)	480	90 km west of Sylt	96 turbines in pilot phase (planned 980)	Approved August 2004
North Sea Windpower (Enova GmbH)	240	39 km north of Juist	48 turbines in pilot phase (planned 286)	Approved February 2005
DanTysk (Gesellschaft für Energie und Oekologie mbH)	400	70 km west of Sylt	80 turbines in pilot phase (planned 300)	Approved August 2005
Nördlicher Grund (Nördlicher Grund GmbH)	400	84 km west of Sylt	80 turbines in pilot phase (planned 402)	Approved December 2005
Global Tech I (Nordsee Windpower GmbH & Co.KG)	400	93 km north of Juist	80 turbines in pilot phase (planned 320)	Approved May 2006
Hochsee Windpark Nordsee (EOS Offshore AG)	400	90 km north of Borkum	80 turbines	Approved July 2006
Gode Wind (Plambeck Neue Energien AG)	400	38 km north of Juist	80 turbines	Approved August 2006
BARD Offshore 1 (BARD Engineering GmbH)	400	89 km northwest of Borkum	80 turbines	Approved April 2007
Meerwind Ost & Meerwind Süd (Meerwind Südost GmbH & Co Rand KG und Meerwind Südost GmbH & Co Föhn KG)	200	24 km north of Helgoland	40 turbines (each)	Approved May 2007
Hochsee Windpark He dreiht (EOS Offshore AG)	400	85 km north of Borkum	80 turbines in pilot phase (planned 119)	Approved December 2007
Borkum West II (Prokon Nord Energiesysteme GmbH)	400	45 km north of Borkum	80 turbines	Approved June 2008
Gode Wind II (PNE Gode Wind II GmbH)	240 - 400	33,7 km north of Juist	80 turbines	Approved July 2009
Delta Nordsee II (Offshore-Windpark Delta Nordsee GmbH)	192	38,9 km northwest of Juist	32 turbines	Approved August 2009

Denmark

According to the Danish Government's action plan for energy, 'Energy 21' (published in 1997), 4000 MW of offshore wind power should be installed by 2030. The target for onshore wind energy is 1500 MW. This scheme would enable Denmark to cover more than 50% of the total electricity consumption by wind energy.

At the moment, three offshore wind farms are in operation in the North Sea (Table 3.6.4). The latest one, of about 200 MW, Horns Rev II was inaugurated in September 2009.

In the Danish Conservation Area, the construction of wind turbines is not allowed, although nothing is particularly mentioned in the newly revised Statutory Order for the Conservation Area, which came into force on 1 March 1998. According to § 13-4 of the Statutory Order, the construction of wind turbines is not allowed in the sea territory of the Wadden Sea Area.

Currently, there are two wind energy installations in the Wadden Sea Area (outside the Conservation Area), on the islands of Fanø (sixteen turbines), and Ho Bugt (three). The farm and group

Table 3.6.4: Offshore wind farms in the Danish part of the North Sea.

Name (company)	Capacity (MW)	Location	Characteristics	Status
Horns Rev (Elsam essential energy)	160	14 – 20 km off Skallingen	80 turbines	In operation since 2002
Rønland	17	1 km off Limfjord	8 turbines	In operation since 2003
Horns Rev II	200	30 km off Jutland west coast	91 turbines	In operation since 2009

are both encompassed by a local planning scheme and can be replaced by similar new ones in accordance with these plans.

On the mainland outside the Wadden Sea Area, there are scattered areas on the geest where single and groups of turbines and wind farms are located: east of Esbjerg, near to the salt marshes of Måde; in the Tjæreborg marsh; a wind farm at Hjerpsted Bakkeø up to the Wadden Sea; a few wind turbines in Tønder Marsh; and a reservation area for large wind turbines in the lower geest up to the marshlands north of the river Konge Å.

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WADDEN SEA ECOSYSTEM No. 25

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Extraction and Dredging

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3.7 Extraction and Dumping

Extraction of sand (Photo: RWS-DNN).

3.7.1 Introduction

Sand extraction has a long history as a traditional use of the area. The main purposes were the use of the material for building dikes, dwelling mounds and roads. During the past decades, this activity has steadily declined. Today, still a certain amount of sand is used only for purposes of coastal protection, e.g. beach nourishment, dike and dwelling mound (on the Halligen) reinforcement.

3.7.2 Extraction of sand and shells

This chapter gives a short overview about major changes in policy and practice regarding extraction of sand and shells from the cooperation area since 2005. For detailed statistics on sand extraction see 1999 QSR.

The Netherlands

Shells

Present policy on shell extraction was drafted in the document Shell Extraction Policy in 1998 and evaluated in 2004. The two most important changes have been a closing of areas where yields were low and limitation of shell extraction to three locations (Marsdiep, Vlie and Friese Zeegat). The total allowable amount of shells to be extracted in the Dutch Wadden Sea and the adjacent North Sea coast is based on a long-term average of natural calcimass production. Actually, 50% of this natural production are allowed to be extracted but with a maximum of 90,000 m^3.

In the tidal inlets Eierlandsche Gat, Zeegat Ameland and Lauwers extraction is not allowed anymore because of absence of exploitable shell deposits. Any extraction in the Ems estuary remains subject to the Environment Protocol (1996) of the Ems-Dollard Treaty between the Netherlands and Germany.

An issue for further attention is the importance of subtidal shell deposits for epibenthic biodiversity. This is being studied in an area in the eastern Dutch Wadden Sea. The study will be evaluated not earlier than 2009.

Sand

Since 1999, extraction of sand is only allowed as a side product of regular maintenance of shipping lanes, incidental deepening of main shipping lanes or clearance for the sake of construction.

Commercial sand extraction was moved to the North Sea outside the 20 m depth contour.

Trilateral Policy and Management

The extraction of sand in the Conservation Area will be limited to the dredging and maintenance of shipping lanes. This sand can be used for, inter alia, sea defense purposes. In specific cases, sand may also be extracted for sea defense purposes. (WSP § 4.1.11)

The extraction of sand in the Wadden Sea Area outside the Conservation Area should make maximum use of sand generated by the maintenance of shipping lanes. It should be carried out in such a way that the environmental impact is kept to a minimum and permanent, or long lasting, effects are avoided and, if this is not possible, compensated. Permits for small scale extractions of sand will remain in force. Small scale extractions of mud and sea water for medical purposes will remain permitted. (WSP § 4.1.12)

Increased attention will be given to the role of the offshore zone in the total Wadden Sea sand balance. (WSP § 7.1.2)

Sand extraction will only be carried out from outside the Wadden Sea Area. Exemptions for local coastal protection measures may be granted, provided it is the Best Environmental Practice for coastal protection. (WSP § 7.1.3)

With regard to the extraction of shells, the Wadden Sea Plan announces a study into the shell production in the Wadden Sea Area with the aim of obtaining information on natural accretion, on the basis of which new quota for sustainable shell extraction will be fixed. (WSP § 4.2.5)

The impact of dumping dredged materials will be minimized. Criteria are, amongst others, appropriate dumping sites and/or dumping periods. (WSP §§ 4.1.15; 6.1.13).

Table 3.7.1: Extracted Sand in the Dutch Wadden Sea. All quantities are hopper cubic meters. *In 2007, 320,000 m³ of the 625,000 m³ is dredged for the incidental deepening Harlingen – Noordzee (pers. comm. RWS-DNN, 2009).

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007*	2008
m^3	79,000	86,000	95,000	363,000	436,000	452,000	525,000	556,000	625,000	462,000

Germany

Shells

The extraction of shells in the German National Parks is not allowed. For the Ems-Dollard area, policies with regard to shell extraction will be laid down in the Environmental Protocol of the Ems-Dollard Treaty between The Netherlands and Germany.

Sand

Commercial sand extraction is not allowed in the Niedersachsen National Park. Sand is only extracted for dredging of shipping lanes and coastal defence purposes.

In the Hamburg National Park sand extraction is not allowed.

In the Schleswig-Holstein National Park, no sand for commercial purposes is extracted, but for coastal defence purposes or for dredging of navigational channels. In the period 1999-2003, on average 1.1 million m^3 per year was extracted for coastal defense purposes ((NPG § 2 (2)).

West of the island of Sylt, one of the largest marine sand extraction areas of the world named 'Westerland II' is used to obtain material for coastal protection of the island. 24 million m^3 sand have been extracted from that area until the end of 2006.

A new sand extraction area, called 'Westerland III', is now in a planning procedure. It is located 5 km^2 west of Sylt and encompasses the area of 'Westerland II' which, in turn, will be closed in April 2009. It is planned to extract about 20-25 million m^3 sand from an area of about 55 km^2 until 2030. An environmental sustainability survey showed that 'Westerland III' will not have any serious effect on the fauna of the sea. Although this area seems to be a considerable rearing area for harbour porpoises (*Phocoena phocoena*) the effect of the ship is negligible, as the porpoises are only affected temporarily while the ship is working. In contrast to that, common scoter (*Melanitta nigra*) will definitely be affected by sand extraction by displacing. In addtion to that, the bottom of the sea will be reduced from 11 to 23 m. Thus, the diving depth of the birds will be exceeded (GFN, 2008).

Adjacent to the Wadden Sea, two sand extraction areas (HBH 1, Brewaba 1) are in a planning procedure. They are located near Nordergründe outside of the Wadden Sea Area. At the moment, there are no extraction activities, but it is planned to extract about 20 million m^3 of sand from an area of about 900 ha.

Denmark

Shells

In the Danish part of the Wadden Sea Area the extraction of shells is not allowed.

Sand

The extraction of sand for commercial purposes is not allowed in the Danish part of the Wadden Sea Area. Permission for the extraction of sand for sea defense purposes may be granted if such material cannot be found behind the dike or can not be collected in combination with the deepening of shipping lanes. In the past years, the possibility of using dredged material for sea defense purposes has not been used.

Sand extracted for deepening of shipping lanes to Esbjerg and Fanø and is dumped back into the system (see chapter 3.7.3).

3.7.3 Dumping of dredged materials

Material dumped into the Wadden Sea mainly originates from dredged material removed for the maintenance of shipping lanes. In specific cases, dredged material may be used for sea defense purposes.

During the period 2004-2006 (average 23.9 million t/yr) the amounts of dredged material dumped into the whole Wadden Sea Area varied between about 13-30 million t/yr (dry weight) (see Table 3.7.2 and Figure 3.7.1). On average, 18.5 million t/yr (dry weight) were dumped into the German part of the Wadden Sea, 3.4 million t into the Dutch and 2.9 million t into the Danish Wadden Sea. The dumping sites and the average amount for each region are shown in Figure 3.7.2.

Because maintenance dredging is the main source of dumped material, the amounts depend mainly on natural variation of sedimentation and resuspension processes. In general, no clear trend in the amounts of dredged material dumped into the Wadden Sea can be observed. During the period 1999-2003, yearly amounts have been decreased in the Elbe, Jade and Weser areas (Figure 3.9.3.1) compared to the years before. However, in the following years yearly amounts have been increased considerably. A comparison with earlier data before is difficult to be made because the reporting requirements to OSPAR changed from tons wet weight of dredged material to tons dry weight in 1995.

Reference values of dredged material, so-called 'Action list levels', have been developed by different Contracting Parties. An overview on national action levels for dredged material is given by OSPAR (OSPAR Commission 2004a). Most countries use a '3 category action level' approach in which two discriminatory concentration levels are used. Concentrations of contaminants in the material falling below the lower limit represent those of little concern. Those falling between the lower and the upper concentration level may trigger further investigation of the material proposed for dumping. Those concentrations above the upper level generally mean that dumping of the material at sea is not permitted. Where action levels have not been developed, a 'case by case' approach is taken for each application considered individually (OSPAR Commission, 2004a).

As Contracting Parties to the OSPAR Convention of 1992, The Netherlands, Germany and Denmark are obliged to report each year to the OSPAR Secretariat on all dumping operations of the previous year. The 'OSPAR Guidelines for the Management of Dredged Material' were adopted in 1998, revised in 2004 and are being implemented in national guidelines (OSPAR Commission, 1998, 2004b).

The Netherlands

The amounts of dredged material dumped into the Dutch Wadden Sea showed significant changes during the period 2004-2006 varying between 0.3-7.5 million t (dry weight) per year (see Table 3.9.3.1). With an annual average of 3.4 million t there is a slight increase compared to the period 1998-2003 when an annual average of 1.4 million t was reported in the 2005 QSR.

In the Fourth National Policy Document on Water Management of 1998, the Dutch government agreed to the development of a new assessment system. Thus, during period 1998-2002, scientific research was performed which resulted in an alternative method of testing dredged material, the so-called Chemical-Toxicity-Test (CTT).

In order to get a better insight into the combined toxic effects of contaminants in dredged material, so-called levels for three sediment bioassays

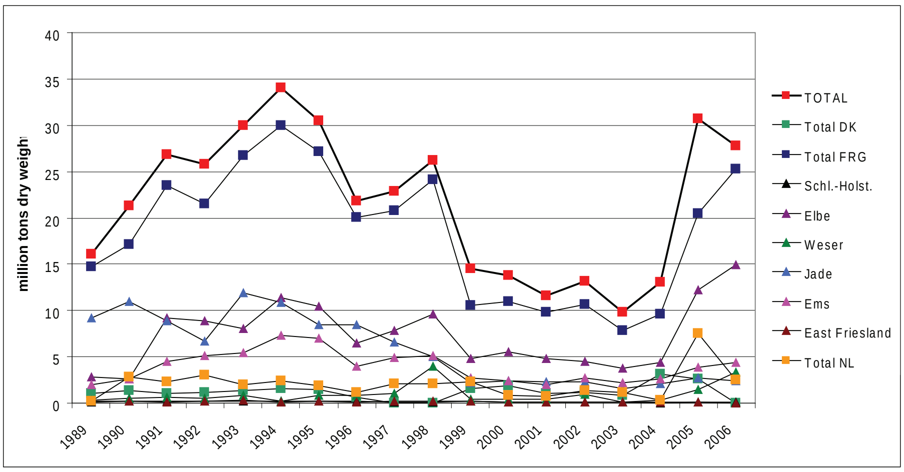
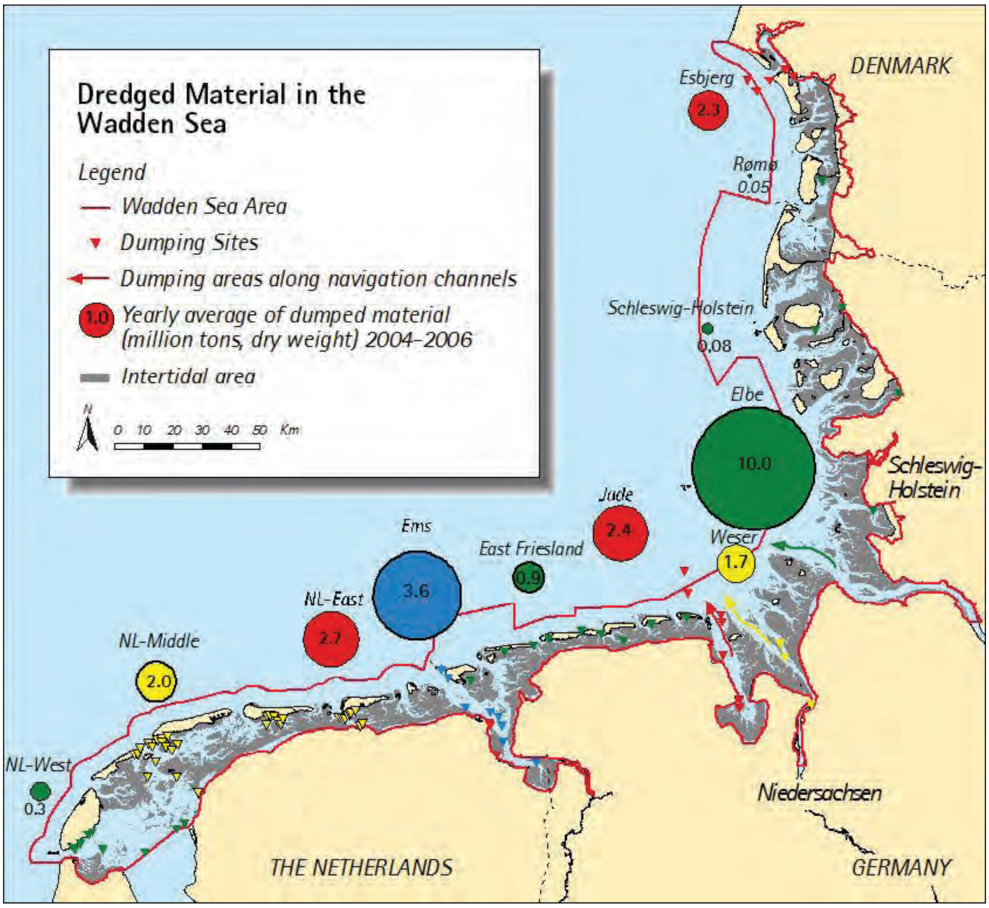


Figure 3.7.1: Amounts of dumped dredged material in the Wadden Sea (tons dry weight) (period 1989 – 2006 (dumping areas see Table 3.9.3.1). Data source: OSPAR Annual Reports, 1999, 2005 QSR. Until 1997 (for NL until 1994), data were reported as tons dry wet weight; for comparison, the figures before 1998 (for NL before 1995) have been converted to dry weight (wet weight/1.97).

Figure 3.7.2: Map of dumping sites and yearly average amount of dumped dredged material in the Wadden Sea in the period 2004-2006. Data source: OSPAR.



were selected and implemented into the Dutch legislation (Schipper et al., 2003, Stronkhorst et al., 2004). Since bioassays represent a new element in assessment of dredged material, there is at this stage no representative dataset available to develop quality standards for dumping of dredged material within the Surface Water Contamination Act (Wvo) and Maritime Water Contamination Act (Wvz), in the sense of test values that when they are exceeded leads to disqualification of a particular batch of dredged material.

As such, use is still being made of a measurement obligation and signal function for bioassays.

In the Netherlands, all measured contaminant contents, except PAHs, are normalized to a 'standard soil' composition. Sediment quality criteria have been developed for selected heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), mineral oil (C10-40), sum of 10 PAH compounds, sum of 7 PCBs (PCB 28, 52, 101, 118, 138, 153, 180), HCH-isomers, Heptachlor Heptachlorepoxide, Aldrin, Dieldrin, Endrin, DDT incl. derivates, HCB, TBT; additionally, levels for 3 bio-assays (only valid for the North Sea) were defined (OSPAR Commission, 2004b).

Germany

In 1998, the so far highest value of 24 million tons of dredged material (dry weight) was reported. The amounts decreased in the following years to values between 7.8-11 million tons (dry weight) per year. In 2005 there was a significant increase to a value of 20 million tons (dry weight) and in 2006 a value of 25 million tons was reported.

In 1999, the 'Directive for dredged material management in Federal Coastal Waterways' entered into force which incorporates the relevant provisions of the latest guidance provided under the London, OSPAR and Helsinki Conventions (HABAK, 1999).

These guidelines are set up for the Federal Waterway and Shipping Administration and are therefore only applicable to Federal waterways and not to waterways under the responsibility of the federal states. A working group with members of federal and state authorities has been installed to develop common guidelines regarding dumping operations in German coastal waters, estuaries and rivers.

Permits for dredging/dumping of dredged material are issued by the competent authorities of

Area	OSCOM Code	2004	2005	2006	Average/year
Germany					
Schl.-Holst.	D10-13,40,49,52,53	48,000	104.000	82.000	78.000
Elbe	D14,47	4,376,000	12.186.556	14.949.000	10.503.852
Weser	D15,16,39,46	334,000	1,451,097	3,369,000	1,718,032
Jade	D17-20,41,42	2,119,000	2,735,829	2,452,000	2,435,610
East Friesland	D21-28,30-33,36,43-45,50	122,000	106,000	40,000	89,333
Ems	D34,37-38	2,614,000	3,890,755	4,431,000	3,645,252
Total FRG		**9,613.000**	**20,474,237**	**25,323,000**	**18,470,079**
Netherlands					
West	NL13	307,532	352,996	267,972	309,500
Middle	NL14	n.i.	2,787,502	1,233,697	2,010,600
East	NL15	n.i.	4,417,194	979,452	2,698,323
Total NL		**307,532**	**7,557,692**	**2,481,121**	**3,448,782**
Denmark					
Esbjerg	RIB01-08	3,104,800	2,662,800	1,240,000	2,883,800
Rømø	RIB01-04	56,320	n.d.	43,500	56,320
Fanø	SJ-09	n.i.	16.800	31.800	
Total DK		**3,161,120**	**2,662,800**	**n.d**	**2,911,960**
TOTAL		**13,081,652**	**30,694,729**	**27,804,121**	**23,860,167**

Table 3.7.2: Amounts of dumped dredged material (tons dry weight) per area and country (period 2004–2006) (source: OSPAR reports, for the period 1989–1997 see 1999 QSR Table 2.10, for the period 1998–2003 see 2005 OSR Table 2.11.1).

the Federal States ('Länder'). Permits are not issued for dredging/dumping activities of the German Federal Waterway and Shipping Administrations (the responsible Directorate does not issue permits for its own activities). However the dredging/dumping activities of the Federal Waterway and Shipping Administrations are governed by national regulations which are in accordance with OSPAR and London Convention requirements.

Action levels for trace metals and organic contaminants in dredged material applied to dredged material from German federal waterways for trace metals and organic contaminants represent 'management' values. They were introduced in 1992 and 1997, respectively. The action levels are neither ecotoxicological quality criteria nor quality targets. These action levels are not applied to dredged material from waters under the responsibility of the federal states (Länder).

Action levels are related to the sediment fraction < 20 µm, dry weight and exist for selected heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and organic compounds (PCB 28, 52, 101, 118, 138, 153, 180, HCHs, HCB, Pentachlorbenzene, Octachlorostyrene, DDT, DDD,DDE, six PAH compounds and mineral oil).

For TBT, action levels were implemented in 2001. They were agreed between the Federal Authorities and the federal states (Länder) and are applicable to dredged material from all coastal waterways. The implementation of action levels is tiered in three phases according to the schedule of IMO for the ban of TBT in antifouling coatings of ships, although with a time lag of two years. Action levels for tributyltin (TBT) in dredged material (in µg TBT/kg total sediment) were defined with a lower level of 20 and an upper level of 600.

The upper level decreases from 600 µg TBT/kg in 2001 and 300 µg TBT/kg in 2005 to 60 µg TBT/kg in 2010.

Denmark

Dredged material dumped in the Danish Wadden Sea mainly originates from maintenance dredging of navigation channels and harbors of Esbjerg (about 2.6-3.1 million t dry weight/yr) and Rømø (about 56.000 t dry weight/yr) and Fanø (about 10.–30.000 t dry weight/yr) resulting in a total annual average of 2.9 million t dry weight for the period 2004-2006.

In 2005 a 3-category system with 2 levels of actions values was developed, and published the 1st of October 2005 as Guideline No. 9607 on dumping of dredged materials – later revised in Guideline No. 9702 from the 20th October 2008 on dumping of dredged material by the Agency for Spatial and Environmental Planning, Ministry of the Environment.

The Danish action values have been based on data from the Netherlands and Finland. Some adjustments to Danish circumstances have been made. The lower action levels correspond to background levels or levels of expected no-effect. The upper action levels are based on international recognised levels, which mean that ecotoxicological data are taken into account:

1. If chemical analysis of the material to be dumped shows concentrations below the lower action levels a permit for dumping can be given without further specific evaluations - taking into account proper site selection.
2. If the chemical analysis shows concentrations of contaminants between the two action levels a more comprehensive study and evaluation has to be carried out, based on the amount to be dumped and the concentrations of contaminants.
3. If the chemical analysis shows concentrations above the upper action levels dumping at sea will normally not be permitted, pending a throughout evaluation of the case, and the material must be deposited at land.
4. Besides the evaluation based on chemical concentrations an evaluation of the amount of contaminants - especially TBT and copper - are also carried out.

Permits for dumping of dredged material are given by the three Environment Centres in Århus, Roskilde and Odense, the Agency for Spatial and Environmental Planning, Ministry of the Environment. In the Wadden Sea area this means the Environment Centre in Odense.

The general principles the system developed in Denmark for dumping of dredged material have been laid down following the guidelines from the global London Convention 1972 and the regional marine conventions OSPAR and HELCOM. The following contaminants are evaluated against action levels: Cu, Hg, Ni, Zn, Cd, As, Pb, Cr, TBT, PCBs, PAHs

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Marine Litter

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3.8 Marine Litter

3.8.1 Introduction

Litter, which is omnipresent in the marine environment, is a constant threat to wildlife, a hindrance to human activities, incurs immense economic costs world-wide, is unsightly and reduces the recreational value of our coasts. Plastic, the main component of marine litter world-wide, is slow to decompose and breaks down into even smaller pieces, so-called micro plastics, the environmental impact of which is largely unknown. Sources of marine litter are varied and can be sea or land-based. Land-based sources include sewage outlets, recreational activities on the coast, illegal fly-tipping and river outlets. Sea based sources of marine litter are shipping, and fisheries including aquaculture, offshore installations and recreational sailing. In the southern North Sea, investigations have shown that shipping, including fisheries, is the main source of marine litter pollution. Numerous studies have documented the scale of marine litter pollution in the Wadden Sea region since the early 1980s (Clemens, 1992; Clemens *et al.*, 2002; Fleet, 2003, Gerlach, 1994 and 1999; Hartwig, 1994, 2000, 2001a and 2001b; Hartwig and Clemens, 1999; Nassauer, 1981; Niedernostheide and Hartwig, 1998; Schrey, 1987, van Franeker 2005). Attempts to reduce the input of litter into the marine environment have been shown to be insufficiently effective. This has led to an increase in interest in the marine litter pollution problem in recent years. Two projects were initiated at the beginning of the century within the OSPAR Convention.

First, the OSPAR Pilot Project on Marine Litter Beach Monitoring began in 2000 in response to the conclusions made on marine litter pollution in the OSPAR Quality Status Report 2000 (QSR, 2000). The QSR concluded that litter pollution of the North and Baltic Seas had not improved since their designation as Special Areas according to MARPOL Annex V. The QSR concluded further that litter pollution should be assessed on reference beaches using improved and more standardized methodologies to assess the scale, impact and trends in quantities of marine litter throughout the OSPAR area. Since 2000 surveys of beached litter have been carried out using standardized methodology at over 50 sites on the Northeast Atlantic coast as part of the OSPAR Marine Litter Beach Monitoring Program (OSPAR Commission, 2007). This chapter includes regional data from this program.

Secondly, in 2002 the results of a pilot study, commissioned by the Dutch government, on marine litter monitoring using Northern fulmars *Fulmarus glacialis* were published (van Franeker and Meijboom, 2002). The amount of litter in the stomachs of fulmars beached in the Netherlands between 1982 and 2000 was the basis of the pilot study. The pilot project was further developed (van Franeker *et al.* 2005; van Franeker and SNS Fulmar Study Group 2008) and now forms the basis of the OSPAR EcoQO "Plastic in Fulmar Stomachs" for the North Sea region (OSPAR-BDC 2008). The most recent published results from this program are presented below.

Further evidence for the environmental impact of litter is taken from the analysis of data from marine mammals and birds beached in the Wadden Sea region. To complete the picture results of marine litter programs, investigations and activities of other organizations within the Wadden Sea are presented.

3.8.2 Ecological and socio-economical importance

Marine litter causes severe ecological damage to marine life. Marine animals suffer from entanglement, suffocation, and starvation due to marine litter ingestion. The United Nations Environment Program estimated in 2004 that plastic waste kills up to 1 million seabirds, 100,000 sea mammals and countless fish each year (UNEP, 2004).

A study of socio-economic impacts of marine litter in coastal communities around the North Sea (Hall 2000) illustrated that a wide-range of impacts lead to immense costs for local communities.

Problems associated with marine litter include:

- Effects on human health and safety,
- Cleaning operations and waste disposal on beaches, in harbors and at sea,
- Effects on tourism and recreation *e.g.* on local business or publicity through annoyance of public,
- Effects on shipping *e.g.* fouled rudders, anchors and propellers, damaged hulls and engines, waste management in harbours,
- Effects on fisheries and aquaculture *e.g.* reduced catch, damaged nets, contamination of catch, contaminated cages, loss of stock,
- Effects on agriculture adjacent to the coast *e.g.* harm to livestock through ingestion and contamination of stock fences.

The main cost to local authorities throughout the study area was for beach cleaning running into many millions of Euro annually.

The impact of marine litter on the health and productivity of marine environment through direct mortality and sub-lethal effects on animal populations is difficult to quantify. The fulmar project has shown, however, that, at least in some marine species, litter can be a serious problem. Numerous records of stranded animals on the Wadden Sea coast document that marine mammals and birds ingest and become entangled in litter items regularly. The fact that 80% of foamed types of floating plastic debris freshly washed ashore on the Dutch island of Texel showed peck marks made by birds, indicates that birds mistake debris for food items or routinely test floating objects to see if they are edible (Cadée, 2002). Marine litter has been documented widely as a mode of transport for invasive species and floating and drifting litter items have increased dramatically the variability and variety of rafting materials that can be used for 'hitch-hiking' by invasive species in recent years (Aliani and Molcard, 2003).

Microscopic plastic fragments and fibres (microplastics) are now widespread in the marine environment and accumulate in the pelagic zone and sedimentary habitats. The fragments appear to have resulted from degradation of larger items. Amphipods (detritivores), lugworms (deposit feeders), and barnacles (filter feeders) have all been shown to ingest plastics within a few days (Thompson *et al.*, 2004). Small plastic particles absorb chemical substances that can be transferred to the organisms that ingest them (Teuten *et al.* 2007). The present and future environmental consequences of microplastics are unknown.

3.8.3 Policy

A series of conventions and regulations at local, national, regional and international levels have been implemented to combat marine litter pollution since the early 1970s. A comprehensive list of these measures is included in OSPAR (2009). Two of these regulations are under review at the time of writing:

Annex V of the International Convention for the Prevention of Pollution from Ships 1973 (MARPOL 73/78).

This annex, which regulates garbage from shipping world-wide, has prohibited the discharge of plastics from shipping into the marine environment since 1988. In addition the North Sea and adjacent areas were designated as Special Areas with regard to MARPOL Annex V in 1991. In accordance with the regulations for Special Areas, all discharges of garbage (except food waste) into the sea are prohibited. The Convention also comprises an obligation for countries surrounding Special Areas to provide appropriate reception facilities for ship-generated waste in their ports and harbors.

The EU Directive on port reception facilities for ship-generated waste and cargo residues (EC2000/59).

The Port Waste Reception Facilities Regulations, which entered into force in 2003, aim to reduce the illicit discharge of ship generated waste and other pollutants to a minimum, in order to protect the marine environment. Ports must set up waste handling plans and make available adequate reception facilities. Every ship is required to deliver all ship-generated waste and cargo residues to ports. All ships are to pay a set fee for waste disposal, irrespective of their actual use of the facilities. Ships that do not deliver waste in one port will be reported to their next port of call for a more detailed inspection. Member states must ensure proper monitoring of compliance with the directive, by means of spot checks and the exchange of information between ports. The European Maritime Safety Agency (EMSA) has been assigned by the European Commission to evaluate the functioning of the Port Reception Facilities in the different member states and to report on this in early 2009.

The need for a measure of effectiveness of these regulations led to the implementation of the two above mentioned OSPAR-Programs.

3.8.4 Available data

The beaches covered in the Beach Litter Monitoring program are exposed to the North Sea and Fulmars occur offshore of the Wadden Sea islands. Both OSPAR programs thus measure the amount of litter in North Sea waters adjacent to the Wadden Sea. However, as the main source of litter in the Wadden Sea is the North Sea, both programs actually measure the input of litter into the Wadden Sea region. Both programs mainly monitor litter items that float. Litter items that are not buoyant are underrepresented in the results. The results of some surveys of litter on the mainland coast and on islands within the Wadden Sea have been published for the period 1991-2002 (Fleet, 2003).

Five sites of the OSPAR Beached Litter Monitoring Program lie within the Wadden Sea region one – Terschelling - in the Netherlands and four - Juist, Minsener Oog, Scharhörn and Sylt - in Germany. All five sites have been monitored since 2002. Litter is assessed four times a year in spring (April), summer (mid June - mid July), autumn (mid

Sept. - mid Oct.) and, if possible, winter (mid Dec. - mid Jan.). All litter items on 100 m of beach are assessed and assigned to 107 different litter types, which are in turn assigned to eleven different categories. Litter items are removed during the survey so that litter accumulation and not the standing crop of litter is assessed.

The Fulmar Litter EcoQO Monitoring program includes birds collected on Dutch beaches from the early 1980s onward (van Franeker, 1985). For the 1980s a total of 69 fulmars beached in the Netherlands have been analyzed, the Dutch sample size for the 1990s is 223 and for the 2000s (until 2006) 396. In the period 2002-2006, a total of 268 birds from German North Sea beaches have been analyzed (van Franeker and the SNS Fulmar Study Group, 2008).

In April 2005, beached litter on the island of Texel was investigated during the "Schoon Strand" action day (van Franeker, 2005). The standing crop of litter - all litter found - on the Texel beach was collected, identified, counted, weighed and disposed of. The results, which provide a startling snapshot of the marine litter problem, are presented below. An investigation six weeks later on the same beach provides further information on the rate of accumulation of litter.

Deaths caused by litter entanglement are recorded regularly in Beached Bird Surveys on Dutch and German coasts. First overviews of entangled birds and mammals found during beached bird surveys in the period 1983-90 in the German Wadden Sea region were published by Hartwig *et al.* (1985 and 1992). A more recent analysis for the Dutch coast is in press (Camphuysen, 2008). The unpublished results of the analysis of recent beached bird data from the German Wadden Sea coast are included. Beached marine mammals in Germany are routinely examined for the occurrence of litter entanglement and ingested litter. The results of the analysis of these investigations are presented below.

Coastwatch Europe started in 1987 in Ireland and became an international network in 23 European countries of environmental groups, universities and other educational establishments, who in turn work with local groups and individuals around the coast of Europe. Common aims of Coastwatch have been the protection and sustainable use of our coastal resources, and informed public participation in environmental planning and management, including Coastal Zone Management. Annual marine litter surveys on beaches, following a set method, have been an important part of the Coastwatch work. In the Netherlands, several beaches in the Wadden Sea have been cleaned with the help of volunteers and school children. The amounts and composition of the waste collected on the beaches was assessed.

3.8.5 Levels of litter pollution

OSPAR Beached Litter Monitoring Programme

The amount of litter found on the tideline varies greatly between beaches depending on the orientation of the coast to prevailing water currents and wind. Weather conditions in the period between surveys influence the number of litter items reaching the shore and cause variation between surveys in the number of items recorded on the same beach. The number of items found per survey of a 100 m stretch of beach on four beaches in the Wadden Sea region in the period 2002-2008 ranged from 10 to 1,117 with on average 236 items of litter found per survey (no. of surveys 111). The average number per survey varied from 89 on Juist to 482 on Terschelling.

Fulmar Litter EcoQO Monitoring

On average in the southern North Sea in the period 2002-2006, 94% of all fulmars had at least one piece of litter in their stomach. The average number of items per stomach was 32.4 with an average weight of 0.30 g. In terms of the OSPAR Ecological Quality objective, on average for the same period 57% of all beached fulmars had more than 0.1 g of litter in their stomachs, which is nearly six times the value required by the EcoQO (van Franeker and the SNS Fulmar Study Group, 2008).

Schoon Strand Texel April and May 2005

During the investigation on average 739 items and 909 kg of litter were collected per km of beach. The accumulation rate of litter on the beach on Texel NL in April and May 2005 was in the order of 7-9 kg per km per day, about half of which was wood and the remainder mainly plastic (van Franeker, 2005 and unpublished data).

Beached Bird Surveys

Fifteen species of Sea- and Waterbird were recorded as victims of entanglement with litter on the German North Sea coast in the 1980s. The most common victim was the Gannet, with 20% of all corpses of this species found to be entangled (Hartwig *et al.*, 1985 and 1992). Of the 215,347 more or less complete corpses of birds found on the Dutch coast since 1970, 513 were

Table 1:
The twelve species most frequently recorded as entangled in debris or fishing gear and the percentage of the total number of individuals found washed ashore in the Netherlands in the period 1979-2007. NZG/NSO database (Camphuysen, 2008).

Species	Entangled	%	Total number
Northern gannet *Morus bassanus*	126	6.5	1,946
Herring gull *Larus argentatus*	123	0.6	19,494
Common eider *Somateria mollissima*	59	0.2	37,784
Common guillemot *Uria aalge*	43	0.1	43,071
Great black-backed gull *Larus marinus*	34	1.1	2,986
Eurasian oystercatcher *Haematopus ostralegus*	17	0.1	17,859
Common coot *Podiceps cristatus*	15	0.3	4,712
Black-legged kittiwake *Rissa tridactyla*	15	0.1	11,572
Northern fulmar *Fulmarus glacialis*	13	0.2	6,441
Black-headed gull *Larus ridibundus*	10	0.2	5,654
Red-throated diver *Gavia stellata*	9	0.9	1,011
Great cormorant *Phalacrocorax carbo*	9	1.1	820

entangled in litter or fishing gear. Half these birds were Northern gannets and herring gulls. Ranked after the proportion of entangled individuals in the total number of birds found, four coastal species (great black-backed gull, red-throated diver, great cormorant, and herring gull) and one pelagic seabird (northern gannet) were the top five species affected by entanglement (Tab. 3.1) (Camphuysen, 2008). The values for sea- and waterbirds beached on the German North Sea coast in the period 1992-2007 and included in the German North Sea beached bird database are 0,26 ±0,11% (n entangled= 230; n total= 87,074). The species lists are not identical. However, as in the Netherlands, the gannet remains the species most frequently found entangled on German North Sea coasts and 12.3% of all gannets recorded there are entangled.

Marine litter is almost certainly responsible for a higher proportion of overall bird deaths as the number of deaths caused by ingestion is largely unknown.

Table 3:
The proportion of items found in eleven litter categories during OSPAR Beach Litter Monitoring on beaches in the Wadden Sea region in the period 2002-2008.

Type of material / category	Proportion of total number of litter items found %
Plastic/polystyrene	75.3
Wood	8.3
Glass	5.4
Paper/cardboard	3.2
Rubber	3.0
Metal	2.4
Cloth/textile	1.4
Sanitary	0.6
Ceramic/pottery	0.2
Medical	0.1
Faeces	0.1

Beached mammals

In the period 1998-2006, the stomach contents of 47 harbour porpoises (*Phocoena phocoena*) found on the German North Sea coast were investigated in detail by the "Forschungs- und Technologie Zentrum" in Büsum (FTZ). Nylon thread and plastic material were found in the stomachs of two of these individuals. Of the 24 stomachs of harbour seals (*Phoca vitulina*) stranded on the German North Sea coast in the period 1997-2007 and analyzed by the FTZ, one was found to contain plastic material. Furthermore the FTZ investigated 1,596 seals stranded on the German North Sea coast in the period 1997-2008. Two of these individuals were entangled in fishing nets and the head of one individual was caught in a plastic ring. All three entanglements caused impairment to the health of the animals involved (U. Siebert and A. Gilles, pers. comm.).

Other Data

Denkinger *et al.* (1990) investigated the occurrence of plastic pellets in the jetsam washed ashore on the Schleswig-Holstein mainland coast in the period September 1987- April 1989. Plastic pellets were found to be ubiquitous on the west coast of Schleswig-Holstein. An extrapolation of the results gave an estimate of several tons of pellets washed ashore each year.

3.8.6 Composition of litter

OSPAR Beached Litter Monitoring Program

Three quarters of the litter items found on beaches in the Wadden Sea region in the period 2002-2008 were plastic. The proportion for the other litter categories was in each case less than 10% of the total number of items (Table 2). The most common items found on the beaches were rope, cords and nets which accounted for 30% of the total number of litter items. Various forms of packaging

Table 3: Categorization of objects found in fulmar stomachs.

Industrial plastic pellets: Small, often cylindrically-shaped, granules of about 4 mm in diameter that are the raw material for producers of plastic products.

User plastics: all non-industrial remains of plastic objects differentiated in the following subcategories:

- Sheet like user plastics *e.g.* pieces of plastic bags, foils etc.
- Thread like user plastics *e.g.* remains of ropes, nets, nylon line, packaging straps etc. Sometimes 'balls' of threads and fibres form in the gizzard;
- Foamed user plastics *e.g.* foamed polystyrene *e.g.* from cups or packaging or foamed polyurethane from *e.g.* mattresses or construction foams;
- Plastic fragments of more or less hard plastic items that are used in a huge number of applications *e.g.* bottles, boxes, toys, tools, equipment housing, toothbrushes, lighters etc;
- Other plastic-like items or items that do not fit into a clear category *e.g.* cigarette filters, rubber, elastics etc.

Rubbish other than plastic: *e.g.* paper, galley food remains, various other types of rubbish *e.g.* pieces of timber (manufactured wood); paint chips, pieces of metals etc. fish hooks

Pollutants: *e.g.* pieces of slag, tar balls and chemical lumps of paraffin-like materials or sticky substances arbitrarily judged to be unnatural and of chemical origin and feather conglomerations suggesting the preening of such substances out of the plumage.

accounted for 28% of the total number of items and plastic and polystyrene pieces of unidentifiable origin for a further 16% of the total.

Fulmar Litter EcoQO Monitoring

The objects found in fulmar stomachs are assigned to three broad categories – plastics, non-plastics and pollutants *e.g.* paraffin and tar balls. The plastic category is divided into industrial plastics (plastic pellets) and user plastics, which is further divided into five sub-categories (Table 3).

The majority of the litter items found in fulmar stomachs in the Netherlands in the period 2002-2006 were user plastics (on average 28 items weighing 0.24 g). In comparison on average only three items of industrial plastics weighing 0.06 g and only two items of pollutants weighing 0.59 g were found in the stomachs. The average amount of the category “other rubbish” is less than one item. Composition of plastic litter in fulmar stomachs found on Dutch coasts has changed in the period 1980-2006. Although about 50% of total plastic litter mass found in the stomachs in the 1980s was industrial plastic, it accounts for only 20% of the total today.

Schoon Strand Texel April and May 2005

The composition of the litter collected in April 2005 was analysed in detail. By number 56% of the litter was plastic, 14% rope and nets (also nearly all plastic), and 16% wood. By weight 54% wood, 25% rope and nets and 19% other plastic materials. An especially interesting result of the Texel investigation was that left-hand shoes and gloves were more common on the southern part of the beach and right-hand shoes and gloves were more common on the northern part of the island in the middle of the island their distribution was more or less equal.

Beached Bird Surveys and beached mammals

Nylon fishing lines, pieces of fishing nets and all other kinds of ropes and lines, often from fisheries activities, were the main cause of entanglement in birds beached on Dutch coasts (Camphuysen 1990, 1994, 2001, 2008). The most common litter items recorded in the German beached bird database as involved in entanglement of birds were line/rope entanglements (48% of all litter victims), net entanglements (39%) and fishing hooks (7%) (OSPAR, 2009).

3.8.7 Sources

Identifying sources of marine litter is difficult as many types of items can come from multiple sources. The large diversity of items found on German North Sea coasts and the composition of the litter recorded during the OSPAR-Project, as well as during the German surveys over the period 1991-2002, indicate that shipping, the fisheries industry and offshore installations are the main sources of litter found on German and Dutch beaches. The relative proportions of litter originating from these different sources cannot be determined exactly. The larger proportion of litter recorded on German North Sea beaches certainly originates from shipping with a considerable proportion of this originating in the fisheries industry (Fleet, 2003). This has not changed since the 1980s when Vauk and Schrey (1987) stated that major sources of litter in the North Sea were commercial shipping and fisheries. According to van Franeker and Meijboom (2002) these are supplemented by coastal recreational activities, the offshore industry - although the latter is thought to be a minor source because of strict waste management practices - and litter entering the North Sea by wind, currents, or river-transport from land based sources. Litter also enters the southern North Sea from the English Channel, as records of litter identified as originating on the French Atlantic coast have shown (Fleet, 2003). From the study on Texel in 2005 it was concluded that various indicators show that around 90% of the litter originated from shipping and fisheries (Van Franeker, 2005).

The results of the regional analysis of the OSPAR Beach Litter data (see above) indicate that one of the main sources of pollution is the fisheries industry in the form of lost or discarded nets. The data from the Dutch and German beached bird surveys show also that litter from fisheries activities is the main cause of entanglements providing a direct connection between litter discard and environmental infringement.

Various forms of packaging also account for a large proportion of the litter recorded on the OSPAR beaches. So-called professional items (nets, rope, oil cans, strapping bands etc.) accounted for 39% of the identifiable litter on these beaches and consumer items (bottles, food cans plastic bags etc.) for a further 26%.

During the "Schoon Strand" survey on Texel the origin of 119 litter items was identified by registering the language used on labels. The majority of the labels were Dutch (42%) and large proportions were English, German and French (Figure 3.1). As ships can buy supplies in foreign harbors this does not necessarily indicate the state of origin of the people disposing of litter.

3.10.8 Trends in litter pollution

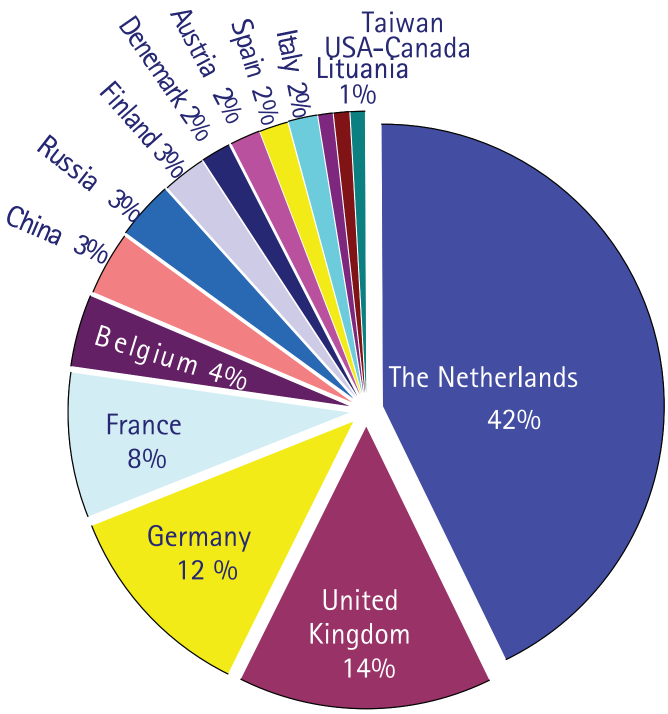
OSPAR Beached Litter Monitoring Program

The amount of litter beached on the coast varies immensely between locations depending on prevailing winds and water currents and local sources of litter. Comparisons of the amount of litter reaching the shore over time are only realistic for set stretches of coast as in the OSPAR Beached Litter Monitoring Program (2002-2008) and the surveys carried out on the German Wadden Sea coast for period 1991-2002.

The OSPAR Beach Litter Program was not able to detect any general trends in the amount of litter recorded on beaches in the NE Atlantic in the period 2001-2006. A non-significant increase in the amount of litter was recorded for beaches in the southern North Sea and a significant increase in fisheries litter was recorded for the NE Atlantic (OSPAR Commission, 2007). The analysis of beached litter surveys from the German Wadden Sea coast for the period 1991-2002 was also not able to detect any general trends in the number or weight of beached litter. The amount of plastic, polystyrene and foam rubber as well as the amount of fisheries items recorded on the survey sites did not generally alter in the study period. Glass bottles and jars, milk cartons and machined wooden items, however, generally decreased (Fleet, 2003).

Initial analysis of the OSPAR Beach Litter Monitoring data indicates that in general the amount

Figure 1: Proportions of countries of origin as derived from barcodes or label information on litter items found on Texel, April 2005 (translated from Van Franeker, 2005).



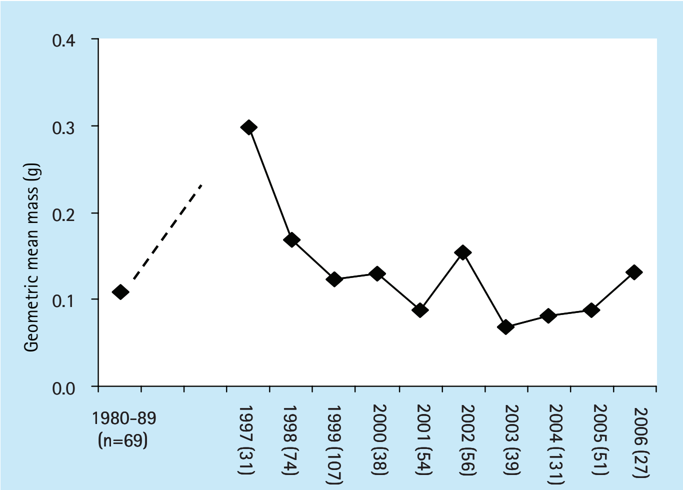


Figure 2: Plastic mass Netherlands 1982-2006 – Annual geometric means for the mass of plastic in the stomach of beached fulmars in the Netherlands (from: van Franeker and the SNS Fulmar Study Group, 2008).

of litter found on beaches in the OSPAR region has decreased in the period 2001-2008. However, the amount of litter found on southern North Sea beaches has increased in the same period. Increases in the southern North Sea were recorded for the source-categories shipping (operational waste and galley waste), fisheries and sanitary waste (TAUW 2009).

Fulmar Litter EcoQO Monitoring

Long-term trends of the overall mass of plastics in fulmar stomachs from the Netherlands for the period 1979-2006 demonstrate that litter pollution increased strongly from the 1980s to the 1990s but has subsequently decreased to approximately the level recorded at the beginning of the study period (Figure 3.2). However, different types of plastic show different trends. User plastics were largely responsible for the increase and following decrease in overall mass. The amount of industrial plastics has decreased constantly since the early 1980s and is now about half its original value. Similar observations have been done in the Pacific Ocean (Vlietstra and Parga, 2002) and South Atlantic (Ryan, 2008). Over the recent 10 year period 1997-2006 the significant strong decrease in total plastic is largely due to a reduction in user plastics. However, the decrease largely took place in the early part of the period, and appears not to continue in the most recent years. (van Franeker and the SNS Fulmar Study Group, 2008).

Beached Bird Surveys and beached mammals

In the period 1979-2003, the level of entanglements recorded in the 12 most frequently entangled species of beached birds on the Dutch coast was roughly stable at 0.31 ± 0.13% per annum (mean ± SD; 405 casualties out of a total of 142,030 birds). A higher level of entanglements (0.75 ± 0.10% per annum; 74 casualties out of 10,181 birds) was recorded during the period 2004-2007 (Figure 3.3) (Camphuysen, 2008).

The level for the German North Sea coast in the period 1992-2003 was 0.23±0,11% (n entangled=170; n total=69,508) and was 0,35±0,06% (n entangled=60; n total=17,566) in the period 2004-2007, also indicating an increase.

The recent increase in entanglements is both remarkable and unexplained and deserves future attention and further research (Camphuysen, 2008).

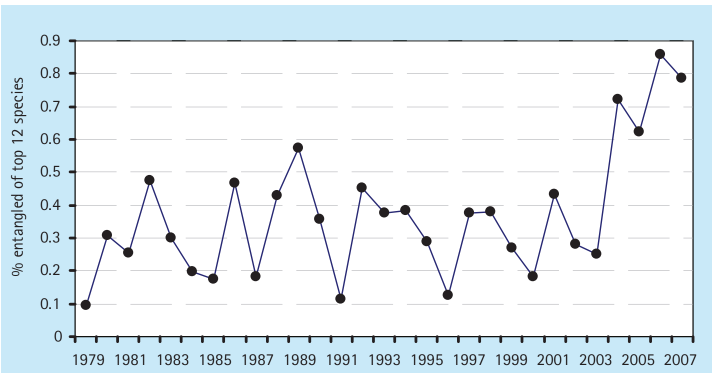


Figure 3: Percentage (%) of the top-twelve most frequently entangled species washed ashore in the Netherlands since 1979 that were recorded as entangled. Files NZG/NSO (beached bird survey program) 1979-2007.

3.8.9 Conclusion

Assuming that litter levels in the Wadden Sea region are close to those measured in the bordering parts of the North Sea, the pollution level is high, though not the highest in the North Atlantic region. The average geometric mean mass of litter in fulmar stomachs collected in the southeast North Sea is intermediate between those collected in the relatively cleaner Scottish Island waters and those from the English Channel (van Franeker and SNS Fulmar Study Group, 2008). Litter levels on OSPAR survey beaches in the southern North Sea region were significantly lower than on beaches in the northern North Sea and Celtic sea areas (OSPAR Commission, 2007).

Litter thus remains a serious ecological, environmental and economical problem in the region with plastic litter from packaging and debris from the fisheries industry the main problems. There are no indications that the amount of litter entering the marine environment has decreased in recent years, despite clear regulations targeted to reduce input. The discharge and accidental loss of fishing tackle appears to be an increasing problem for the Wadden Sea region reflected in greater numbers of fisheries related debris on beaches and higher mortality among seabirds. The fulmar data indicates that levels of industrial plastics (pellets) are decreasing, however, the amount of litter found in fulmar stomachs in the Wadden Sea region remains far higher than the targeted fulmar EcoQo level. Microplastics have not yet been investigated in the Wadden Sea region. Investigations, however, indicate that they are widespread in the marine environment and that they are certainly already present in the Wadden Sea ecosystem.

3.10.10 Recommendations

- The awareness of the issues and regulations relating to marine litter needs to be improved. In addition to raising general awareness, special efforts are recommended for the stakeholders in the shipping and the fishing industries as they are the two main sources of marine litter in the Wadden Sea region. In addition, the recreational boating sector in the Wadden Sea may need to be targeted,
- The main current monitoring systems, i.e. the OSPAR Beach Litter Survey for coastal litter and the OSPAR Fulmar Litter EcoQO for the ecological state of the marine environment should be strongly supported by Wadden Sea countries, where possible be intensified for the Wadden environment and be complemented by specially focused incidental investigations,
- The recent increase in the frequency of entanglement of birds in litter recorded during beached bird surveys should be investigated. The possibility of a relationship with the increase in fisheries litter recorded during the OSPAR beach litter needs to be discussed,
- There is no information on the occurrence of microplastics for the Wadden Sea region. An investigation of the incidence of microplastics in sediments and organisms in the Wadden Sea region should open research into this impending environmental threat.

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4.1 Climate

4.1.1 Introduction

There is little difference within the Wadden Sea area in major climatic conditions (de Jong, 1999): for that reason the main focus here is on climate change in Northwest Europe and its effects on the Wadden Sea system. The only exception might be local wind climate, a subject which has received some attention, but which may be relatively important in understanding future coastal and Wadden Sea development. In this chapter we will discuss new insights to consider the present-day situation and look forward into the coming century to form an idea of the changes that may be expected. The chapter is partially based on Kabat *et al.* (2009a).

4.1.2 Climate change

4.1.2.1 Global changes

In 2007, the Intergovernmental Panel on Climate Change (IPCC) stated in their fourth assessment report (AR4) that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). However, IPCC AR4 (2007) was limited to science published by early 2006. Subsequent research shows increasing rates of: 1) Global greenhouse gas emissions: 3.3%/yr in the 2000s, versus 1.3%/yr in 1990s; 2) Temperature rise, especially in polar regions; 3) Ice melt (Arctic: 40% loss since 1980 and accelerating in 2006-07 (Schubert *et al.*, 2006; Bogataj, 2007; Clark *et al.*, 2008; Csatho *et al.*, 2008, but also see van der Wal *et al.*, 2008 and Nick *et al.*, 2009). Furthermore there is uncertainty concerning the continuity of the Atlantic Meridional Overturning Circulation (AMOC) and the possibility of a massive release to the atmosphere of methane trapped in permafrost and on continental margins (Schubert *et al.*, 2006; Clark *et al.*, 2008). As a result, there is serious doubt whether the IPCC AR4 report did not underestimate some of the effects (a.o.: Schubert *et al.*, 2006; Rahmstorf *et al.*, 2007).

The IPCC AR4 results on global climate change have been converted towards local climate scenarios (for instance KNMI'06; Van den Hurk *et al.*, 2006), These local scenarios involve local circulation patterns for western Europe because the wind direction strongly determines the weather and climatological characteristics (Lenderink *et al.*, 2007; Van Oldenborgh and Van Ulden, 2003). The Royal Netherlands Meteorological Institute (KNMI) applies four scenarios of climate change (Table 1) composed of a moderate (G) and high (W) temperature increase and a changing (+) and non-changing circulation pattern. Next to that, two scenarios have been constructed for sea level rise. On behalf of the Delta Committee maximum scenarios for sea-level rise have been added (Vellinga *et al.*, 2008). To that end, the scenario for wind climate and storm-surge levels have also been re-examined. The scenarios allow for regional differentiation. For the period until 2050, scenarios are relatively accurate as they are governed by the greenhouse gas releases of today (Lowe *et al.*, 2009). However, for the period thereafter, the uncertainties are larger because the climate will depend on the emissions in the years to come (IPCC, 2007), and from poorly understood climate feedback mechanisms such as the relation between global warming and the sudden release of methane from the oceans and permafrost areas on land (Friedlingstein *et al.*, 2006). Uncertainties for temperature changes are much smaller than for precipitation, wind and sea-level rise (Kabat *et al.*, 2009a).

4.1.2.2 Temperature

Since the 19th Century, average global atmospheric temperature has risen by some 0.7+/- 0.2°C The increase in air temperatures in Northwestern Europe is faster than the world average increase (Figure 4.1.1). This is due to the increase in the number of winds from the west in late winter to early spring and the increase in radiation in spring and summer (Van Oldenborgh *et al.*, 2009).

The yearly average air temperature in The Netherlands (De Bilt) has risen by some 1.2°C in the course of the 20th Century. The higher mean temperatures coincided with a decrease in the number of days with a minimum temperature less than 0°C and an increase in days with a maximum temperature higher than 20°C (Sluijter, 2008).

It is to be expected that temperatures will rise. Climate models predict an increase for global mean air temperature of 1°C up to 6°C for the year 2100 relative to 1990 (IPCC, 2007). Dutch predictions indicate an average rise of summer temperatures with some 0.9-2.8°C by 2050 and 1.7-5.6°C by 2100, with, however, large local differences. At the same time the number of days with maximum temperature above 20°C, 25°C and 30°C will rise so that the coast will have as many warm days as at present does the inland (van den Hurk *et al.*, 2006). Extreme temperatures will increase stronger than average temperatures (Sterl *et al.*, 2008b) leading to maximum temperatures well above 40°C at the end of 2100 (Sterl

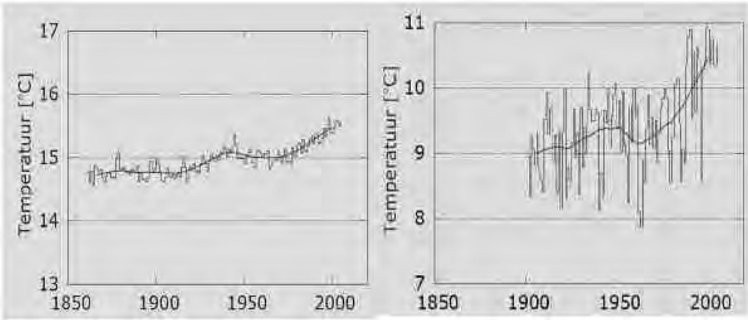


Figure 4.1.1: Difference between global temperature (left) and local temperature (Source: De Bilt, Kabat *et al.*, 2009a).

et al., 2008a). According to the Dutch scenarios, the average winter temperature will also increase by between 0.9-2.3°C by 2050 and 1.8-4.6°C by 2100. The number of days with ice will decrease, especially if the wind will come more from the west. Similarly, the German GKSS Research Station projects increasing temperatures for Northern Germany. Results are presented in the internet (www.norddeutscher-klimaatlas.de). Until the middle of the century, yearly mean temperatures may rise between 1.2-2.2°C with a "best-guess" of 1.8°C. For the end of the century, temperatures are projected to be between 2.0-4.9°C higher (mean 2.9°C). For the same projection period, the number of days with frost might decrease by up to 45 days per year. As already stated before, days with ice cover in the Wadden Sea would become very rare.

Temperature of the seawater

There is a strong correlation between the temperature of the North Sea and air temperatures in western Europe, which influence each other depending on the wind direction. Therefore, on a yearly basis, the temperature in the Wadden Sea region depends mainly on the dominant wind direction, but, in the long-run, mainly on global climate development (Verbeek, 2003). Because North Sea water is mainly derived from the warm North Atlantic current it increases the air temperature above land by some 1.5°C; an effect which is stronger in winter than in summer (Wessels *et al.*, 1999). Observations of the Sea Surface Temperature (SST) from the western Wadden Sea (Marsdiep Inlet) show a cooling trend in the late 19th Century, followed by a steady warming since ~1980 of 1.5°C (van Aken, 2008a), consistent with the trends in the North Sea area. Ongoing research and analyses shows that the year-to-year variations in SST as well as the long-term trends correlate well with changing atmospheric circulation and with changes in cloudiness (H. van Aken, pers. comm.).

Sea-water temperature is expected to continue to rise since it is closely correlated with the tem-

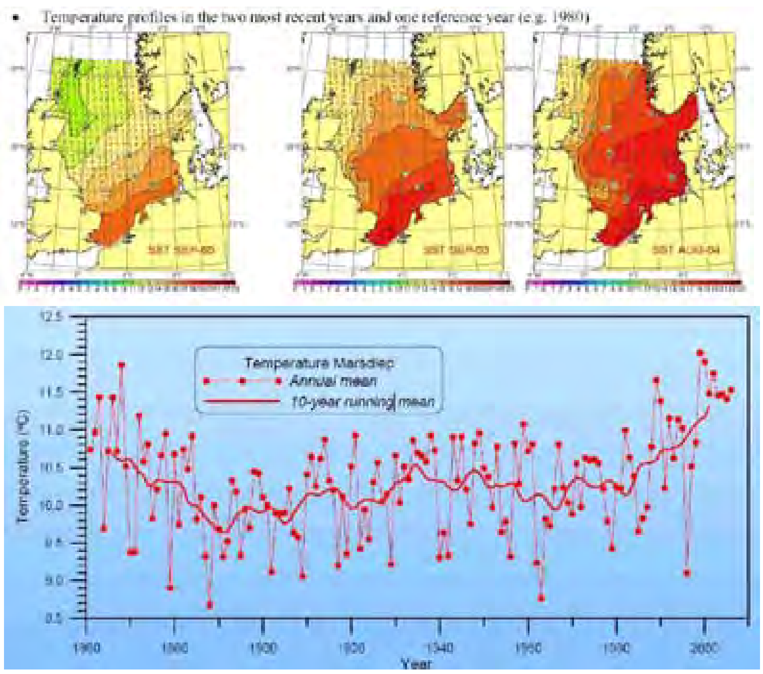


Figure 4.1.2: Trends in the sea-surface temperature of the North Sea waters in September 2003 and August 2004 as compared to reference of September 1980 (source: Hadley Centre, 2009) and the water temperature of Marsdiep Inlet (van Aken, 2008a) The development of the water temperature is a reflection of the west European climatic variability (van Aken, 2003). An overall increase in water temperature has been apparent since ca. 1980. (Courtesy Kabat *et al.*, 2009a).

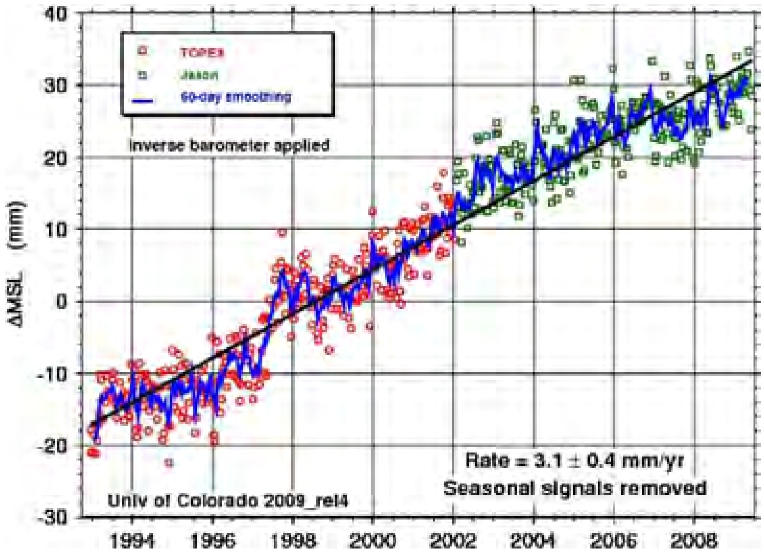


Figure 4.3: Global mean sea level based on the TOPEX-Jason satellite data after correction for seasonal effects and inverted barometer effects (source: http://sea-level.colorado.edu/).

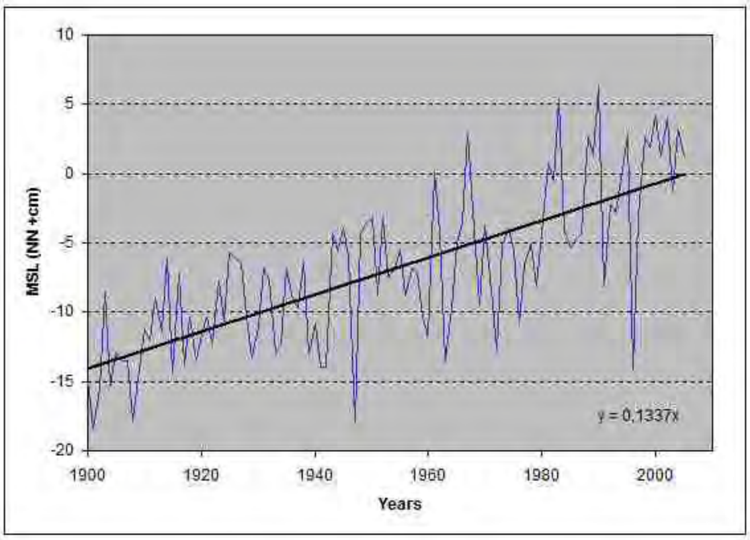
perature of the atmosphere (Figure 4.1.2; Becker and Pauly, 1996; Wessels *et al.*, 1999). This would result in an increase in the longer run of 2-5°C in yearly average temperatures (Kabat *et al.*, 2009a). It should, however, be noted that a weakening of the North Atlantic Current due to its own warming and an increased freshwater influx from the North Pole could have a cooling effect on northwest Europe (Dickson *et al.*, 2002; Clark *et al.*, 2002, 2008). Nevertheless, most climate models simulating a decrease in North Atlantic Current strength with increasing atmospheric greenhouse gas concentrations still show a warming over Europe, implying that greenhouse warming is overwhelming the cooling effect of weakened warm ocean currents (Gregory *et al.*, 2005).

4.1.2.3 Sea levels, wind and storm surges

Average global tide-gauge records show a relative sea-level rise of ca. 1.8 mm/yr over the past century. This is more than could be expected on the basis of a 1 mm/yr contribution from the melting of global land ice reservoirs (Mitrovica *et al.*, 2006), and a 0.4 mm/yr contribution from thermal expansion of the world ocean to absolute sea-level rise (Antonov *et al.*, 2005). Correcting the tide-gauge records for the vertical land motion with GPS techniques reduced the estimated global average sea-level rise to 1.3 mm/yr (Wöppelmann *et al.*, 2007). Berge-Nguyen *et al.* (2008) concluded, on the basis of a combination of thermosteric sea-level data based on temperatures in the top 700 meters of the ocean, tide gauge, satellite altimetry, and ocean reanalysis data, that sea level rose over the period 1950-2003 by some 1.5 mm/yr. It thus seems likely that absolute sea-level rise over the past century has mainly been a function of climate change. Over the period 1992-2009, satellite data are available covering the global oceanic sea-level rise. After correction for seasons and inverted barometer effects, an average global sea-level rise is observed of 3.1 ±0.4 mm/yr over the period 1992-2009 (http://sealevel.colorado.edu/current/sl_ib_ns_global.jpg). This deviation from the long-term average has been explained by increases in thermosteric effects (contribution 1.2, vs. 0.4 mm/yr) and a faster melting of Greenland (0.4 vs. 0.2 mm/yr), Antartica (0.5 vs. 0.3 mm/yr) and glaciers (0.9 vs. 0.4 mm/yr) for the period 1993-2005 (Nerem, 2005).

Combining data from reliable stations over the past 50-100 years from the Dutch and German Wadden Sea indicates a mean average sea-level rise varying from station to station between values of 1-2 mm/yr and average high-water rise between 2-2.5 mm/yr (Hofstede, 2005; 2007; Dillingh, 2008; Von Storch *et al.*, 2008; Kabat *et al.*, 2009a). Local sea-level rise in the Wadden area is attributed to global trends, and partly to local and regional effects such as atmospheric circulation, oceanic currents, subsidence due to isostasy (0.3 mm/yr) and gas mining and water-management works (the latter especially after 1950 [Kooi *et al.*, 1998; CPSL, 2005; Katsman *et al.*, 2008a]). The increased global rate of sea-level rise of 4.1 mm/yr, as observed from the satellite data, has not yet been observed along the tidal gauges of the Wadden Sea coast (Figure 4.1.4; Hofstede, 2007; Dillingh, 2008). It should be noted, however, that the tide gauges represent a rather restricted part of the oceans (Nerem *et al.*, 2006). Furthermore on a decadal timescale, the length scales of sea level change are quite

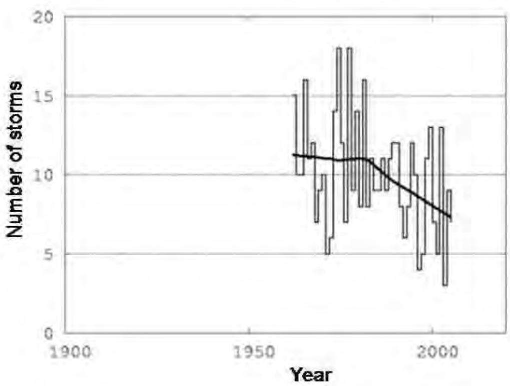
Figure 4.1.4: Mean sea-level rise in the Wadden Sea from 1900-2005, averaged over 10 long-term tidal gauge stations (Den Helder, Harlingen, Terschelling-West, Delfzijl, Norderney, Cuxhaven, Büsum, Husum, Wittdün, List; adapted from Hofstede (2007) and corrected for varying base levels).



large (up to 1,000 km), and as a result many tide gauges in a region are highly correlated with each other (Holgate, 2007). From observations of selected stations, it seems that local sea-level rise may vary on a decadal scale and in such a period reach annual velocities of +/-15 mm/yr (Holgate, 2007). Thus, if it is assumed that the satellite data are correct, an acceleration of sea-level rise in the Wadden Sea might yet occur.

IPCC AR4 estimates of global sea-level rise by 2100 are 18-59 cm (Meehl *et al.*, 2007). However, these estimates have been challenged on the basis that large ice sheets appear to be changing much more rapidly (Nerem, 2005; Ekström *et al.*, 2006; Velicogna and Wahr, 2006) than models predict (Overpeck *et al.*, 2006); a reality recognized by the IPCC summary report (IPCC, 2007). Locally large differences in sea-level height can occur under the influence of currents in the atmosphere and oceans (IPCC, 2007; Von Storch and Woth, 2008), and by changes in the gravity field and redistribution of mass (a.o. land ice) (Mitrovica *et al.*, 2001; Katsman *et al.*, 2008b).

Figure 4.1.5: Annual number of storms in The Netherlands (>6 Bft inland and >7 Bft at the coast; Source: KNMI, Kabat *et al.*, 2009a).



Wind direction and force, air pressures, sea-level height and tidal amplitude determine the height of the water levels and thus of storm surges. In addition, waves amplify the effect of storm surges, especially on the North Sea coasts where long waves can reach the dunes if the beach plain is not too broad. In the back-barrier area, mainly locally generated wind waves are important, possibly with the exception of the inlet channels. Storm activity and the related storm surge and wave conditions in the Wadden Sea show pronounced inter-annual and inter-decadal variability, with maxima around 1920, 1950 and 1990 (Flather *et al.*, 1998; Langenberg *et al.*, 1999; Schmidt, 2001; Weisse *et al.*, 2002, 2004; Matulla *et al.*, 2007). In the past decennia the atmospheric flow above the northern part of the Altantic Ocean which determines European storms was on average stronger than in the period before and followed a more northerly path. It is not clear if this should be attributed to the enhanced greenhouse effect (KNMI, 2006). In The Netherlands the average wind force has decreased slightly (Sluijter, 2008; WSH, 2009). An analysis of the Dutch storm climate over the period 1962-2002 showed a marked decrease of strong wind (7 Bft along the coast), with 5-10%/10 yrs (Smits *et al.*, 2005). Trends in stronger storms (10 Bft) cannot be determined significantly (Sluijter, 2008; Smits *et al.*, 2005).

For the Dutch coastal area the wind coming from the NNW is quite important for set-up of the water levels due to the long fetch over the North Sea. Although the number of western winds increases in the late winter and early spring, the number of N to NW winds is not changing (Figure 4.1.5; Van Oldenborgh *et al.*, 2009). An analysis of the number of storms with a set-up of more than

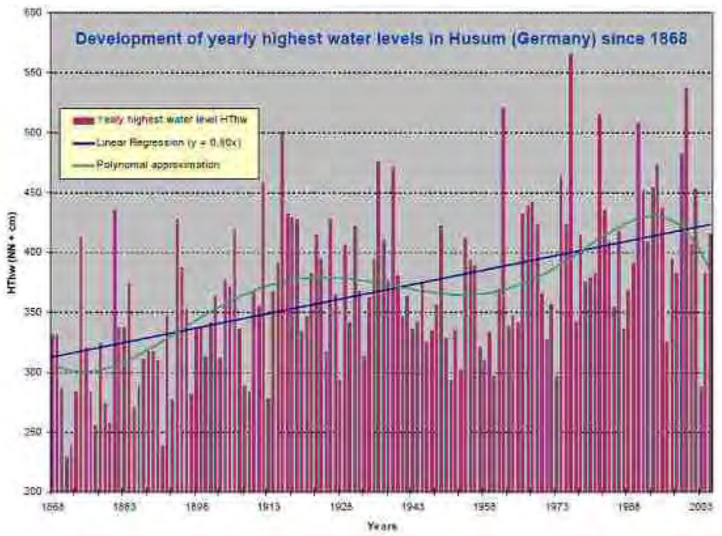


Figure 4.1.6: Development of the highest annual water levels at Husum, Germany since 1868 (adapted from Hofstede, 2007).

0.9 m does thus not show a trend. In contrast to this are observations in the Schleswig-Holstein sector of the Wadden Sea that show a strong trend of up to 8 mm per year since 1868 in the yearly highest water levels (Figure 4.6). Apart from artificial causes (building of a dam that closed the Husumer Bight to the north in the 1920s), this may be the result of a shift in storm wind directions. The polynomial approximation in Figure 4.1.6 shows a significant decrease since the mid 1990s.

Regional scenarios project an absolute mean sea-level rise of 20-35 cm in 2050, and 40-80 cm in 2100 (Van den Hurk *et al.*, 2006; Katsman *et al.*, 2008b). In order to guarantee the safety of The Netherlands in the long run, the Dutch Delta Committee has been asked to predict plausible upper limit scenarios. Based on the findings of the IPCC AR4 report (IPCC, 2007), the scenarios of KNMI (Van den Hurk *et al.*, 2006) and new insights in ice sheet dynamics (Katsman *et al.*, 2008b) the scenarios show good agreement with the KNMI scenarios until 2050, but an increase in absolute sea-level rise along the Wadden coast of 120 cm by 2100 (Figure 4.1.7; Vellinga *et al.*, 2008) with large uncertainties (Katsman *et al.*, 2008b, Kabat *et al.*, 2009a&b).

Climate scenarios suggest that the average wind force will hardly increase until 2100 (KNMI, 2006; Van den Hurk *et al.*, 2006; Sterl *et al.*, 2008c). Wind direction also determines the number of days with high water levels (Von Storch and Woth, 2008). Some climate models show a continuing increase in the number of western winds, but not of northern winds. However changes are small compared to the natural variability (Sterl *et al.*, 2008c). It should, however, be noted that the uncertainties in the future storm climate predictions remain large, especially due to the uncertainties in the emission scenarios which influence atmospheric pressure patterns and wind climate (Von Storch and Woth, 2008; Kabat *et al.*, 2009a).

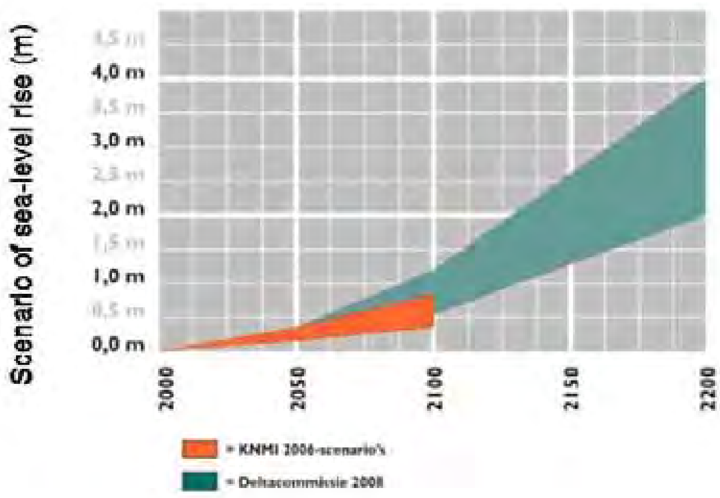


Figure 4.1.7: Scenarios for absolute sea-level rise of KNMI (2006) and Vellinga (2008) (Sources: Delta Committee, 2008; Kabat *et al.*, 2009a).

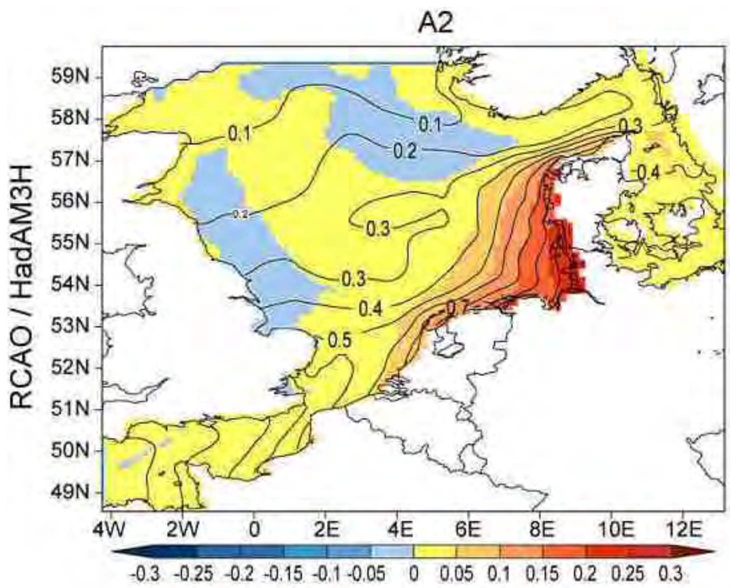


Figure 4.1.8: Simulated difference in the annual 99.5 percentile values of water level increase (in m), between 2071-2100 and 1961-1990, at IPCC scenario A2 (Weisse *et al.*, 2009). Contours show the values for the period 1961-1990.

Important details of changes in wind climate in the Wadden Sea area and its influence on wave climate and surge levels are as yet unclear (Kabat *et al.*, 2009a). As an example, model studies indicate that in the German Bight storm surge, water levels may increase strongly along the coast and up to about 0.3 m in the German sector of the Wadden Sea (Weisse *et al.*, 2009; Figure 4.8). Another example is that the 99 percentile of the significant wave height in models is underestimated (Sterl *et al.*, 2008c).

To estimate the possible extreme changes in water levels at the coast, a first order approach is to add the mean sea-level rise and the storm surge levels and to discard non-linear effects (Vellinga *et al.*, 2008). Applying this method, Woth *et al.* (2006) projected storm surge water levels (including mean sea-level rise) in the inner German Bight to be about 0.6 to 0.7 m higher at the end of this century compared to the end of the last century.

Precipitation and evaporation

After the little Ice Age, roughly since 1825, the Wadden Sea climate has become more maritime in character. Thus, in The Netherlands the annual precipitation increased since 1906 by 18% with marked seasonal differences (autumn and winter by 26%, spring 21%, summer 3% – KNMI, 2006) These figures are comparable to those estimated for Germany and Denmark. Extreme precipitation events have gradually increased since the 1970s (Klok, 1998; Sluijter, 2008). In general, coastal precipitation increases faster than further inland and is enhanced by higher sea-water temperatures. In The Netherlands the intensity of precipitation in the coastal zone increases by some 15% for every degree of water-temperature increase, against 5% for inland locations (Lenderink and Beersma, 2008; Lenderink *et al.* (2009). Especially in autumn, precipitation in the Wadden Sea area is higher than inland, whereas in spring inland precipitation is higher (Heijboer and Nellestijn, 2002).

In scenarios without changes in wind circulation patterns, the precipitation in The Netherlands is thought to increase by 3%/1°C global temperature increase, both in the summer and winter half year. Scenarios with a change in circulation pattern expect an extra increase in precipitation during winter (7%/1°C) and a decrease in summer (-10%/1°C), especially due to a reduction in the number of rainy days (KNMI, 2006). As noticed above, coastal precipitation patterns might differ somewhat from the inland averages. Increased precipitation may also lead to increased run-off through rivers to the Wadden Sea, leading to a further decrease of salinity of the Wadden Sea water (cf. Marsdiep tidal inlet; van Aken, 2003). On the other hand, a precipitation deficit along the Rhine might influence the water discharges in the summer season strongly. For Northern Germany, the GKSS Research Station (www.norddeutscher-klimaatlas.de) projects a mean increase in precipitation between 1 and 13% (8-102 mm). The increase mainly occurs in the winter season (16 to 58%), whereas the summer will probable become dryer.

Part of the precipitation is evaporated (Kruijt *et al.*, 2008). Based on a model, the evaporation for a well-watered meadow has been calculated for two stations along the Wadden Sea (Eelde and De Kooy; Heijboer and Nellestijn, 2002). A clear increase in the evaporation can be observed since the 1980s (Figure 4.1.9).

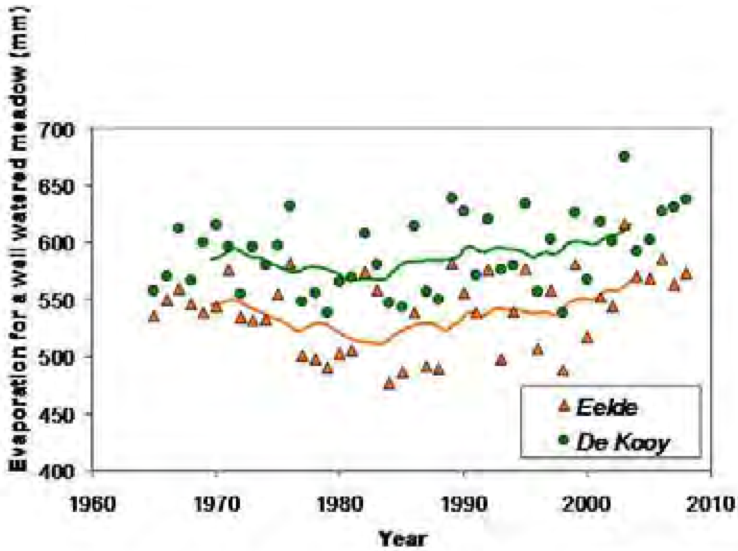


Figure 4.1.9: Evaporation for a well-watered meadow for the Wadden Sea region (Data: KNMI; Kabat *et al.*, 2009a). The line is the 10-year average.

The difference between precipitation and modelled evaporation for a well-watered meadow is the potential precipitation deficit (Beersma *et al.*, 2004). It can be used as a drought indicator but is not the absolute measure for droughts. The available data indicate no trend for long-term maximum precipitation deficit (Figure 4.1.10). The precipitation deficit along the coast is larger than the inland average (Kabat *et al.*, 2009a).

For nature management and agriculture, the precipitation deficit in the summer half year (starting 1 April) is most important. The KNMI 2006 scenarios indicate that the precipitation deficits during the summer half year will increase and that extreme years will occur more frequently than nowadays (Table 4.1.1: KNMI)

4.1.3 Possible consequences

4.1.3.1 Water and sediments

With increasing water temperature, the kinematic viscosity of water decreases. As a result, the mobility potential of non-cohesive sediments decreases, whereas the particle settling velocities increase (Krogel and Flemming 1998). The effect of an increase in water temperatures on settling and resuspension rates of sediment may lead to a shift in the timing of sediment redistribution and of stabilization, which may have consequences for the pelagic (via effects on turbidity) and benthic (via effects on habitats) biomass and production (4.3.1 of Philippart and Epping, 2009).

The runoff of fresh water has increased considerably, leading locally (for instance Marsdiep

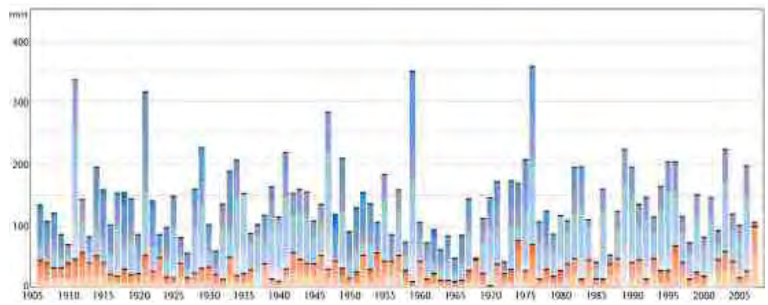


Figure 4.1.10: Maximum potential precipitation deficit in April-September (blue) and March-April (red) from 1906 to 2007 (Source: Lenderink and Beersma, 2008).

	1906-2000	G	G+	W	W+
Average maximum precipitation deficit (mm)	144	151	179	158	220
Repetition time for a maximum precipitation deficit as in 2003 (yrs)	9.7	7.9	4.1	6.5	2.0

Table 4.1.11: Average maximum precipitation deficit in the summer half year (starting 1 April) in 2050 for four different climate scenarios (source KNMI).

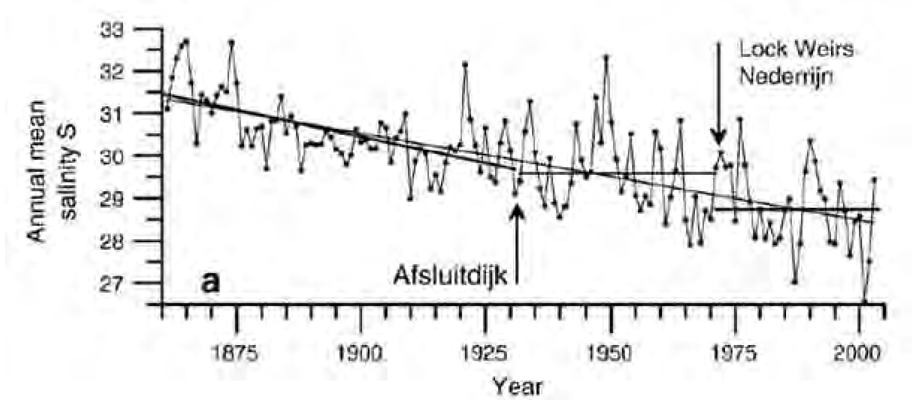


Figure 4.1.11: Salinity in Marsdiep Inlet (van Aken, 2008b).

Inlet, Figure 4.1.11) to lower salinities. In itself such lower salinities are not the major problem, since many organisms can cope well with slightly brackish conditions. However, problems are caused by pulses of almost completely fresh water during several days during extreme run-off from the rivers. If such pulses are not avoided it can, at least locally, lead to a decrease in the number of species (Kabat *et al.*, 2009a).

In the study on behalf of the Delta Committee it was found that higher sea-water levels will cause considerable problems to the fresh water management along low lying areas and rivers. The salt water intrusion hinders the discharge of surplus fresh waters, but will also hinder fresh water intake from rivers (for drinking water or agriculture) where saline waters enter the river mouths further. Also, it was realized that the higher sea levels also resulted in higher river levels, making extensive dyke re-enforcements necessary (Deltacommissie, 2008).

The higher precipitation deficits may pose problems for the water availability, especially on the barrier islands. In the long run this cannot be compensated for by pumping larger amounts of ground waters, which will also lead to deficits for nature (Witte *et al.*, 2008). Locally this may lead to dryer dune valleys with more drought resistant plant species. In The Netherlands, the barrier islands have decided to become autonomous for their drinking water demands without relying on extra pumping. A number of measures have been proposed for each island, such as water storage basins, desalination, etc. (Kok, pers. inf.).

Sediment is needed in the back barrier inter- and supra-tidal area to compensate sea-level rise. The major part of the sediment is sand derived from the North Sea coast and through internal sediment redistribution from the deeper channels towards the wadden and salt marshes (Hofstede, 2002). A minor part is finer material which is derived from the Flemish banks and, to a lesser extent, rivers. Historical and model studies suggest that there is an upper limit to the volume of sand which becomes available to the back barrier areas (van Goor, 2001; Van Goor *et al.*,2001, 2004; Hoeksema *et al.*, 2004; Min. EZ, 2006). Above this limit the system cannot keep up with sea-level rise and tidal shoals will drown gradually (CPSL, 2001). The limit for the rate of sea-level rise which still can be compensated by sedimentation is in debate, but thought to be lower for large tidal basins than for small tidal basins (Hofstede, 2002; Hoeksema *et al.*, 2004; Min. EZ, 2006). Long-term beach erosion may increase due to accelerated sea-level rise (SLR) and may lead to landward retreat or even deterioration of barrier chains such as the Wadden Sea islands (Fitzgerald *et al.*, 2008). Sediment transport from the coastal zone increases with increasing wind driven transport (van Goor, 2001). Changes in wind direction or force might therefore lead to changes in sediment availability. It should be realized that, given the height distribution of the tidal flats and the projected acceleration for 2050 and 2100 the loss of intertidal shoals will most likely be relatively small. Extensive tidal flats will most likely still be present in 2100.

On the barrier islands, at many places natural sedimentation on the island is hindered by dykes, artificial dune rows or other human intervention like placing sand fences on the beach. In general this leads to lower sedimentation rates in dunes, wash-overs and tidal marshes, making the back-barrier parts of the islands more vulnerable to accelerated sea-level rise. It is thought that the sand eroded from the North Sea coast is in general transported into the back-barrier area. However, in recent research it was found that a fair part of the sand is deposited in the first dune rows (Arens, 2008), showing the potential for island-ward sediment transport. Furthermore the lack of natural dynamics enhances succession strongly and rare species characteristic of pioneer conditions become rarer or disappear and habitats become smaller (Petersen and Lammerts, 2005; De Leeuw *et al.*, 2008; Ten Haaf and Buijs, 2008; Löffler *et al.*, 2008). Especially open and nutrient-poor habitats have given way to grassy vegetation poor in species, both on the dunes and in the tidal marshes. Currently studies are carried out to investigate how such effects might be mitigated.

4.1.3.2 Regime shifts

There are clear indications that rather abrupt shifts occur between different but persistent conditions in ecosystems and that such "regime shifts" can be caused by abiotic factors (Scheffer *et al.*, 2001a,b). During the past 50 years, two big changes have occurred in the North Sea which likely led to shifts in ecosystem conditions. The first change was during the 1970s when water temperature, salinity and the Atlantic inflow were lower than average. The second change is from the 1980s up to present, with higher than average temperature, salinity and Arctic inflow (Reid *et al.*, 2003; Beaugrand, 2004). Fast and wide spread shifts in plankton (Cadee and Hegeman, 2002), benthic life and fish populations characterize both periods with marked regional differences (Figure 4.12; Beaugrand *et al.*, 2003; Weijerman *et al.*, 2005). Currently, the spring blooms of phytoplankton in the Wadden Sea occur ever later in the Wadden Sea but earlier in the North Sea. As a result, fish larvae and young shrimp occur earlier in the Wadden Sea. Such shifts in seasonal dynamics lead to a mismatch between phytoplankton and zoöplankton peaks, between shrimp and shellfish larvae, between zooplankton and fish, and between fish and sea birds (Beaugrand *et al.*, 2003; Edwards and Richardson, 2004). These observations indicate that shifts in population sizes of many species may be expected.

4.1.3.3 Fish

Changing water temperatures can have strong effects on the species of the North and Wadden Sea. The reproductive potential of fish is for instance influenced by temperature. Some species show a positive correlation between development of larvae and water temperature, but in other species the correlation is inverse (Tulp *et al.*, 2006). In addition, indirect influences such as oxygen uptake may lead to population effects (Pörtner and Knust, 2007). Currently, several studies report trends suggesting migration due to climate change, such as a northward migration of warm water species (anchovy) and disappearance of cold water species (Beaugrand *et al.*, 2002, 2009; Brander *et al.*, 2003; Beare *et al.*, 2004; Perry *et al.*, 2005; Tulp *et al.*, 2006).

4.1.3.4 Bird life

Migration patterns of birds are also influenced by changes in temperature and food availability in the various locations they use. In the period 1987-2004, a decrease was observed in the population of 12 out of 34 species of migrating birds which are important for the Wadden Sea area (Blew *et al.*, 2007). The decrease is caused by a decrease in the quality of the habitat and in the quantity and quality of the food available in the intertidal zone. Indications that climate change is directly and indirectly involved are becoming stronger (Bairlein and Exo, 2007). However, the influence of climate change is hard to quantify, since other human induced disturbances also play a significant role (Reineking and Südbeck, 2007).

In the Wadden Sea, marked differences occur in the numbers of wintering birds in cold and warm winters (Meltofte *et al.*, 1994; Figure 4.1.13). For some species it is known that the spring population is smaller with a higher spring temperature, because species migrate sooner towards Nordic areas. Migration patterns might also change; a fact which should be taken into account when studying population size development (Reineking and Südbeck, 2007).

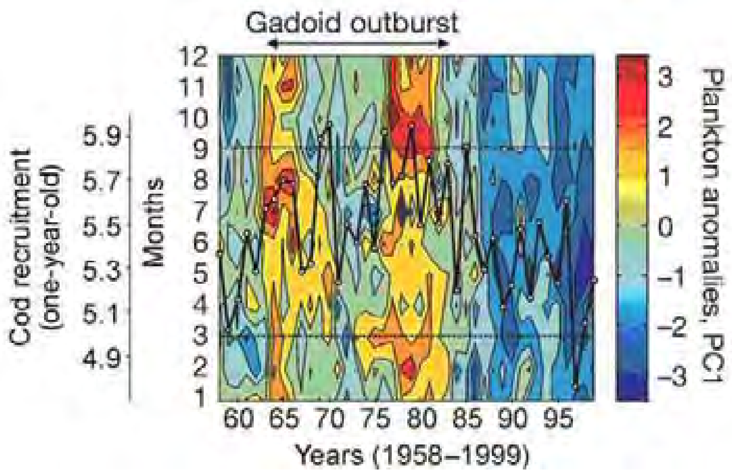


Figure 4.1.12: Illustration of a fast change in the plankton population in the North Sea and its consequences (Beaugrand *et al.*, 2003). Between 1958 and 1983 the anomaly is mainly positive and after that it is mainly negative. In the first period the recruitment of cod (black line) is on average high ("Gadoid outburst"), in the second period it is low.

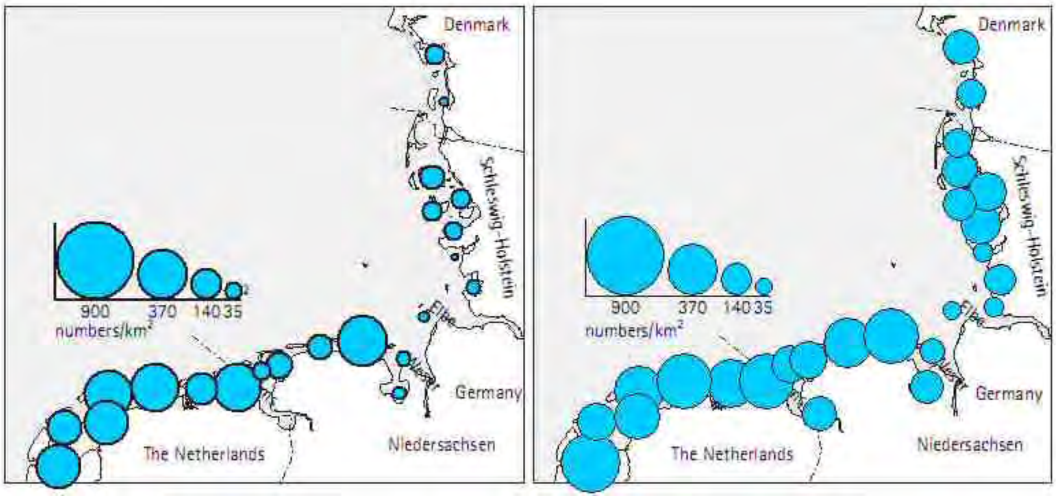


Figure 4.1.13: Waders in the Wadden Sea in cold (left) and mild winters between 1980-1991 (Meltofte *et al.*, 1994).

Climate change is expected to have strong effects on the terrestrial and semi-terrestrial ecosystems of the Wadden Sea area, such as dunes and tidal marshes. Temperature, precipitation and evaporation will have their influence on the growth and living conditions of species and on ecosystem processes. Species may become less abundant or even disappear, while others may invade the area.

Further consequences for the ecosystem are discussed in the following chapter 4.2 by Philippart and Epping.

4.1.4 Next steps

Coastal waters have been changing and will change due to past and current activities and changes in climate settings. The potential climate scenarios provided here are likely? based on the current state of knowledge of climate change. The effect on the ecosystem is still based on limited knowledge of isolated processes. As stated by Philippart and Epping (2009): "Understanding the functioning of the Wadden Sea [morpho-hydro-] eco-system as a composite, including positive and negative feedback mechanisms, is urgently needed to develop prognostic models and to construct reliable future scenarios." To this end, monitoring has to be extended to improve both temporal and spatial resolution to improve both the abiotic and biotic modeling of the Wadden Sea system.

Since not everything can be monitored, scientists and policy makers are advised to identify abiotic key-processes and key factors which dominate the hydro-morphological development of the area and to study this both in the field and under laboratory conditions. In this way adaptation strategies can be developed which make optimal use of the abiotic factors which form the area, for instance by increasing the natural resilience of it. For the abiotic conditions these are, amongst others (Speelman *et al.*, 2009):

- the influence of subsidence;
- the influence of the geo(morpho)logical build up of the area on current processes;
- the natural dynamics of the barrier islands (overwash, erosion and eolian sand transport);
- the dynamics and long-term development of tidal marshes, shoals, estuaries and outer deltas;
- the sediment balance of the Wadden area;
- the differences in dynamics of the various inlet systems (with special attention to shoal-channel interactions);
- quantification of processes (water movements, sand- and mud-transport, vertical sedimentation rates and their interactions on several temporal and spatial scales).

Effort should focus on ensuring that the level of detail (complexity) of the models matches what can and will be measured. For biota see following chapter 4.2 of Philippart and Epping (2009).

As a summary of strategic research topics: in order to adequately understand and project the consequences of climate change for hydromorphodynamics, biodiversity and ecosystem functioning of the sea, we need to (1) extend our coastal monitoring efforts; (2) extend our knowledge on sensitivities and adaptation capabilities of (abiotic) key processes and (biotic) species in the marine environment; and (3) develop fit-for-purpose models to manage our marine environment.

4.1.5 References

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Eric Epping

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4.2 Climate change and ecology

4.2.1 Observed and expected changes

The Northern Hemisphere has been warmer since 1980 than for any period during the last 2,000 years, and has experienced a stronger temperature increase for northern than for southern latitudes. Observations of the Sea Surface Temperature (SST) from the western Wadden Sea have shown a cooling trend in the late 19th Century, as well as a steady warming trend between ~1980 and the early 21st Century (Figure 4.2.1; Van Aken, 2008). Ongoing research and analyses shows that the year-to-year variations in SST as well as the long-term trends correlate well with changing atmospheric circulation and with changes in cloudiness (Van Aken, 2010).

Climate models predict an increase for global mean air temperature of 1°C up to 6°C for the year 2100 relative to 1990 (IPCC 2007). In Europe, the average temperature increase will probably be slightly faster than the world average. Based on the most recent results from climate research, KNMI (Royal Netherlands Meteorological Institute) has developed four climate scenarios for The Netherlands (see Table 4.2.1). Although the rate of change varies between these scenarios, a number of key characteristics of climate change in The Netherlands and bordering areas are common across all of them, viz. a continuation of the rise in temperature, an increased frequency of mild winters and hot summers, an increase in precipitation during winters, an increase in extremes in precipitation, and a further rise of the sea level (http://www.knmi.nl/climatescenarios/knmi06/).

4.2.2 Synergistic effects

Throughout the history of Wadden Sea observations, several drivers (*e.g.*, large infrastructural works, eutrophication, fisheries, pollutants, and invasive species) have been identified that changed the functioning of the Wadden Sea ecosystem. Some have been effective for a restricted period of time and have been countered by effective measures and policies, whereas others continue to affect the functioning. Most of these drivers have often been treated as isolated actors for change. More likely, several drivers have been acting in concert which may have amplified or suppressed responses to individual drivers. The reduction in nutrient supply, for example, has not been followed by a decrease in productivity and biomass of phytoplankton. This lack of response may be due to concurrent ecosystem changes (*e.g.*, lower stocks of filter-feeding bivalves) that prevent a restoration according to the original nutrient-primary production relationships (see Figure 4.2.2).

In a similar way, the response of marine systems to climate change will also depend on other human-induced changes in the marine environment (such as fisheries, nutrient enrichment of many coastal regions, ocean acidification, contamination and the introduction of non-native species). These changes are likely to result in more fragile marine ecosystems, which will challenge the effectiveness of the management strategies to reduce the impacts of climate change. Future effects of climate change should, therefore, always be considered with regard to synergistic effects of other drivers on the Wadden Sea ecosystem.

4.2.3 Possible consequences

Climate change may stress the present structure and functioning of the food web and may result in a cascade of yet unknown effects. For example, the response of organisms and of the ecosystem as a whole may not only depend on these absolute shifts in temperature, but on the phasing of the new temperature regimen (tidally, daily

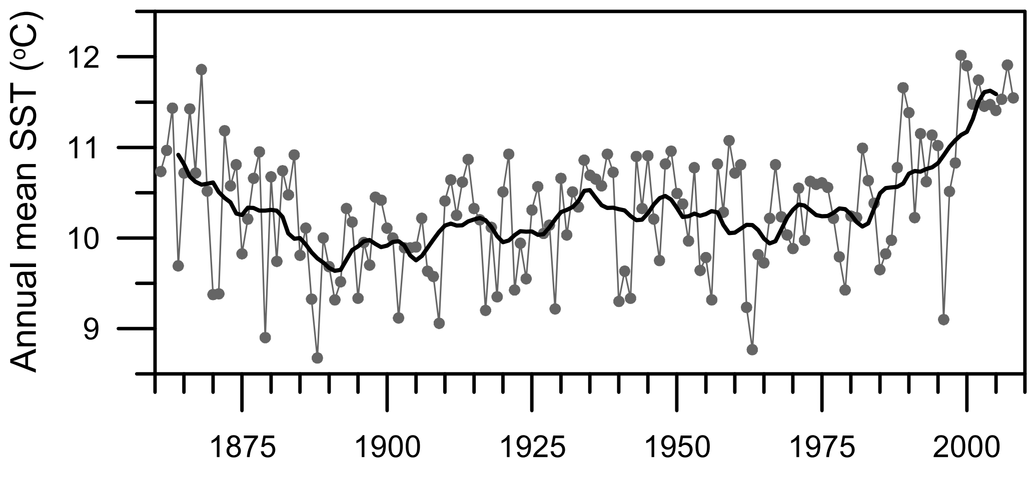

Figure 4.2.1: Long-term field observations on water temperature (annual means) in the Marsdiep tidal inlet between 1861 and 2008. The thick line indicates the 10-year running average (Van Aken, 2008).

Table 4.2.1: Climate change in The Netherlands around 2100 compared to the baseline year 1990, according to the four KNMI'06 climate scenarios (http://www.knmi.nl/climatescenarios/knmi06/). The climate in the baseline year 1990 is described with data from the period 1976 to 2005. The seasons are defined as follows: 'winter' stands for December, January and February, and 'summer' stands for June, July and August.

2100		Moderate	Moderate+	Warm	Warm+
Global temperature rise		+2°C	+2°C	+4°C	+4°C
Change in air circulation patterns		no	yes	no	yes
Winter	Average temperature	+1,8°C	+2,3°C	+3,6°C	+4,6°C
	Coldest winter day per year	+2,1°C	+2,9°C	+4,2°C	+5,8°C
	Average precipitation amount	+7%	+14%	+14%	+28%
	Number of wet days (≥0,1 mm)	0%	+2%	0%	+4%
	10-day precipitation sum exceeded once in 10 years	+8%	+12%	+16%	+24%
	Maximum average daily wind speed per year	-1%	+4%	-2%	+8%
Summer	Average temperature	+1,7°C	+2,8°C	+3,4°C	+5,6°C
	Warmest summer day per year	+2,1°C	+3,8°C	+4,2°C	+7,6°C
	Average precipitation amount	+6%	-19%	+12%	-38%
	Number of wet days (≥0,1 mm)	-3%	-19%	-6%	-38%
	Daily precipitation sum exceeded once in 10 years	+27%	+10%	+54%	+20%
	Potential evaporation	+7%	+15%	+14%	+30%
Sea level	Absolute increase	35-60 cm	35-60 cm	40-85 cm	40-85 cm

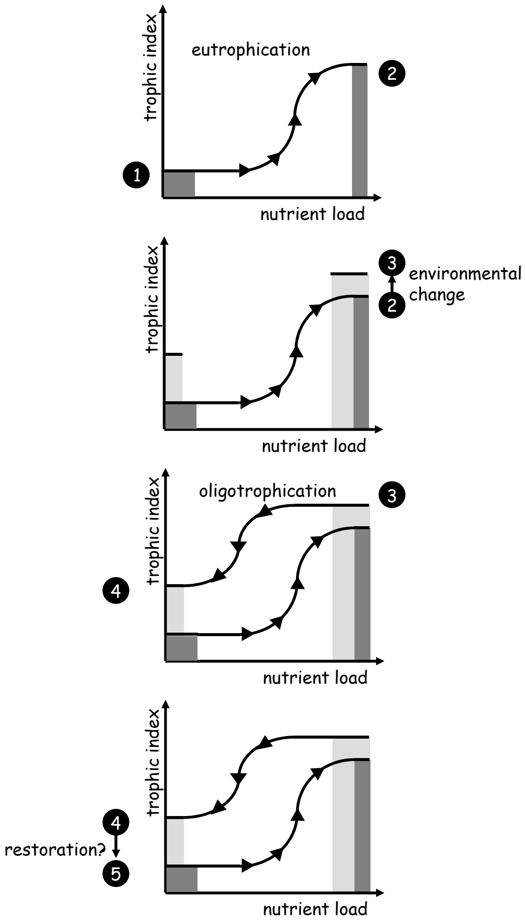

Figure 4.2.2: Conceptual model of environmental changes in the Wadden Sea. An increase in nutrient loads ("eutrophication") causes a change in a trophic index (e.g., primary productivity) from a low to a higher value. During this period of eutrophication, however, other environmental conditions may alter as well (e.g., a decline in stocks of filter-feeding bivalves as the result of overfishing or climate change) preventing a relaxation to initial conditions.

and seasonally) with other key variables as well. Extreme scenarios involve major changes in the present balance between the surface of tidal and subtidal areas, between autotrophy and heterotrophy, between pelagic and benthic production, and between import and export of energy and matter. These shifts in ecosystem functioning will inevitably have consequences for possibilities and limits of sustainable use and for the protection of natural ecosystems and their services. For the Wadden Sea, we envision the following possible developments.

4.2.3.1 Sediments

With increasing temperature, the kinematic viscosity of water decreases. As a result, the mobility potential of non-cohesive sediments decreases, whereas the particle settling velocities increase (Krögel and Flemming, 1998). The effect of an increase in water temperatures on settling and resuspension rates of sediment may lead to a shift in the timing of sediment redistribution and of stabilization, which may have consequences for the pelagic (via effects on turbidity) and benthic (via effects on habitats) biomass and production.

Rising sea level not only inundates the lower coastal regions but also contributes to the redistribution of sediment along sandy coasts. Long-term beach erosion may increase due to accelerated sea-level rise (SLR) and may eventually lead to the deterioration of barrier chains such as the Wadden Sea (Fitzgerald *et al.*, 2008). If SLR is not compensated by sedimentation, tidal exchange through inlets increases, which leads to sand sequestration in ebb-tidal deltas and (further) erosion of adjacent barrier shorelines.

4.2.3.2 Nutrients

The combination of a decrease in oxygen solubility and an increase in sulfate reduction rate with increasing temperatures, may promote low redox conditions, or even the formation of sulfureta in sediments. This transition may induce major shifts in the geochemistry of sediments and in the biogeochemical cycles of essential elements.

A higher annual river runoff will inevitably result in relatively higher TN and TP outputs from the IJsselmeer to the Wadden Sea, thereby counteracting ongoing de-eutrophication measures and stimulating coastal eutrophication (Van Raaphorst and De Jonge, 2004). It will also result in an increased input of sediment by means of river runoff, which will lower the transparency of the Wadden Sea, affecting the absolute and relative production by phytoplankton and microphytobenthos.

4.2.3.3 Primary producers

Enzymatic process rates, like respiration, on average increase by a factor of 2-3 with a rise in temperature of 10°C. Photosynthesis, however, is temperature sensitive only at light saturating conditions, when the carboxylation rate is limited by RuBisCO activity. At non-saturating conditions, photosynthesis is far less sensitive to changes in temperature. The temperature-induced increase in respiration without a concomitant increase in gross photosynthesis will reduce the rate of photosynthesis and alter the fitness of individual phototrophic species. As a consequence, the species composition of the phototrophic community may change. On an ecosystem level, the differential effect of temperature on photosynthesis and respiration may also result in a more heterotrophic nature of the Wadden Sea, with a concomitant reduction in net productivity and food availability.

A change from a rather constant to a strongly pulsed supply of riverine nutrients may drastically change the microalgal competition for nutrients and favour large phytoplankton species (Stolte and Riegman, 1995). Because of their larger storage capacity, these species are better competitors under high and fluctuating nutrient regimes than smaller algae (Sommer, 1984; Stolte *et al.*, 1994; Grover, 1997). Reduced grazing pressures and enhanced rates of sedimentation may result in an enhanced carbon and energy flux to benthic communities (Thingstad and Sakshaug, 1990; Riegman *et al.*, 1993).

An earlier seasonal onset of zooplankton grazing due to increased spring temperatures (Wiltshire and Manly, 2004) may restrain the peak in microalgal biomass during the spring phytoplankton bloom, and promote regenerative production by flagellates at the expense of diatoms.

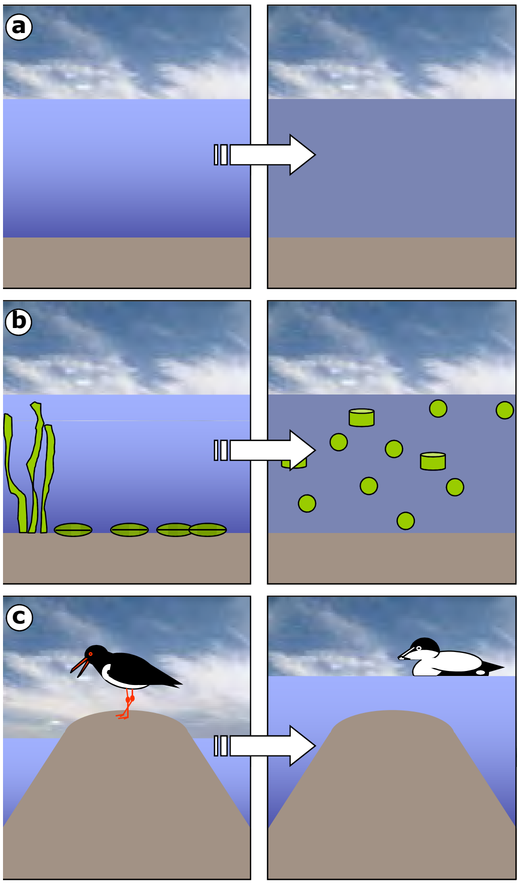

Figure 4.2.3: Some examples of possible developments within the Wadden Sea under various scenarios of climate change. (a) An increase in rainfall and storminess may result in higher concentrations of total suspended matter and subsequently to increased turbidity of the waters of the Wadden Sea. (b) Increased turbidity and riverine nutrient loads may result in a shift within primary producers from benthic (seagrass and microphytobenthos) to pelagic (phytoplankton) species. (c) If sea level rise is not compensated by an increase in sedimentation, the subsequent drowning of the tidal flats may reduce species that feed on tidal flats during emergence and favour those that mainly rely on subtidal food sources (Drawings by KP).

An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species such as a shift within macrophytes from seagrasses (*Zostera noltii*) to widgeon grass (*Ruppia maritima*) (Van Katwijk *et al.*, 2005).

4.2.3.4 Secondary producers

On the level of higher organisms, the demand for oxygen may exceed the capacity of oxygen supply to tissues at elevated temperatures, restricting whole-animal tolerance to thermal extremes (Portner and Knust, 2007). Mismatches in metabolic balances, food availability and relationships between predators and preys affect mortality and reproduction rates, and have resulted in shifts from Arctic to Atlantic species in the more northern seas and from temperate to more subtropical species in southern waters (Philippart *et al.*, 2007). With increasing temperatures, more shifts and the establishment of new trophic relationships are to be expected.

For the Wadden Sea, an increased frequency of mild winters will favour macrobenthic species which are sensitive to cold winters, and result

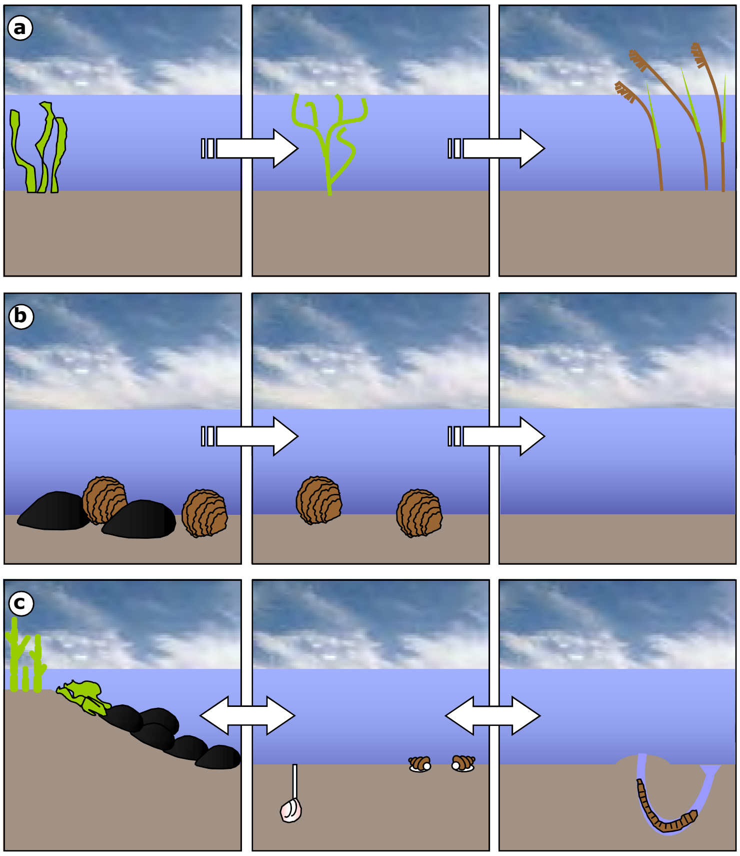

Figure 4.2.4: Some examples of possible developments within the Wadden Sea under various scenarios of climate change. (a) An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species near the freshwater sources, e.g., a shift from *Zostera* to *Ruppia* and *Phragmites*. (b) A decrease in pH values may affect calcifying species with *Mytilus* being more vulnerable than Crassostrea. (c) Climate-induced changes in macrozoobenthos communities will change the effects of this fauna on the sediment, e.g., by means of stabilisation, de-stabilisation and bioturbation (Drawings by KP).

in greater weight loss in all bivalves during the winter and low reproductive success in the subsequent summer for various important (bivalve) species (*e.g.*, *Mya arenaria*, *Mytilus edulis* and *Cerastoderma edule*) (Beukema, 2002), possibly as a consequence of enhanced predation on bivalve spat by juvenile shrimps (Beukema, 1992; Philippart *et al.*, 2003). The reproductive success of warm-water species, such as *Crassostrea gigas*, may be favoured by higher temperatures in (late) summer (Diederich *et al.*, 2005).

An increase in river runoff and subsequent lowering in salinity may lead to shifts from marine to more brackish species such as a shift within polychaetes from lugworms (*Arenicola marina*) to nereid polychaetes (*Nereis diversicolor* and *N. virens*) (Zipperle and Reise, 2007).

4.2.3.5 Ecosystem functioning and feedbacks

Changes in the balance between production by phytoplankton and microphytobenthos may affect the cycling of energy and matter (*e.g.*, via pelagic zooplankton versus filter-feeding macrozoobenthos), the food availability for macrozoobenthos (*e.g.*, filter-feeding bivalves versus deposit-feeding polychaetes), and the fate of energy and matter (*e.g.*, export through pelagic communities versus local retention in benthic communities).

For example, changes in standing stocks of filter-feeding bivalves may affect algal stocks due to changes in grazing pressure, affect growth of other benthic species due to reduced or enhanced competition for food, and change the food availability for shellfish-eating fish and birds (Beukema, 2002; Cadée, 2008). In addition, changes in reef-building bivalves (such as *Mytilus edulis* and *Crassostrea gigas*) as the result of acidification (Gazeau *et al.*, 2007) will affect the balance between erosion and sedimentation and, as the result of supplying specific habitats for marine flora and fauna, the local biodiversity (Cadée, 2007; Kochman *et al.*. 2008).

In addition, changes in macrozoobenthos communities will change the effects of this fauna on the sediment (*e.g.*, by means of stabilisation, de-stabilisation and bioturbation), subsequently affecting bio-irrigation of oxygen and nutrients, survival of resting stages of planktonic organisms such as copepods, diatoms and dinoflagellates, and the burial rates of 'solid particles' such as clay, organic matter, eggs and shells (Reise, 2002; Widdows and Brinsley, 2002; Meysman *et al.*, 2006).

4.2.4 Next steps

Coastal waters are most likely to change as the result of past and current activities and changes in climate settings. The potential climate scenarios provided here are highly speculative and are based on still limited knowledge of isolated processes. Understanding the functioning of the Wadden Sea ecosystem as a composite, including positive and negative feedback mechanisms, is urgently needed to develop prognostic models and to construct reliable future scenarios. A European and integrated coastal monitoring network is required to keep close track of variations and trends in the coastal environment.

National and European policies tend to focus on state variables (such as phytoplankton biomass), which may signal environmental changes, but are of limited use for identifying the causes of change. There is, therefore, a need to extend conventional monitoring programs with a parallel assaying of key processes. Since ecosystem functioning often comes down to species, we should encourage the painstaking work of monitoring marine organisms to species level, including their larval and postlarval stages (early warning system approach). In order to project the consequences of environmental changes for biodiversity, we have to assess the plasticity of (key) species towards environmental conditions.

This knowledge should be integrated in mechanistic ecosystem models as a tool for managing the marine environment (*e.g.*, examining scenarios of nutrient reduction, protected areas and exploitation of marine resources). Effort should focus on ensuring that the level of detail (complexity) of the models matches what can and will be measured, including species-specific data. The latter will enable appropriate parameter values to be obtained and ensure that the models are fit-for-purpose and not unnecessarily complicated.

As a summary of strategic research topics to adequately understand and project the consequences of climate change for biodiversity and ecosystem functioning of the sea, we therefore need to (1) extend our coastal monitoring efforts; (2) extend our knowledge on sensitivities and adaptation capabilities of key species in the marine environment; and (3) develop fit-for-purpose models to manage our marine environment.

More explicitly, we advocate including measurements of process rates to present monitoring efforts on state variables at several specific locations, reflecting the various habitats and large-scale variation throughout the Wadden Sea. These sites should not only be used for monitoring, but also be the focus points for experiments and teaching and learning about the ongoing changes in ecosystem functioning and the factors that are underlying these changes.

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WADDEN SEA ECOSYSTEM No. 25

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Thematic Report No. 5.1

Hazardous Substances

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5.1 Harzardous substances

5.1.1 Introduction

The Wadden Sea is monitored for chemicals under several monitoring programs. The Trilateral Monitoring and Assessment Program (TMAP) covers the entire Wadden Sea Area. The trilateral Wadden Sea Plan is the framework for management and policy for the Dutch-German-Danish Wadden Sea. For hazardous substances, the targets are: to reach background concentrations for natural compounds and zero-discharges for man-made substances.

The Joint Assessment and Monitoring Programme (JAMP) of OSPAR, including the Coordinated Environmental Monitoring Programme (CEMP), the Riverine Inputs and Discharges (RID) and Chemical Atmospheric Monitoring Programme (CAMP), covers the entire North-East Atlantic Ocean and bordering seas. The national programs follow the delimitation of the Water Framework Directive (WFD) waterbodies and River Basin Districts (RBD), extending to the 12 nautical miles from the coastal base-line for priority compounds. The monitoring requirements of the Marine Strategy Framework Directive (MSFD) have to still be implemented (see also Box).

Assessment approach

The Wadden Sea is part of many national and international agreements and laws. The assessment approach was chosen in such a way that it harmonizes the information and makes it suitable to use between those platforms (Box 5.1).

Assessment Procedure of QSR 2010 Monitoring Data

For the purpose of the assessment, the Wadden Sea was divided into 12 subareas, which deviates slightly from the QSR of 1993, 1999 and 2004, but improves consistency with the WFD waterbodies and river basin districts classification (Figure 5.1.1). The WFD waterbodies division cross-cutting with the QSR areas was dealt with by grouping the data of monitoring locations within the waterbody transitional water, dominated by riverine water, and coastal water euhaline [CW-NEA1/26], dominated by coastal marine water [>30 psu], and polyhaline [CW-NEA3/4], mixing trajectory coastal marine and estuarine water [18-30 psu]). Areas will be referred to by their QSR code as shown in Table 5.1.1.

Before data evaluation, harmonized parameterization was checked and quality control of data performed. In the assessment procedure a contaminant was followed from its riverine source to the accumulation in sediment and biota. The data was evaluated visually for temporal and spatial trends over the total assessment period 1988-2007 and a ten years period from 1998-2007. The actual concentrations were compared with Environmental Quality Standards (EQS), as implemented by the WFD (2008) (Table 5.1.2), and with Background and Environmental Assessment Criteria (BAC and EAC respectively), as accepted by OSPAR (2009) (Tables 5.1.2, 5.1.3). The Effect Range 10 percentile (ERL), developed by US EPA to assess the quality of coastal and marine environments, was additionally used by OSPAR in the 2010 Quality Status Report to assess sediment quality for metals, PAHs and some pesticides.

As for metals, copper and zinc are not included in the WFD or OSPAR lists. Nickel is newly included in this QSR, following the Priority Substances (PS) daughter directive of the WFD. Nickel data were not available for all Wadden Sea subareas.

Quantitative differences in riverine metal loads into the Wadden and North Sea are mainly due to the diversity of river flows (Figure 5.1.2). What the rivers would contribute, if they were of the same size, is shown by calculating the loads at a 'standard' flow rate of 10^9 $m^3 \cdot y^{-1}$. In fact this represents the difference in yearly-averaged concentration in river water. The 'standard' flow equals a river of the size of the Weser.

Riverine inputs of hazardous substances were supplied by annual reports to OSPAR. Atmospheric inputs were available from OSPAR modeling the JAMP/CAMP monitoring. Monitoring data of metals and organic compounds in sediment and biota were taken from the TMAP data units and the German Environmental Specimen Bank. Denmark does not report riverine metal inputs.

Different methods used in monitoring, sample preparation and analyses of hazardous substances in sediment (ref. 2004 QSR) are still seriously hampering a full comparison of monitoring results. The issue has also being discussed for a number of years within OSPAR (see JAMP guidelines), which is the most appropriate forum for harmonization of marine chemical monitoring.

For metals, the main obstacle is the choice of sediment matrix, which is <63µm in Dutch and Danish data, and mostly <20µm in German data. To partly overcome this metals problem, the correction procedure of Koopmann *et al.* (1993) was applied to achieve inter-comparability between data obtained from <20µm and <63µm sediment grain size fractions.

Other standardization methods to improve inter-comparability of metals results have been considered.

Box 5.: EU Directives, international and regional agreements relevant to the Wadden Sea

(modified after HARBASINS, 2008).

WFD - Water Framework Directive:
Establishing a framework for the protection of surface waters (rivers, lakes, transitional and coastal) and groundwater on an EU level. Targets are a Good Ecological Status (GES) and a Good Chemical Status (GCS) by 2015. The Water Framework Directive integrates current eutrophication aspects of the Urban Waste Water Treatment Directive and the Nitrates Directive into the classification system of "good ecological status" (GES). Hazardous Substances are partly assessed for GCS on exceeding Environmental Quality Standards (EQS) criteria by the Priority Substances (PS) daughter directive. As "other relevant / river basin specific substances", additional hazardous substances are assessed under the GES. The EQS target has been revised by the Directive 2008/105 Priority Substances (December 16th, 2008) and defined mandatory for total water, filtered water (metals), biota for 33 + 8 substances, of which 20 Priority Hazardous Substances (Table 5.1.1). Optional EQS for sediment and/or biota may be defined by member states to replace those in Annex I for selected hazardous substances, offering the same level of protection. Maximum Allowable Concentrations (MACs) are defined by the Directive for peak concentrations. Annual Averages (AAs) are the long term EQS level.

MSFD – Marine Strategy Framework Directive:
Aiming at a Good Environmental Status (GEnS) of European marine waters by 2021 to protect the resources ("ecological goods and services") by demanding cooperation between member states. The MSFD sets common objectives for EU marine regions and sub-regions as management units, selected hydro-morphological, oceanographical and bio-geographical features. The management targets are under development by the Marine Strategy Coordination Group, which met for the first time on May 15th, 2009.

BHD / NATURA2000 - Wild Birds and Species & Habitats Directives:
Protecting bird species within the European Union through the conservation of populations and their habitats, respectively contributing to biodiversity through the conservation of natural habitats and of wild fauna and flora. Maintenance or restoration of favourable conservation status, natural habitats and species of wild flora and fauna of community interest is assessed. The BHD areas form an ecological network known as NATURA2000, consisting of Special Protection Areas for birds and Special Areas of Conservation for habitats and species, both listed in the BHD. Hazardous Substances are not to contaminate water, sediment or biota. The provisions of the WFD and regional sea conventions, i.c. OSPAR, to abate pollution are to be followed as management targets.

ICZM –Integrated Coastal Zone Management:
Concerning the planning and management of resources within the coastal area, across the range of habitats and land use types, including land and water management. Management of resources and human activities (fishing, tourism, urban and industrial development) exerting particular pressures upon the conservation of natural habitats and species of the coastal zone. The EU Recommendations on ICZM aim to improve management of the coastal zones as well as the implementation of other EU legislation and policies. Coastal Member States are encouraged to develop and implement a national strategy for integrated coastal zone management. The target is to raise awareness of all stakeholders of the increasing pressures on coastal areas, of which the Wadden Sea is particularly sensitive, and the importance of carefully integrated planning.

OSPAR- Oslo and Paris Convention:
The International Convention for the Protection of the Marine Environment of the Northeast Atlantic is the main intergovernmental convention to regulate and control marine pollution in the North Sea and the North-east Atlantic. It covers all human activities that might adversely affect the marine environment. Fisheries regulations cannot be adopted under the convention although it now covers the health of habitats through the Annex V agreement. The recently re-negotiated EU Common Fisheries Policy now has a habitat protection remit. The strategy towards hazardous substances is to prevent pollution of the marine areas by continuously reducing discharges, emissions and losses. The target for hazardous substances is to achieve near-background for naturally occurring and close-to-zero for man-made synthetic substances in the marine environment. OSPAR (2007) updated the 'List of Chemicals for Priority Action'. The assessment criteria by OSPAR are listed in Table 5.1.2 (sediments) and 5.1.3 (biota).

TWSC-Trilateral Wadden Sea Cooperation:
A regional agreement on formal cooperation between The Netherlands, Germany and Denmark, underlining the Wadden Sea as one ecological entity where protection measures can be implemented more effectively and successfully by a common and coordinated management approach. The objective of the trilateral management approach is to safeguard the natural functioning of the ecosystem through proper regulation of human activities. Ecological Targets, defined as management targets, for hazardous substances are to reach background concentrations for natural compounds and zero-discharges for man-made substances.

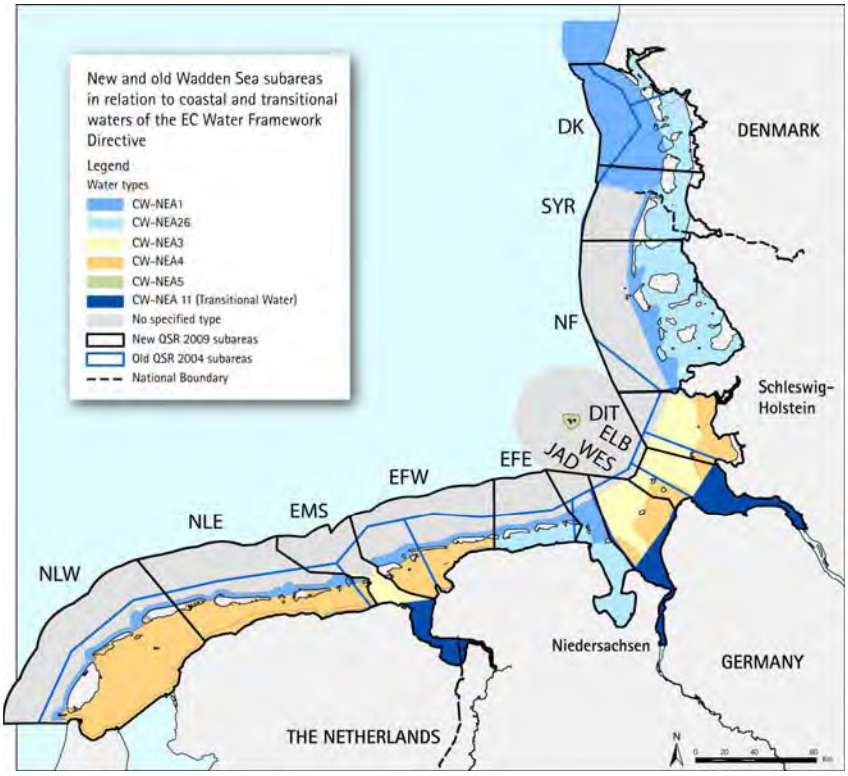


Figure 5.1.1: Map of the Wadden Sea with the subareas used for evaluation and assessment of hazardous substances.

Table 5.1.1. Summary description of Wadden Sea subareas according to the QSR 2009.

Code	Description
NL-West	Western Dutch Wadden Sea/ Rhine North sub-area (Netherlands West). Receives freshwater from Lake IJsselmeer (RBD Rhine North) at Den Oever and Kornwerderzand. Average outflow $16.3 \cdot 10^9$ m^3 y-1. The originally Rhine water passes through the river IJssel and Lake IJsselmeer in about 50 days. The North Sea coastal water entering the Wadden Sea at the Marsdiep constitutes about 15% Rhine water.
NL-East	Eastern Dutch Wadden Sea (Netherlands East). Receives freshwater from Lake Lauwers. The area is at the upper polyhaline range, being more under the influence of North Sea coastal water.
Ems-Dollard	Ems-Dollard. Outflow of the rivers Ems and Westerwoldsche Aa, 90% respectively 10% of the average flow of $3.4 \cdot 10^9$ m^3 y-1. Enhancing industrial and harbour activities border the area at Emden, Delfzijl and Eemshaven.
East-Frisia West	East Frisian Wadden Sea West, west of Brokum till the halfway point of Baltrum island. Few local freshwater sources. Some small harbours. Dominated by North Sea coastal water.
East-Frisia East	East Frisian Wadden Sea East, halfway point of Baltrum until Jade Busen.
Jade	Jade Bay. The harbour of Wilhelmshaven is the main activity in the area. Virtually no freshwater enters the area. The area is considered to be dominated by coastal North Sea water, which gets enriched by sediment efflux of components during high tide.
Weser	Weser area. The river Weser outflow at an average rate of $11.3 \cdot 10^9$ m^3 y-1. The river borders are densely populated. Harbour activities are present at the cities of Bremen and Bremerhaven.
Elbe	Elbe area. The river Elbe outflow at an average rate of $24.5 \cdot 10^9$ m^3 y-1 (~ 43% of the total freshwater input of the international Wadden Sea). The river is bordered by large cities (e.g. Hamburg), harbours and industrial activities.
Dithmarschen	Dithmarschen. The river Eider constitutes a relatively small freshwater source of about $0.9 \cdot 10^9$ m^3 y-1 on average. The population density is moderate. Some small recreational and fisheries harbours are present.
North-Frisia	North Frisian Wadden Sea. Virtually no freshwater input and a low population density. The area is considered to be dominated by coastal North Sea water.
Sylt- Rømø	Sylt-Rømø basin. The area is physically bordered by the dams connecting Sylt and Rømø to the mainland. The area is considered to be dominated by coastal North Sea water. The freshwater input from southern Jutland area was about $0.8 \cdot 10^9$ m^3/yr in 1990, which was about $1.3 \cdot 10^9$ m^3/yr to northern Ribe area in the same year.
Denmark	Ribe-Konge Å (Knudedyb), Rejsby-Brøns Å (Juvredyb), Varde-Sneum Å (Grådyb). The rivers are fairly small rivers, constituting a small freshwater input of about $1.2 \cdot 10^9$ m^3 y^{-1}on average. Only Varde Å has a free (without sluices or dam) outflow to the Wadden Sea. The area is considered to be dominated by North Sea coastal water. The city of Esbjerg is the main center of population, harbour and industrial activity.

Table 5.1.2: Assessment Criteria for WFD Priority Substances in *(total) water*. The EQS (Environmental Quality Standards) are normalised to concentrations in unfiltered water. Except for metals which are in filtered water. AA: Annual Average; MAC: Maximum Allowable Concentration. All units: µg·l^{-1}. n.a.: not applicable. (Total) water monitoring and EQS maybe replaced by sediment and/or biota monitoring and EQS by member states, offering the same level of protection and by notifying the EU Commission. The EQS in the biota column are mandatory (After: Directive 2008/105 Priority Substances; EC/EP, 16 December 2008). Original WW concentrations in biota recalculated to DW assuming 20% dry mass.

Nr	Priority Substance (Number) Compound	CAS	AA-EQS (non-inland surface waters)	MAC-EQS (non-inland surface waters)	AA-EQS (biota mg·kg^{-1} DW)	Identified as Priority Hazardous Substance	Under review as PS or PHS
1	Alachlor	15972-60-8	0.3	0.7		X	
2	Anthracene	120-12-7	0.1	0.4			
3	Atrazine	1912-24-9	0.6	2.0			
4	Benzene	71-43-2	8	50			
5	Brominated diphenylether 28,47,99,10,153,154	32534-81-9	0.0002	n.a.		X	
6	Cadmium + compounds	7440-43-9	0.2	1.5 (class 5)		X	
6a	Carbon tetrachloride	56-23-5	12	n.a.			
7	C10-C13 Chloroalkanes	85535-84-8	0.4	1.4		X	
8	Chlorfenvinphos	470-90-6	0.1	0.3			
9	Chlorpyrofos(-ethyl)	2921-88-2	0.03	0.1			
9a	Cyclodiene pesticides :						
	Aldrin	309-00-2					
	Dieldrin	60-57-1					
	Endrin	72-20-8					
	Isodrin	465-73-6	∑= 0.005	n.a.			
9b	DDT+DDD total	n.a.	0.025	n.a.			
	p'p'DDT	50-29-3	0.01	n.a.			
10	1,2-Dichloroethane	107-06-2	10	n.a.			
11	Dichloromethane	75-09-2	20	n.a.			
12	Di(2-ethylhexyl)-Phthalate	117-81-7	1.3	n.a.			
13	Diuron	330-54-1	0.2	1.8			
14	Endosulfan	115-29-7	0.0005	0.004		X	
15	Fluoranthene	206-44-0	0.1	1			
16	Hexachloro-benzene	118-74-1	0.01	0.05	0.050	X	
17	Hexachloro-butadiene	87-68-3	0.1	0.6	0.275	X	
18	Hexachloro-cyclohexane	608-73-1	0.02	0.04		X	
19	Isoproturon	34123-59-6	0.3	1.0			
20	Lead + compounds	7439-92-1	7.2	n.a.			
21	Mercury + compounds	7439-97-6	0.05	0.07	0.100	X	
22	Napthalene	91-20-3	1.2	n.a.			
23	Nickel + compounds	7440-02-0	20	n.a.			
24	(4-)Nonylphenol	104-40-5	0.3	2.0		X	
25	Octylphenol 4-(1,1',3,3'-tetramethylbutyl)-phenol	140-66-9	0.01	n.a.			
26	Pentachloro-benzene	608-93-5	0.0007	n.a.			
27	Pentachloro-phenol	87-86-5	0.4	1			
28	Benzo[a]pyrene (1)	50-32-8	0.05	0.1		X	
28	Benzo(b)fluor-anthene (2)	205-99-2				X	
28	Benzo(k)fluor-anthene (3)	207-08-9	∑= 0.03	n.a.		X	
28	Benzo[ghi]perylene (4)	191-24-2				X	
28	Indeno[1,2,3-cd]pyrene (5)	193-39-5	∑= 0.002	n.a.		X	
29	Simazine	122-34-9	1	4			
29a	Tetrachloro-ethylene	127-18-4	10	n.a.			
29b	Trichloro-ethylene	79-01-6	10	n.a.			
30	Tributyl compounds (cation)	36643-28-4	0.0002	0.0015		X	
31	Trichloro-benzenes	12002-48-1	0.4	n.a.			
32	Trichloro-methane	67-66-3	2.5	n.a.			
33	Trifluralin	1582-09-8	0.03	n.a.			
Substances under review							
	AMPA	1066-51-9					X
	Bentazon	25057-89-0					X
	Bisphenol-A	80-05-7					X
	Dicofol	115-32-2					X
	EDTA	60-00-4					X
	Free Cyanide	57-12-5					X
	Glyphosphate	1071-83-6					X
	Mecoprop (MCPP)	7085-19-0					X
	Musk Xylene	81-15-2					X
	Perfluorooctane Sulphonic Acid (PFOA / PFOS)	1763-23-1					X
	Quinoxyfen	124495-18-7					X
	Dioxins						X
	PCBs						X

Table 5.1.3: Assessment criteria used in the CEMP data assessment in OSPAR.

Group	Substance	SEDIMENT[1] (µg/kg dry weight)						Mussels (M) and Oysters (O) (µg/kg dry weight)				FISH (µg/kg wet weight, except: EACpassive for CB: lipid weight (lw)			
		Background/low concentrations		Blue (T_0)		Green (T_1)			Blue (T_0)	Green (T_1)			Blue (T_0)	Green (T_1)	Amber (T_1)
Group	Substance	BC	LC Spain	< BAC	< BAC Spain	< EAC	< ERL	BC/LC	< BAC	< EAC	< EC	BC/LC	< BAC	< EAC passive	< EC max. food limit
Metals	Cd	200	86	310	129		1200	M-600 O-1800	M-960 O-3000		M-5000 O-5000	a	26		1000 (bivalve. tissue)
	Hg	50	53	70	91		150	M-50 O-100	M-90 O-180		M-2500 O-2500	a	35		500
	Pb	25000	15500	38000	22400		47000	M-800 O-800	M-1300 O-1300		M-7500 O-7500	a	26		1500 (bivalve. tissue)
	As	15000		25000			---								
	Cr	60000		81000			81000								
	Cu	20000		27000			34000								
	Ni	30000		36000			---								
	Zn	90000		122000			150000								
	TBT	---		---		---		1.0	5.0	12.0					
PAHs	Naphthalene	5	---	8	---		160	---	---	340					
	Phenanthrene	17	4.0	32	7.3		240	4.0	11.0	1700					
	Anthracene	3	1.0	5	1.8		85	---	---	290					
	DBT	0.6	---	---	---		190	---	---	---					
	Fluoranthene	20	7.5	39	14.4		600	5.5	12.2	110					
	Pyrene	13	6.0	24	11.3		665	4.0	9.0	100					
	Benz[a]anthracene	9	3.5	16	7.1		261	1.0	2.5	80					
	Chrysene (Triphe-nylene)	11	4.0	20	8.0		384	4.0	8.1	---					
	Benzo[a]pyrene	15	4.0	30	8.2		430	0.5	1.4	600					
	Benzo[ghi]perylene	45	3.5	80	6.9		85	1.5	2.5	110					
	Indeno[1,2,3-cd]pyrene	50	4.0	103	8.3		240	1.0	2.4	---					
PCBs	CB28 *	0.0/0.05		0.22		1.7		0.0/0.25	0.75	3.2		0.0/0.05	0.10	64 lw	
	CB52	0.0/0.05		0.12		2.7		0.0/0.25	0.75	5.4		0.0/0.05	0.08	108 lw	
	CB101 *	0.0/0.05		0.14		3.0		0.0/0.25	0.70	6.0		0.0/0.05	0.08	120 lw	
	CB105	---		---		---		0.0/0.25	0.75	---		0.0/0.05	0.08	---	
	CB118 *	0.0/0.05		0.17		0.6		0.0/0.25	0.60	1.2		0.0/0.05	0.10	24 lw	
	CB138 *	0.0/0.05		0.15		7.9		0.0/0.25	0.60	15.8		0.0/0.05	0.09	316 lw	
	CB153 *	0.0/0.05		0.19		40		0.0/0.25	0.60	80		0.0/0.05	0.10	1600 lw	
	CB156	---		---		---		0.0/0.25	0.60	---		0.0/0.05	0.08	---	
	CB180 *	0.0/0.05		0.10		12		0.0/0.25	0.60	24		0.0/0.05	0.11	480 lw	
	Sum PCBs (*)			0.97		65.2			3.85	130.2			0.58	2604 lw	
Pesticide	γ-HCH	0.0/0.05	0.13				3.0	0.0/0.25	0.97	1.45	---	---	---	11b	
	α-HCH	---	---				---	0.0/0.25	0.64	---	---	---	---	---	
	DDE (p,p')	0.0/0.05	0.09				2.2	0.0/0.25	0.63	---	---	0.0/0.05	0.10	---	
	Hexachlorobenzene	0.0/0.05	0.16				20.0	0.0/0.25	0.63	---	---	0.0/0.05	0.09	---	
	Dieldrin	0.0/0.05	0.19				2.0	---	---	---	---	---	---	---	

a: datasets too limited to allow recommendation for BCs for metals in fish; b: EAC for fish liver derived by applying a conversion factor of 10 on EAC for whole fish. [1] Sediments: metals normalized to 5% Al; organic substances to 2.5% TOC

The analysis in the <63µm fraction and standardisation of metal concentrations to 5% aluminum (5% Al) is common practice in OSPARs CEMP (Webster *et al.*, 2008). Application of this approach is however strongly determined by sediment destruction methods prior to the metal analysis (including aluminum), which differs between countries and is another source of variation.

Total Organic Carbon (TOC) was introduced by Cato (1977) and Johannesson *et al.* (2003). Though this method is not sensitive for differences in grain size, it is, however, quite sensitive to the accuracy of TOC measurements, especially in the lower TOC range (< 0.5%). This also affects the standardisation of organic compounds in sediment, which are normalized to 2.5% TOC containing sediments, following OSPAR (Webster *et al.*, 2008).

For metals both 5% Al or <20µm fractions would be a good choice, given a harmonized destruction and sieving method.

Concerning organic compounds 2.5% TOC or <63µm would be a good choice, where the fraction of 20-63µm is particularly relevant for PAHs.

For this QSR all data for metal concentrations in sediment were recalculated to $mg{\cdot}kg^{-1}$ dry weight in the sediment fraction <63µm. Organics concentrations were recalculated to mg (resp. µg)$\cdot kg^{-1}$2.5% TOC in the <63µm or <20µm fraction.

Data in blue mussel (*Mytilus edulis*) were recalculated to mg (resp. µg)$\cdot kg^{-1}$ dry weight (dry, homogenized tissue weight). The results of five length classes of blue mussel size were pooled, causing a larger within-year variation between maximum and minimum values. Average and maximum values were considered to be most informative in visual trend analysis, as well as ecotoxic effects. Arithmetic trend analysis was not considered suitable for these data-sets.

5.1.2.1 Natural Contaminants: Metals

Target

Background concentrations of natural micropollutants in water, sediment and indicator species.

QSR 2004

Main reductions in riverine inputs and concentrations in sediment and biota of the five metals took place in the late 1980s until the 1990s. The proposed background in sediments was exceeded by mercury, lead and zinc, and in blue mussels by cadmium, copper, mercury and lead and thus the Targets were not met. Nickel as a new compound of high priority in both OSPAR and Water Framework Directive, needs to be included in the monitoring of the Wadden Sea. Harmonization of monitoring methods to improve comparability, and quality and availability of the data stored in databases, have to be progressed further still.

Cadmium

QSR 2004

All rivers showed a continuing decrease in cadmium loads, taking into account flow and precipitation rate related variations. Elbe and Weser generally return a factor of 4 higher than Lake IJssel, Ems and Eider, both in load and year averaged concentration. Atmospheric input of 158 $kg{\cdot}y^{-1}$ is about 3% of the total riverine input (5,520 $kg{\cdot}y^{-1}$).

Reduction of cadmium in dredged material from the Elbe was consistent with the decrease in riverine input and concentrations in sediments. In the south-western Wadden Sea subareas sediment, cadmium concentrations decreased from the early 1990s to 2002. North-western areas do not reveal this trend due to relatively low cadmium levels all the time. Temporal trends in mussel tissue were obscured by highly variable concentrations.

Ecological Relevance of Cadmium

Cadmium occurs naturally in ores and is found at background levels in the marine environment. Cadmium for industrial or commercial use is derived from mining, smelting and refining of zinc. Its main use in batteries has almost ceased in Europe. Cadmium and its salts are still used as intermediates and catalysts in electroplating, as pigment in paint, stabilizers of plastic, and in photographic processes and dyes.

Cadmium is toxic, particularly causing kidney malfunction, bioaccumulates in plants and organs of animals. As such it is of concern for the marine environment and humans by consumption of fish and other seafood. Primary sources of cadmium are emissions to air from combustion processes. Releases to water are secondary sources. The main pathway of cadmium to the sea is via air by which it can be carried long distances from its source. Following the regulated closure of the cadmium refineries in Europe, the diffuse sources are gaining importance.

Cadmium Input

Riverine cadmium loads continue to decrease during the period 1986-2006. After correction for flow related variations, the reduction amounts ~60% for the Elbe, Weser and Ems (Figure 5.1.3). Concentrations in Elbe and Weser water are a factor of 4 higher than in Lake IJssel, Ems and Eider. The decrease levels off between 2002 and 2006.

The high river flows of 2002 caused a quan-

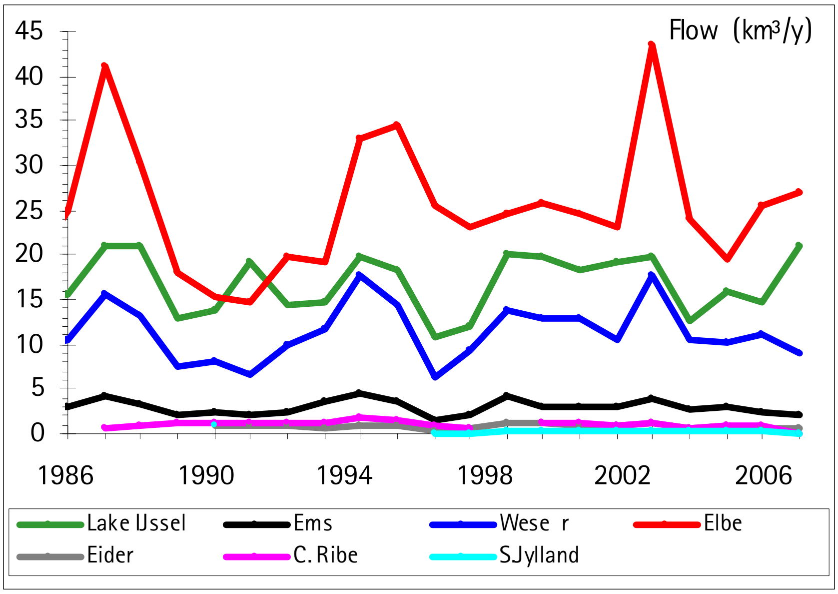


Figure 5.1.2: Riverine flows of main rivers entering the Wadden Sea region. Flow as km^3·y^{-1}.

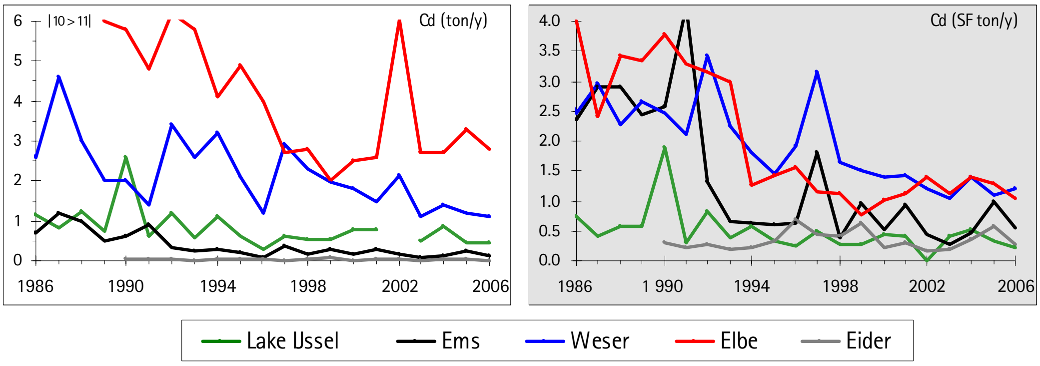


Figure 5.1.3: Left: Riverine inputs of Cadmium (tonnes/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} m^3·y^{-1} (comparable to the average flow of the Weser). The major decrease occurred until 2002. The rivers Elbe and Weser water concentrations are twice those of Lake IJssel, Eider and Ems.

titative increase in cadmium input by Elbe and Weser, but not in the cadmium concentration in the water.

Atmospheric input is modeled at >0.022 mg Cd·m-2·y^{-1}, which is almost uniform over the entire Wadden Sea. The modeled net deposition flux has significantly decreased between 1996 and 2006 with 60%. For the entire North Sea, the riverine discharges and atmospheric input contributed 73% and 27% respectively to the total input (OSPAR, 2009).

Cadmium Concentrations in Sediment

Wadden Sea sediments cadmium leveled off to a basic level of 0.2 – 0.6 mg·kg^{-1} dry weight <63µm (Figure 5.1.4). Highest levels are found in the south-western regions, lowest in the northern Wadden Sea, while high, but unexpected peaks were observed in North-Frisia (~0.83 mg·kg^{-1} dry weight <63µm) and Sylt-Rømø (~0.95 mg·kg^{-1} dry weight <63µm).

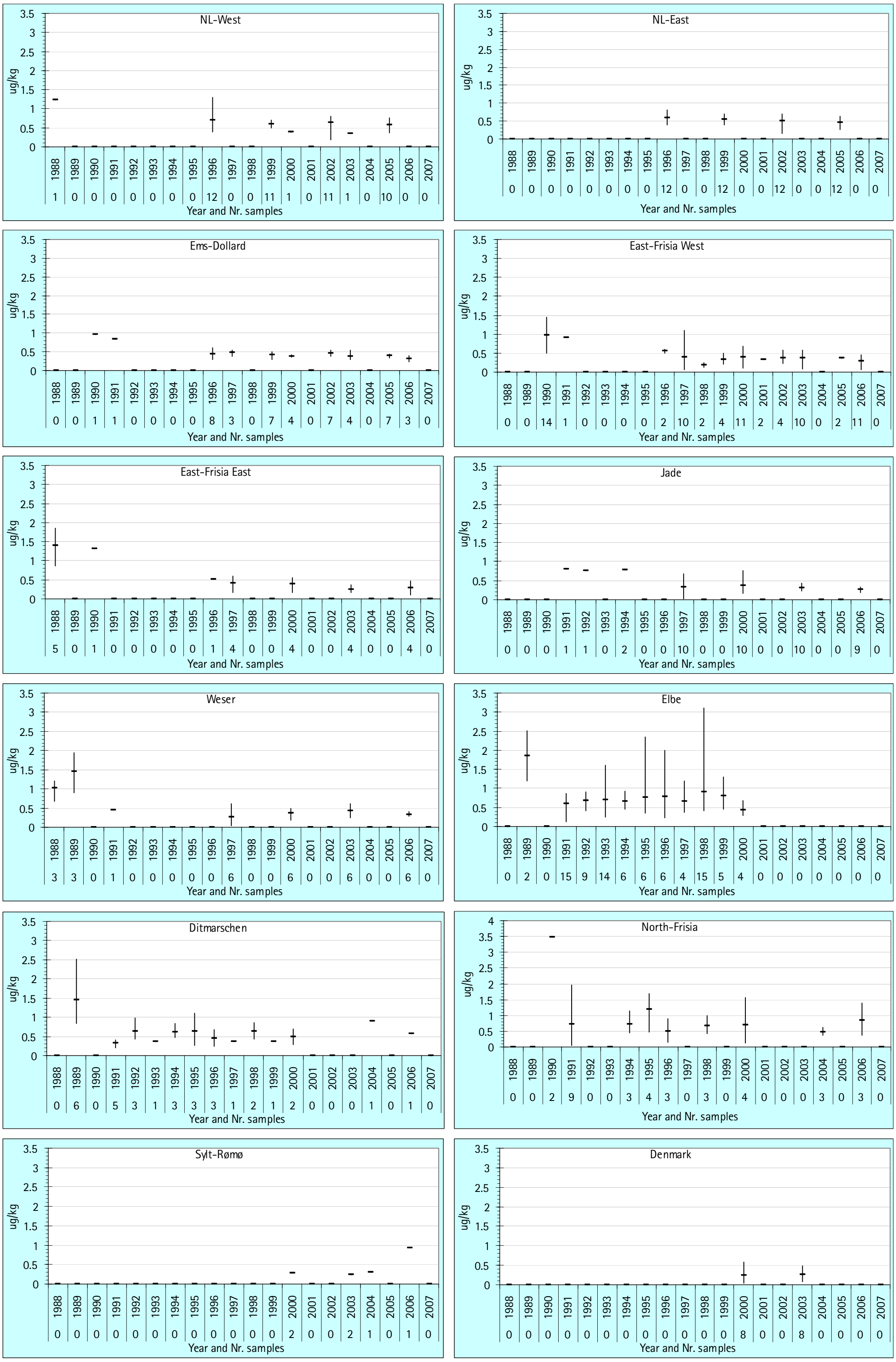
The OSPAR BAC value (Table 5.1.3) is 0.31 mg·kg^{-1} 5%Al, which is very near 0.3 mg·kg^{-1} dry weight <63µm. Cadmium can not be considered as being near background in most subareas, exceedance being 3- to 4-fold. Deep-core Skagerrak sediment shows a background of 0.1 mg·kg^{-1} dry weight <63µm (HARBASINS project, 2008). Cadmium does not exceed the risk level (ERL) for food web accumulation (OSPAR, 2009).

Cadmium Concentrations in Blue Mussel

The average concentrations in mussel tissue (Figure 5.1.5) increased in the long term trend over the period 1994 - 2007. In some areas the increase is considerable – up to 300%. The riverine inputs of the Ems and Eider do not point in this direction. The Elbe tends to slightly increase its cadmium input and has levelled off since 1999, peaking in 2002. This likely affects the increasing trend in blue mussel in 2004.

The geographical differences in mussel cadmium levels do not match those of the riverine concentrations, nor the quantitative input.

Figure 5.1.4
Cadmium concentrations (mg·kg−1 dry weight) in sediment (fraction <63 µm). OSPAR Background Assessment Criteria (BAC): 0.31mg·kg⁻¹ 5%Al (Source: OSPAR, 2009).



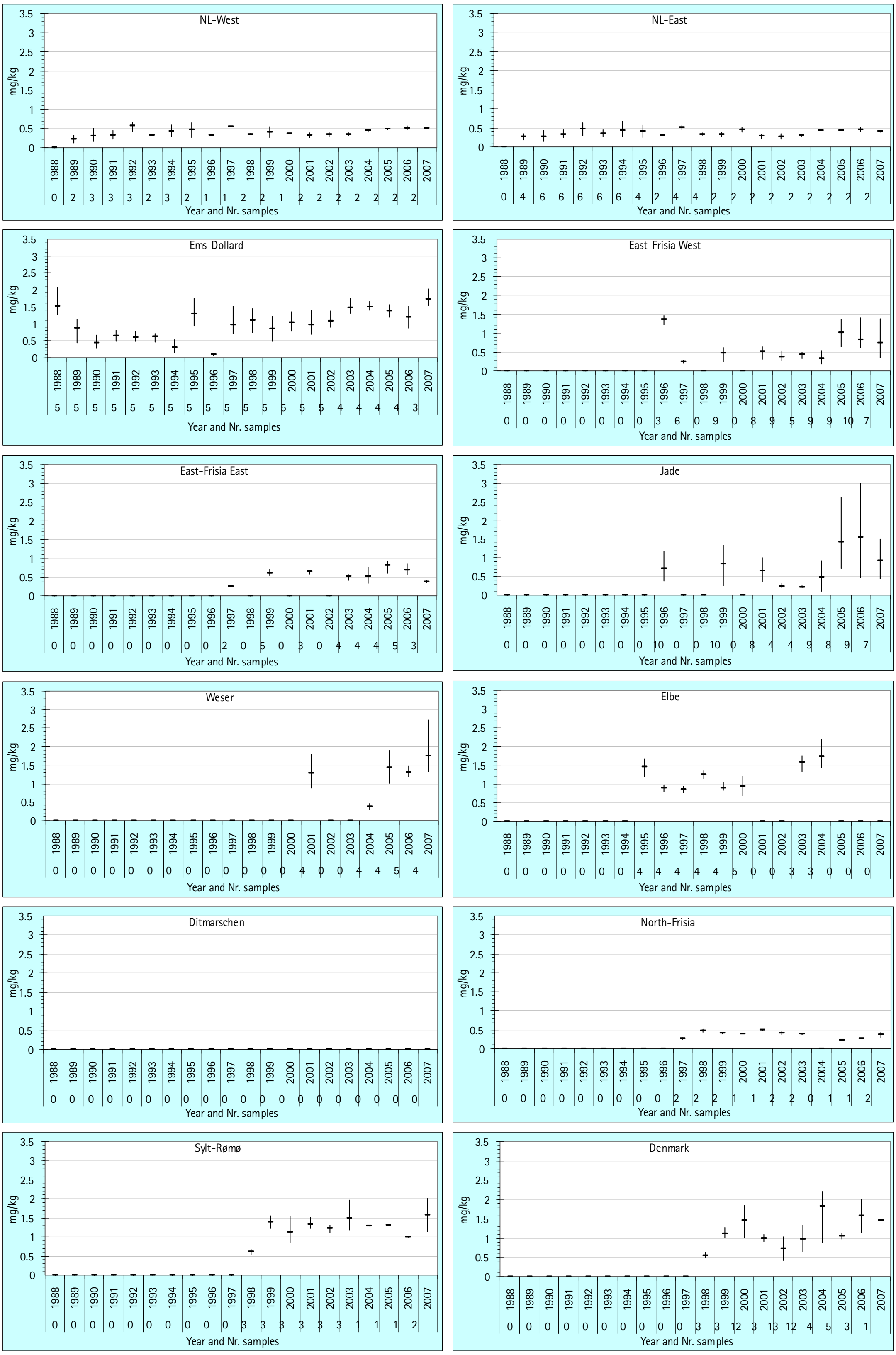


Figure 5.1.5: Cadmium concentrations (mg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*). OSPAR Background (BAC) and Environmental (EAC) Assessment Criteria: 1.94 and 2.8 mg·kg^{-1} dry weight respectively. The OSPAR Low Concentration (LC): 0.6 mg·kg^{-1} dry weight (median level of regional medians in the OPSRA area) (source: OSPAR, 2009).

The concentrations in blue mussel are 3 – 4 times higher in Ems-Dollard, Weser, Elbe, Sylt-Rømø and Denmark regions and range between 1.5 – 2.5 mg·kg^{-1} dry weight. Lowest levels of 2007 were found in the NL-West, NL-East, East-Frisia East and North-Frisia regions, ranging between 0.3 – 0.5 mg·kg^{-1} dry weight.

The EAC of 2.8 mg·kg^{-1} dry weight (OSPAR, 2009) was not exceeded in any of the regions, although getting close in some. The Low Concentration is exceeded in the Ems-Dollard, Elbe, Sylt-Rømø and Denmark regions by a factor of 3. The 2007 maximum levels exceeded the BAC background of 1.94 mg·kg^{-1} dry weight in Sylt-Rømø, Elbe (2004), Weser and Ems-Dollard regions by less than a factor of 2. Generally cadmium levels in blue mussel can be considered as below or near background.

Copper

QSR 2004

The concentrations of copper in the Elbe remained at the reduced level of 1994. The reduction in riverine loads has been marginal since 1989, except for the Elbe, with a highly increased load in 2002 due to the flood. The riverine input was strongly related to river flow and thus precipitation. This implies that a period of reduction in water concentration, coinciding with an increasing riverine flow, covered up strong reductions. This situation occurred in Lake IJssel, the Ems and Weser between 1985 until 1987.

Copper concentrations in sediments varied greatly. Most concentrations were at the proposed background levels. Also no significant temporal trends in blue mussels could be discerned due to large interannual and sample variation.

Copper Input

The major reductions in concentrations of copper occurred between 1986 and 1994. Concentrations in the Elbe and Eider gradually increase between 1996 and 2006 (Figure 5.1.6).

The annually averaged concentration in Elbe water is a factor 4 higher than in Lake IJssel water, while Weser, Ems and Eider have intermediate levels.

Copper Concentrations in Sediment

Wadden Sea sediments copper leveled off to a basic level of 10 - 30 mg·kg^{-1} dry weight <63µm (Figure 5.1.7). Highest levels are found in the south-western regions, lowest in the northern Wadden Sea. The OSPAR BAC value (Table 5.1.3) is 27 mg·kg^{-1} 5%Al, which is very near 27 mg·kg^{-1} dry weight <63µm. Copper can be considered as being at background levels according to OSPAR, although deep-core sediment in the Skagerrak shows a background of 9 mg·kg^{-1} dry weight <63µm.

Copper Concentrations in Blue Mussel

Temporal trends in the western Wadden Sea are absent over the period 1990-2007. The Elbe, North-Frisian and Danish areas show an irregular pattern (Figure 5.1.8). Copper levels in blue mussel are occasionally consistent with the increasing riverine input.

Mercury

QSR 2004

Reduction in Elbe mercury loads and concentration in 1994 was followed by a continued, but smaller decrease until 2002. Uniquely, the Weser water concentration of mercury seemed to increase with the river flow rate, indicating that Weser mercury input depended on the atmospheric wet deposition rate. Year-averaged mercury concentrations, derived from OSPAR flux data, are over 10 times higher in the Elbe, Weser and Ems, than in Lake IJssel and Eider. Atmospheric input to the Dutch Wadden Sea is about 2% of the total riverine input into that area.

In all subareas in 2000/2003, sediment concentrations were within the range of the provisional ecotoxicological assessment criterion for mercury by OSPAR. In most sub-areas the mercury levels

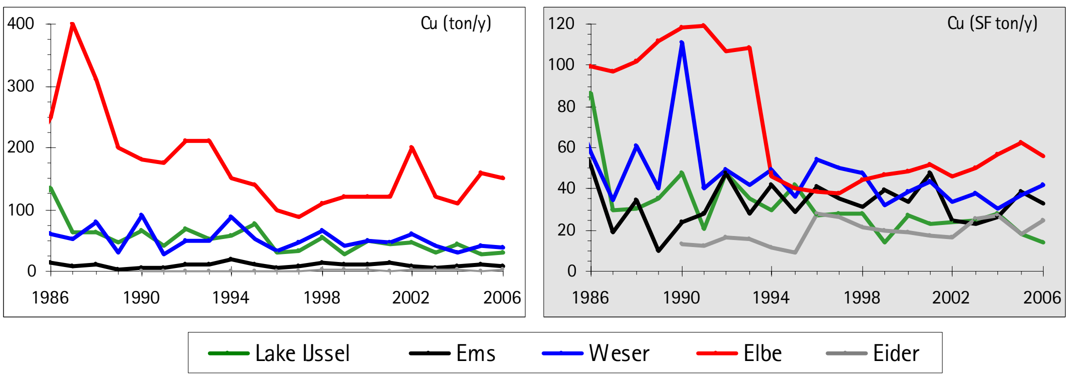


Figure 5.1.6
Left: riverine inputs of Copper (tonnes/ year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} m^3·y^{-1}, which is comparable with the average flow of the Weser. The major decrease occurred until 1994. The 2006 river Elbe water has concentrations which are a factor 4 higher than those of Lake IJssel, while Weser, Ems and Eider are intermediate.

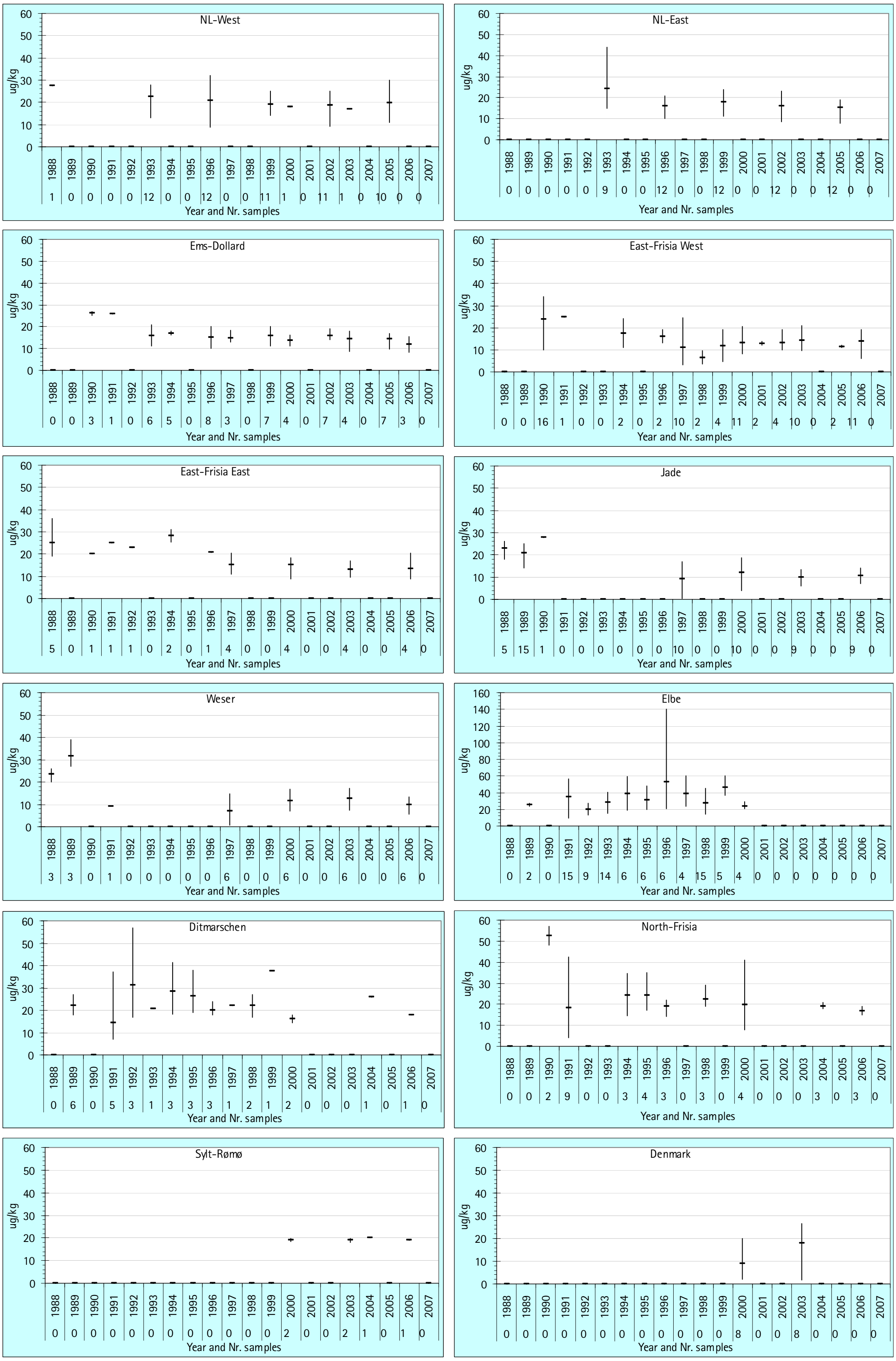
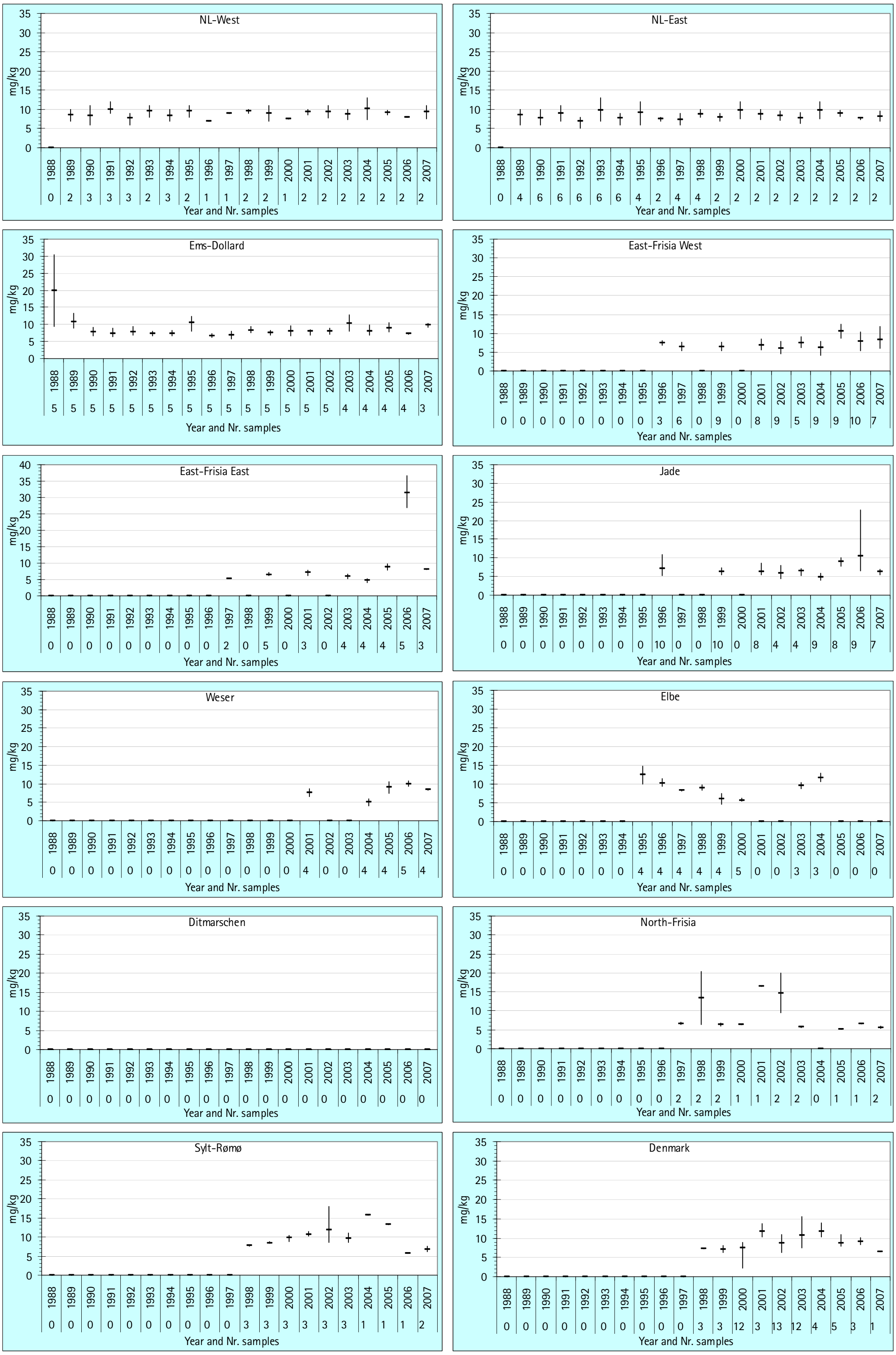


Figure 5.1.7: Copper concentrations ($mg \cdot kg^{-1}$ dry weight) in sediment (fraction <63 µm). OSPAR Background Assessment Criteria (BAC): 27 $mg \cdot kg^{-1}$ 5%Al (Source: OSPAR, 2009). Note: different scale for the Elbe.

Figure 5.1.8:
Copper concentrations (mg·kg-1 dry weight) in blue mussel (*Mytilus edulis*).



in blue mussels were higher than the proposed background by OSPAR.

Mercury Input

The drastic reduction in Elbe mercury loads and concentration in 1994 was followed by a constant, flow rate dependent input until 2006 (Figure 5.1.9). The Weser loads and concentrations peaked between 1991/1997 and 2000/2006. The Weser and Ems concentration of mercury increases with increasing river flow rate. Both rivers are known to follow wet deposition rate which enhances the (re)mobilisation of mercury. This may imply that the input source is predominantly land run-off or erosion.

Year-averaged mercury concentrations in 2006, derived from OSPAR input data, are 20-10 times higher in the Elbe and Weser respectively than in Ems, Lake IJssel and Eider.

Mercury Concentrations in Sediment

In Wadden Sea sediments, mercury leveled off to a basic level of 0.1 - 0.4 mg·kg^{-1} dry weight <63µm (Figure 5.1.10). Highest 2005/2006 levels are found in NL-West, East-Frisia East, Weser and Dithmarschen. The OSPAR BAC value (Table 5.1.3) is 0.07 mg·kg^{-1} 5%Al, which is very near 0.07 mg·kg^{-1} dry weight <63µm. Mercury can not be considered as being near background according to OSPAR as it exceeds this up to 5-fold. Deep-core sediment in the Skagerrak shows a background of 0.01 mg.kg^{-1} dry weight <63µm (HARBASINS project, 2008). Mercury exceeds the risk level (ERL) for food web accumulation (OSPAR, 2009) in all sub-areas.

Mercury Concentrations in Blue Mussel

No trend is apparent in the south-western areas, except that highs tend to fade out and concentrations range between 0.1 - 0.3 mg·kg^{-1} dry weight.

The initial reduction in the Elbe area between 1994 and 2000 to less than 0.1 mg·kg^{-1} dry weight is followed by a continued increase in 2003 and 2004 till 0.3 mg·kg^{-1} dry weight. This may tentatively be the aftermath of the 2002 Elbe flood, remobilizing mercury-contaminated sediments. No increase was measured in Elbe water (Figure 5.1.11).

In the Sylt-Rømø and Denmark areas, levels increased between 1998 and 2004 from ~0.2 till ~0.5 mg·kg^{-1} dry weight. Between 2005 and 2007 levels seemed to decrease again, to ~0.3 mg·kg^{-1} dry weight. The transport of Elbe-flood residual, contaminated, suspended sediment may be in play in these areas, but apparently it does not affect the North-Frisian area.

Mercury pressure in blue mussel is 2 - 3 times higher in the more contaminated Wadden Sea regions Ems-Dollard, East-Frisia West, Elbe (2004), Sylt-Rømø and Denmark. In these areas, maximum mercury levels were a factor 2 - 3 higher in 2006/2007 than the background assessment concentration of 0.14 mg·kg^{-1} dry weight (OSPAR, 2009; Table 5.1.3). Food consumption safety levels were not exceeded.

The WFD EQS of 0.1 mg·kg^{-1} dry weight (assuming 20% dry matter in blue mussel tissue) is exceeded in many regions.

Mercury Concentrations in Bird Eggs

Mercury contents in eggs of the common tern (Sterna hirundo) and oystercatcher (Haematopus ostralegus) are reported by Becker and Dittmann in chapter 5.2. Peak levels occur in the Elbe area, while trend peaks around 2003 also suggest a link to the 2002 Elbe flood. The recent relative increase of mercury in common tern and oystercatcher eggs at Griend (NL West) in 2005 and 2006 also occurs with relative maxima in flounder (2006) and blue mussel (2004). Only indirect food-web links exist between the dietes of blue mussel (phytoplankton), flounder, oystercatcher (all macrozoobenthos) and common tern (fish; later in the breeding season).

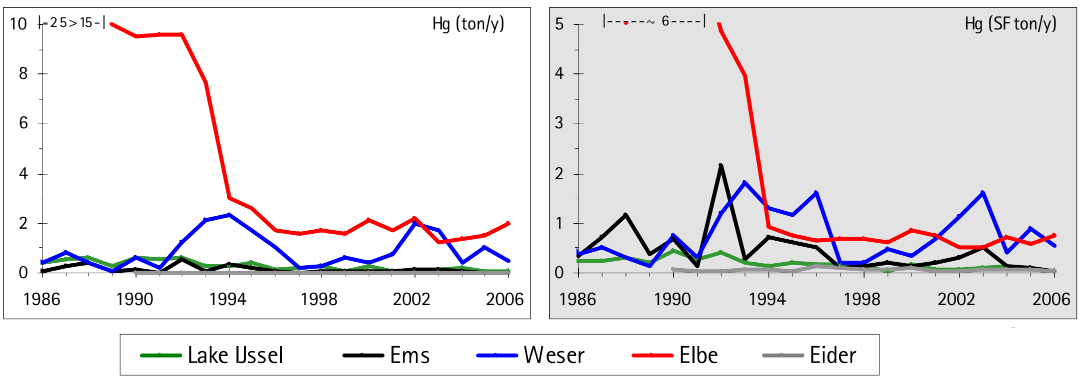
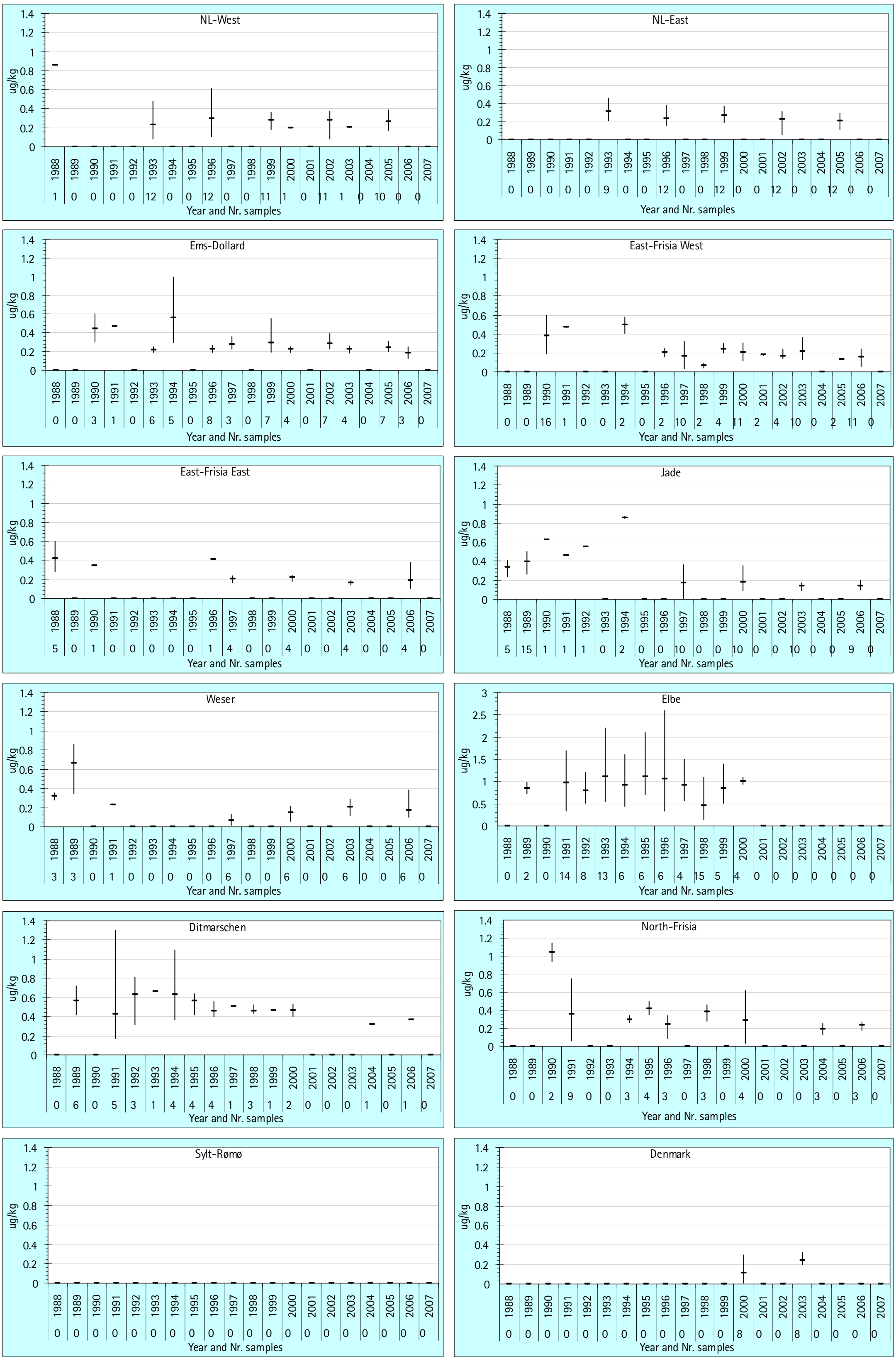


Figure 5.1.9: Left: Riverine inputs of Mercury (tonnes/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} m^3·y^{-1} (comparable to the average flow of the Weser). The major decrease occurred until 1996/1994. The rivers Elbe and Weser water concentrations (refer to right panel) are considerably higher, respectively factor 20 and 10, than of Lake IJssel, Eider and Ems.

Figure 5.1.10: Mercury concentrations (mg·kg⁻¹ dry weight) in sediment (fraction <63 µm). Note the different scale in the Elbe subarea. OSPAR Background Assessment Criteria (BAC): 0.07 mg·kg⁻¹ 5%Al (Source: OSPAR, 2009).



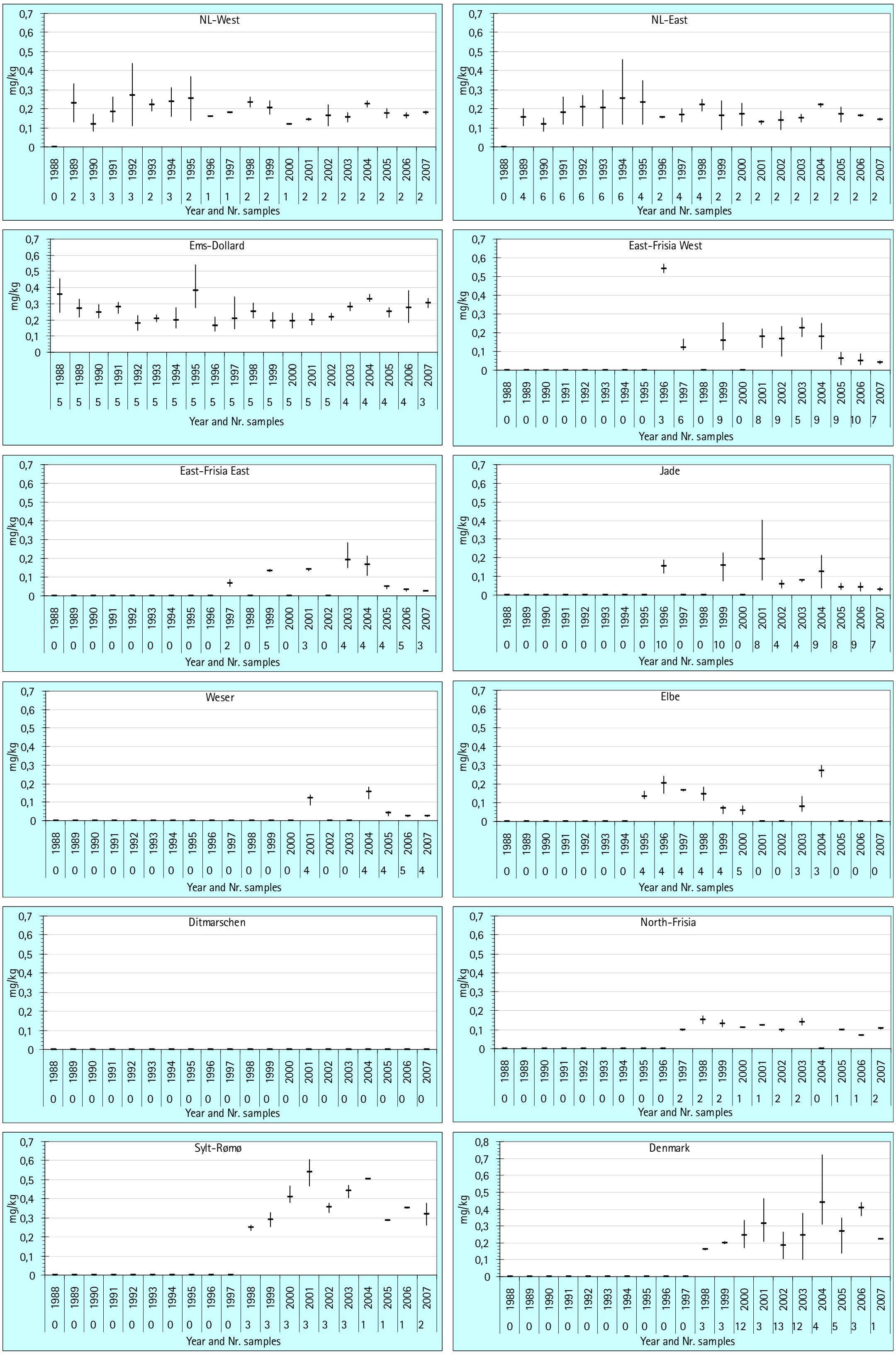


Figure 5.1.11: Mercury concentrations ($mg \cdot kg^{-1}$ dry weight) in blue mussel (*Mytilus edulis*). OSPAR Background (BAC) and Maximum Foodstuff Assessment Criteria: 0.14 and 2.5 $mg \cdot kg^{-1}$ dry weight respectively. The OSPAR Low Concentration (LC): 0.05 $mg \cdot kg^{-1}$ dry weight (Median level of regional medians in the OSPAR area) (Source: OSPAR, 2009).

Lead

QSR 2004

The drastic reduction in the Elbe input led to concentration stabilizing at the 1994 level, with a slight increase up to 2002. The load and concentration in the Weser were variable with a slight overall increase (1985 compared with 2002). An intermediate concentration and input peak (1991-1999) temporarily more than doubled concentration and input. Year-averaged concentrations of lead in Elbe and Weser water, derived from OSPAR flux data, were at the same level and 2-3 times higher than in Lake IJssel, Ems and Eider in 2002. Lead input and concentrations in Lake IJssel and the Ems did not show a significant trend.

Most sub-areas showed a downward trend of lead in sediment. Significant trends could not be determined due to large inter-sample variations; however both maxima and minima were decreasing. In the Dutch sub-areas, the lead content in blue mussels was 2-3 times higher than in the other sub-areas of the Wadden Sea.

Lead Input

Major decreases in riverine input occurred up to 1999 (Figure 5.1.12), whereas Lake IJssel input decreased further in 2005-2006. Elbe and Weser water concentrations of lead are 3-4 times the concentrations in the Ems, Eider and Lake IJssel.

Lead Concentrations in Sediment

Wadden Sea lead sediments leveled off to a basic level of 20 - 85 mg·kg^{-1} dry weight <63µm (Figure 5.1.13). Highest levels are found in the south-western regions, lowest in the northern Wadden Sea. The OSPAR BAC value (Table 5.1.3) is 38 mg·kg^{-1} 5%Al, which is very near 38 mg·kg^{-1} dry weight <63µm. Lead can be considered as being near background according to OSPAR in 2005/2006, except for the peak levels in most regions. However, deep-core sediment in the Skagerrak shows a background of 18 mg·kg^{-1} dry weight <63µm (HARBASINS project, 2008). Lead exceeds or equals the risk level (ERL) for food web accumulation (OSPAR, 2009) in all sub-areas.

Lead Concentrations in Blue Mussel

Lead concentrations accumulated in blue mussel are relatively high in Ems-Dollard and Dutch Wadden Sea areas, ranging 2.5 - 6 mg·kg^{-1} dry weight (Figure 5.1.14) The German and Danish areas range 0.6 - 1.6 mg·kg^{-1} dry weight. It is as yet unclear whether this large difference might be caused by monitoring or data irregularities. The length class averaged concentration relatively increased between 1997 and 2007 in all areas north and east of the Ems-Dollard. This may be due to north-bound residual transport of sediments and suspended matter.

The OSPAR BAC of 1.52 mg·kg^{-1} dry weight was exceeded in 2007 levels in the Ems-Dollard (factor 5) and NL-West/East (factor 2). In other Wadden Sea regions 2007 levels are near or below background concentration.

Zinc

QSR 2004

The reduction of zinc input into the Elbe ended by 1997. The Elbe and Weser had higher zinc concentrations, being four- to eightfold the concentration in Lake IJssel, Ems and Eider. Recent trends are that zinc is almost absent and mainly flow-related. The atmospheric input of zinc to the Wadden Sea is about 1% of the summed riverine input.

Zinc levels in sediment fraction <63µm were variable and no trend was detectable. Despite the variable concentrations of zinc in the blue mussel, a distinct upward trend could be discerned for one sub-area and to a lesser extent for another between 1989 and 1999. On the other hand two sub-areas showed a decrease in concentration between 1996 and 2002.

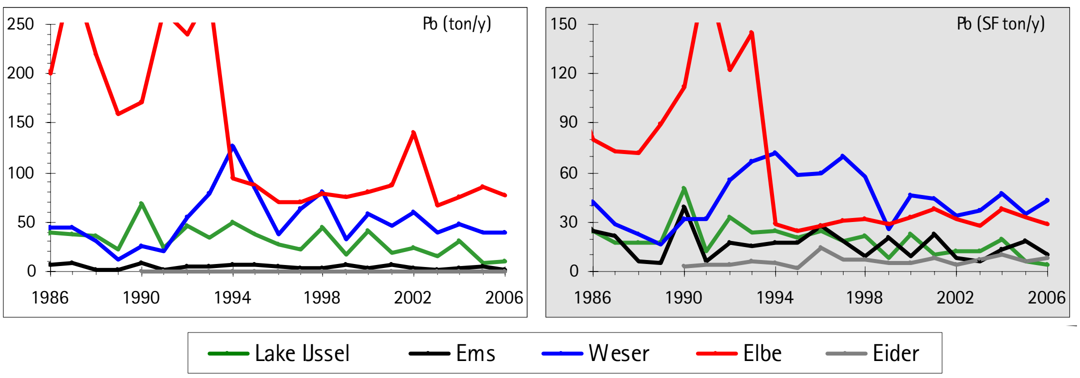


Figure 5.1.12: Left: Riverine input of Lead (tonnes/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} m^3·y^{-1} (comparable to the average flow of the Weser). The major decreases occurred until 1994 (Elbe) and 1999 (Weser). The rivers Elbe and Weser water concentrations are 3 – 4 fold those of Lake IJssel, Eider and Ems.

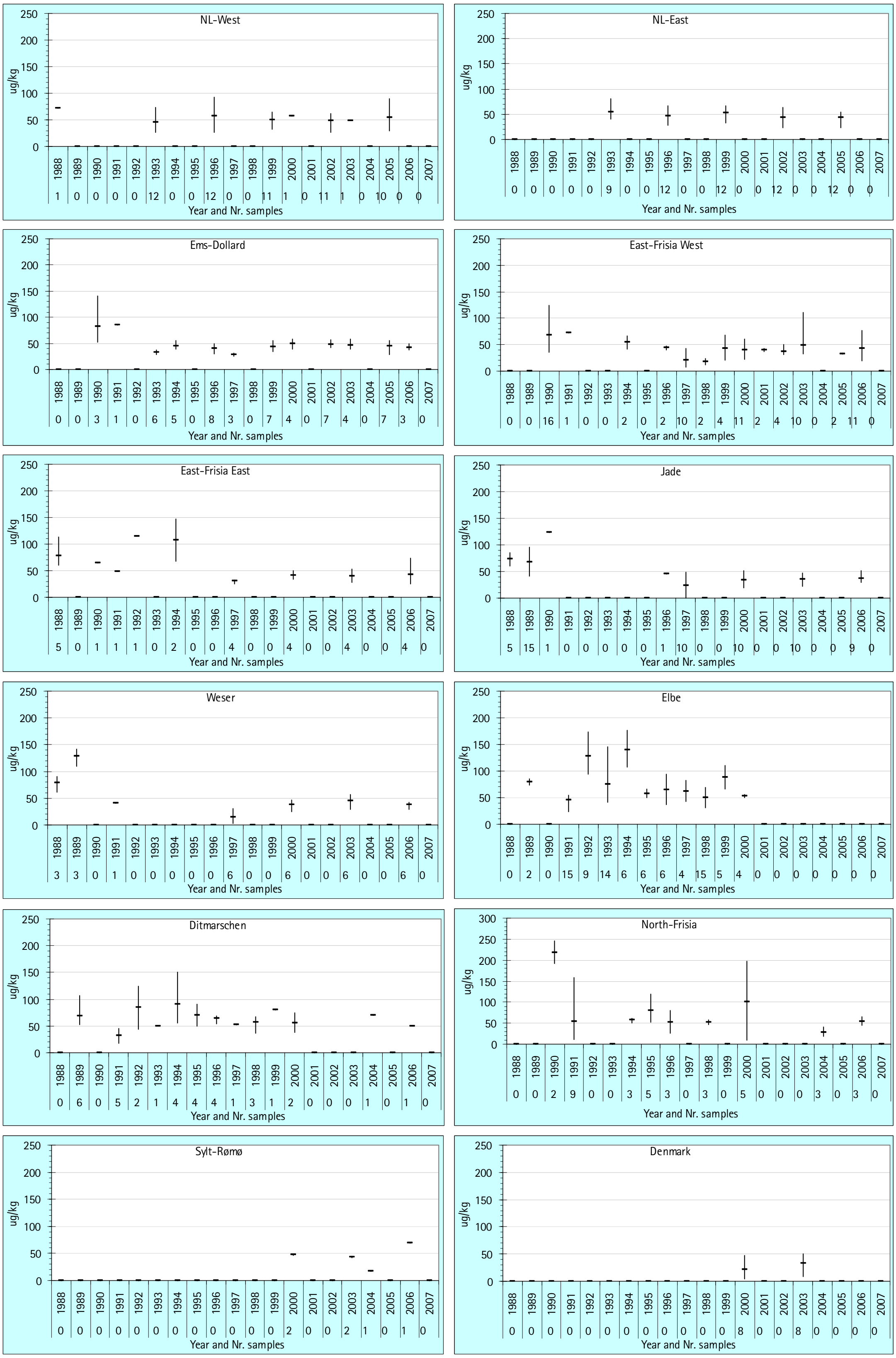


Figure 5.1.13: Lead concentrations ($mg\cdot kg^{-1}$ dry weight) in sediment (fraction <63 µm). OSPAR Background Assessment Criteria (BAC): 38 $mg\cdot kg^{-1}$ 5%Al (Source: OSPAR, 2009).

Figure 5.1.14: Lead concentrations (mg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*). OSPAR Background (BAC) and Environmental (EAC) Assessment Criteria: 1.5 and 8.5 mg·kg^{-1} dry weight respectively. The OSPAR Low Concentration (LC): 0.8 mg·kg^{-1} dry weight (Median level of regional medians in the OSPAR area) (Source: OSPAR, 2009).

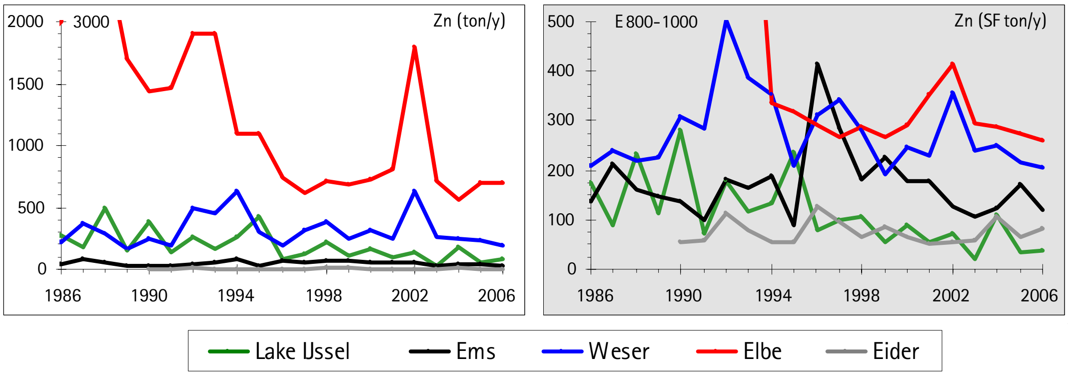


Figure 5.1.15 Left: Riverine inputs of Zinc (tonnes/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} $m^3 \cdot y^{-1}$ (comparable to the average flow of the Weser). The major decreases occurred until 1994 (Elbe) and 1999 (Weser). The rivers Elbe and Weser water concentrations are 3 – 4 fold those of Lake IJssel, Eider and Ems.

Zinc Input

The period of drastic reduction of zinc input to the Elbe ended by 1997 (Figure 5.1.15). The Elbe and Weser had the higher zinc concentrations, being 4- to 8- times the concentration in Lake IJssel, Ems and Eider. Recent trends show it to be almost absent and mainly flow-related. The 2002 flooding incident is evident in the Elbe input, but enhanced precipitations also increased the Weser input.

Zinc Concentrations in Sediment

Wadden Sea sediments zinc leveled off to a basic level of 50 - 250 $mg \cdot kg^{-1}$ dry weight <63µm (Figure 5.1.16). Highest levels are found in the north-eastern regions, lowest in the south-western Wadden Sea. The OSPAR BAC value (Table 5.1.3) is 122 $mg \cdot kg^{-1}$ 5%Al, which is very near 122 $mg \cdot kg^{-1}$ dry weight <63µm. Zinc can be considered as being near background according to OSPAR in 2005/2006 in the south-western regions, North-Frisia and Denmark. Exceedance is up to 2-fold in Dithmarschen, Sylt-Rømø and possibly Elbe (2003 latest data). Deep-core sediment in the Skagerrak shows a background of 61 $mg.kg^{-1}$ dry weight <63µm (HARBASINS project, 2008).

Zinc Concentrations in Blue Mussel

It is well known that blue mussels are capable of regulating their internal zinc concentrations through the formation of metallothioneines. Nevertheless, distinct regional differences and trends are apparent. Relatively high concentrations, increasing in the period 1994-2007 with 270% to over 160 $mg \cdot kg^{-1}$ dry weight, occur in the Ems-Dollard. All other Wadden Sea regions show no trend and zinc concentrations of 80-100 $mg \cdot kg^{-1}$ dry weight (Figure 5.1.17).

Nickel

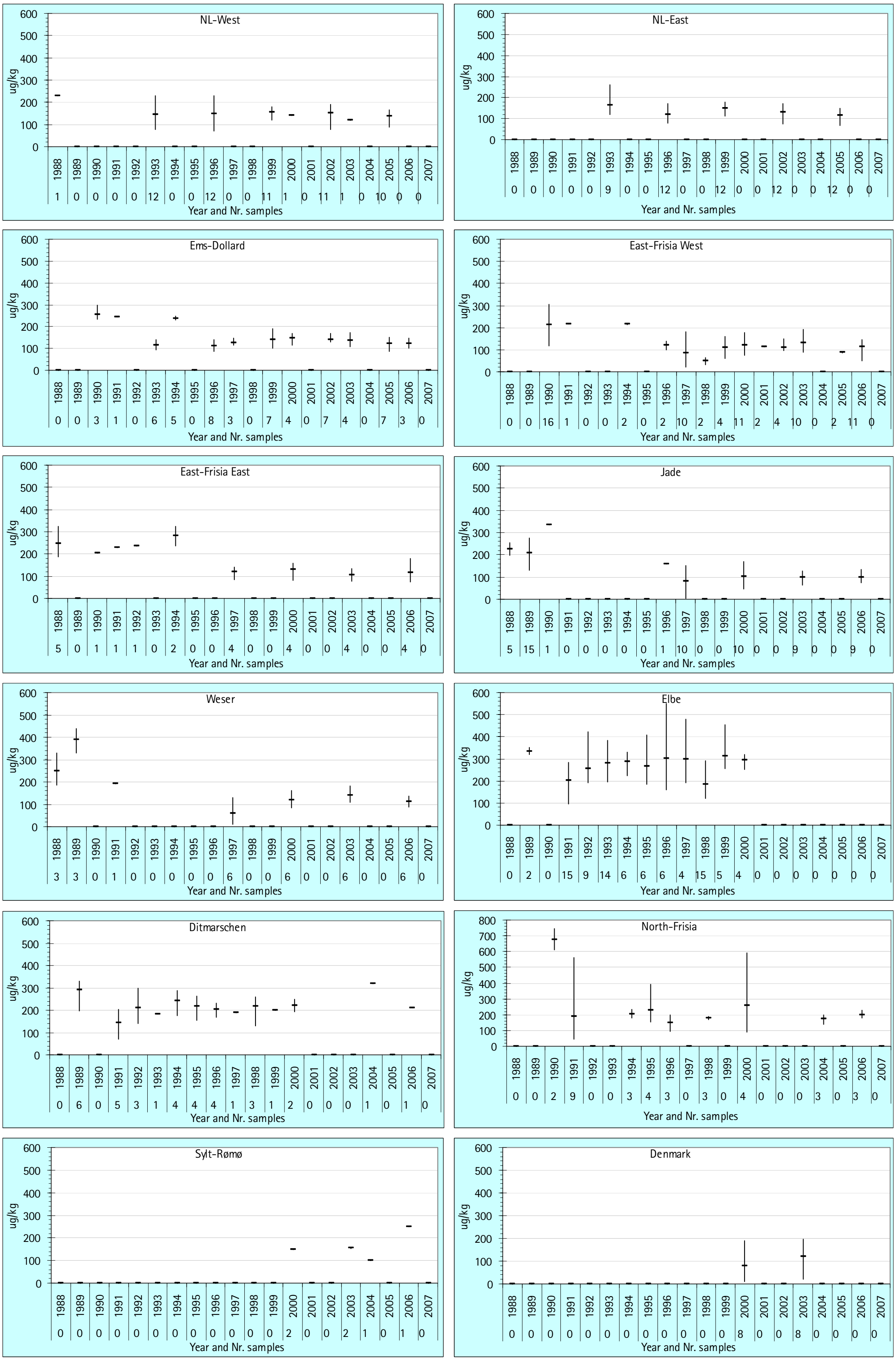
Nickel Concentrations in Sediment

Wadden Sea sediment nickel in the south-western regions is at a basic level of 20-30 $mg \cdot kg^{-1}$ dry weight <63µm (Figure 5.1.18). Higher levels are found in the north-eastern regions, 30-50 $mg \cdot kg^{-1}$ dry weight <63µm. The OSPAR BAC value (Table 5.1.3) is 36 $mg \cdot kg^{-1}$ 5%Al, which is very near 36 $mg \cdot kg^{-1}$ dry weight <63µm. Nickel can be considered as being near background according to OSPAR in the south-western regions. Nickel is above background in the north-eastern regions where an increasing trend is manifest as well. Deep-core sediment in the Skagerrak shows a background of 35 $mg.kg^{-1}$ dry weight <63µm (HARBASINS project, 2008).

Nickel Concentrations in Blue Mussel

Nickel concentrations in blue mussel in all Wadden Sea regions are at a basic level of 2-4 $mg \cdot kg^{-1}$ dry weight. Except the Ems-Dollard region, which is over twice as high, with an increasing trend over the period 1990-2007 (300-400% increase) up till 8 $mg \cdot kg^{-1}$ dry weight (Figure 5.1.19).

Figure 5.1.16: Zinc concentrations ($mg \cdot kg^{-1}$ dry weight) in sediment (fraction <63 µm). Note the different scale in the North-Frisia subarea. OSPAR Background Assessment Criteria (BAC): 122 $mg \cdot kg^{-1}$ 5%Al (Source: OSPAR, 2009).



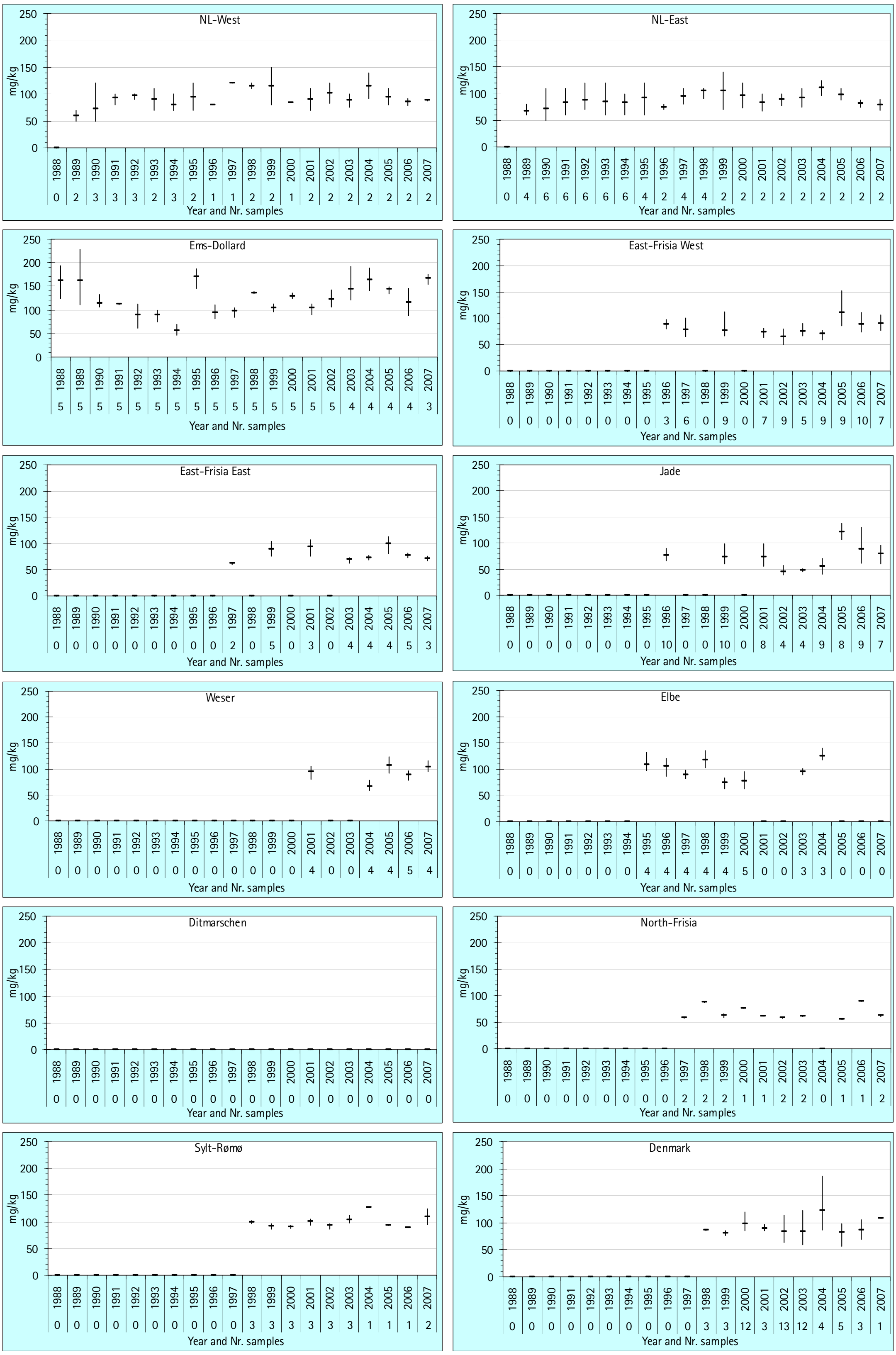
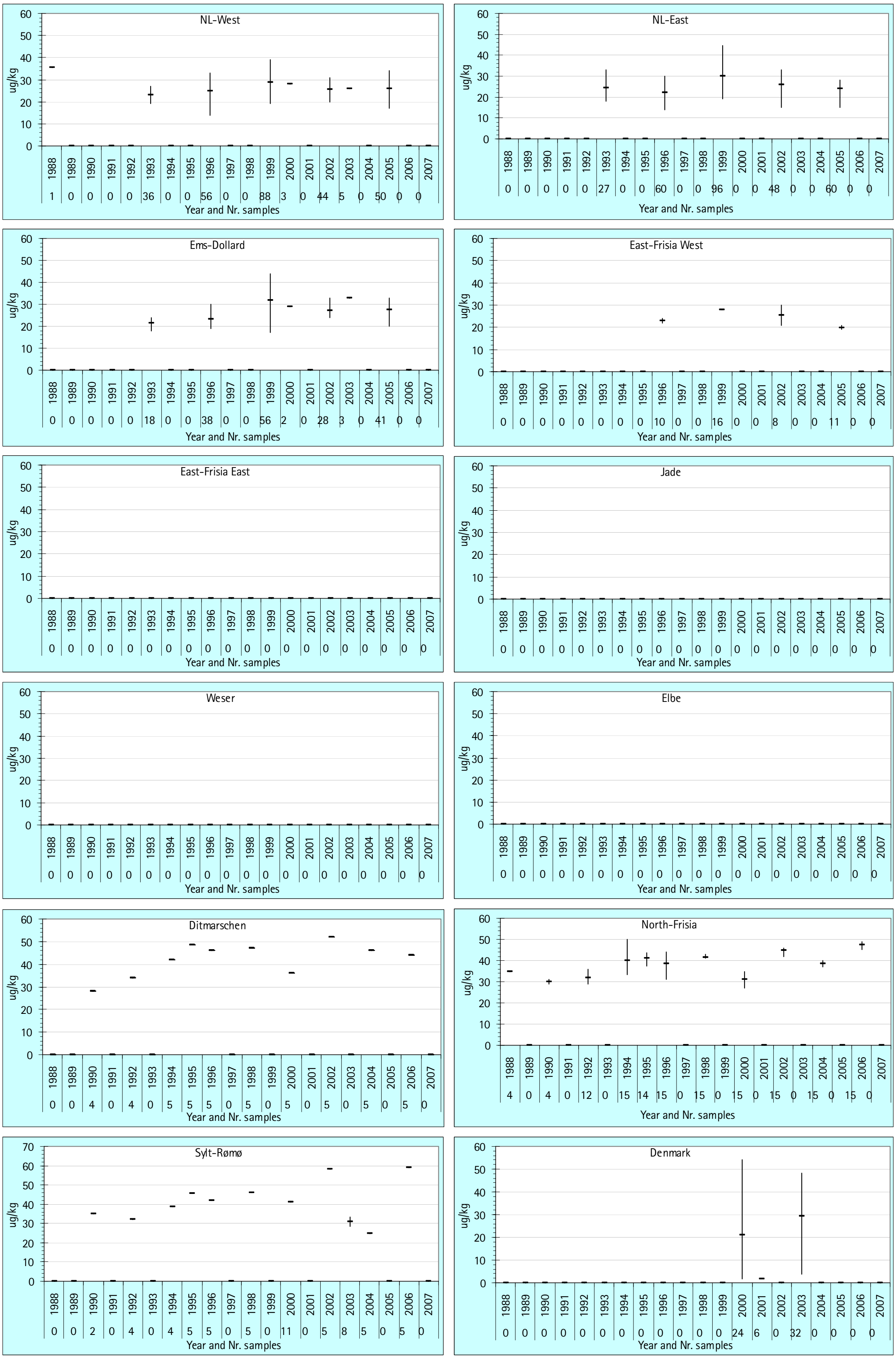


Figure 5.1.17: Zinc concentrations ($mg \cdot kg^{-1}$ dry weight) in blue mussel (*Mytilus edulis*).

Figure 5.1.18: Nickel concentrations (mg·kg^{-1} dry weight) in sediment (fraction <63 µm). OSPAR Background Assessment Criteria (BAC): 36 mg·kg^{-1} 5%Al (Source: OSPAR, 2009).



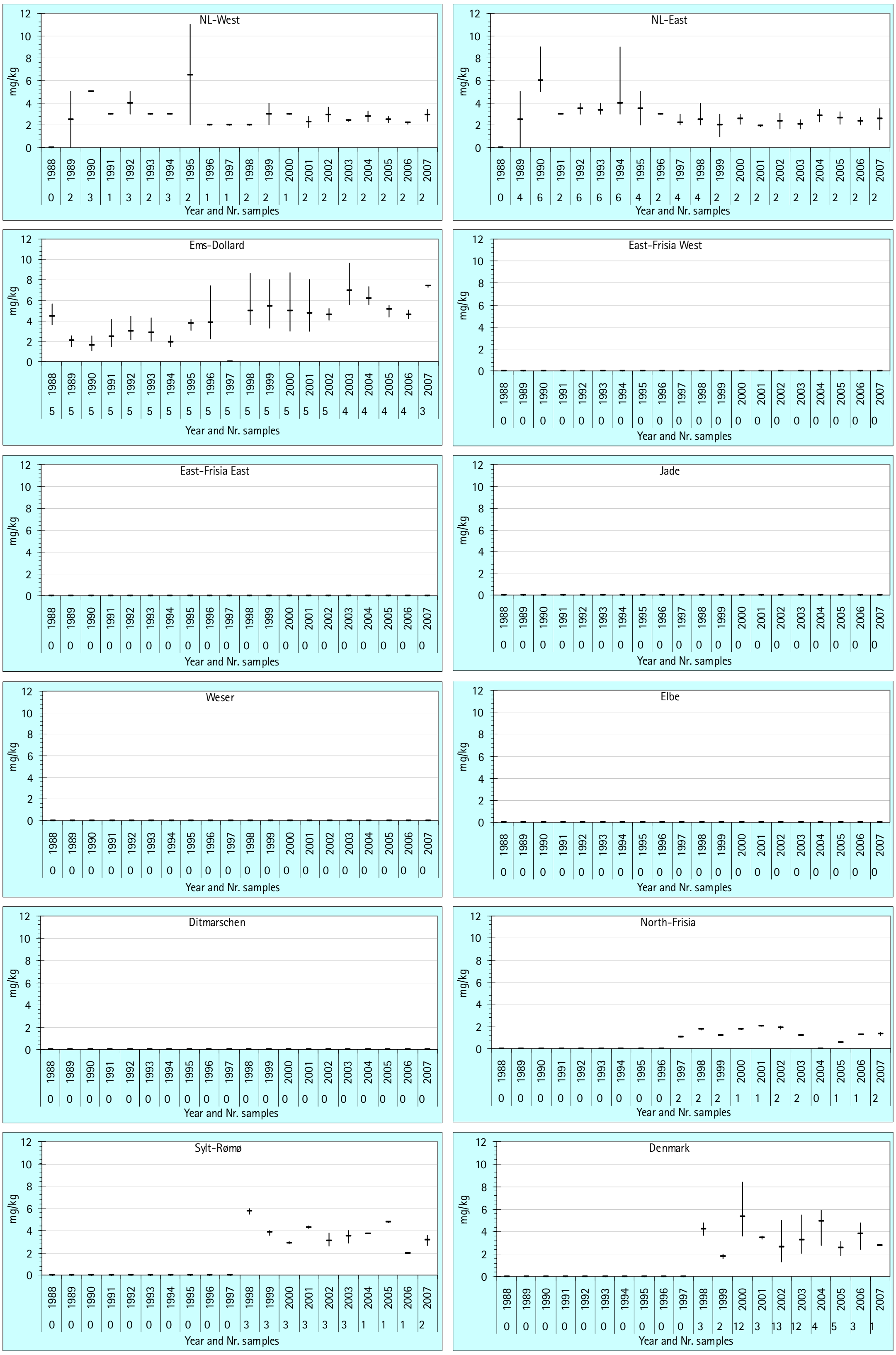


Figure 5.1.19: Nickel concentrations ($mg \cdot kg^{-1}$ dry weight) in blue mussel (*Mytilus edulis*).

Summary of metal trends and target evaluation

Major reductions in input and concentration of metals (Cd, Cu, Hg, Pb, Zn) in the Wadden Sea occurred mainly in the late 1980s until the 1990s.

The Elbe region is an exception, where levels of cadmium, mercury, lead and, only in blue mussels, zinc decreased in the period 1994-1998.

The Nickel concentrations in sediment tend to increase in the Eastern Wadden Sea. In the Ems-Dollard, Nickel concentrations in blue mussel increased by a factor of 4 between 1990 and 2007.

The OSPAR Background Assessment Criterion in sediments was exceeded by cadmium (factor 1-3), mercury (factor 1-5) and lead (factor 1-2), mainly in the south-western regions. Zinc and nickel exceeded the background in the north-eastern regions (factor 2). The targets are not fully met yet, but progressing over the past 5 years.

The OSPAR Background Assessment Criteria of blue mussel are exceeded for mercury (factor 2-3) and lead (factor 2-5) in some regions. The target for these metals has not been reached yet. The target for cadmium has been reached over the past 5 years.

The WFD EQS for mercury in biota is not exceeded in 2007 in any region, although some regions are at a less than factor 2 safety margin.

Climatic incidents, most obvious after the Elbe flood of 2002, show short-term effects on riverine load of contaminated re-suspended sediments and increase metal levels for cadmium, mercury and lead (in the case of the 2002 Elbe flood) in blue mussel in the coastal marine region. This effect could not be demonstrated in sediment by absence of data for this matrix.

Harmonization of methods to improve comparability and quality of information, as well as the quality and availability of data stored in the TMAP data units, requires further progress. Examination of the database by experts familiar with all aspects of monitoring as well as data analysis and standardization (data users) in cooperation with database experts is advised.

5.1.2.2 Organic micropollutants (PAHs)

PAH Data

The availability of data for polyaromatic hydrocarbons (PAHs) is limited to concentrations in sediments and blue mussels (*Mytilus edulis*) reported for Dutch and Danish Wadden Sea regions only. The sum 6 of Borneff PAH could not be completed for the Danish regions, because the PAH Benzo(b)fluor-anthene (BbF) and Benzo(k)fluor-anthene (BkF) were missing. The PAH Fluoranthene (Flu) was taken as the example PAH, which has amongst the highest PBT (persistency, bioaccumulative, toxic) properties of the 6 of Borneff PAHs (ref. QSR 2004). Where available, OSPAR 2010 QSR data have been used for additional analysis.

PAH Inputs

No data is available for riverine inputs, in part because PAHs dissolve poorly in water. Recent data on atmospheric deposition of PAHs were not available.

PAH Concentrations in Sediment

OSPAR sediment data indicate that the 6 of Borneff PAHs are mainly above the ERL. Exceedance is caused mainly by Benzo-ghi-Perylene and to a lesser extent Indeno[123-cd]pyrene (InP). InP concentration in a Skagerrak deep-core sediment, dated at ~1811, was valued at 79 $\mu g \cdot kg^{-1}$ dry weight 5%Al (HARBASINS project, 2008).

PAH Concentrations in Blue Mussel

Recent trends in the sum of 6 Borneff PAH (Fluoranthene, Benzo b- and k- Fluoranthene, Benzo-a-Pyrene, InP and Benzo-ghi-Perylene) concentrations are downward, while periodically fluctuating in all examined regions (Figure 5.1.20). The periodic amplitude and concentrations of 6 Borneff PAH in the Ems-Dollard is pronounced and might be related to dredging events. Fluoranthene (data not shown) was taken for OSPAR BAC and EAC check. 2007 concentrations in blue mussel are above OSPAR Background Assessment Concentration (BACFlu = 12.2 $\mu g \cdot kg^{-1}$ dry weight; OSPAR, 2009), a factor 2 in Sylt-Rømø and Denmark regions, a factor 4-5 in The Netherlands and Ems-Dollard regions. The Environmental Assessment Concentrations (EAC) is not exceeded anywhere (at ~ 50 - 60%).

The 6 of Borneff PAHs from the Jade area (wet weight concentrations) show a decreasing trend between 1990 and 2006 as well (Figure 5.1.21).

No recent data were available for NL-West and NL–East, none for the remaining areas.

Flu (data not shown) was taken for OSPAR BAC and EAC check. 2007 concentrations in blue mussel are above the OSPAR Background Assessment Concentration (BACFlu = 12.2 $\mu g \cdot kg^{-1}$ dry weight; OSPAR, 2009), a factor 2 in Sylt-Rømø and Denmark regions, a factor 4-5 in The Netherlands and Ems-Dollard regions. The Environmental Assessment Concentrations (EAC) is not exceeded anywhere (levels are at ~ 50 - 60 %) (Table 5.1.3).

Figure 5.1.20: Sum of 6 Borneff PAH concentrations (µg·kg^{-1} dry weight) in blue mussel (Mytilus edulis). No (recent) data were available for most regions. Ems-Dollard shows periodic fluctuations, where peak periods are enhanced compared to other regions. Note: 6 Borneff PAH: Fluoranthene (Flu), Benzo-a-Pyrene (BaP), Benzo-b-Fluoranthene (BbF), Benzo-k-Fluoranthene (BkF), Benz-ghi-Perylene (BghiPe), Indeno[1,2,3-cd]pyrene (InP).

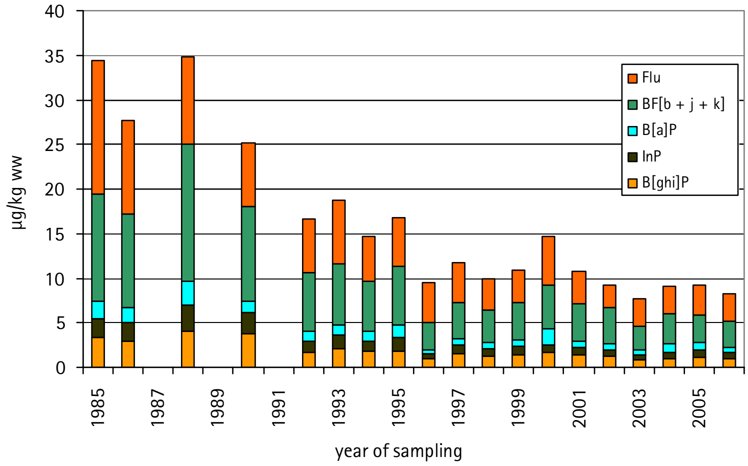


Figure 5.1.21: Borneff PAHs concentrations (µg·kg^{-1} wet weight) in blue mussel (*Mytilus edulis*) in Jade areas (Source: German Specimen Bank). Note: Fluoranthene (Flu), Benzo-a-Pyrene (BaP), Benzo-b-Fluoranthene (BbF), Benzo-k-Fluoranthene (BkF), Benz-ghi-Perylene (BghiPe), Indeno[1,2,3-cd]pyrene (InP).

Summary of Trends and Target Evaluation

The available data on natural organic micropollutants do not indicate a significant trend.

PAHs exceed the OSPAR background in all examined areas.

Target Assessment and Recommendations for Naturally Occurring Contaminants

Metals (Cd, Cu, Hg, Pb, Zn) in the period 1996-2007 remained at the same level as in 1995, decreasing further at a moderate rate both in input and concentrations. Elevated water discharges result in significantly higher river loads, like in 2002 in the Elbe and Weser. In decreasing order of importance, Elbe, Weser and Lake IJssel, are the three quantitatively most important contributors of metals to the Wadden Sea. As a rough estimate, calculated from the yearly averaged riverine input data, the WFD EQS would not be met for mercury in the Elbe and Weser (Table 5.1.2). Nickel data in riverine water were not available.

Sediment concentrations of mercury and lead exceeded OSPAR (2009) BAC background concentrations (Table 5.1.3). Additionally in the north-eastern regions, zinc and nickel exceed the background levels. WFD has no EQS for metals in sediment.

Concentrations of mercury and lead in blue mussels exceed the OSPAR (2009) BAC background values. The WFD EQS for mercury in biota was met in all Wadden Sea regions (Table 5.1.2).

In eggs of oystercatcher and common tern, mercury levels generally decreased further. Exceptions, however, are recently increasing mercury levels in the western Dutch Wadden Sea.

Polyaromatic hydrocarbons (PAHs) riverine input and atmospheric deposition are poorly known. Trends in concentrations in sediment, taken from the OSPAR QSR 2010, of the 6 of Borneff PAHs in blue mussel are not significant and often periodically fluctuating.

A summary of trends and most recent concentrations in monitored matrices is provided in Table 5.1.4 and 5.1.5.

5.1.2.3 Natural Micropollutants: Target Assessment and Recommendations

Target

- Background concentrations of natural micropollutants in water, sediment and indicator species.

Target evaluation

- For metals in sediment, the target was reached for copper in all sub-areas of the Wadden Sea. For cadmium, mercury, lead, and in the north-eastern regions zinc and nickel as well, the target has not yet been reached. Enhanced concentrations occur in areas influenced by climatically enhanced river discharges and concomitant (re)suspended sediment transport.
- For metals in blue mussels, the target for copper, zinc and nickel (except Ems-Dollard) has been reached. Cadmium, mercury and lead require more effort to reach the targets in most of the sub-areas.· Mercury in bird eggs does not yet meet target levels.
- Regarding the effects range level (ERL) (OSPAR, 2009), mercury and lead concentrations in the sediments pose a risk to the Wadden Sea ecosystem in the majority of sub-areas.
- Regarding the effects range level (ERL) (OSPAR, 2009), concentrations of cadmium, lead and mercury in Wadden Sea biota (blue mus-

sel) do not pose a risk to the ecosystem.
- Regarding the effects range level (ERL) (OSPAR, 2009), concentrations of PAHs in Wadden Sea biota (blue mussel) do not pose a risk to the ecosystem.

Conclusions

- For metals, riverine input is quantitatively the most important input to the Wadden Sea.
- Input of metals continued to decrease or remained unchanged. In some years enhanced loads were due to high river discharge; for organic micropollutants no trend was evident.
- The River Elbe flood of August 2002 may have caused short-term and regional increase of cadmium and mercury levels in bird eggs.
- The progress regarding harmonization of methodology of standardization, data quality control and database storage, allowing reliable comparison of data, both in JAMP or in TMAP, is not satisfactory and can be improved further.

Recommendations

- Continued attention to reduction of metal discharges through rivers debouching into the Wadden Sea.
- Continued effort to harmonize methods of analysis and of standardization, both being necessary to enable reliable comparisons at a geographical scale.
- Continued effort to improve data quality and communication between monitoring data analysts, database and monitoring experts is fundamental.
-

5.1.3 Xenobiotics

Introduction

Compounds which are not of biogenic or geochemical origin and usually solely man-made are referred to as 'xenobiotics', unknown to nature as we know it. A large variety of xenobiotics are on the 'List of chemicals for priority action' (OSPAR, 2007) and the 'Priority Substances' list of the Water Framework Directive. Most of the PBT criteria (persistent, bioaccumulative, and toxic) apply to classical xenobiotic compounds, making them environmentally hazardous. An important, newly emerging mode of 'toxicity' of many xenobiotics is disruption of internal physiological (endocrine and hormonal) and ecological (selection and competition) processes (refer to section 5.1.4). This group of compounds includes many medium-polar compounds like pharmaceuticals and herbicides.

Several groups of xenobiotics are being phased out in the temperate zone of the northern hemisphere. Their physico-chemical properties enable them to be carried large distances in the atmosphere, transporting concentrations of these compounds to the polar region (OSPAR, 2009).

Ecological Target

Concentrations of man-made substances resulting from zero discharges

QSR 2004

The 2004 QSR summarized that, in general, riverine inputs and concentrations in sediment and biota of most of the investigated xenobiotics had decreased, but that, for some compounds, elevated concentrations could still be observed, especially with regard to Tributyltin (TBT).

PCBs

QSR 2004

The Elbe input reduced drastically between 1988 and 1991. Relative peak concentrations of PCB input and in water concentration were highest in the Weser and Ems. PCB inputs have not been reported for Elbe since 2000 and Eider since 1997.

PCB concentrations in mussel show variable trends and non-explainable variations in some sub-areas. A significant decrease occurred in the Northern Wadden Sea between 1994 and 2003. In flounder liver, PCB concentrations show a consistent decrease between 1986 to about 1998 in subarea NL3; for other areas, no overall trend could be detected. Long term data for PCB concentrations in bird eggs show a big decrease until 1992, after which trends were not clear any more.

Ecological Relevance of PCBs

PCBs cause endocrine disrupting effects, are extremely persistent and biomagnify in the food web. PCBs are transported over large distances, causing relatively high levels in higher trophic levels like mammals and birds, in remote areas like the Nordic regions. As such PCBs are on the list of the Stockholm Convention. As a PBT compound group, PCBs are Chemicals of Priority Action (OSPAR, 2007).

PCB Input

Riverine inputs of PCBs, as reported by OSPAR, are shown in Figure 5.1.22. The Elbe shows the most remarkable decrease in PCB input between 1988 and 1999, at which time reporting ends.

The relatively dry year of 1996 rendered a peak in PCB input and water concentration, except for Lake IJssel. The peak concentration was highest in Ems and Weser. A correlation may exist between relative peaks in concentration and lower flows

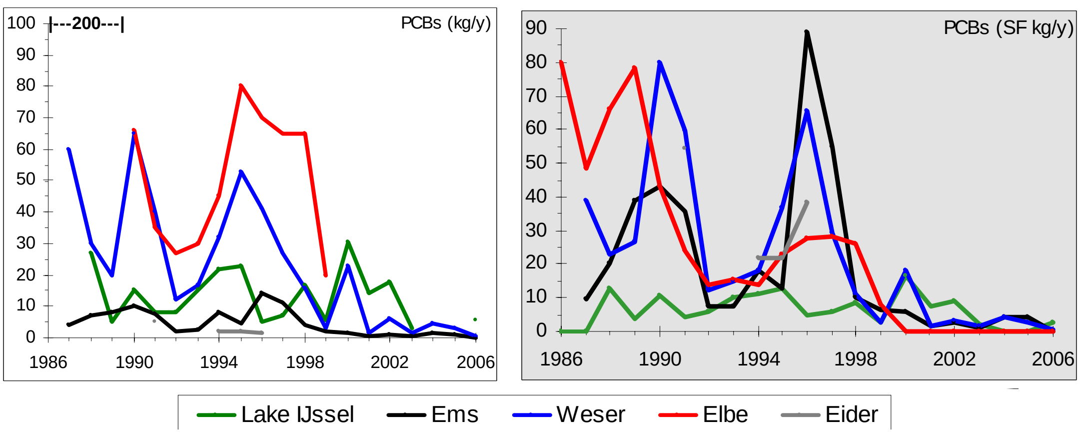


Figure 5.1.22: Left: Riverine inputs of PCBs (kg/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} $m^3 \cdot y^{-1}$ (comparable to the average flow of the Weser). The major decreases occurred until 1994 (Elbe) and 1999 (Weser). The rivers Elbe and Weser water concentrations are 3 – 4 fold those of Lake IJssel, Eider and Ems.

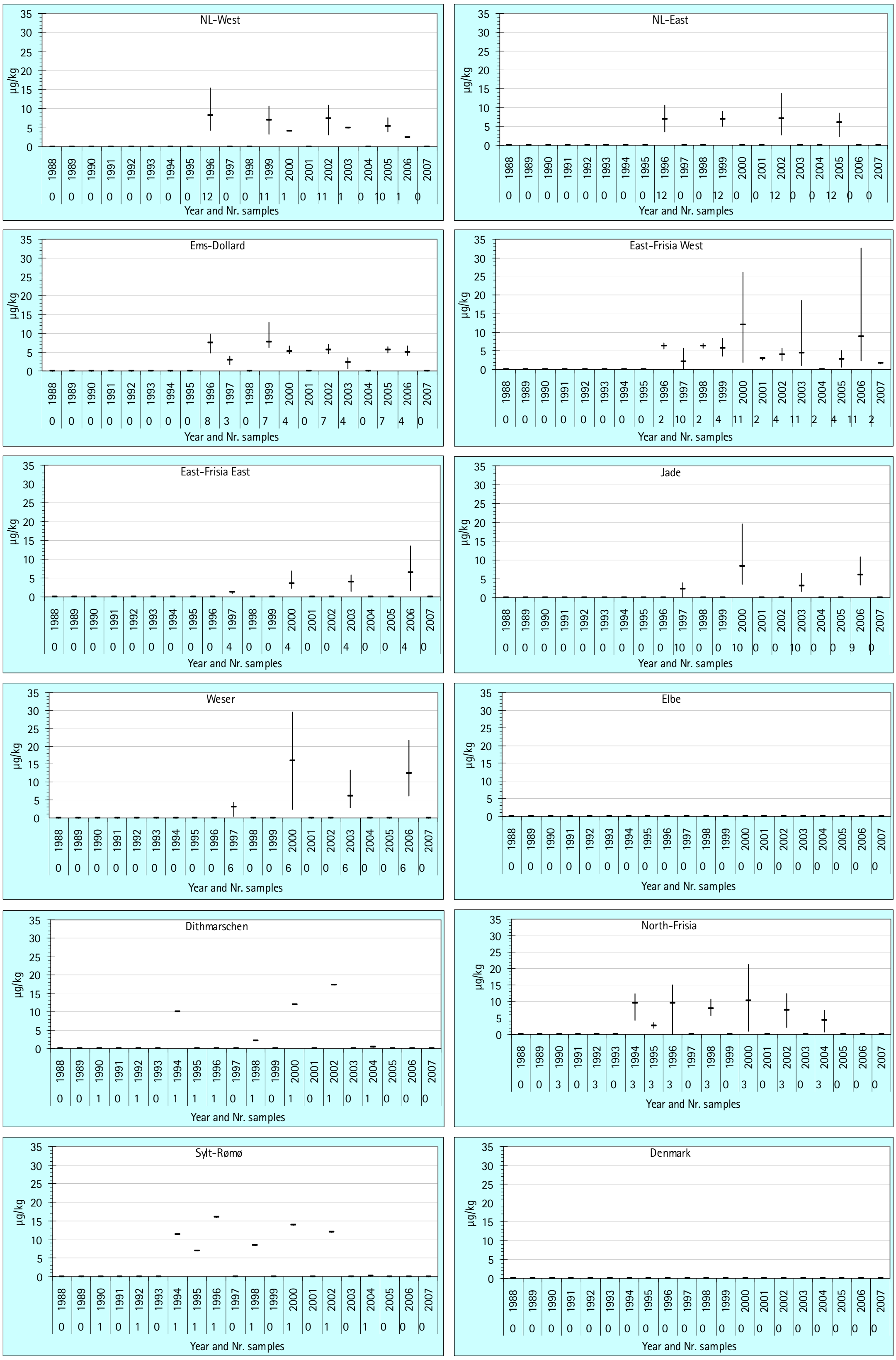


Figure 5.1.23 Sum PCB concentrations (µg·kg-1 2.5% TOC) in sediment. OSPAR Background Assessment Criteria (BAC): 0.97 µg·kg-1 dry weight. OSPAR Environmental Assessment Criterion (EAC): 65.2 µg·kg-1 dry weight (Source: OSPAR, 2009).

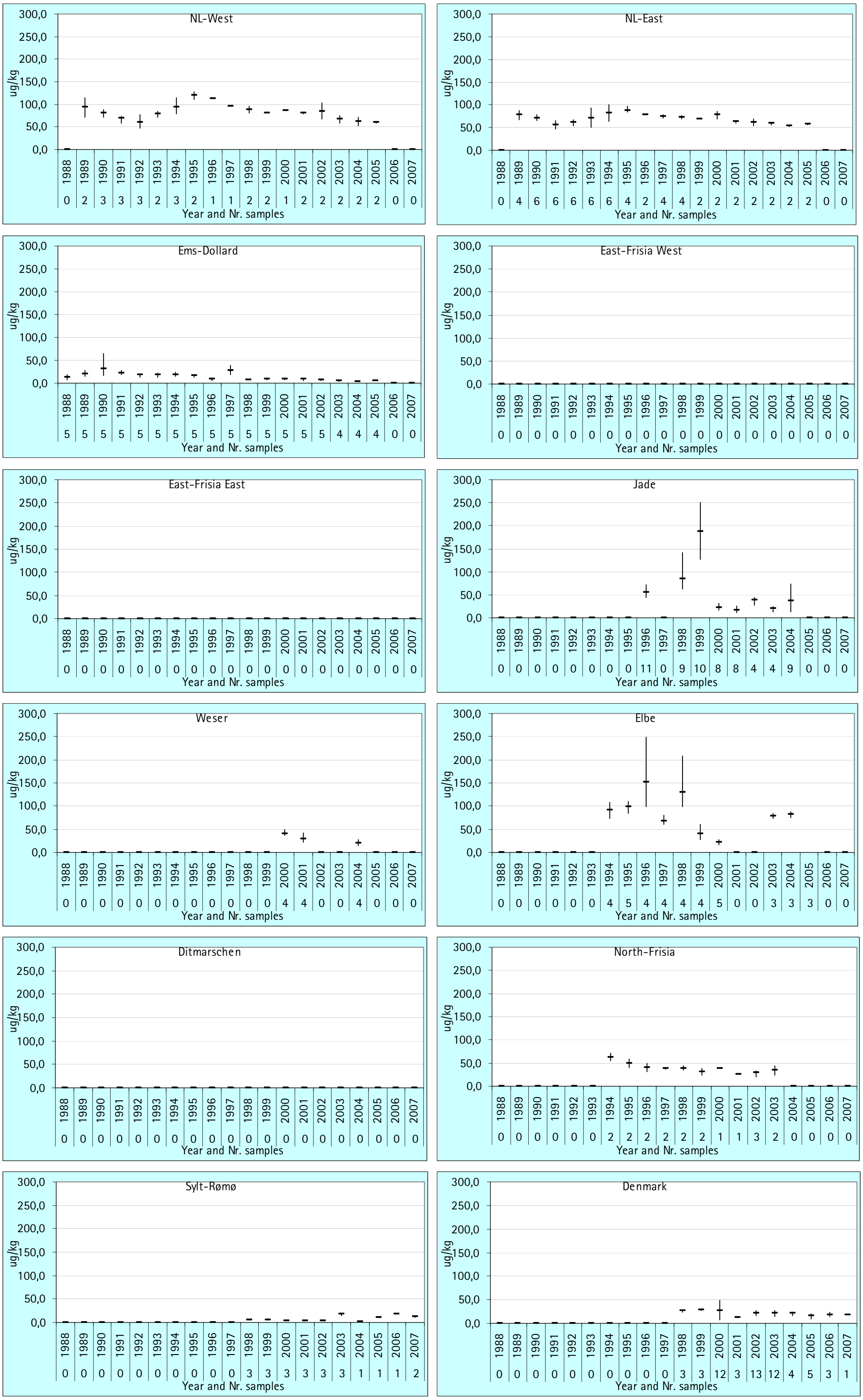


Figure 5.1.24: Sum PCB concentrations (µg·kg⁻¹ dry weight) in blue mussel (*Mytilus edulis*). OSPAR Background Assessment Criteria (BAC): 1.0 µg·kg⁻¹ dry weight. OSPAR Low Concentration (LC): 4.6 µg·kg-1 dry weight (median level of regional medians in the OSPAR area) (Source: OSPAR, 2009).

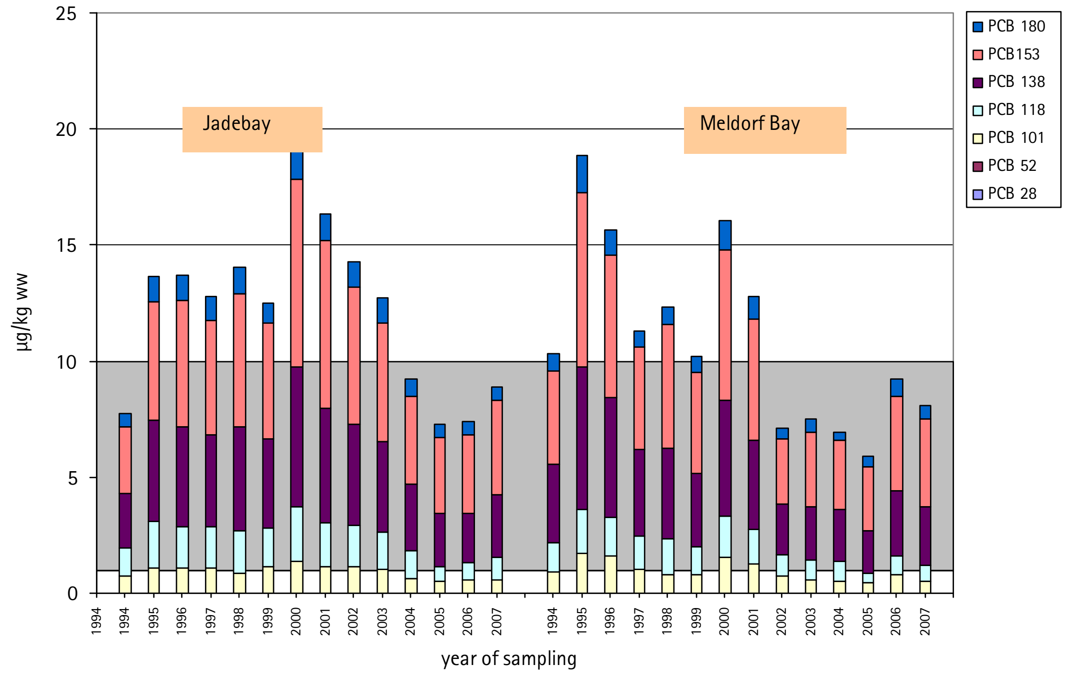


Figure 5.1.25: Summed PCBs concentrations (µg·kg^{-1} wet weight) in eelpout muscle (*Zoarces viviparous*) in Jade (left) and Dithmarschen (right) areas (Source: German Specimen Bank). Note: grey highlighted is the EAC Sum 7 PCB: 1–10 µg kg^{-1} wet weight.

for rivers with a direct run-off (cf. de Jong *et al.*, 1999). Only Lake IJssel has no direct run-off and a hydrology that favors settling of PCBs in its sediments.

Weser and Ems water concentrations were amongst the highest. In the absence of Elbe and Eider data, Lake IJssel shows highest input and concentrations in 2006.

Atmospheric input in deposition is monitored and modeled by OSPAR-CAMP, reporting a significant 74% reduction for the North Sea region between 1998 and 2006 (OSPAR, 2008).

PCB Concentrations in Sediment

The trend of PCBs in sediment is variable and characterised by no or slow decrease and occasionally peak levels. Concentrations are above the OSPAR Background Assessment Criterion but do not exceed the Environmental Assessment Criterion (Figure 5.1.23).

PCB Concentrations in Blue Mussel and Eelpout

The sum of 6 PCB (Σ6PCB) values show variable, but generally downward trends (Figure 5.1.24 and Figure 5.1.25 [wet weight]). In the northern Sylt-Rømø Wadden Sea an upward trend occurred between 1998 and 2007, but levels are still at the lower end. In the East-Frisia East region (Elbe river) an increase occurs in 2003/2004, which can be attributed to the 2002 flood incidence. Einsporn *et al.* (2004) noted enhanced toxic effects in blue mussel attributed to the Elbe flood.

Northern Wadden Sea levels are ~18 µg kg^{-1} dry weight, compared to ~80 µg kg^{-1} dry weight in Dutch, Jade and Elbe regions.

The concentrations of Σ6PCB in blue mussels exceed the OSPAR (2008) Background Assessment Criteria by a factor of 4 (Denmark) to 18 (Dutch, Jade and Elbe regions).

PCB Concentrations in Bird Eggs

The long-term data for concentrations of PCBs in eggs of the common tern (Sterna hirundo) and oystercatcher (Haematopus ostralegus) show a large decrease until 1993. After an unexplained peak in 1994, concentrations continued to decrease again.

The concentrations of Σ6PCB congeners in the eggs of the common tern are about twice those of the oystercatcher. This can be attributed to the higher trophic level, and therefore a higher biomagnification factor, of the common tern, as a fish eater, compared to the oystercatcher, as a benthos eater. Concentrations in the Ems-Dollard and Elbe areas are amongst the highest in both bird species and about twofold compared to the other locations. The concentrations in oystercatcher eggs compared to blue mussel (on a dry weight basis) are ~40 times higher, pointing at biomagnification.

Lindane (γ-HCH)

QSR 2004

Lindane input to the Elbe and water concentrations drastically increased between 1996 and 2000, followed by a similar dramatic decrease in 2001. Other rivers showed an ongoing decrease throughout the assessment period.

Most sub-areas show a downward trend in Lindane concentrations in the blue mussel. During recent years, Lindane concentrations in blue mussels were at the same level in all sub-areas of the Wadden Sea, while the contents of flounder liver have been rather variable. Concentrations of Lindane in bird eggs showed a steady decrease in most sub-areas.

Ecological Relevance of Lindane and other HCHs

Lindane is a neurotoxin and energy metabolism inhibitor. Crustaceans are especially sensitive; the inhibiting effect on carbohydrate metabolism affects winter survival. The compound is carcinogenic and active as an endocrine disrupter in birds and mammals. Metabolism is impeded by presence of chlorobenzenes. Lindane is still used in creams and shampoos to control lice and mites (scabies). Lindane was adopted as an Annex C chemical at the Stockholm Convention conference in May 2009, which includes regulation and long range transport of POPs (Persistent Organic Pollutants) from the tropics to the Nordic regions.

Lindane is one of the hexachlorocyclohexane isomers and most frequently used, but is in fact the one of least environmental concern. The β-HCH isomer, always occurring in the technical Lindane mixture, is considered a larger problem, since it was observed as the predominant environmental pathway of the relatively readily water-soluble HCHs (Deutch *et al.*, 2002) and was found more frequently in human blood and breast milk (WWF, 2004). The available data for the Wadden Sea do not show accumulation of HCH isomers other than Lindane in blue mussels and flounder liver.

Lindane Input

The Lindane input and water concentrations generally decrease in all rivers in the period 1986-2006 (Figure 5.1.26).

Lindane Concentrations in Blue Mussel and Eelpout

Most sub-areas of the Wadden Sea show a downward trend in blue mussel (Figure 5.1.27) and eelpout muscle tissue (Figure 5.1.28; wet weight). A 97% reduction occurred between 1988 and 2005 in the Ems-Dollard area, though more recently they slightly increased.

Anomalously high concentrations were observed in the Jade and Weser areas. 2004 levels are 10-40 times higher than in Elbe and Ems-Dollard areas respectively. We have no explanation for this phenomenon.

In the Elbe area, concentrations in blue mussel increased between 2002 and 2004, which is reflected in the upward trend in oystercatcher eggs at Trischen (Elbe area). This might be related to the Elbe flood of 2002 and related to transport of Lindane contaminated sediments from areas like Bitterfeld (Joziasse *et al.*, 2007).

Lindane Concentrations in Bird Eggs

Between 1999/2000 and 2008, concentrations of Lindane in eggs of the common tern and oystercatcher decreased in most sub-areas of the Wadden Sea, except the Elbe (Hullen, Neufelderkoog, Trischen) area.

An intermediate peak appeared in the Elbe area 2004/2005, consistent with enhanced levels in blue mussel. The same picture occurs with other organochlorines, suggesting that the source of the increased Lindane, DDT and HCB originates from downstream transported sediments, remobilized during the 2002 Elbe flood. This would imply a ~2 year lag between the upstream incident and the

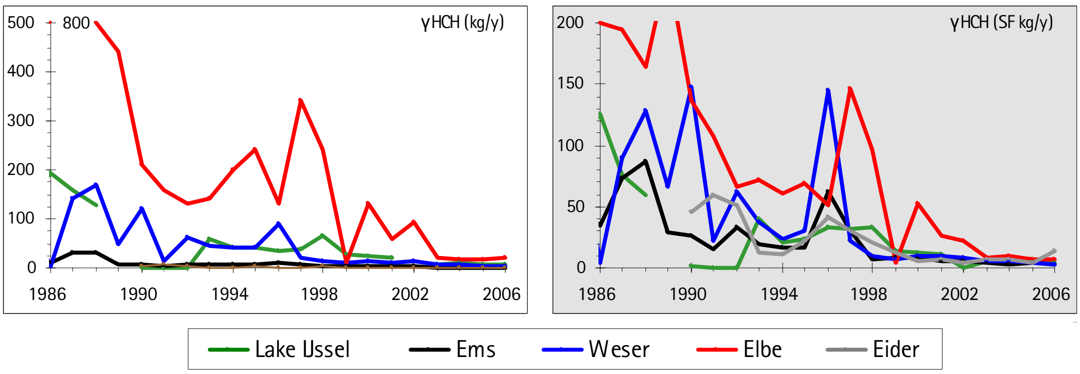


Figure 5.1.26 Left: Riverine inputs of Lindane (γ-Hexachlorocyclohexane, γHCH) (kg/year). Right: Corrected for flow differences to a standardized flow (SF) of 10^{10} $m^3 \cdot y^{-1}$ (comparable to the average flow of the Weser). The downward trend continues till 2003 (Elbe).

Figure 5.1.27: Lindane (γ-Hexachlorocyclohexane, γHCH) concentrations (µg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*). Please note the deviating y-scale in areas East-Frisia West and East, Jade and Weser. The OSPAR (2010) Background (BAC) and Environmental (EAC) Assessment Criteria are resp. 0.97 and 1.45 µg·kg^{-1} dry weight.

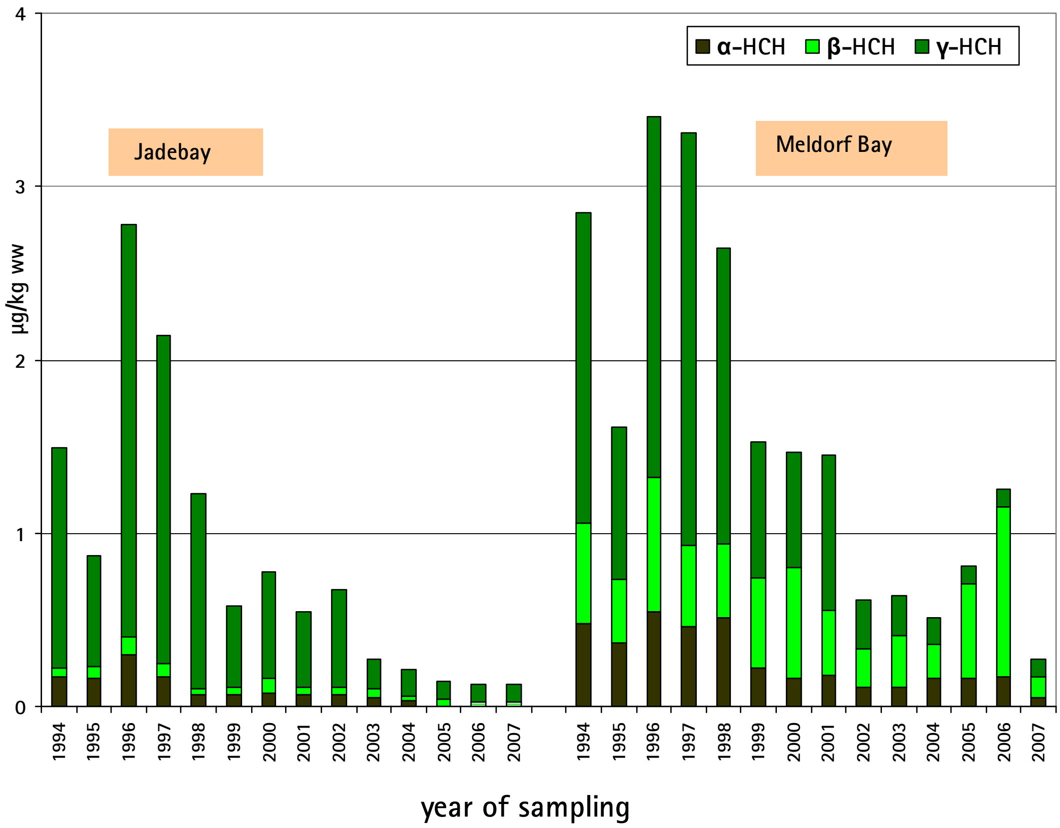


Figure 5.1.28: HCHs concentrations (µg·kg^{-1} wet weight) in eelpout (*Zoarces viviparous*) in Jade (left) and Dithmarschen (right) areas (Source: German Specimen Bank).

occurrence in biota of the estuarine and coastal waters. The transfer in the food web is direct, where, in oystercatcher, it is known that contaminants are directly transferred from the mothers' food into the eggs (Wendeln, 2000).

The 2008 geographical distribution of Lindane concentrations is slightly higher in Common Tern eggs in the eastern Wadden Sea (Elbe and Dithmarschen areas).

DDT, DDD, DDE (DDTs)

Ecological Relevance of DDTs

DDT (Dichloro-Diphenyl-Trichloroethane), and its metabolites DDD (Dichloro-Diphenyl-Dichloro-Ethane) and DDE (Dichloro-Diphenyl-dichloro-Ethylene), are persistent, biomagnifying chemicals. They cause endocrine disruption in birds and mammals and are neurotoxins (a.o. to insects) by cholinesterase inhibition. DDT is still used in malaria dominated areas today.

DDT is regulated under the Stockholm convention, which includes long range transport of POPs (Persistent Organic Pollutants) from the tropics to the Nordic regions.

DDTs Input

Atmospheric transport and deposition are an important source of DDTs in the temperate and Nordic latitudes. Dichlorodiphenyldichloroethylene (DDE), as the end product of DTT breakdown, primarily accumulates in the environment at higher trophic levels such as in humans (Polder *et al.*, 2002; WWF, 2004). The DDT/DDE ratio in humans was typically around 0.14 and is decreasing, indicating a reduced DDT input in the environment.

DDTs Concentrations in Blue Mussel and Eelpout

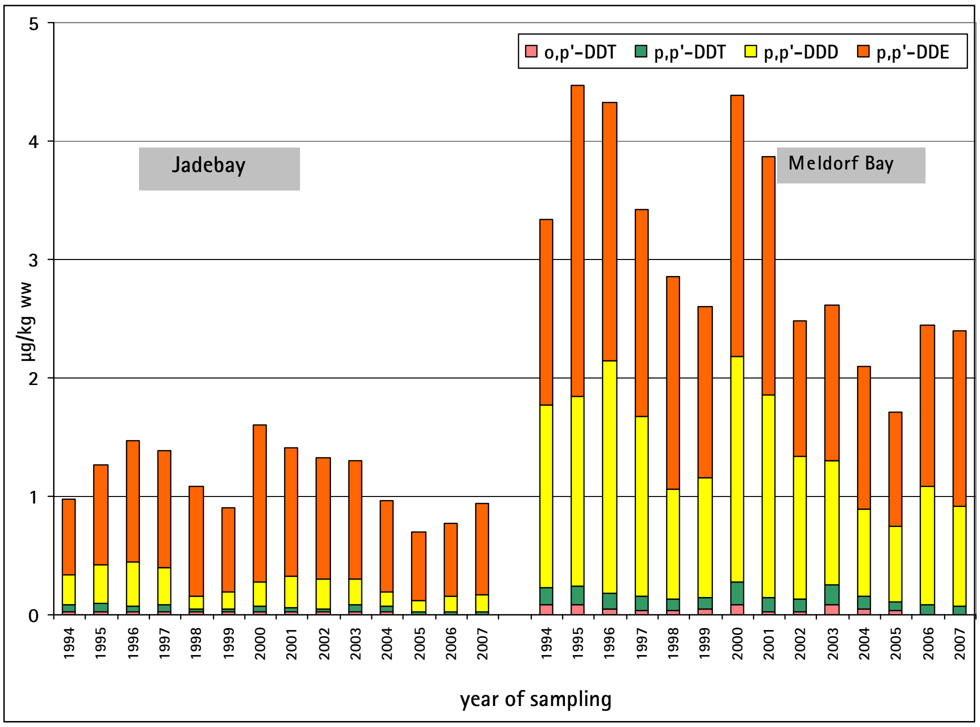
In blue mussel, concentrations of DDT (not shown), DDD (Figure 5.1.29), and to a lesser extent also of DDE (not shown), decreased between 1988 and 2007. The reduction in the Ems-Dollard area was 85% in this period. Sum of DDTs in eelpout muscle tissue shows a downward trend as well in the Jade and Dithmarschen regions (Figure 5.1.30).

DDD and DDE levels are typically twice as high as the DDT. ΣDDTs (sum of DDT, DDD, DDE) is relatively high in Ems-Dollard and Elbe regions.

The increase in DDD in the Elbe region between 2003 and 2005 is probably caused by the Elbe flood of 2002. This is in accordance with the observed increase of concentrations of DDD and DDE in Elbe suspended matter in August 2002 (CWSS, 2002) and the behavior of Lindane. Such an increase was however less conspicuous in eelpout muscle tissue in the Ditmarschen region (Figure 5.1.29).

Figure 5.1.29: DDD (pp') (pp'-Dichloro-Diphenyl-Dichloroethane) concentrations (µg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*).

Figure 5.1.30: DDTs concentrations (µg·kg^{-1} wet weight) in eelpout (*Zoarces viviparous*) in Jade (left) and Dithmarschen (right) areas (Source: German Specimen Bank).



DDTs Concentrations in Bird Eggs

Between 1998 and 2008, concentrations of (sum of) DDTs in eggs of the common tern and oystercatcher decreased in most sub-areas of the Wadden Sea, except the Ems-Dollard (Delfzijl) area, where a positive trend occurs.

Intermediate peaks appear in the Elbe area in several years. The peak of 2004, while lower than the one of 2007, is consistent with enhanced levels in blue mussel. As mentioned, the same picture occurs with other organochlorines and originates from downstream transported sediments, remobilized during the 2002 Elbe flood. This would imply a ~2 year lag between the upstream incident and the occurrence in biota of the estuarine and coastal waters. The transfer in the food web is direct, where it is known that in oystercatcher, contaminants are directly transferred from the mothers' food into the eggs (Wendeln, 2000).

In 2008, DDT concentrations are highest in common tern eggs in the Elbe area (factor 4-10 compared to other areas) and relatively high in the Ems-Dollard area (factor 3 compared to other areas).

Hexachlorobenzene (HCB)

QSR 2004

HCB was widely used as pesticide and in the synthesis processes until it was banned in most applications in 1988. It is highly persistent and bioaccumulative and levels found in human blood are amongst the highest of organochlorines. Low levels in the Danish Wadden Sea, but showing large variations.

Average HCB content in sediments decreased in the Dutch parts of the Wadden Sea. Though not significant, it constitutes a 50% reduction. HCB levels in blue mussels are higher in the Lower Saxon parts and in Schleswig-Holstein, as compared to other sub-areas in the Wadden Sea. This may be related to residual south to north transport along the North Sea coast. HCB concentrations in oystercatcher eggs at Delfzijl showed a decrease of approximately 80% between 2001 and 2003.

Ecological Relevance of HCB

HCB is predominantly hazardous because of its bioaccumulative and persistent properties. The toxicity of HCB consists of interference with the immune system and increased incidence of tumors and functional disorder in metabolically active organs like thyroid, liver and kidney. HCB is toxic from algae up to mammals (Chaufan *et al.*, 2006; Eggesbø *et al.*, 2009).

As a volatile POP (Persistent Organic Pollutant), HCB tends to migrate to the Nordic regions by long range atmospheric transport and is banned globally under the Stockholm Convention.

HCB (Hexachlorobenzene) was widely used as a pesticide and in synthesis processes until it was banned in most open applications in 1988. HCB, however, is still a by-product of the production of chlorinated organic solvents, though strictly

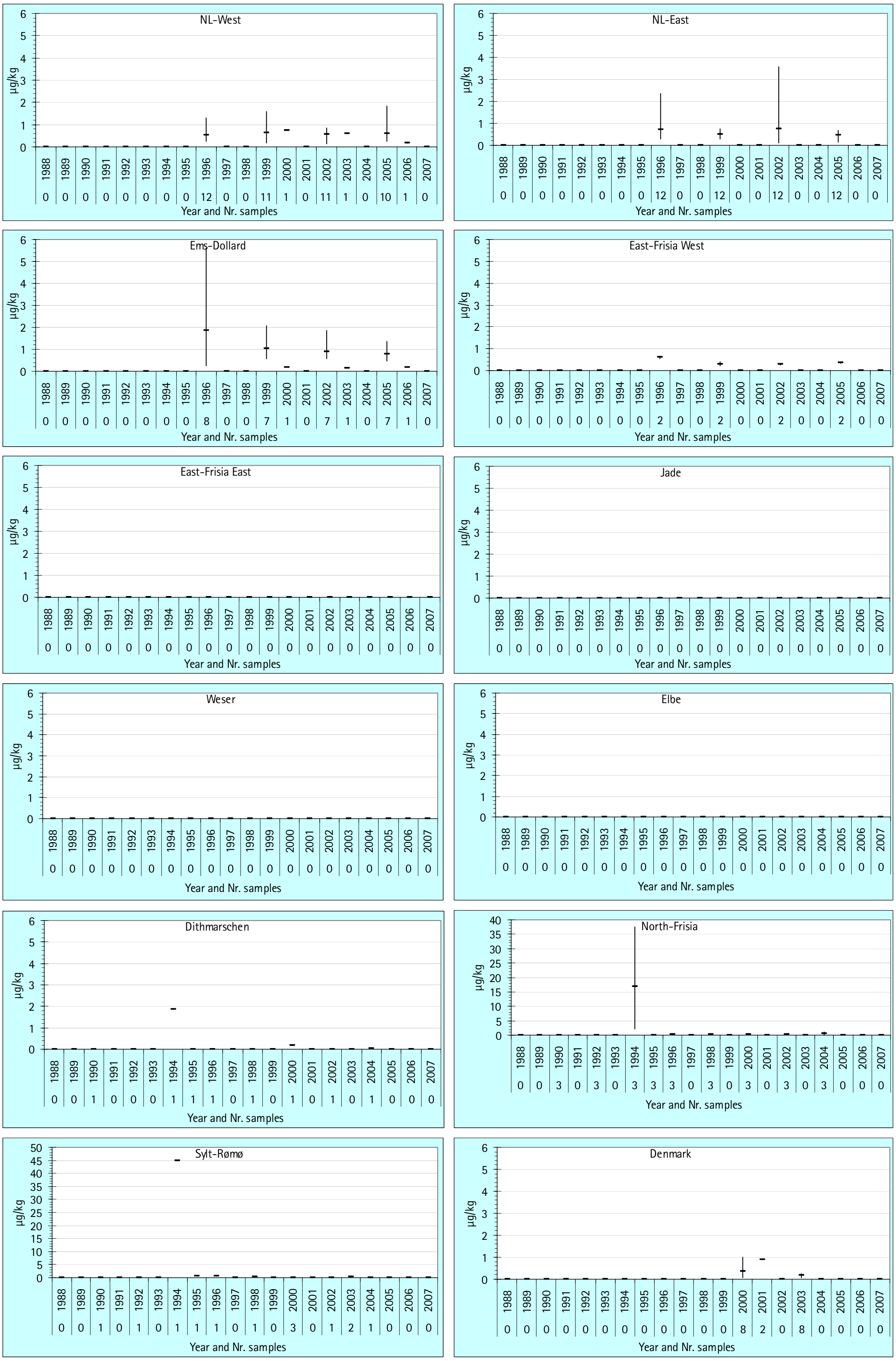
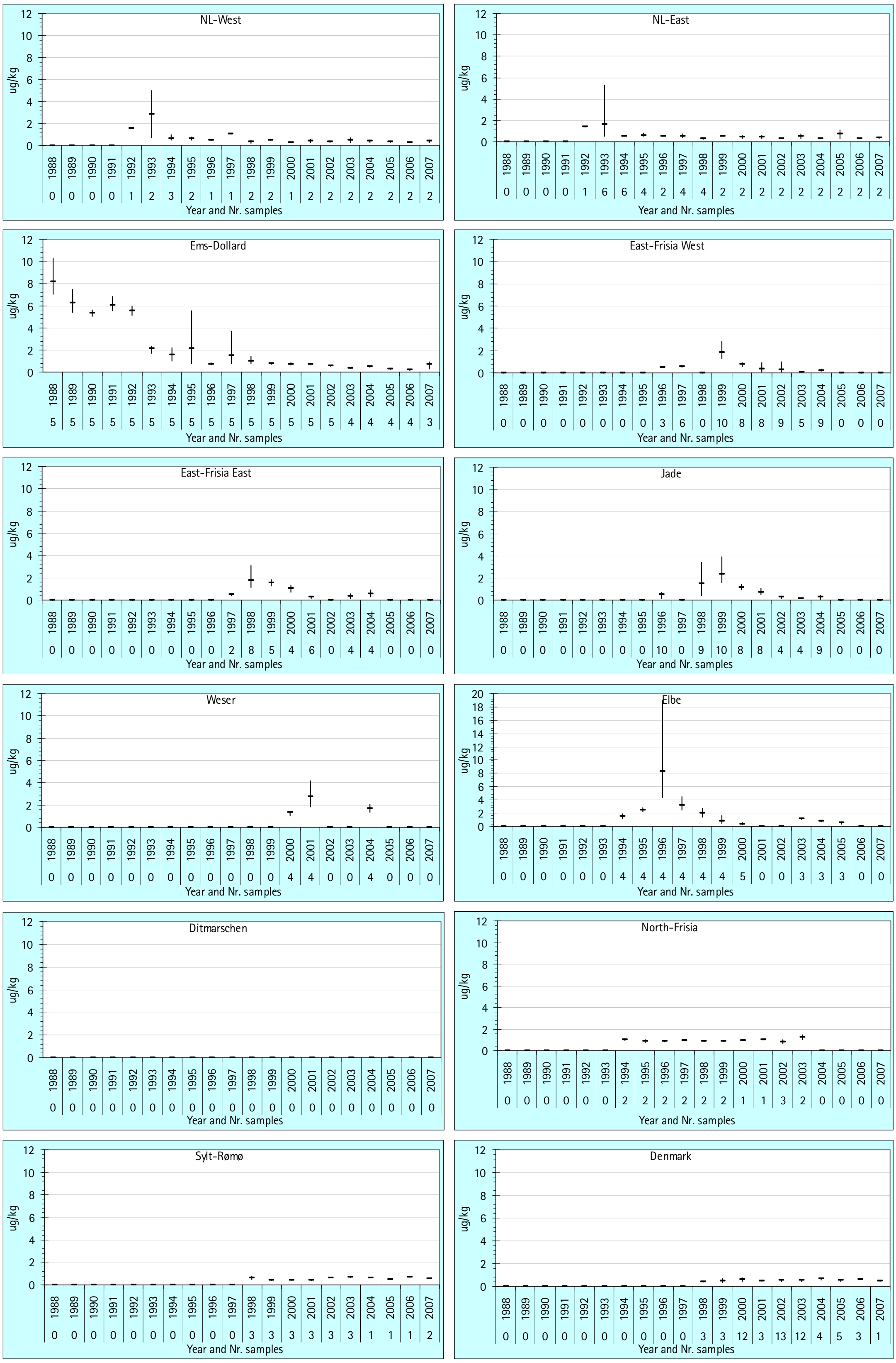


Figure 5.1.31: HCB concentrations (µg·kg^{-1} 2.5% TOC) in sediment. OSPAR background concentration: 0 – 0.05; effect range low (ERL) 20 µg·kg^{-1} 2.5% TOC.

Figure 5.1.32:
HCB concentrations (µg·kg^{-1} dry weight) in blue mussel (Mytilus edulis).



regulated. HCB is highly persistent and bioaccumulative. HCB levels found in human blood are amongst the highest of organochlorines together with DDE (metabolite of DDT), β-HCH and PCBs (WWF, 2004).

HCB Concentrations in Sediment

The hexachlorobenzene concentrations in sediment have been decreasing (Ems-Dollard) or remained at the same level. The OSPAR background concentration (Table 5.1.3) is reached only in Dithmarschen (Figure 5.1.31). Effect concentrations (OSPAR ERL) were not observed.

HCB Concentrations in Blue Mussel

The 1998-2007 trends are downward or absent in all Wadden Sea regions (Figure 5.1.32). The previously most contaminated regions, Ems-Dollard and East-Frisia East, have reached levels comparable to the average Wadden Sea after an 97% respectively 95% reduction. The major source, contaminated sediments, has been reduced, although extraordinary erosion causes slight enhancements. The 2002 Elbe flood has already been shown as an example.

Geographically most recent 2007 data show a minimal difference between regions and vary between 0.3 - 0.9 µg kg^{-1} dry weight.

HCB Concentrations in Bird Eggs

Trends in HCB concentrations in eggs of the oystercatcher and common tern are downward with the exception of HCB in oystercatcher eggs at Delfzijl (Ems-Dollard region). Refer to chapter 5.2 for a more extensive description.

Geographically HCB levels are highest in the Elbe and Dithmarschen regions, followed by the Ems-Dollard and East-Frisia East regions.

Organic Tin compounds (TBT, TPT)

QSR 2004

Tributyltin (TBT) Acts as a hormone disruptor, causing mollusks to develop female sterility (imposex), finally leading to extinction. The marine source is mainly from ships. TBT accumulates in sediments and biota. Highest concentrations were found in marinas, up to 100 fold the levels in more remote reference areas. Intercomparison between Wadden Sea regions was hampered because of methodological differences in both sampling and analysis.

No input data is available from monitoring. In 2002, Ecotoxicological Assessment Criterion by OSPAR was exceeded by a factor of 400 in sediments of the Dutch Wadden Sea. Similarly, it was exceeded by a factor of 15 in blue mussels.

Ecological relevance of Organic Tin compounds

Tributyltin (TBT) acts as a hormone disruptor, causing molluscs to develop female sterility (imposex), finally leading to the extinction of the population. For further information see section 5.7.1.

Triphenyltin (TPT) compounds were not addressed in the 1999 QSR. TPT is mainly applied as biocide for potato crops, and is as toxic as TBT.

The use of TBT as active component in antifouling paints has been banned by the IMO in September 2008, although the use already decreased from 2001 (OSPAR, 2009a).

TBT and TPT Inputs

No input data is available from monitoring. Models have been developed to estimate leaching out of applications, showing that this process is an important diffuse source (in: Bellert *et al.*, 2004).

Organic tin compounds have been extensively monitored in The Netherlands. Some results will be shown.

TBT and TPT Concentrations in Water

The Water Framework Directive requires monitoring of TBT in a one liter sample of total water. The current analytical methods are not sensitive enough to detect significant levels of TBT in such samples, although high suspended matter concentrations favor the limit of quantification. No monitoring data in total water were available from the TMAP data-units.

TBT and TPT Concentrations in Blue Mussel

Organotin (TBT and TPT) concentrations in blue mussels (Figures 5.1.33 and 5.1.34) strongly reduced between 2001 and 2006, probably as a result of the reduced application in shipping antifouling. The reduction was around 80% to more than 90% in all regions where monitoring data were available (NL-West, NL-East, Jade, North-Frisia, Sylt-Rømø, Denmark). Geographically highest levels occur in NL-West and Jade in both past and present at ~60 µg kg^{-1} dry weight.

Summary of Trends

Most of the well known persistent and non-polar xenobiotics have reached a basic leveled-off concentration in the sediments and biota of the Wadden Sea. Trends are sometimes changing due to residual south to north transport in the Wadden Sea and remobilization from old deposits, e.g. by climatic incidents like the Elbe flood 2002.

The less persistent, non-polar organic tin (TBT) compounds show a drastic reduction recently, attributed to the ban on TBT containing anti-fouling paints used on ship hulls.

Figure 5.1.33: TBT concentrations (µg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*). Note the differences in the scale of NL-West and NL-East (higher than in the other two regions).

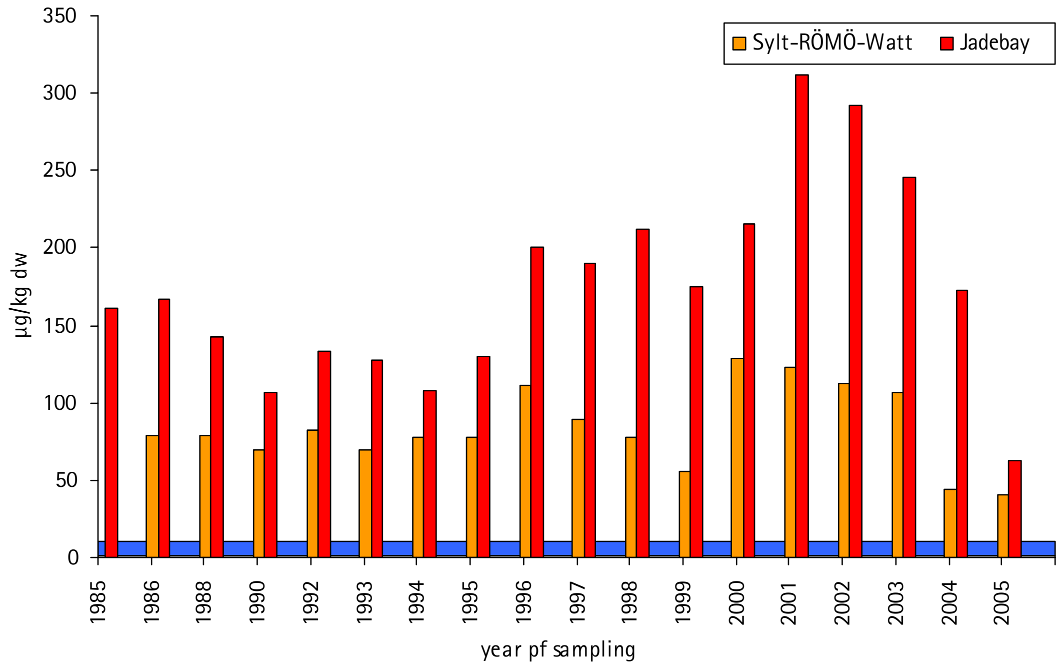


Figure 5.1.34: TBT concentrations (µg·kg^{-1} dry weight) in blue mussel (*Mytilus edulis*) in the Jade and Sylt-Rømø areas (Source: German Specimen Bank). Note: blue highlighted is the EAC of TBT = 1-10 µg kg-1 dry weight (dw).

PCBs are still widespread, but concentrations have decreased considerably over the past 20 years. They still, however, exceed agreed background levels many-fold.

Lindane and DDTs further decreased, though being sensitive to erosion of old deposits, e.g. by extreme floods, the concentrations tend to fluctuate.

HCB is at a basic level in all subareas of the Wadden Sea.

The target 'concentrations ...as resulting from zero discharges' is not reached completely as diffuse sources are still present. Concentrations of the well-known PBT compounds do not continue to show decreasing trends, which may be considered as getting close to the target.

A summary of trends and most recent concentrations in monitored compartments is provided in Table 5.1.4 and 5.1.5.

Table 5.1.4: Temporal development and % reduction of selected hazardous substances in monitored environmental compartments.

Area	River	Cd	Cu	Hg	Pb	Zn	Ni	γ-HCH	HCB	sum6PCB	sum6PAH	TBT
IJsselmeer	lacustrine input t/y; kg/y	▼60%	▼50%	▼85%	▼80%	▼70%		▼90%		▼30%		
NL-West (92-07)	sediment <63µ blue mussel bird eggs	~/= ~/=	▼10% =	~/= ~/▼	~/= ~/▼	▼10% =	~/▼10%	nd	▼75%	~/= (05)	~/=	▼85% (09-06)
NL-East (92-07)	sediment <63µ blue mussel bird eggs	▼20% ~/=	▼40% =	▼30% ~/▼	▼20% ~/▼	▼30% =	~/▼25%	nd	▼75%	~/= (05)	~/=	▼85% (09-06)
Ems river	riverine input	▼60%	▼40%	▼98%	▼50%	▼40%		▼90%		▼99%		
Ems-Dollard (92-07)	sediment <63µ blue mussel bird eggs	▼60% ~/▲230%	▼50% =	▼60% ~/▼▲	= ~/▲250%	= ~/=	~/▲200%	▼80%	▼90%	▼60% (05)	~/▲▼	nd
East-Frisia West (96-07)	sediment <63µ blue mussel bird eggs	▼50% ~/▼▲	▼10% ~/▲	~/▼20% ~/▲(max)	= ~/▼▲300%	= =	nd	~/▲ (04)	▼50% (04)	~/▼75% (04)	nd	nd
East-Frisia East (97-07)	sediment <63µ blue mussel bird eggs	▼50% ~/=	▼30% ~/▲	▼50% ~/▲▼	= ~/▲▼	= =	nd	~ (04)	= (04)	~/= (04)	nd	nd
Jade (96-04)	sediment <63µ blue mussel bird eggs	▼20-70% ~/▲	~/= ~/=	▼20-80% ~/=	= ~/▼▲	~/= =	nd	~/▲	▼50%	~/▼50%	nd	nd
Weser	riverine input	▼70%	▼20%	▼60%	▼30%	▼60%		▼90%		▼97%		
Weser (00-04)	sediment <63µ blue mussel bird eggs	~/= ~/▲	▼15% ~/=	~/= ~/=	= ~/▲150%	= =	nd	▲250%	~ /▲125%	▼50%	nd	nd
Elbe	riverine input	▼50%	▼30%	▼80%	▼70%	▼60%		▼85%				
Elbe (94-05)	sediment <63µ blue mussel bird eggs	~/▲▼(max) ~/▲150%	~/▲▼ ~/▼▲	~/= ~/▼▲	~/▼60% ~/▼▲	= ~/=	nd	~/▼80%	▼75%	~/▼10%	nd	nd
Dith-marschen (94-07)	sediment <63µ blue mussel bird eggs	~/= nd	~/= nd	▼40% nd	~/▼ nd	~/= nd	nd	nd	nd	nd	nd	nd
Eider	riverine input	▼10%	▲140%	▲150%	▲180%	▼30%		=				
North-Frisia (94-07)	sediment <63µ blue mussel bird eggs	~/= ~/=	~/▼ ~/▲▼	▼20% ~/=	~/= ~/▼	= =	~/=	▼75% (03)	~ (03)	▼50% (03)	nd	▼50%
Sylt-Rømø (98-07)	sediment <63µ blue mussel bird eggs	▲ (06) ~/▲	= ~/▲▼	nd ~/▲▼	~/▲▼ ~/▲250%	(▲) (06) =	~/▼40%	▼60%	=	▲200%	~/= (Flu)	▼90%
Denmark	riverine input	nd	nd	nd	nd	nd		nd		nd		
Denmark (98-07)	sediment <63µ blue mussel bird eggs	= ~/▲	▲ (max) ~/=	▲ (00-03) ~/▲▼	~/▼▲ ~/▲300%	(▲) (03) ~/=	~/▼25%	▼75%	=	~/▼30%	~/= (Flu)	~/▲200%

Note: The period is indicated between brackets. Temporal increase: ▲ / decrease: ▼. Percent change as to the starting year. = : no change. ~ : variable, fluctuations. ▲▼ or ▼▲: periodic peaks (increase-decrease; decrease-increase resp.). Deviating period indicated in italics between brackets. (max): maxima (highest concentrations). Bird eggs: average of common tern (CT) and oystercatcher (OC) eggs, unless otherwise mentioned. nd: no data.

Table 5.1.5: Actual levels (2007, or as recent as available) of contaminants in Wadden Sea matrices. All data in µg/kg dry weight (DW).

River area	Matrix	Cd mg/kg^{DW} (1% TOC)	Cu mg/kg^{DW} (1% TOC)	Hg mg/kg^{DW} (1% TOC)	Pb mg/kg^{DW} (1% TOC)	Zn mg/kg^{DW} (1% TOC)	Ni mg/kg^{DW} (1% TOC)	HCH (µg/kg^{DW})	HCB (µg/kg^{DW})	Σ6PCBs (µg/kgDW)	Σ6PAHs (µg/kgDW)	Flu 1% TOC	BaP 1% TOC
IJsselmeer													
NL-West	sediment (05) blue mussel (07) bird eggs(08)	0.6 (0.2) 0.5 nd	20 (6) 9.3 nd	0.3 (0.1) 0.2 1250-10001)	54 (17) 2.7 nd	137 (43) 88 nd	2.9	nd 0.5-0.5[1)]	0.4 15-7.5[1)]	60 (05) 3500-1750[1)]	154 (02) nd	60	16
NL-East	sediment (05) blue mussel (07) bird eggs	0.5 (0.2) 0.4 nd	15 (6) 8.2 nd	0.2 (0.1) 0.1 1100-7501)	43 (17) 2.3 nd	115 (46) 79 nd	2.6	nd nd-nd	0.4 10-5[1)]	57 (05) 4500-2750[1)]	109 (02) nd	46	10
Ems river	Ems												
Ems-Dollard	sediment (06) blue mussel (07) bird eggs	0.3 (0.1) 1.7 nd	12 (4) 9.8	0.2 (0.1) 0.3 750-700[1)]	42 (15) 5.8 nd	121 (43) 167 nd	7.4	1.2 1.0-[0.5-6.0][1)]	0.7 30-[10-40][1)]	45 (05) 6500-3750[1)]	153 nd	45	13
East-Frisia West	sediment (06) blue mussel (07) bird eggs	0.3 (0.5) 0.7 nd	14 (24) 8.3 nd	0.2 (0.3) 0.2 1500-nd[1)]	43 (82) 1.5 nd	115 (200) 90 nd	nd	28.1 nd-nd	0.2 15-nd[1)]	15 2500-nd[1)]	nd	nd	nd
East-Frisia East	sediment (06) blue mussel (07) bird eggs	0.3 (0.5) 0.4 nd	14 (21) 8.2 nd	0.2 (0.3) 0.1 1250-1100	43 (68) 0.7 nd	115 (176) 71 nd	nd	26.3 11.0-nd[1)]	0.5 25-7.5[1)]	26 5000-2000[1)]	nd	nd	nd
Jade	sediment (06) blue mussel (07) bird eggs	0.3 (0.2) 0.9 nd	11 (7) 6.2 nd	0.1 (0.1) 0.1 nd-nd	36 (26) 0.8 nd	99 (69) 80 nd	nd	33.2 nd-nd	0.3 nd-nd	36 nd-nd	nd	nd	nd
Weser													
Weser	sediment (06) blue mussel (07) bird eggs	0.3 (0.3) 1.7	10 (8) 8.5	0.2 (0.1) 0.1 nd-nd	39 (32) 1.6	111 (91) 104	nd	45.8 nd-nd	1.7 nd-nd	21 nd-nd	nd	nd	nd
Elbe													
Elbe	sediment(00) blue mussel (04) bird eggs	0.4 (0.2) 1.7 nd	24 (12) 11.7 nd	1.0 (0.5) 0.3 3000-1200[1)]	53 (26) 1.3 nd	295 (144) 125 nd	nd	0.5 25.0-11.0[1)]	0.5 120-25[1)]	83 (04) 6250-2500[1)]	nd	nd	nd
Dith-marschen	sediment (06) blue mussel bird eggs	0.6 (0.2) nd nd	18 (5) nd nd	0.4 (0.1) nd 1550-1600[1)]	49 (15) nd nd	210 (65) 63 nd	nd	5.0-3.0[1)]	nd 35-12.5[1)]	nd 4500-2000[1)]	nd	nd	nd
Eider													
North-Frisia	sediment (06) blue mussel (03) bird eggs	0.8 (0.2) 0.4 nd	17 (5) 5.7 nd	0.2 (0.1) 0.1 1500-1150[1)]	54 (15) 0.6 nd	200 (58) 63 nd	1.4	1.3 nd-nd	1.3 10-5[1)]	34 2000-1000[1)]	nd	nd	nd
Sylt-Rømø	sediment (06) blue mussel (07) bird eggs	0.9 (0.2) 1.6 nd	19 (5) 6.8 nd	nd 0.3 nd-nd	69 (16) 1.6 nd	250 (59) 110 nd	3.2	0.6 nd-nd	0.6 nd-nd	12 nd-nd	nd	20	4
Denmark													
Denmark	sediment (03) blue mussel (07) bird eggs	0.3 (0.1) 1.5	18 (5) 6.5 nd	0.2 (0.1) 0.2 nd-950[1)]	33 (11) 1.1 nd	120 (38) 109 nd	2.8	0.5 nd-nd	0.5 nd-10[1)]	18 nd-900[1)]	nd	22	3

Note: nd: no data; Σ6PCBs: sum CB 28,101,118,138,153,180; Σ6PAHs: sum of Fluoranthene, Benzo-b/k-Fluoranthene, Benzo-a-Pyrene, Indene-123,cd-Pyrene, Benzo-ghi-Perylene (Borneff PAHs). 1% TOC: sediment data were standardized to sediment containing 1% (T)OC by the formula: Cm (1% TOC) = Cm * (1/[TOC]). Cm : metal content, (T)OC : organic carbon content

[1)] Bird eggs concentrations: left figure common tern – right figure oystercatcher. Conversion from fresh weight to dry weight assuming 80% moisture. Data after Becker et al. (2009), this QSR.

5.1.3.2 Newly emerging xenobiotics

New compounds are being developed continuously, some to replace the ones that have been banned, mostly for new purposes in applications. The EC regulation on chemicals and their safe use (REACH, EC 1907/2006) aims to guarantee environmental safety from the source. Diffuse emission from applications and consumer products is an uncontrollable source of many compounds. Alternatively, many of the compounds exert their environmental effect by synergism.

Compounds disrupting Endocrine Processes

Brominated Flame Retardants (BFRs)

Ecological Relevance of BFRs

BFRs are widely produced and used throughout the world to reduce the flammability of materials, mostly synthetic polymers. Flame retardants (FRs) slow down the initial burn rate, thereby increasing the time span to 'flash-over', the moment that the generated heat sets all combustible materials on fire.

The compound group belongs to the (halogenated) flame retardants ((H)FRs) and can be split into four different types (BSEF, 2000):

- Tetrabromobisphenol-A (TBBPA)
- Hexabromocyclododecane (HBCDD)
- Polybrominated Biphenyls (PBBs)
- Polybrominated Diphenyl Ethers (PBDEs)

The production of PBBs was stopped in September 2000 and its use in the EU has been restricted since 2006. Octa-BDE and Penta-BDE have been banned by the EU in 2004. The use of poly-BDEs in electrical and electronic appliances has been restricted since 2006. Deca-BDE (BDE 209) was exempted from this restriction until 2008 and is currently in the process of REACH registration. The use of HBCDD and TBBP-A is currently not regulated and most widely used. Three major HBCDD isomers, as well as Octa- and Penta-BDE, are included for phase-out under the Stockholm Convention in 2009 and currently placed on the "Candidate List of Substances of Very High Concern" under the REACH regulation (2008). They fulfill the PBT (persistent, bioaccumulative, toxic) criteria of both OSPAR and the EU REACH. HBCDD is suspected reprotoxic.

Monitoring of BFRs

BFRs are only recently part of national monitoring programs and data are not yet available. Adoption of BFRs in the trilateral monitoring program, as has been decided for the OSPAR JAMP, would enable the progress of environmental measures to be reviewed. Monitoring of the Poly-Brominated-Diphenyl-Ethers (PBDE-penta mix) is required under the WFD in the total water matrix (water including suspended particulate matter).

No actual data on BFRs are available in the trilateral monitoring program.

PerFluorinated Octane Sulfonates (PFOS)

Ecological Relevance of PFOS and PFOA

Perfluoroctane sulfonate (PFOS) and perfluoroctanoic acid (PFOA) belong to the group of perfluorinated chemicals (PFCs). PFOS and PFOA are synthetically produced or (PFOA) are the break-down product of PFCs. The heat stable, persistent and both hydro- and lipophobic properties of these compounds have found extensive application in repellents (a.o. fire-fighting foam, insecticides), coatings (a.o. metal plating, fabrics, carpet, paper, floor polish) and cleaners (a.o. shampoos). The most extensive sources currently in Europe are fire-fighting foams and metal plating. The largest producer in the USA (3M) announced that it would phase out PFOS and PFOA in May 2000, due to the disclosure that these compounds were widely present in wildlife and humans (WWF, 2004). The compounds are considered bio-persistent, bioaccumulative and toxic as endocrine disruptors of thyroid functioning. PFOS accumulate in active protein-rich organs (e.g. liver) and blood. PFOS was decided for restricted use under Annex B (specific exemptions for production and use) under the Stockholm POP Convention in its meeting in Geneva (October 2009).

PFCs are extremely persistent, accumulate in animal and human proteins and interfere with hormone-controlled physiological processes.

Inputs of PFOS

The sources of PFCs to the water environment are open applications (e.g. fire-fighting foams) and the waste phase of consumer products in waste water treatment effluents and sludge, and leachates from landfills. Losses to the atmosphere by combustion and during application are of particular concern because of the long-range transport of PFCs to remote, natural areas.

Monitoring of PFOS

Monitoring data of PFCs were not available at a trilateral level. Some national monitoring programs started recently. These data indicate that bioaccumulation occurs at all food web levels, bioconcentrating in liver tissues of fish and mammals and bird eggs (OSPAR, 2010). The accumulating PFOS is PerFluoralkylated Acid (PFA), which is extremely persistent and found to be toxic mainly to birds and mammals (Vos *et al.*, 2008).

PFOS are under review for possible identification as priority substances under the WFD.

No actual data on PFOS are available in the trilateral monitoring program.

Alkylphenols

Ecological Relevance of Alkylphenols
Alkylphenols (APs, e.g. Octylphenol, Nonylphenol, moderately polar) and their Ethoxylates (APEs, e.g. Triton X-100, polar) are used as additives in plastics and as the active ingredient in industrial non-ionic detergents and emulsifiers.

Alkylphenols are of environmental concern due to their persistence and hormonal disruptive action (xeno-estrogens; Jonker *et al.*, 2005).

Input of Alkylphenols
The production and use of alkylphenols and its industrial sources are regulated by EC law. Diffuse applications and sewage constitute remaining inputs to the environment. No data on alkylphenols were available from monitoring.

Monitoring of Alkylphenols
The alkylphenols Octylphenol and Nonylphenol are to be monitored under the WFD Priority Substances list in total water (water including suspended particulate matter).

No actual data on alkylphenols are available in the trilateral monitoring program.

Bisphenol-A

Ecological Relevance of Bisphenol-A
Bisphenol-A (BPA) is an important intermediate in the production of epoxy resins, polycarbonate (a.o. used in bottles) and flame retardants. The global production of BPA increased from 1.1 million ton in 1993 to an estimated 2.6 million ton in 2002. Its chemical properties make BPA relatively hydrophilic (Groshart *et al.*, 2001a).

BPA is toxic to fish and invertebrates (at 1-10·103 $\mu g \cdot l^{-1}$) and readily degradable (Staples *et al.*, 1998). Toppari *et al.* (1995) report estrogenic potential, which is why BPA is included in the list of suspect endocrine disruptors. Canada put BPA on the list of toxic compounds for human applications in 2009.

Input of Bisphenol-A
Major emission sources to surface waters estimated by Groshart *et al.* (2001a) are thermal paper recycling (~72 %) and production and use of plastics (PVC, Phenoplast, ~21 %). BPA in consumer products, particularly polycarbonate bottles and drinking beakers, led to a ban in Canada in 2009.

Monitoring of BPA
Older data from Vethaak *et al.* (2002) report high concentrations of BPA (100-320 $ng \cdot l^{-1}$) in surface water of the Dutch Wadden Sea and Ems-Dollard estuary in 1999. These high concentrations may be related to the industrialized area of Delfzijl, and compare to levels in polder ditches and the rivers Rhine and Meuse. Concentrations found in other Dutch coastal waters range from below detection limit (North Sea) to 80 $ng \cdot l^{-1}$ (Western Scheldt) (Vethaak *et al.*, 2002).

BPA was not found in sediment of the Dutch locations investigated (Vethaak *et al.*, 2002), but BPA did occur in Wadden Sea flounder (Platichthys flesus) muscle tissue (1.2-2.6 $\mu g \cdot kg^{-1}$ wet weight [24% dry weight]) and blue mussel (*Mytilus edulis*) tissue (18-22 $\mu g \cdot kg^{-1}$ wet weight [~20% dry weight]) (Vethaak *et al.*, 2002).

BPA is under review for possible identification as priority substance under the WFD. No actual data on BPA are available in the trilateral monitoring program.

Phthalates

Ecological Relevance of Phthalates
Phthalates are a large group of 'softeners' widely used in many plastics. In some plastics, such as flexible PVC, phthalates constitute 50% of the total weight, which are not chemically bound to the material. Alternative applications are phthalate additions to heat-exchange fluids, ink, paint, adhesives, pesticides (Vethaak *et al.*, 2002). About 2.7·109 $kg \cdot y^{-1}$ of phthalates are produced globally (van Wezel *et al.*, 1999), the major part of which is used in PVC (WWF, 2004).

In the marine environment Di(2-ethylhexyl)phthalate (DEHP) is predominant. Due to its high hydrophobicity (Kow = 7.5; Staples *et al.*, 1997) DEHP adsorbs to sediments and suspended matter (Furtmann, 1999) and bioaccumulates. Due to their bi-polar structure, phthalates may form micelles in water, increasing their apparent solubility (Staples *et al.*, 1997).

Biodegradation of phthalates occurs, with a reported half-life of 20-40 days for DEHP. DEHP, however, is found in North Sea sediments in high concentrations (Åkerman *et al.*, 2004).

Due to the wide spread use of phthalates, specifically of DEHP, in plastics, uncontaminated sampling is a tedious job.

Three OSPAR priority phthalates are suspected of endocrine disruption and have been classified in the EU as carcinogenic, mutagenic and reprotoxic. As such, DEHP has been placed on the "Candidate List of Substances of Very High Concern" under the REACH regulation (October 2008). The high production and use volumes in consumer products cause a relatively high flow to the environment. Though moderately biodegradable, this causes a high flow and hence a relatively high level of particularly DEHP in the food web (OSPAR, 2009a).

Input of Phthalates

Because of the classification of DEHP under REACH, the industrial consumption of DEHP and Dibutyl (DBP) and Benzylbutyl Phthalata (BBP) is declining. Due to the vast amounts used in the production of long-life consumer goods, the diffuse releases of phthalates can be expected to continue for decades.

There are indications that phthalates behave like long-range transported POPs, although currently not considered for adoption in the Stockholm Convention (OSPAR, 2009a).

Input of phthalates is not monitored trilaterally.

Monitoring of Phthalates

DEHP is reported to be widespread in blue mussel, fish and sediments since 2000. The compound is to be monitored as priority substance under the WFD in total water.

No actual data on phthalates are available in the trilateral monitoring program.

Compounds disrupting ecological processes

IRGAROL

Ecological Relevance of IRGAROL and other Herbicides

Herbicides are compounds that disrupt hormonal processes in plants or (reversibly) block photosynthesis. They are selective to kill certain plants (plant hormone imitation), or non-selective (photosynthesis inhibitors).

The compound N'-tert-butyl-Ncyclopropyl-6-(methylthio)-1,3,5-triazine-2,4-diamine (IRGAROL 1051 or Cybutryne) is used as the active ingredient of marine anti-fouling agents and paints. Its application is world wide and the compound is found in coastal and estuarine waters and sediments. Few measurements on IRGAROL are available. IRGAROL is not recognized as a 'chemical of priority action' (OSPAR, 2002) nor subject to 'Ecotoxicological Assessment Criteria' (OSPAR, 2003). It has been shown to reduce the growth rate of marine algae at concentrations found in marine coastal waters (Buma *et al.*, 2009). Although it does not kill the algae, the discriminatory species sensitivity could affect the competition process of algal dominance in coastal marine waters like the Wadden Sea and North Sea.

Input of IRGAROL

Anti-fouling paints containing IRGAROL were introduced on the European market around 1985, being solely produced by Ciba Specialty Chemicals Inc. (Rasenberg and van de Plassche, 2002). Main sources of environmental contamination are located at maintenance sites (shipyards) and harbours (leaching). IRGAROL leaches out of the paints at about 2.6-5 ng·cm-2·day^{-1} (Rasenberg and van de Plassche, 2002).

Monitoring of IRGAROL

In the few measurements available, IRGAROL ranges from 28 (in marinas) to 0.2 (open Dutch Wadden Sea) ng·l^{-1} in water and was not demonstrated in sediments (Bellert and van de Ven, 2003). Ecotoxicological effects are not expected at concentrations of up to 0.24 ng·l^{-1} (van Wezel and van Vlaardingen, 2001), implying that IRGAROL exceeded this upper limit by a factor of more than 100. Although IRGAROL is considered as hardly biodegradable, bioaccumulation does not readily occur due its quick elimination and relatively low Log Kow of 3.95.

Ecotoxicological Risks of IRGAROL

IRGAROL acts on the photosynthetic capacity by blocking the photosystem II (Holt, 1993), implying main toxicological risk to algae, macrophytes and photosynthetic bacteria. Scarlett *et al.* (1997) reports 50% effect levels (EC50) on photosynthetic activity of the green alga Enteromorpha intestinalis at 2.5 µg·l^{-1}. Chronic toxicity on growth of the diatom Skeletonema costatum was reported at concentrations higher than 0.14 µg·l^{-1} (Jongbloed and Luttik, 1996). Reduction of species specific growth rates of marine algae are reported between 0.011 and 0.604 µg·l^{-1} (Buma *et al.*, 2009). The concentrations found in literature are in the range of IRGAROL concentrations in coastal water and may thus affect algal species competition and dominance.

Polycyclic Musk Fragrances

Polycyclic musk xylene compounds such as Galaxolide (HHCB) and Tonalide (AHTN) are used as substitutes for the more expensive original musk in personal care products. In contrast to the original fragrance, synthetic musks are persistent in the environment and accumulate in aquatic organisms. Synthetic musk compounds are only slightly toxic but are long-term inhibitors of the cellular defense system (multixenobiotic resistance), which may aggravate adverse effects of other pollutants.

Perfume and consumer product companies began to phase out their use of polycyclic musks in Europe in the mid of 1990s, and a slow decrease in the concentrations in marine organisms can be observed (Wenzel *et al.*, 2003).

There are no monitoring data available and also OSPAR assigns no high priority to adopt these compounds in monitoring. OSPAR promotes exposure and risk assessments to investigate reasons for concern. Musk xylenes are currently under REACH evaluation to review possible identification as priority substance under the WFD.

Pharmaceuticals

Ecological Relevance of Pharmaceuticals
The attention given to pharmaceuticals, including bacteriocides, and their effects in the environment is limited. The use of pharmaceuticals, both human and veterinary, is increasing and includes the use in marine fish farming and personal and household care products. Studies indicate that a broad range of medicines – antibiotics, cytostatics, psychiatric, anti-inflammatory, beta-blocker drugs – and bacteriocides – like triclosan - are found in sewage treatment effluent and reach the marine environment. Just one example is Clotrimazol, which exerts adverse dioxin-like effects in low concentration. It is advised to support the note by OSPAR to enhance the evidence base for Clotrimazol and other pharmaceuticals and their risk for life in the Wadden Sea.

5.1.3.3 Man-made Substances (Xenobiotics): Target Assessment and Recommendations

The xenobiotics monitored in the TMAP are classical pollutants like PCBs, HCB, DDTs, TBT compound, Lindane and other pesticides.

Monitoring of riverine input of the xenobiotic compounds is restricted to PCBs and Lindane. The inputs show a strong decrease until 1999, continuing more moderately until 2006. Monitoring of riverine input of xenobiotics is not sufficient to draw conclusions on the success of measures on the other classical xenobiotics. Focus on source control alone misses diffuse sources by applications in consumer products, which may have a long usage life-time.

The persistency of some xenobiotics constitutes the main environmental problem, which property is the fundament of biomagnification and causing increased toxic effects. The Elbe flood (August 2002) showed how old deposits may be remobilized and transported to the Wadden Sea, causing an increase of DDT and DDE levels in blue mussels.

Alternatively, high production and application volumes, which maintain high levels in the environment while not being that persistent, cause another environmental problem. The strong reduction of TBT concentration in the blue mussel after the start of the phase-out in 2002 is an example. TBT is metabolized under oxygen-rich conditions, but survives much longer in the deeper sediments due to anoxic conditions there.

Generally speaking, the monitoring data show a decrease of xenobiotic concentrations in all monitored compartments. Unexplained peaks continue to occur, however, which may be related to old deposits, Altogether these fluctuations still have effects on the sensitive biota. This implies that efforts to further reduce diffuse and also global emissions and losses need to continue.

Newly emerging xenobiotics, such as brominated flame retardants, perfluorinated octane sulfonates (e.g. PFOS), Irgarol (anti-fouling agent), alkylphenoles, Bisphenol-A and phthalates are not monitored in the framework of the TMAP. Some of these compounds are monitored at a national level.

The ecotoxicological effects of some of these compounds are not well known. Many other compounds besides the classics like PCBs, have been proven to cause disruption of hormone-regulated endocrine processes in marine animals. They have been demonstrated to occur in the Wadden Sea, but so far there is little indication of hormonal disruption among fish and invertebrates, in contrast to findings in estuarine and coastal waters in the UK and the southern Baltic Sea. They still should be a reason for concern, more so because the increasing complexity of xenobiotic mixtures hampers timely recognition of biological effects.

Bioassays, biological indicators of toxic chemicals in environmental samples, in combination with Effect Directed Analysis (EDA) and Toxicity Identification Evaluation (TIE) have been developed as biological effect assessment techniques to assist in determining truly hazardous chemicals in time. These techniques could be used to identify river basin and Wadden Sea specific priority substances before they exert larger scale biological effects interfering with the Ecological Status.

Target

- Concentrations of man-made substances at levels resulting from zero discharges

Target Evaluation

- For a number of xenobiotic compounds, discharges to and concentrations in the Wadden Sea have continued to decrease. However, the target has not been reached due to the remaining diffuse losses and numerous hazardous substances still being in use in the consumer goods and products.
- TBT concentrations strongly decreased in blue mussel during the last 5 years, probably as a result of the reduced application in shipping anti-fouling.

Conclusions

- Further reduction of riverine discharges and of environmental concentrations have occurred. However, there are exceptions for certain compounds and localities and there is a very poor data set on xenobiotics in riverine discharges.
- The ban and phase-out of TBT in anti-fouling paints explicitly showed its successful effect in rapidly decreasing contamination of blue mussel in The Netherlands. TBT effects on sensitive species, like marine snails, are still observed because the effect level was exceeded many fold. This may improve as well in future.
- PCBs are still wide-spread, but concentrations have decreased considerably over the past 20 years. They, however, still exceed agreed background levels. HCB is at a basic level in all sub-areas of the Wadden Sea.
- Lindane and DDTs further decreased, though being sensitive to erosion of old deposits, e.g. by extreme floods, the concentrations tend to fluctuate and contribute to temporary increases of xenobiotic inputs and concentrations.
- Concentrations of the well-known PBT compounds do not continue to show decreasing trends, which may be considered as getting close to the target.
- Many newly developed xenobiotics, including hormone disruptors, have a wide occurrence in the Wadden Sea ecosystem, but are not monitored in the TMAP framework.
- The progress made in biological effects assessment techniques could be considered as an additional tool in tracing the cause of a problematic Ecological Status.

Recommendations

- More attention for emerging compounds, in concerted action with OSPAR and EU directives, which give rise to concern due to high persistency, high production volumes and application in consumer goods (e.g. personal care products).
- More attention and ecotoxicological research into the combined effects of ever more complex chemical mixtures in the marine (coastal) waters and seas, particularly the sensitive and long-range migrating species.
- To review inclusion in TMAP of priority substances among the newly developed xenobiotics and hormone disruptors in connection with the requirements of the EC Water Framework Directive and in concerted action with OSPAR. This includes the (total) water compartment.
- Pilot in trilateral application of biological effects assessment techniques (bioassays, EDA, TIE) as a management and monitoring tool.
- Pilot in trilateral application of new monitoring techniques (like passive sampling) as time-integrating method to monitor bioavailable substances.

Newly Emerging Compounds and Alternative Monitoring Approaches

Newly (e.g., Water Framework Directive) emerging compounds are not yet part of the TMAP, while certain matrices may efficiently be analyzed for some of those compounds.

It is recommended that the TMAP is updated by considering additional chemical analyses in bird eggs, mussels, flounder and sediment, especially organotins, brominated flame retardants, perfluorinated surfactants, alkylphenols, musks and pharmaceuticals/bacteriocides. New types of monitoring methods (like e.g. passive sampling) and warning instruments (e.g. bioassays and effect directed analysis) may be explored to enhance effectiveness of (chemical) monitoring programs to derive eco-functional information from the field and enable adaptive management as an element of the ecosystem-based approach.

In the Water Framework Directive, compound levels negatively influencing the chemical and ecological targets are of priority importance. This demands a different type of assessment of chemical monitoring data, e.g. by looking for those locations where contaminant levels deviate from the average.

Data Management and Quality Assurance

Data management and quality assurance of chemical data (heavy metals and xenobiotics) in different matrices (except for bird eggs) is still a problematic issue in the Trilateral Monitoring and Assessment Program, which is rooted in existing national monitoring programs. On one hand, this ensures cost effectiveness, but on the other it hampers inter-comparability of methods, which are not well harmonized. Full harmonization between countries of the method selected is more relevant than determining which method is the better one. Further dialogue between the coordinators of national monitoring programs, TMAP and CEMP has to solve this harmonization and standardization aspect to gain reliable and comparable information.

During the preparation of this QSR, problems were encountered regarding, for example, grain-size correction of concentrations in sediment, switched wet/dry weight data in blue mussels, unclear tissue definition in flounder, incomplete or wrong co-variables and possibly sample contamination.

It is therefore strongly recommended that, based on the experiences of this QSR preparation, thorough quality screening of Wadden Sea database data is undertaken regularly by personnel trained to check and evaluate chemical monitoring data. Communication between experts in the field of monitoring, database configuration and data evaluation is indispensable.

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Contaminants in Bird Eggs

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5.2 Contaminants in Bird Eggs

5.2.1 Introduction

Since 1998, the parameter "Contaminants in Bird Eggs" has been implemented in the Trilateral Monitoring and Assessment Program (TMAP; Becker et al., 2001). Each spring, eggs of common tern Sterna hirundo and oystercatcher Haematopus ostralegus were sampled, at in total 16 breeding sites of the Wadden Sea (Figure 5.2.1). In these eggs concentrations of mercury and organochlorines, including polychlorinated biphenyls (ΣPCB) and some pesticides, were determined.

In the last QSR 2004, the main findings of spatial and temporal variation were presented (Becker and Muñoz Cifuentes, 2005). These showed that in the beginning of the 2000s, the Elbe estuary was still a hot spot for chemical contamination, but also some pollutant inputs in the western Wadden Sea were obvious. Even if levels of most contaminants had decreased since the beginning of the 1990s and seemed to remain more or less stable in the mid-1990s, concentrations of some substances had increased again in bird eggs, indicating new inputs of pollutants into the Wadden Sea.

In this contribution, we update the information presented by the last QSR 2004 (Becker and Muñoz Cifuentes, 2005) and by Becker and Muñoz Cifuentes (2004), and evaluate recent levels of contaminants in bird eggs from the Wadden Sea as well as their current trends. We focus on the geographical variation of bird egg contamination from The Netherlands to Denmark in 2008 and on temporal trends for three periods, viz. in the short term 2004–2008, medium term 1998–2008 and long term 1981–2008, the latter including data collected previously to the TMAP-project (Becker et al., 1991, 1992, 2001).

Furthermore, we present the geographical variation in the concentrations of dioxin-like PCBs, given as toxicological equivalents (TEQs). These TEQs give the summarized concentrations of 10 from 12 dioxin-like PCBs (Figure 5.2.6), each multiplied by a specific toxic equivalency factor (TEF, Van den Berg et al., 1998), depending on the toxicity of the substance in relationship to the most toxic substance "dioxin" (2,3,7,8-TCDD) for which TEF is defined as 1.

In addition, we address ecotoxicological aspects and compare the pollutant levels with the Wadden Sea Plan targets. Specific Ecological Quality Objectives (EcoQOs) concerning the concentrations of mercury and organochlorines in North Sea seabird eggs have been developed by ICES (2003, 2004) and OSPAR (2007). In 2008 and 2009, a pilot project has been carried out to analyze the status of contaminants in bird eggs in the North Sea and to evaluate the proposed EcoQOs (OSPAR 2007). We briefly mention this pilot project and relate the TMAP findings to the EcoQO.

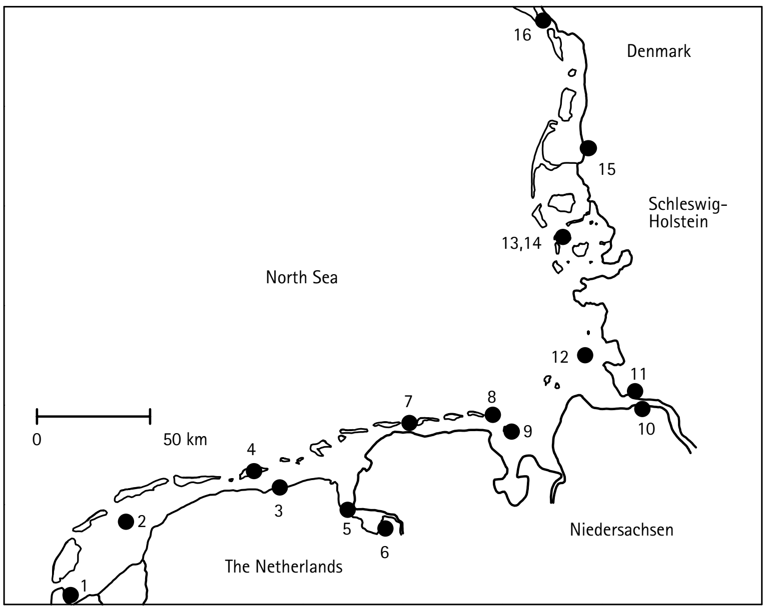


Figure 5.2.1: Sampling sites of common tern (CT) and oystercatcher (OC) eggs analyzed for contaminants. The Netherlands: 1 Balgzand, 2 Griend, 3 Julianapolder (CT until 2004), 4 Schiermonnikoog (CT since 2005), 5 Delfzijl; Germany, Niedersachsen: 6 Dollart, 7 Baltrum, 8 Minsener Oog, 9 Mellum, 10 Hullen; Germany, Schleswig-Holstein: 11 Neufelderkoog, 12 Trischen, 13 Norderoog (until 2006), 14 Hooge (since 2007); Denmark: 16 Langlie. At the sites 4 and 11, only common tern eggs, at the sites 3, 6, 7, 9 and 16, only oystercatcher eggs were taken; at all other sites, eggs of both species were collected.

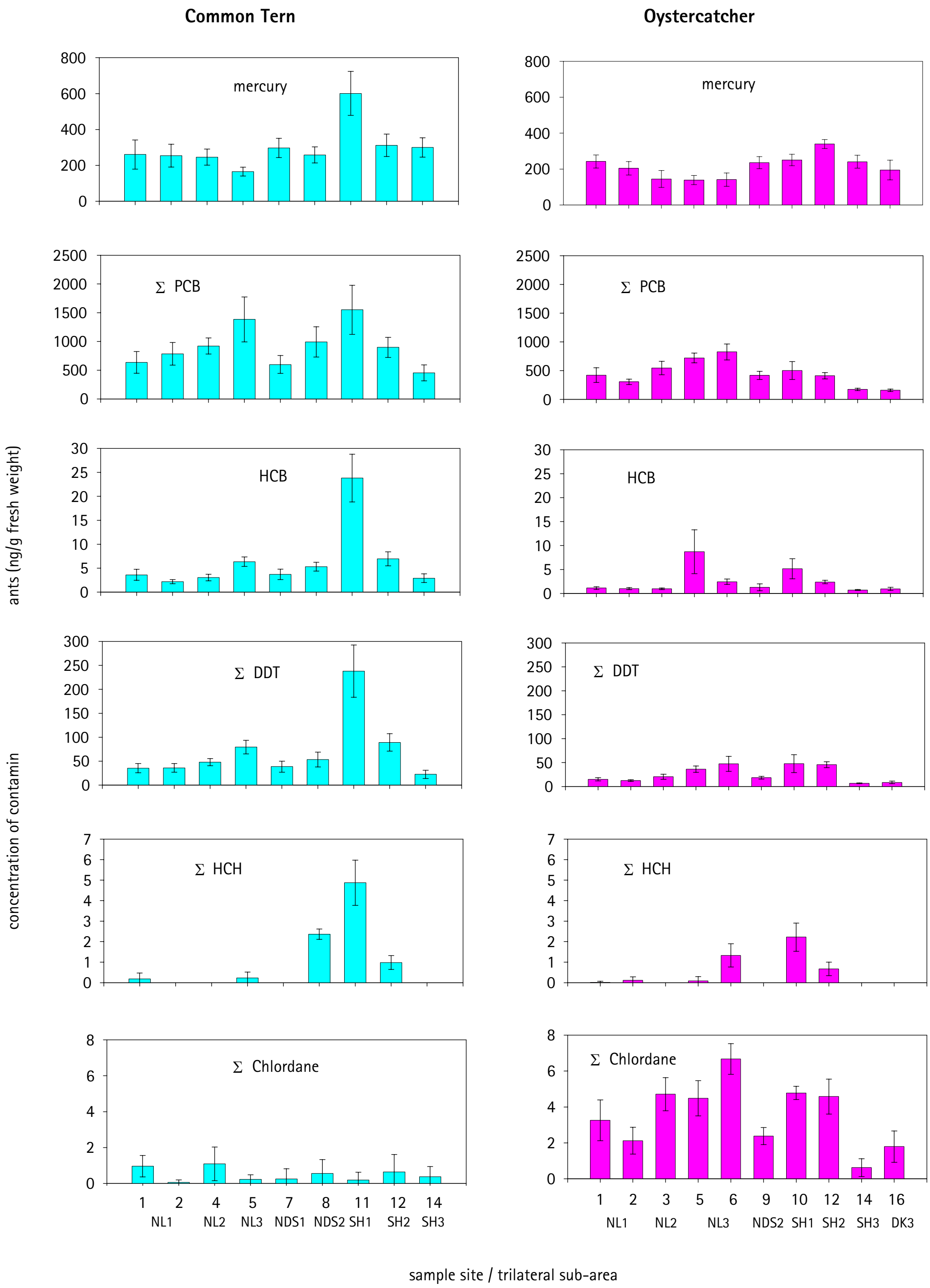


Figure 5.2.2: Geographical variation of the contaminants analyzed in common tern and oystercatcher eggs in 2008 in the Wadden Sea. See Figure 1 for location of sampling sites. Mean concentration (ng/g fresh weight of egg content) and 95% confidence intervals are presented for mercury, ΣPCB congeners, HCB, sum of DDT and its metabolites (ΣDDT), sum of HCH-isomers (ΣHCH), and sum of cis- and trans-chlordane and cis- and trans-nonachlor concentrations (ΣChlordane). At most sites, n=10 eggs were sampled.

5.2.2 Geographical trends

As in previous years also in 2008 the contaminants' levels showed distinct geographical patterns in both species (Figure 5.2.2; cf. Figure 5.2.1 for sampling sites). In common tern eggs, concentrations of mercury, ΣPCB, HCB, ΣDDT and ΣHCH were highest at the Elbe estuary. For ΣPCB, and to a lesser extent also for ΣHCB and ΣDDT, a second spatial peak was recorded at Delfzijl at the Ems estuary. Among the PCB congeners, exceptionally high levels were recorded for PCB64 in eggs from Minsener Oog (Mean±SD 35.7±11.1 ng/g). Concentration of ΣChlordane was highest at Schiermonnikoog.

In oystercatcher eggs, concentrations of mercury and ΣHCH were highest in the Elbe estuary, those of ΣPCB, HCB and ΣChlordane reached a maximum at the Ems estuary, where elevated

ΣHCH levels were also found. ΣDDT concentration showed peaks at both estuaries. Exceptionally high levels were recorded for PCB64 in eggs at Dollart (119.0±52.3 ng/g). Furthermore, high levels were found for TEQ component PCB126 at Neufelderkoog, Elbe estuary (see chapter 5.2.5). Mercury concentration showed increased values at Balgzand.

Summarizing, the results identify the estuaries of the two rivers Ems and Elbe as the sites where concentrations of most contaminant groups were highest. In the common tern, peaks of most contaminants were particularly pronounced at the Elbe estuary. In the oystercatcher, this was true for both the Ems and the Elbe estuary. For most pollutants and most sites, contamination was higher in the common tern than in the oystercatcher (Figure 5.2.2). However, contamination of ΣChlordane was clearly higher in the oystercatcher.

5.2.3 Temporal trends

An overview of middle-term (1998-2008) and short-term (2004-2008) temporal trends of contaminant concentrations is given in the Figures 5.2.3 and 5.2.4 and in Table 5.2.1. Between 1998 and 2008, concentrations of HCB, ΣHCH in common tern eggs decreased significantly at most or, for some of the compounds, even all sites. Concentrations of mercury, ΣPCB and ΣChlordane decreased significantly at 4 from 8 sites but no general geographical patterns in these decreases were detectable. On the other hand, significant increases were recorded for concentrations of ΣPCB and ΣDDT at Delfzijl.

During the last five years (2004-2008), concentrations of HCB and ΣPCB decreased significantly at 6 of 8 sites, those of mercury and ΣDDT did so at 5 of 8 and those of ΣHCH at 4 of 8 sites. During this period, significant increases were found for concentrations of ΣHCH at Minsener Oog.

In oystercatcher eggs, concentrations of HCB, ΣPCB and ΣHCH decreased significantly at most or for some compounds even at all sites between 1998 and 2008. The concentrations of mercury decreased significantly at 7 of 10 sites, those of ΣDDT and ΣChlordane did so at 4 of 10 sites. Significant increases during these 11 study years were recorded for mercury at Trischen, German Bight, and Norderoog/Hooge, and for ΣPCB and ΣDDT at Delfzijl.

During the last five years (2004-2008), concentrations of HCB, ΣPCB, ΣDDT decreased significantly at all or nearly all sites. Concentrations of ΣHCH decreased significantly at 6 of 10 sites. Significant increases were recorded for concentrations of mercury at Griend and Hullen and for those of ΣHCH and ΣChlordane at the Dollart.

Summarizing, most of the significant increases of contaminant concentrations were found at Delfzijl. Mercury in oystercatcher eggs was the most frequently increasing contaminant (apart from at Delfzijl, where no case of increase was found). In general, significant contaminant decreases in oystercatcher eggs occurred at a higher number of sites and were more pronounced than in common tern eggs.

Figure 5.2.5 shows the long-term-development of mercury, ΣPCB, HCB and ΣDDT concentration at three selected sites in the western (Griend), central (Trischen) and northern part of the Wadden Sea over a study period of 28 years. During that long period, the contaminants in eggs of both study species showed maximum concentrations in the 1980s. After strong decreases in the early 1990s they stabilized on a lower level with more or less pronounced inter-annual fluctuations until 2008.

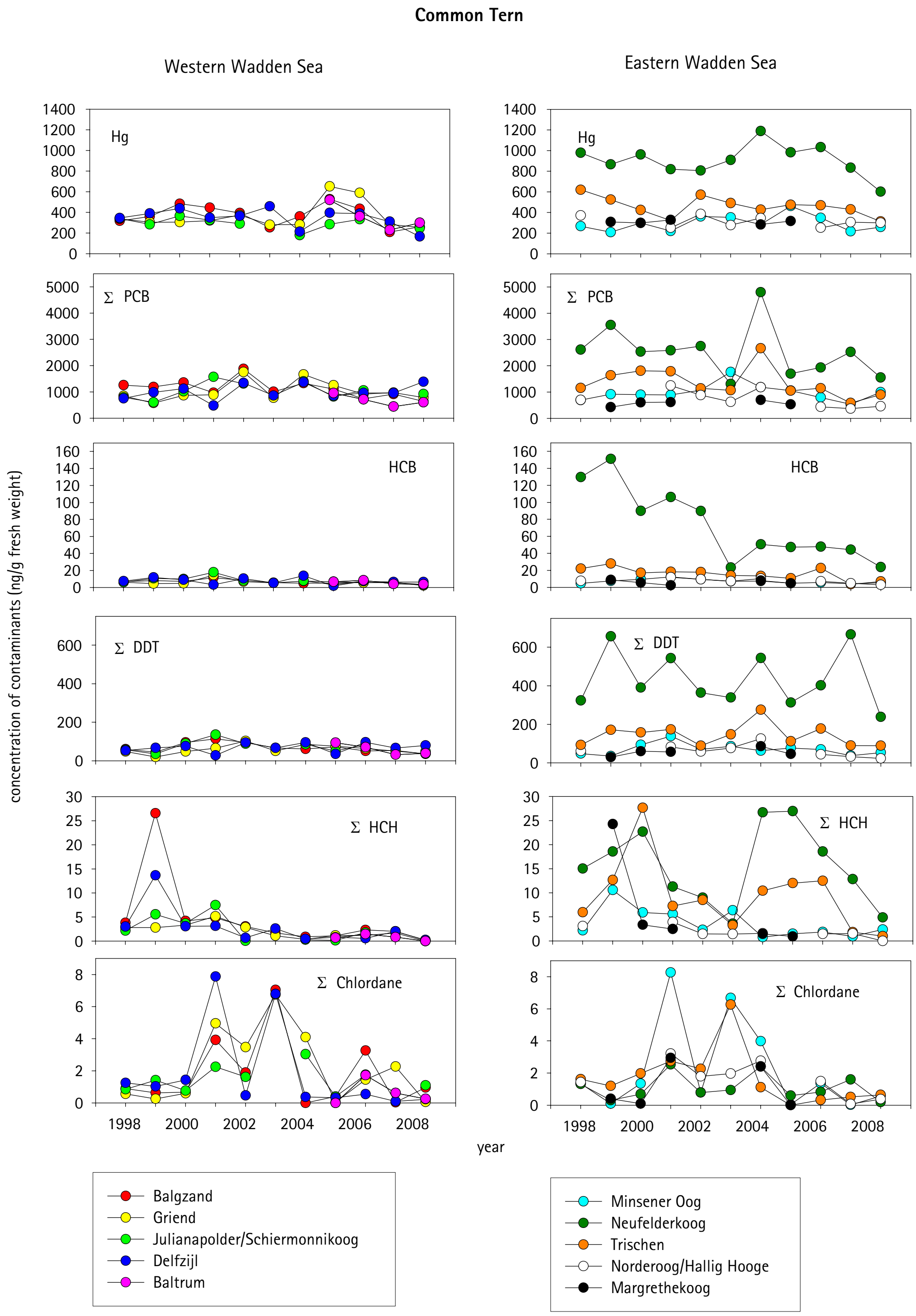
5.2.4 Ecotoxicological aspects

To date, monitoring of birds' breeding success is not included in the TMAP Common Package; consequently information on potential differences in the hatching success of coastal birds breeding in highly and lowly contaminated areas is lacking (cf. Thyen et al., 1998). Muñoz Cifuentes (2004) presented data from the mid 1990s suggesting that the reproductive success of common tern, common gull Larus canus and herring gull Larus argentatus was negatively affected by organochlorine contamination at the Lower Elbe. The current levels of most contaminants in bird eggs, however, are below the known threshold concentrations affecting birds' reproduction (cf. Becker et al., 2001; Muñoz Cifuentes, 2004).

Similar to most chemicals, also the TEQ-levels calculated for dioxin-like PCB-congeners (cf. Muñoz Cifuentes, 2004; see above) showed decreasing trends since 1998 in the Wadden Sea (Table 5.2.1).

However, similar to sporadic increases during previous periods, TEQ concentrations in 2008 were elevated in some areas between Dollart and inner German Bight (Figure 5.2.6; common tern: 152-442 pg/g; oystercatcher: 2-212 pg/g), deviating from the general spatial pattern of ΣPCB (Figure 5.2.2). Such TEQ-concentrations are in a range where negative effects on the hatchability of fish-eating bird species are reported (90-4,000 pg/g, Hoffmann et al., 1996; see for details Muñoz Cifuentes, 2004). Given a lipid content of 8,2%

Figure 5.2.3: Middle-term (1998-2008) trends of contaminant concentrations in common tern eggs from selected sampling sites (cf. Figures 5.2.1 and 5.2.2). Dots indicate arithmetic means (ng/g fresh weight of egg content).



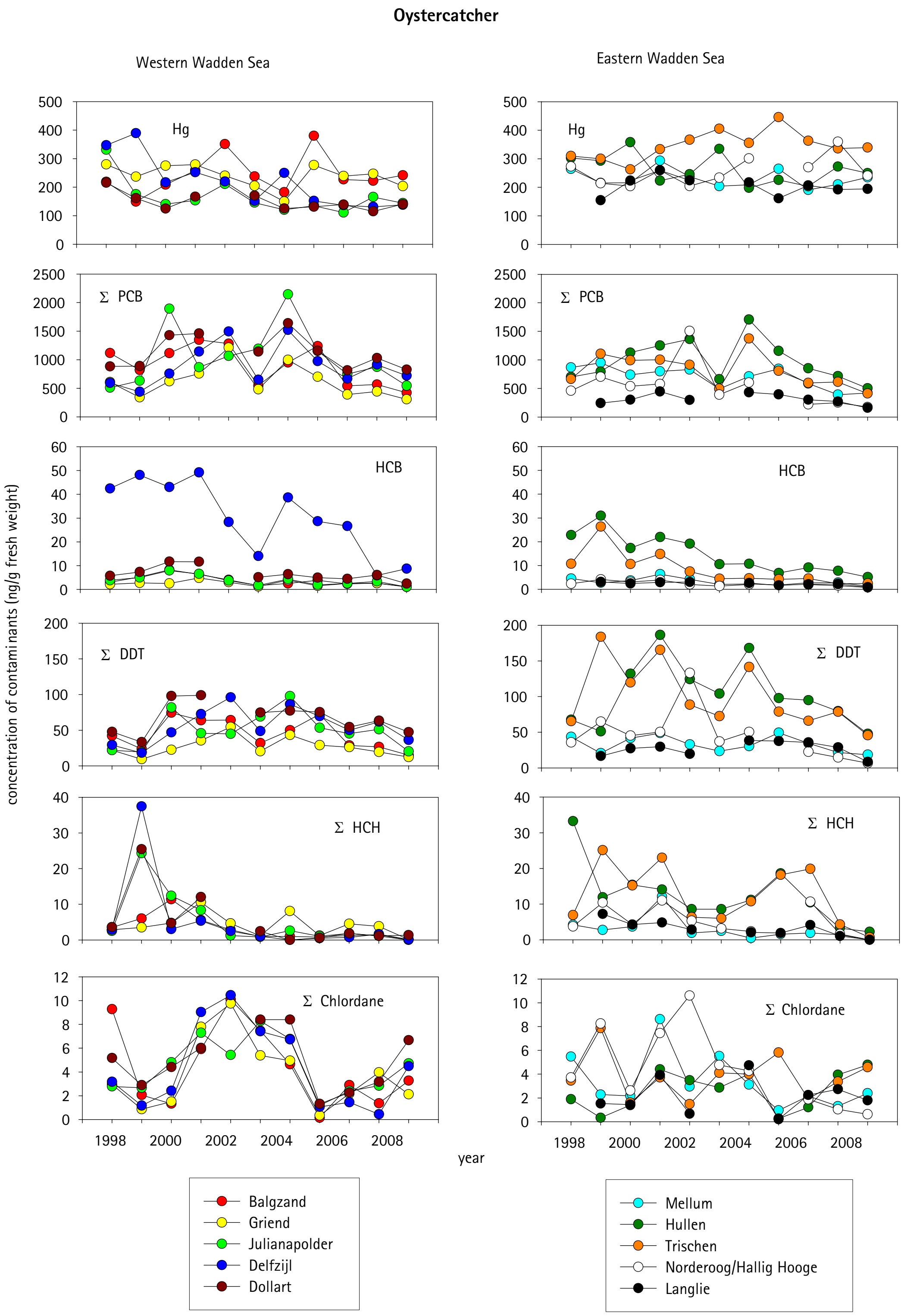


Figure 5.2.4: Middle-term (1998–2008) trends of contaminant concentrations in oystercatcher eggs from selected sampling sites (cf. Figure 1 and 2). Dots indicate arithmetic means (ng/g fresh weight of egg content).

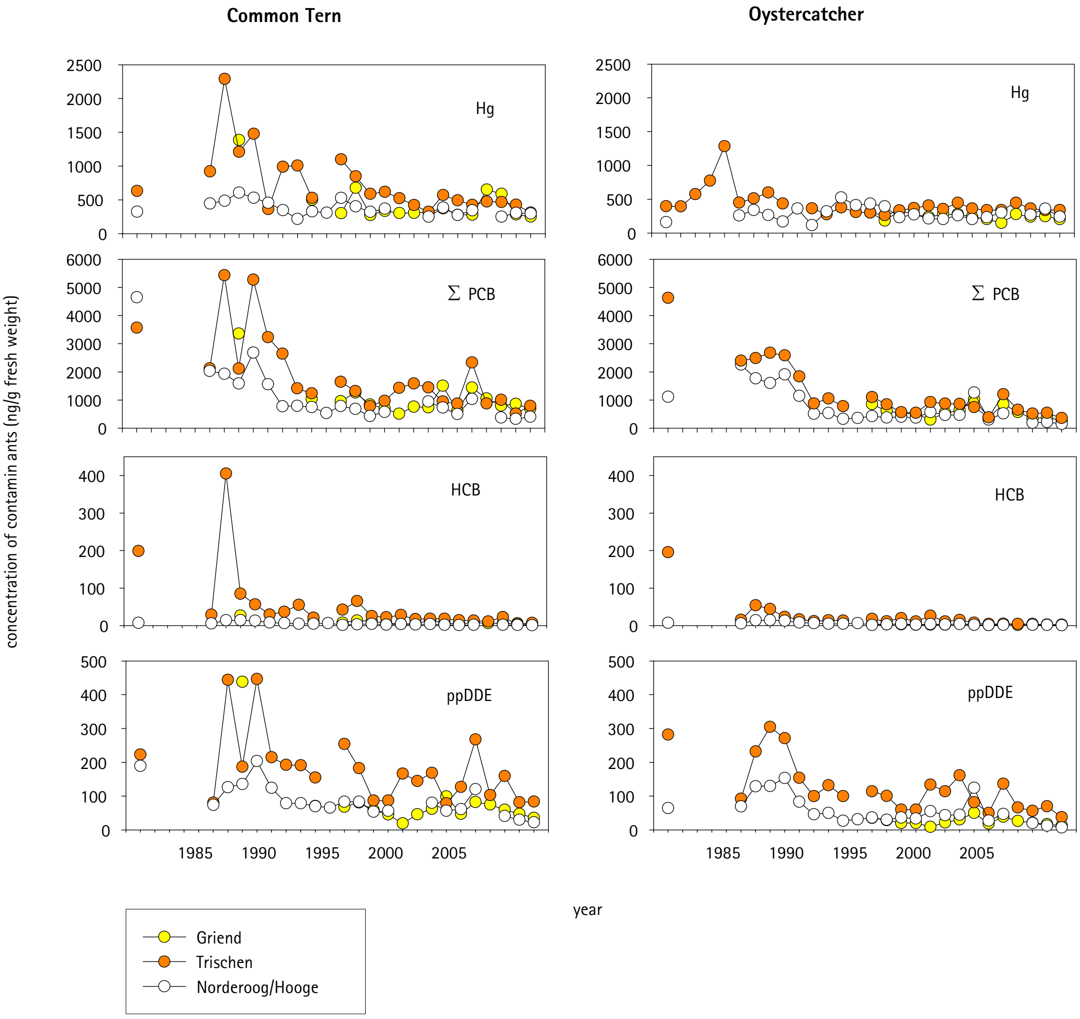


Figure 5.2.5: Long-term (1981-2008) trends of concentrations of mercury, PCBs, HCB and ppDDE in common tern and oystercatcher eggs from three selected breeding sites in the Wadden Sea, Griend (NL1; CT since 1988; OC since 1995), Trischen (SH1) and Norderoog/Hallig Hooge (SH3). ΣPCB: sum of 32 PCB congeners; ng/g fresh weight; dots indicate arithmetic means. Data for 1981-1990 after Becker et al. (1991, 1992), for 1991-2003 after Becker & Muñoz Cifuentes (2005).

for the eggs of the study species (Mattig et al., 2000), TEQ concentrations recorded were up to about 2,500 times higher than the EU limits for chicken eggs destined for human consumption (2 pg/g fat; Chemisches und Veterinärmedizinisches Untersuchungsamt Freiburg, 2006).

5.2.5 Target evaluation

The concentrations of contaminants measured in bird eggs indicate that the burden of pollutants in the Wadden Sea is slowly decreasing towards the proposed Wadden Sea Plan targets, which are background concentrations of micropollutants such as mercury that occur naturally, and zero concentrations in the case of man-made substances such as organochlorines (TMAP, 1997). In 2008, the EcoQOs proposed for contaminants in seabird eggs (ICES, 2003, 2004; OSPAR, 2007) have already been reached for some substances at some sites in the Wadden Sea. For ΣHCH, this is true at the majority of sampling sites, but not for various other substances and locations (mercury, oystercatcher < 100 ng/g : no site; common tern < 200 ng/g: 1 site; ΣPCB < 20 ng/g: no site in both species; HCB < 2 ng/g: oystercatcher, 6 sites, common tern, no site; ΣDDT < 10 ng/g: oystercatcher, 2 sites, common tern, no site; ΣHCH < 2 ng/g: oystercatcher, 9 sites, common tern, 8 sites).

The stagnation of the levels of various substances and some recent increases point to local problems with environmental pollutants. Among these are several contaminants whose use has been prohibited a long time ago, such as ΣDDT and ΣChlordane. At the hot spots of contamination, the present concentrations of ΣPCB and ΣDDT, especially in the eggs of common tern, are still very high in comparison with the target levels.

In the framework of a pilot study on the EcoQO "Mercury and Organohalogens in Seabird Eggs", eggs were sampled at additional sites on the North Sea coast in 2008/2009 (Norway: Rogaland, Sweden: Skagerak, The Netherlands: Rhine-Scheldt

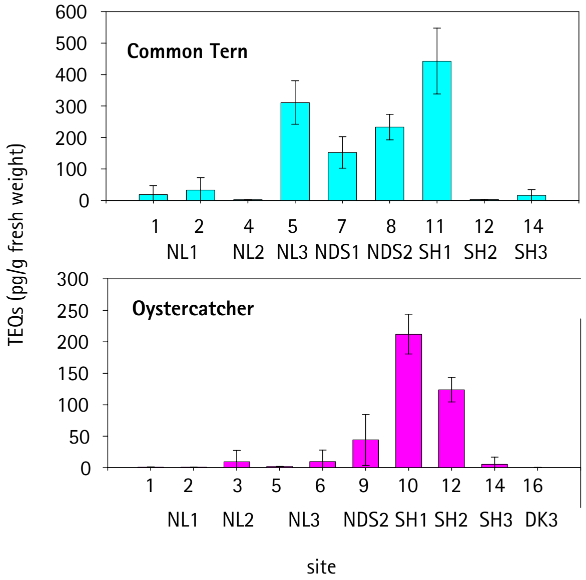


Figure 5.2.6: Geographical variation of TEQs (Toxic Equivalents) analyzed in common tern and oystercatcher eggs in the Wadden Sea in 2008. For location of sites cf. Figures 5.2.1 and 5.2.2. To calculate TEQs of non- and mono-ortho PCB congeners, bird-specific 2,3,7,8-TCDD toxic equivalency factors (TEF) proposed by the WHO (Van den Berg et al., 1998) were used. Non-ortho congeners detected were PCB126 and 169, mono-ortho congeners were PCB105, 114, 118, 123, 156, 157, 167 and 189). Mean concentration (pg/g fresh weight of egg content) and 95% confidence intervals are presented. At most sites, n=10 eggs were sampled.

estuary, Belgium: Zeebrugge, and in 2009 at three sites in the UK). The inter-site comparison of contamination levels indicates that, in most cases, concentrations were lowest at the proposed reference areas in Scandinavia, far distant from industrial hot spots. The tentative EcoQO of mercury (≤200 ng/g in the common tern and ≤100 ng/g in the oystercatcher, based on lowest values ever measured in the Wadden Sea) was reached by oystercatcher eggs at Rogaland (97 ng/g), as well as by Arctic/common tern eggs at Rogaland and Skagerrak respectively (173 ng/g). Nevertheless, the lowest ΣPCB-levels found (Rogaland: oystercatcher 132 ng/g, arctic tern 137 ng/g) were still clearly higher than the target level of 20 ng/g.

5.2.6 Discussion of trends and conclusions

During the last five years, the Elbe estuary persisted to be a hot spot of chemical contamination although the concentrations of most contaminants were decreasing. In comparison with the previous reporting period covered by the QSR 2004, the Ems estuary has emerged as an additional hot spot (Figure 5.2.2). Whereas the previously elevated HCB levels in oystercatcher eggs have decreased in this area (Figure 5.2.3 and 5.2.4), levels of ΣChlordane have increased. ΣPCB and ΣDDT have increased in both species studied. In 2008, levels of some contaminants recorded in bird eggs at the Ems estuary were similar or even higher than those at the Elbe estuary (Figures 5.2.3 and 5.2.4). The higher concentrations of all contaminants except ΣChlordane found in common tern compared to oystercatcher eggs may be a result of the higher trophic level and accumulation rates of the common tern.

Since the beginning of the 1990s (Figure 5.2.5), concentrations of most contaminants have decreased, with some fluctuations in the mid-1990s. These negative trends did continue during the first decade of the 2000s, with pronounced decreases occurring during the last five years. The results indicate that the general contaminant burden on the ecosystem has lowered. Despite this general development, the concentrations of some chemicals have increased in recent years. This may indicate new inputs or remobilization of these substances from sedimentary deposits through natural processes or human activities such as dumping harbour sludge. The increase of ΣPCB, ΣDDT, ΣHCH and ΣChlordane concentrations at the Ems estuary observed in both species (see above) is remarkable as these contaminants have been legally banned for decades (see Becker et al., 2001, for details).

Contrasting with the general long-term trends, sporadic and partly local instances of increased contamination with some substances have occurred since 2004 (Figures 5.2.3 and 5.2.4). In this respect also the exceptionally high levels of PCB64 at two sites in the Lower Saxon Wadden Sea are cause for concern.

The current levels of most contaminants in bird eggs are in general below the known threshold concentrations affecting birds' reproduction. However, the fact that TEQs reached biologically relevant levels at some sites in 2008 shows that the danger of intoxication of birds by environmental chemicals in the Wadden Sea is ongoing, and that even nowadays endangering of bird populations by chemical pollution cannot be excluded.

In 2008, the EcoQOs proposed for contaminants in seabird eggs (ICES, 2003, 2004; OSPAR, 2007) have already been reached for some substances at some sites in the Wadden Sea. The stagnation of the levels of various substances and some recent increases point to local problems with environmental pollutants. At the hot spots of contamination, the present concentrations of ΣPCB and ΣDDT, especially in the eggs of common tern, are still very high in comparison with the target levels.

5.2.7 Recommendations

Considering the current contamination status of bird eggs on the Wadden Sea coast and its recent development, we recommend:

(1) to continue monitoring of the TMAP parameter "Contaminants in Bird Eggs" in a long-term perspective, especially at the identified hot spots, and on an annual basis in order to dispose of the statistical power to separate short term fluctuations from long-term trends and to use the parameter as an early warning of marine pollution with chemicals;

(2) to include new toxic substances in the analytics;

(3) to carefully supervise the TEQs as indicators of toxic PCB congeners;

(4) to continue to pursue the one-lab-approach that has been the basis of the parameter "Contaminants in Birds Eggs" since 1991, in the process saving expensive intercalibration between laboratories and guaranteeing comparability, costs and time;

(5) to continue assessment of the EcoQO "Mercury and Organohalogens in Seabird Eggs" (OSPAR 2007) in order to supplement the geographical coverage of "Contaminants in Bird Eggs" by additional sampling sites and reference areas around the North Sea;

(6) to implement the parameter "Breeding Success" within the TMAP to provide a sensitive ecotoxicological indicator. This parameter should be adequately combined with the parameter "Contaminants in bird eggs", at least at the hot spots of chemical pollution (Elbe and Ems estuaries). The combination of both parameters will present an effective early warning against chemical pollution of the Wadden Sea (Thyen et al., 1998, Muñoz Cifuentes, 2004).

(7) to reinforce the need for continued effort to reduce anthropogenic atmospheric or riverine inputs of hazardous chemicals into the Wadden Sea, in order to avoid impacts on bird populations and the ecosystem. The elevated concentrations of some PCBs in 2008 at the estuaries of the rivers Ems and Elbe (PCB64 and some toxic PCB-congeners) are a warning of the importance of this work.

Table 5.2.1:
Middle (1998-2008) and short term (2004-2008) trends in pollutant levels and TEQs in common tern and oystercatcher eggs. Spearman rank correlation coefficients (rs) were calculated on the basis of n eggs, and p-values are presented. * <0,05, ** <0,01, ***0,001. Positive trends are given bold.

		n	Hg	ΣPCB	HCB	ΣDDT	ΣHCH	ΣChlordane	TEQs
Common Tern									
Balgzand	1998-2008	110	-0,194 *	-0,372 ***	-0,468 ***	-0,246 **	-0,709 ***	-0,92	-0,388 ***
	2004-2008	50	-0,543 ***	-0,546 ***	-0,191	-0,493 ***	-0,083 ***	**0,385** **	-0,694 ***
Griend	1998-2008	110	0,069	0,146	-0,195 *	0,124	-0,703 ***	-0,23	-0,285 **
	2004-2008	50	-0,314 *	-0,630 ***	-0,606 ***	-0,698 ***	0,001	-0,253	-0,659 ***
Julianapolder/	1998-2008	69	-0,241 *	0,125	-0,621 ***	-0,077	-0,625 ***	0,038	-0,313 **
Schiermonnikoog	2004-2008	36	0,194	-0,125	-0,359 *	-0,282	0,001	0,006	-0,589 ***
Delfzijl	1998-2008	110	-0,345 **	**0,191** *	-0,195 *	**0,255** **	-0,637 ***	-0,353 ***	-0,209 *
	2004-2008	50	-0,238	0,021	-0,059	0,094	0,047	-0,047	**0,340** *
Minsener Oog	1998-2008	110	0,168	-0,018	-0,366 ***	-0,023	-0,438 ***	-0,250 ***	-0,078
	2004-2008	50	-0,412 **	-0,363 **	-0,419 **	-0,341 *	**0,465** ***	-0,264	0,177
Neufelderkoog	1998-2004	110	-0,083	-0,346 ***	-0,736 ***	-0,153	-0,145	-0,102	0,018
	2004-2008	50	-0,433 **	-0,450 ***	-0,406 **	-0,225	-0,787 ***	-0,654 ***	-0,157
Trischen	1998-2008	110	-0,312 ***	-0,416 ***	-0,559 ***	-0,110	-0,402 ***	-0,424 ***	-0,350 ***
	2004-2008	50	-0,284 *	-0,643 ***	-0,516 ***	-0,614 ***	-0,713 ***	-0,042	-0,838 ***
Norderoog/Hooge	1998-2008	75	-0,139	-0,598 ***	-0,540 ***	-0,584 ***	-0,569 ***	-0,395 ***	-0,409 ***
	2004-2008	35	0,035	-0,414 *	-0,824 ***	-0,785 ***	-0,672 ***	-0,680 ***	-0,789 ***
Oystercatcher									
Balgzand	1998-2008	110	**0,203** *	-0,523 ***	-0,574 ***	-0,359 ***	-0,792 ***	-0,223 *	-0,375 ***
	2004-2008	50	0,040	-0,612 ***	-0,462 ***	-0,740 ***	-0,258	-0,087	-0,876 ***
Griend	1998-2008	111	-0,125	-0,238 *	-0,306 ***	-0,015	-0,390 ***	-0,037	-0,417 **
	2004-2008	51	**0,309** *	-0,750 ***	-0,503 ***	-0,857 ***	-0,537 ***	-0,118	-0,901 ***
Julianapolder	1998-2008	108	-0,395 ***	-0,024	-0,638 ***	0,069	-0,719 ***	-0,089	-0,241 *
	2004-2008	50	0,167	-0,779 ***	-0,550 ***	-0,800 ***	-0,633 ***	-0,085	-0,776 ***
Delfzijl	1998-2008	110	-0,630 ***	**0,232** *	-0,395 ***	**0,268** **	-0,743 ***	-0,190 *	-0,537 ***
	2004-2008	50	-0,449 ***	-0,529 ***	-0,595 ***	-0,654 ***	0,183	-0,250	-0,720 ***
Dollart	1998-2008	85	-0,408 ***	-0,224 *	-0,564 ***	-0,155	-0,582 ***	-0,063	-0,671 ***
	2004-2008	49	-0,002	-0,561 ***	-0,549 ***	-0,485 ***	**0,591** ***	**0,335** *	-0,711 ***
Mellum	1998-2008	110	-0,103	-0,554 ***	-0,523 ***	-0,316 ***	-0,677 ***	-0,370 ***	-0,465 ***
	2004-2008	50	0,014	-0,684 ***	-0,114	-0,672 ***	-0,193	-0,057	-0,344 *
Hullen	1998-2004	110	-0,292 **	-0,185	-0,627 ***	-0,132	-0,435 ***	0,149	0,057
	2004-2008	50	**0,365** **	-0,762 ***	-0,284 *	-0,632 ***	-0,679 ***	0,247	-0,564 ***
Trischen	1998-2008	108	**0,272** **	-0,459 ***	-0,876 ***	-0,424 ***	-0,391 ***	0,006	-0,170
	2004-2008	50	-0,303 *	-0,749 ***	-0,698 ***	-0,622 ***	-0,685 ***	0,022	-0,538 ***
Norderoog/Hooge	1998-2008	99	**0,244** *	-0,587 ***	-0,578 ***	-0,579 ***	-0,553 ***	-0,587 ***	-0,393 ***
	2004-2008	40	-0,155	-0,688 ***	-0,705 ***	-0,863 ***	-0,664 ***	-0,821 ***	-0,862 ***
Langlie	1998-2008	84	-0,036	-0,231 *	-0,560 ***	0,056	-0,739 ***	0,125	-0,146
	2004-2008	44	-0,092	-0,807 ***	-0,540 ***	-0,750 ***	-0,592 ***	-0,422 **	-0,795 ***

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WADDEN SEA ECOSYSTEM No. 25

Quality Status Report 2009
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Oil Pollution and Seabirds

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5.3 Oil Pollution in Seabirds

5.3.1 Introduction

Oiled seabirds washing ashore, dead or alive, have had a signalling function since the very early days of oil pollution at sea. The number of dead oiled seabirds on the coastline is not in itself a reliable parameter for monitoring changes in oil pollution at sea. The percentage of birds that is oil contaminated among the birds found washed ashore (called the 'oil rate'), however, has proven to be a useful monitoring tool (Camphuysen, 1999, Camphuysen and Heubeck, 2001). Differences in oil rates between sea areas have clearly indicated that chronic oil pollution was more intense around shipping lanes than elsewhere (Camphuysen, 2005, Camphuysen *et al.* 2005, Camphuysen, 2007). In recent years, beached bird survey techniques have been further refined and species-specific oil-rates were introduced as the main instrument to measure trends in chronic oil pollution at sea (Camphuysen and Franeker, 1992, Camphuysen & Heubeck, 2001).

5.3.1.1 Ecological importance

Chronic oil pollution is a constant threat to seabirds and other marine life. Oiled seabirds are the most visible and obvious casualties resulting from oil spills, but the sensitivity to oil of other marine organisms and coastal habitats is enormous (Baker, 1983; Bergman, 1985; Kingston, 1992). This is particularly true for soft-sediment environments, such as the Wadden Sea, and attempts to minimize oil pollution in this area were initiated long ago. However, the most important sources of chronic oil pollution in terms of casualties among seabirds are typically situated offshore, such as shipping and offshore oil and gas exploration (Dahlman *et al*., 1994). In the 1980s and 1990s, tens of thousands of seabirds are known to wash ashore oiled each winter in the southern North Sea alone (Camphuysen, 1989), but as yet it has been difficult to demonstrate effects in terms of major population declines. There are various explanations for this, one of which is the lack of adequate data (age composition of casualties and information on breeding origin; Heubeck *et al*., 2003), but of greater significance is probably the overall success of seabirds due to, for example, shifts in prey availability due to the overfishing of predatory fish (Camphuysen and Garthe, 2000). Oil rates have declined considerably in recent years (2004 QSR), and the estimates of total numbers washing ashore should be lower than estimated previously.

5.3.1.2 Conclusions of the 2004 QSR

The results of beached bird surveys in the Wadden Sea area and its approaches indicated that oil rates have declined significantly over the last decades. The decline is most prominent in the Wadden Sea itself, whereas oil rates of birds found along North Sea shores (including the North Sea side of the Wadden Sea islands) are consistently higher than those in the Wadden Sea. Pelagic seabirds, notably common guillemots, still have relatively high oil rates and the recent designation of North West European waters as a Special Area under MARPOL Annex I (enforced in 1999) has not yet lead to a drastic further decline in oil contamination levels on beached birds. Data from the German North Sea coast suggests further declines after 1999, but recent observations in The Netherlands (winter 2002/03, and winter 2003/04) suggest a reversed trend, with very high oil rates in pelagic seabirds and repeated strandings of oil slicks on beaches (NZG/NSO unpubl. material). This reversal can only partly be attributed to some unfortunate recent oil incidents, such as the sinking of the Tricolor and the Assie Eurolink in December 2002. For most inshore species, as exemplified by shelduck and herring gull, recent oil rates are generally much lower than historic levels within the Wadden Sea). It was considered too early, to assess effects of the designation of the PSSA Wadden Sea in 2002. Longer data sets are necessary to find correlations to the measures taken on the different levels to reduce oil pollution in the area concerned.

5.3.2 Policy

5.32.1 Trilateral policies

Shipping activities are a continuous source of contamination of the marine environment with oil, garbage and hazardous substances (de Jong *et al*., 1999). Information on temporal changes and spatial differences in the oil pollution of the marine environment is being provided by Beached Bird Surveys carried out according to standardized methods and on a long-term basis. Trilateral policies for the reduction of pollution from ships were agreed at the Ministerial Conferences in Stade 1997 (Trilateral policy and management, §2.1.3-5) and in Esbjerg 2001 (Esbjerg Declaration: shore reception facilities §54-56, impacts of shipping §57-62, PSSA Wadden Sea §63-66). The aim of all these measures was the elimination of operational oil pollution, combating illegal discharges and minimizing accidental pollution by oil from shipping.

5.3.2.2 'Special Area' concept

Under MARPOL Annex I, the North Sea was listed as a Special Area in September 1997 with the adoption of the 1997 amendment that came into force on 1 February 1999 (North West European waters were designated a 'Special Area' under MARPOL Annex I). This region includes the North Sea and its approaches (including the international Wadden Sea), the Irish Sea and its approaches, the Celtic Sea, the English Channel and its approaches and part of the North East Atlantic immediately to the West of Ireland. In 'Special Areas', discharge into the sea of oil or oily mixtures from any oil tanker and ship over 400 t is prohibited. The expectations from this step were considerable, because the amounts of oil that are allowed to be spilled at sea in 'Special Areas' are so small that oiled seabirds should not occur, except in occasional oil incidents. Obviously, the declaration of a 'Special Area' status was just the first step. Intensified or at least continuous control through aerial surveillance and harbor inspections is required to prosecute offenders and to bring illegal discharges down to acceptable levels.

5.3.2.3 PSSA Wadden Sea

In 2002, following a joint application of Denmark, Germany and The Netherlands, the Wadden Sea was designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO) (Reineking, 2002). A PSSA is an area that needs special protection because of its significance for recognized ecological or socio-economic or scientific reasons. In addition, the area should be at risk from international shipping activities. The designated PSSA Wadden Sea is the marine area of the Wadden Sea Conservation Area, comprising the Wadden Sea national parks in Germany and the Wadden Sea nature protection areas in Denmark and The Netherlands. The major shipping routes have been excluded from the PSSA. The PSSA Wadden Sea designation will send strong signals to the international shipping community and increase awareness of the particular sensitivity of the area to impacts from shipping, such as oil.

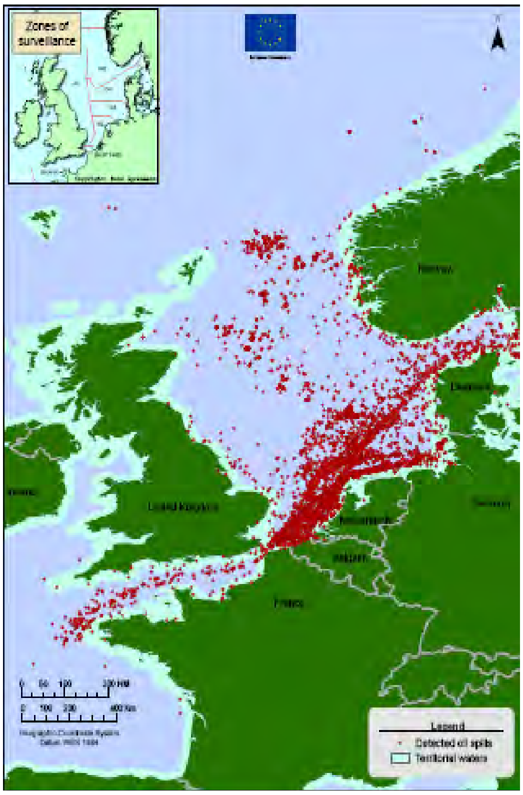

Figure 1: From 1998 to 2004, as represented in this map, a total of 4900 oil spills were detected in the North Sea by the aerial surveillance of the members of the Bonn Agreement (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, United Kingdom). http://serac.jrc.it/midiv/maps/northsea/aerial/oilspill_bonn_1998_2004.pdf

5.3.3 Sources of pollution

The sources of chronic oil pollution are diverse, and estimates of total quantities dumped or released in the marine environment vary widely (GESAMP 1993, Camphuysen, 2007). Chronic oil pollution should refer to mineral oil only, but in fact, numerous lipohilic substances are involved, including mineral oil. Few studies were capable of discriminating between types. While incidents with non-mineral oils are known to occur (Camphuysen *et al.* 1999), and while adverse effects are well known (Bommelé 1991), we have insufficient knowledge about the scale and eventual trends in the levels of non-mineral oil pollutants in the marine environment within Europe (Timm & Dahlmann 1991). With regard to mineral oil pollution, studies in the 1980s and 1990s showed that ordinary ships' fuel oils (notable heavy fuel oils, HFOs), deliberately discharged with bilge waters, are the main source of oil pollution (Dahlmann 1985, Dahlmann 1987, Dahlmann *et al.* 1994). Over 700 samples of plumage of oiled beached birds and from oiled beaches in Germany were analysed during 1998-2001 and again, over 90% of the samples contained (heavy) fuel oil residues and probably included bilge water discharges from large vessels (Reineking & Fleet 2001).

At the 4th Meeting of EGEMP and OCEANIDES (Ispra, 25-26 October 2005), the EC Joint Research Centre (JRC) presented its approach towards a European atlas and database of oil spills in the waters around Europe. This initiative was reinforced in the OCEANIDES project and a detailed presentation was given during the final workshop in 2005. During the first year of the project over 6000 oil spills were recorded, 2100 of which were detected in the Baltic (1998-2002, aircraft), 1868 in the

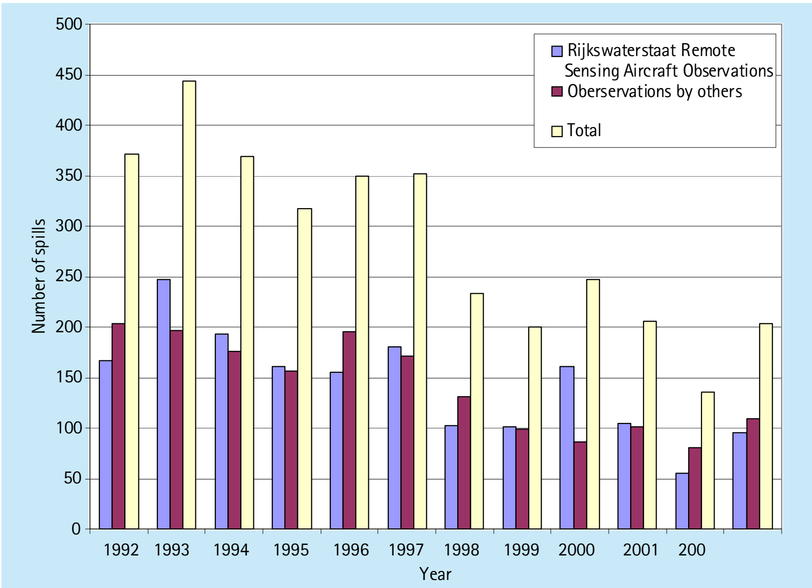

Figure 2: Reported oil spills on the Dutch Continental Shelf 1992 – 2003. (Data from Directoraat-Generaal Rijkswaterstaat, Directie Noordzee; data before 1992 is not reliable).

North Sea (1998-2001, aircraft), and 1638 in the Mediterranean in 1999 alone (satellite). By the end of the project, the data contained information on 17,650 oil spills all over Europe. Summary maps can be downloaded as PDF files at http://serac.jrc.it/midiv/maps/ and composites are reproduced below for the Mediterranean, the Baltic, the North Sea, and the Black Sea (*e.g.* Figure 1).

The results show a clear clustering of recorded slicks around the major shipping lanes in the southern and in the south-eastern North Sea. The clustering of oil slicks around the busiest areas in terms of marine shipping is clearly reflected in oil rates found on beached corpses, both in the past and in recent years, suggesting that the main source of pollution (discharges from ships) remained the same over time. It should be stressed, however, that there is little concrete information about the sources of oil pollution and other liphophilic substances in recent years.

Recent numbers of slick detections for Dutch and German waters are summarised in Figures 2 and 3.

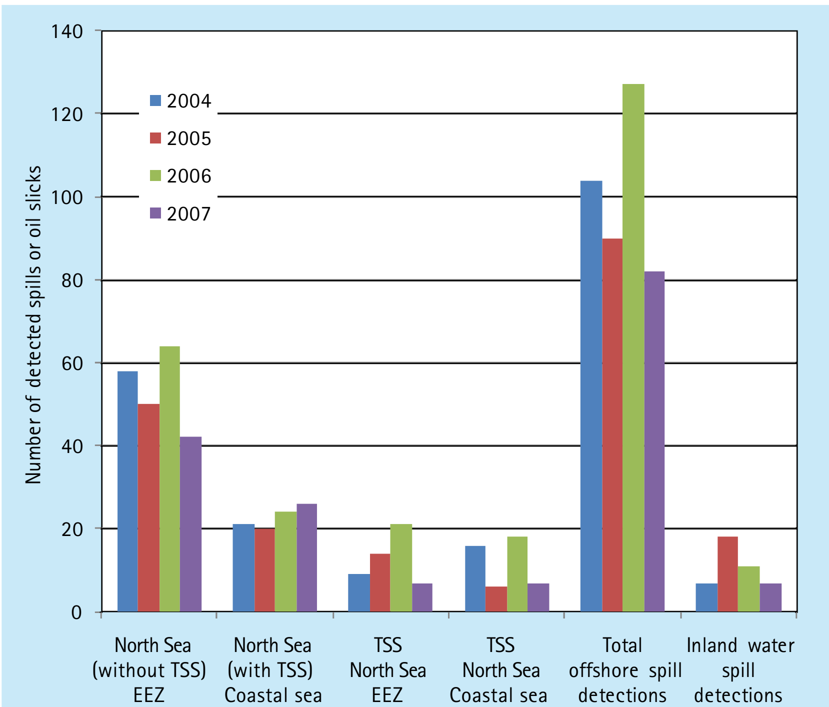

Figure 3: Reported oil spills in German waters, 2004–2007(EEZ = Exclusive Economic Zone, TSS = Traffic Separation Scheme) (Data from the Bundesamt für Seeschifffahrt und Hydrographie).

Oil incidents on the German North Sea coast in the period 2004 to 2009

In the period since the last Quality Status Report was published, one oil spill, involving fuel oil from a cargo ship, polluted the coast of Niedersachsen and two mystery oil spills polluted the Schleswig-Holstein west coast.

In the afternoon of the 6th November 2008 the cargo ship "Duncan Island" lost nine containers near Texel during a storm. One of them tore a hole in the hull in the region of the fuel tanks, so that the ship lost about 90 m^2 of heavy fuel oil. The leaking ship continued its journey eastwards along the coast of Niedersachsen to Cuxhaven, where it finally moored in the harbour there. Due to the storm only small amounts of oil were found on the coasts of the East Frisian Islands. However, in the following days lots of oiled birds were observed on the island's beaches and in the Wadden Sea. Overall 1645 oiled birds were recorded, a lot still alive. Only 80 birds could be sent to a rehabilitation centre, none of which survived. The majority of the oil victims were Common Scoter (26 %), Common Eider (19 %) and Guillemot (11 %). These birds were oiled at sea. However, a large proportion of the birds were oiled on the beaches *e.g.* Sanderling (13.7 %) and Herring Gull (9 %). This accident resulted in the high oiling rate of birds recorded in Niedersachsen in the Winter 2007/08.

Both mystery spills in Schleswig-Holstein were of heavy fuel oil produced from Russian crude oil (information from the BSH-Hamburg). In February 2004 approximately 2000 oiled birds were found dead or dying on the Schleswig-Holstein Wadden Sea coast. 83 % of the oiled birds were Common Scoter, 7 % Common Eider and 3 % Guillemot. The first birds were found on the 5th February and most birds were recovered between the 11th und 19th of February. Nearly all birds were recovered in Northern Friesland, mostly on the islands, Hallig Islands and sandbanks of that region. In February 2008 a second oil spill hit the west coast of Schleswig-Holstein. Although only a small amount of oil was found on the beaches, approximately 1500 oiled birds were recovered. The majority of oil victims were again Common Scoter (97 %). Two percent were Guillemots and 1% Common Eider. The first birds were found on the 3rd February and most birds were recovered between the 5th und 9th of that month. As in 2004 nearly all the birds were found in the Northern Friesian region mainly on the islands of Amrum (61%) and Föhr (27%).

Northern Friesland is a hot spot for oil spills in the Wadden Sea (see figure 4.4.1 Wadden Sea QSR 2004). At regular intervals oil pollution kills huge numbers of mainly Common Scoter in that region. The Common Scoter winter population there numbers about 80,000 individuals. It is a well known fact that the number of birds found dead or dying on the coast represents only a small proportion of the birds actually hit by the oil spill. It can be assumed that a relatively high percentage of the Common Scoter wintering off the North Friesian coast have fallen victim to oil pollution in recent years. To what extent this is affecting the population of this sea duck species is unknown.

5.3.4 Oiled Seabirds

Systematic beached bird surveys, organized to assess the fraction of oiled seabirds washed ashore among the total number of dead birds found on beaches (oil rate), have been intense for decades, particularly in Denmark, Germany and The Netherlands (Joensen, 1972 a,b; Joensen and Hansen, 1977; Reineking and Vauk, 1982; Averbeck *et al.*, 1993; Camphuysen, 1989, 1997; Reineking, 1997; Fleet and Reineking, 2000, 2001; Durinck and Skov, 2001; Fleet *et al.*, 2003). Earlier results indicated slow but consistent declines in oil rates over the past decades (Camphuysen, 1997, 1998; Durinck and Skov 2001; Fleet and Reineking, 2001). Since the 1999 QSR, oil rates of the most common seabird found on North Sea beaches, the common guillemot *Uria aalge*, an indicator for marine oil pollution, have been proposed as one of the Ecological Quality Objectives (EcoQOs) (Camphuysen, 2005) by the Biodiversity Committee (BDC) of the OSPAR Commission. The EcoQO, as agreed by the 5th North Sea Conference, was defined as: the proportion of oiled common guillemots should be 10% or less of the total found dead or dying individuals of this species, in all areas of the North Sea. Common guillemots were chosen on the basis of their wide distribution in winter and their sheer abundance: sufficiently large samples could be obtained each winter in all North Sea countries to calculate a reliable oil rate figure. The methodology of both the surveys and the subsequent analysis of data has been described previously (Camphuysen and Dahlmann, 1995; Camphuysen and Meer, 1996; Camphuysen and Heubeck, 2001, Camphuysen 2005).

In Dutch North Sea waters, the mean oil rate (± SD) of common guillemots has been over the most recent 5 winters (2003/04 - 2007/08) 51.3 ± 17.4% (North Sea coast of Delta area, mainland and Wadden Sea islands included). Within the Wadden Sea the oil rate amounted to 36.5 ±

13.8% over the same seasons (a non-significant difference, t_8 = 1.5, P= 0.086 (one-tailed test). When calculating mean oil rates over the North Sea coast of the Wadden Sea islands only (as in Table 4.6.1), the mean of 47.9 ±17.6% is even less different from the within-Wadden Sea situation.

In German North Sea waters, the mean oil rate (± SD) of common guillemots has been over the most recent 5 winters (2003/04 - 2007/08) 35.9±24.2%. Within the Wadden Sea the oil rate amounted to 30.2 ±17.0% over the same seasons (sample size 2005/06 and 2007/08 >10 but less than 25).

In Danish waters surveys of beached birds following the method recommended by OSPAR were initiated in winter 2004/05 and are performed at four beaches situated along the North Sea coast (Skallingen, Fanø and Rømø) and at the mainland coast (off Ribe). For common guillemots the average percentage of oil rates during the seasons 2004/05 – 2007/08 was 28.1 % and no difference were found between the numbers of guillemots washed ashore along the North Sea coasts and the mainland coast, when corrected for differences in covered coast lengths. For shelduck and herring gull no birds with oil were found during the four winter seasons and for common eider oil rate was 1.0 %.

5.3.5 Trends in oil rates in the Wadden Sea area

In the following analysis, the Danish-German-Dutch North Sea coast has been subdivided into ten sub-regions based on the planning of surveys in each of the participating countries (Table 1). Within the sub-regions a distinction was made between (1) coast exposed to the Wadden Sea (mainland coast as well as island coast facing the mainland) and (2) coast exposed to the North Sea (on islands). The second column (DK) comprises data for the Danish Wadden and North Sea, the last column (NL mainland) includes data for the Dutch mainland coast of the North Sea south of the Wadden Sea.

For common guillemots, one conclusion can be drawn straight away: the EcoQO of 10% oiled has not yet been reached, although an overall decline in oil rates since the mid-1980s is obvious (Table 1; Figure 4). The results give a modest indication of a sharper decline since 1999, and in fact, with the exception of Germany's North Sea exposed coasts, oil rates seem to have stabilized over the most recent years at levels just below 50%. On the Schleswig-Holstein (SH) North Sea exposed coast in Germany, the average oil rate since 1999 is 34%. This is significantly lower than the average for the winters 1992/93 to 1997/98 (62%). On the North Sea exposed coast in Niedersachsen (Nds), this difference was less apparent. Nevertheless, the lowest three oil rates recorded in the period 1992/93-2002/03 in this region were measured in the last three years, with the lowest value on record - 29% - in 2002/03. Camphuysen (2003) observed a reverse trend in oil rates in pelagic seabirds in 2002/03 (Table 1), but concluded that this might have been caused by an unfortunate coincidence of oil incidents (including the 'Tricolor' in the Channel and the 'Assie Eurolink' that sank north of Terschelling). It should be noted, however, that high oil rates in common guillemots occurred again in winter 2003/04 (70%; NZG/NSO unpubl. data; not included in the present analysis), indicating that chronic oil pollution levels are still high.

Oil rates fluctuate from year to year, and where oil incidents or significant local spills may raise oil rates, natural mortality events have a tendency to lower the values found. These fluctuations introduce some noise in the signal received, but we chose not to arbitrarily remove values from the time series, but rather to work with the variability in the material as it was found. It is very interesting to note that several of the more drastic variations between seasons are synchronous in all or at least most sub-regions studied (Table 1; Figure 4).

Common guillemots may not be considered a typical example of the Wadden Sea avifauna; other abundant seabirds deserve attention. For most inshore species, as exemplified by shelduck and herring gull, recent oil rates are generally much lower than historic levels within the Wadden Sea. In the Danish part of the Wadden Sea, a recent increase in the oil rates of gulls and other inshore species has been recorded (Durinck and Skov, 2001). Common eider *Somateria mollissima*, shelduck *Tadorna tadorna*, and herring gull *Larus argentatus* were selected as numerous representatives of the Wadden Sea bird population. Because individual winter seasons did not always provide sufficient samples, the data was grouped in time intervals and overall oil-rates were calculated (Table 2). Two trends are apparent: (1) higher oil rates in the 1970-1980s than in recent years, and (2) for each species, higher oil rates along North Sea shores than within the Wadden Sea itself. The first trend is in agreement with overall declines in oil pollution reported in Western Europe, the second is in line with earlier conclusions that the North Sea (and the shipping lanes in it) is much more oil-contaminated than the Wadden Sea area.

Table 1.
Oil rates in Common Guillemots (% oiled of total number found) in the sub-regions in and around the Wadden Sea in winter 1984/85-2002/03. Blank cells indicate insufficient data (sample 25 individuals or more), or no sampling effort.
DK = Danish west coast including Wadden Sea; German Bight; FRG Nds ws = Wadden Sea exposed coasts in Niedersachsen; FRG Nds ns = North Sea side of the islands in Niedersachsen; FRG SH ws = Wadden Sea exposed coasts in Schleswig-Holstein; FRG SH ns = North Sea side of the islands Schleswig-Holstein; NL ws = Dutch coasts Wadden Sea exposed; NL islands = North Sea side of the Dutch Wadden Sea islands; NL mainl = Dutch North Sea coast southwards of Den Helder.
ns = North Sea exposed (coast of the islands facing the North Sea).
ws = Wadden Sea exposed (mainland coast as well as island coast facing the mainland)

	DK	FRG	FRG	FRG	FRG	NL	NL	NL
Winter		Nds	Nds	SH	SH		Islands	mainl
		ws	ns	ws	ns	ws	ns	ns
1988/89	78.4					52.7	86.7	58.0
1989/90	66.2						67.8	66.7
1990/91	74.8						62.5	84.1
1991/92	85.2						96.7	96.5
1992/93	31.1		50.5		43.4	22.2	18.4	28.1
1993/94	54.2		48.2	65.5	78.7	36.1		50.3
1994/95	71.3		75.0		72.5			47.2
1995/96			53.7					
1996/97			62.1		80.0			83.3
1997/98	55.6		60.2		34.5			62.5
1998/99	43.8	3.9	25.0	29.3	24.6	3.3	27.1	25.6
1999/00	59.6		54.2	11.5	33.3		22.2	65.3
2000/01			40.5	18.5				
2001/02	46.6		37.7	31.3	33.3			60.0
2002/03	56.0		35.3		37.1			98.2
2003/04			47.4	35.1	10.3	43.1	70.2	83.9
2004/05	50.0		41.1	14.8	2.4	43.3	39.7	60.0
2005/06						47.9	57.0	55.6
2006/07	3.8		17.9	23.0	7.4	13.3	23.6	29.1
2007/08			80.3			35.0	48.8	47.4

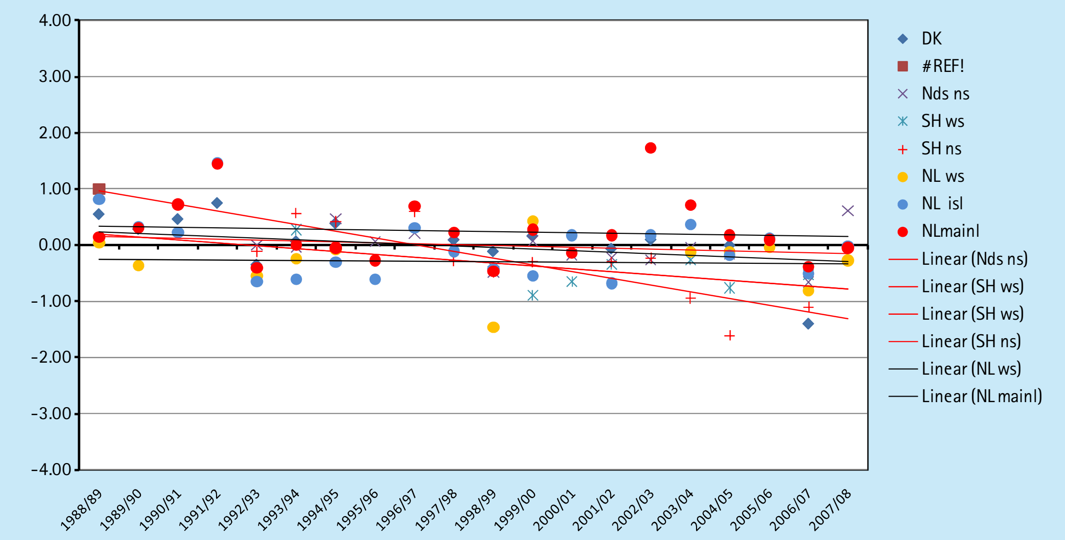

Figure 4: Logit-transformed oil rates in common guillemots in the areas around the Wadden Sea (*cf.* Table 1) and overall declining linear trends in the Netherlands (black lines), and in Germany (red lines). Logit values of 0.0 refer to oil rates to 50%; 100% and 0% are infinitely large positive and negative values respectively.

Table 2:
Grouped oil rates in shelduck, common eider and herring gull (% oiled of total number found) in the sub-regions in and around the Wadden Sea within five-year periods since winter 1977/78. Blank cells indicate insufficient data (sample <25 individuals). See table 1 for sub-regions. ns = North Sea exposed (coast of the island facing the North Sea), ws = Wadden Sea exposed (mainland coast as well as island coast facing the mainland)

	DK	FRG	FRG	FRG	FRG	NL	NL	NL
		Nds	Nds	SH	SH			
Shelduck		ws	ns	ws	ns	ws	islands	mainl.
1977-81						7.1	39.7	26.7
1981-86						7.6	15.1	32.8
1986-91						3.2	22.0	5.7
1991-96			2.3		7.7	1.1	7.9	3.6
1996-01			1.0	11.6	9.4	3.6	2.4	0
2001-06	5.9	4.0	1.5	1.0	0.0	0.5	0	
2007-08			3.7	0.0	7.7	0		
Common Eider								
1977-81						37.9	58.3	68.4
1981-86						22.0	26.2	35.7
1986-91						20.3	47.6	60.7
1991-96			11.1	17.8	30.0	8.0	6.8	29.9
1996-01		1.9	2.2	14.4	7.3	3.2	5.5	16.5
2001-06	12.6	0.0	1.4	4.6	4.9	1.5	3.7	12.5
2007-08		61.1	49.0	7.1	0.7	0.9	1.9	
Herring Gull								
1977-81						21.3	50.3	58.2
1981-86						14.9	31.4	44.3
1986-91						6.1	25.8	25.7
1991-96			4.1	0.0	14.3	5.1	16.6	22.2
1996-01		0.0	2.3	2.7	13.4	4.2	16.9	11.9
2001-06	1.1	2.9	3.2	5.1	5.9	2.2	7.0	15.8
2007-08		8.0	52.6	4.8	0.0	0.0	4.9	0.0

5.3.6 Conclusions

The results of beached bird surveys in the Wadden Sea area and its approaches indicate that oil rates have declined significantly over the last decades. The decline is most prominent in the Wadden Sea itself, whereas oil rates of birds found along North Sea shores (including the North Sea side of the Wadden Sea islands) are consistently higher than those in the Wadden Sea. Pelagic seabirds, notably common guillemots, still have relatively high oil rates and the designation of North West European waters as a Special Area under MARPOL Annex I in 1999 did not lead to a drastic decline in oil contamination levels on beached birds on the coasts in the Wadden Sea region. For most inshore species, as exemplified by shelduck, common eider and herring gull, recent oil rates are generally much lower than historic levels within the Wadden Sea). High oil rates for a number of species in Niedersachsen in the winter 2008/08 are a result of the Duncan Island oil incident.

The effect of the designation of the PSSA Wadden Sea in 2002 is unclear, for within the Wadden Sea, oil rates have always been lower than along the North Sea coasts. The decline in oil rates within the Wadden Sea is consistent with the overall decline in oil rates in Western Europe, but generally slightly steeper.

5.3.7. Evaluation of the target

A specific target regarding beached oiled birds has not been formulated in the Wadden Sea Plan until now. However, the Ecological Quality Objective (EcoQO), as developed within the OSPAR framework and described above, can be applied and evaluated. Although an overall decline in oil rates since the mid 1980s is obvious, the Ecological Quality Objective (EcoQO) of an oil rate of less than 10% in common guillemots has not yet been reached.

5.3.8 Recommendations

Continuation of beached bird surveys in each of the three countries as an important monitoring tool to evaluate trends in chronic oil pollution at sea is strongly recommended. The analysis presented here suffered from inconsistencies over time in the choice of sub-regions, shortening data series and reducing the statistical power of the material. It is therefore strongly recommended to keep the most recent subdivision of the survey area in the future, so that trends can be followed with greater confidence.

It is of great importance to maintain the spread of observer activity over the entire winter period, and not to fall back to a level of isolated mid-winter surveys. The Beached Bird Surveys in the framework of the TMAP should be ensured over the entire winter period with harmonized survey frequency in the three Wadden Sea states.

The implementation of the analysis of oil from bird feathers and beach samples is strongly recommended (cf. Dahlmann *et al.*, 1994; Fleet & Reineking, 2001). Uncertainties with regard to the sources of oil pollution, issues that are difficult to deal with in aerial surveys and satellite monitoring programs, can be solved this way. Oil analysis of beach and/or feather samples can also be successfully used as legal evidence in prosecuting oil discharge by ships (Dahlmann, 1991) and for North Sea wide oil pollution control measures.

With North West European waters established as a Special Area under MARPOL Annex I, a lot has been achieved. However, just making an area a Special Area is rather pointless if this is not enforced by (national) law and if this law is not adequately implemented. It is clear that additional measures are required to make sure that mariners obey the regulations and stop discharging oil or oily waters (<15 ppm) within this area. Among others, the following actions regarding pollution prevention as well as control and enforcement measures would help to reduce chronic oiling as a threat to marine wildlife:

- Mandatory on-board transponders and oil fingerprinting of all vessels in North Sea waters would facilitate surveillance, enforcement and the prevention of pollution;
- Harmonization and implementation of the EC Directive 2000/59/EC on port reception facilities, including 100% indirect financing of waste collection;
- Implementation of a ship accreditation system for skippers who promote and adopt best environmental practices and have clean environmental records;
- Increase of co-operation between EU-countries, including information exchange and increased frequency of joint exercises regarding, for example, aerial surveys;
- Stronger legal deterrence. Imposed (minimum) fines must be increased to clearly reflect the full extent of the crimes under both shipping and environmental laws;
- Improvement / extension of aerial surveillance.

As a more specific step to try and reduce oil rates in seabirds (and to protect sensitive areas), it is recommended to identify, monitor and protect sensitive areas at sea in the North Sea, also areas other than the PSSA Wadden Sea. Spatial patterns and seasonal trends in vulnerable concentrations of seabirds in the North Sea and west of Britain have been identified and published. Despite this knowledge, there is little evidence that this information is being used to improve planning of clean-up operations (*e.g.* Tricolor incident), in the decision process to either immediately combat illegal spills at sea or leave them to disperse naturally (and slower), or in the planning of aerial surveillances for oil at sea. A stronger emphasis on the most vulnerable areas could help to reduce the oil problem.

A final step is education. During training of sea cadets it should be emphasized that even a very small amount of discharged oil can cause immediate and serious damage to the environment, and that it is not so much the amount of oil spilled but the time and location where the oil is released that leads to significant mortality among seabirds and other marine wildlife. It may at least be hoped that the information provided will be remembered and that an illegal discharge will be recognized as a criminal act by the offender himself.

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Eutrophication

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1. Introduction

Eutrophication is one of the factors that influences the quality of the Wadden Sea area. Since the earliest nutrient measurements in the Wadden Sea (Postma, 1954; Postma, 1966; Hickel, 1989) a clear increase in nutrient concentrations has been documented (*e.g.* de Jonge and 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 and de Jong, 1992), increased blooms of green macroalgae (Reise and Siebert, 1994) and anoxic sediments (Black Spots; de Jong *et al.*, 1999a). Recently, decreasing riverine nutrient loads and decreasing phytoplankton standing stock have been observed in the Wadden Sea (Cadée and Hegeman, 2002; van Beusekom *et al.*, 2009).

A trilateral target was adopted to aim for "A Wadden Sea which can be regarded as a eutrophication non-problem area". The concept of the eutrophication problem and non-problem-areas was introduced in the framework of OSPAR (1997).

The following sections summarize the findings of the last QSR (Essink *et al.*, 2005), and the results of the OSPAR Common Procedure in 2008. In the chapter Data Analysis, recent trends in nutrient loads, nutrient concentrations and in phytoplankton and macroalgae biomass are described. A target evaluation and recommendations are given. The present report updates and extends the data analysis of the QSR 2005 (Essink *et al.*, 2005).

1.1 Finding of the QSR 1999

In the 1999 Wadden Sea Quality Status Report, trends in nutrient concentrations of the Wadden Sea were analyzed by Bakker *et al.* (1999) for the period 1985-1996. The authors noted that nutrient concentrations in the Wadden Sea during winter are correlated with salinity. Therefore, actual concentrations cannot be directly compared unless they are standardized to a specific salinity. Details of the 'concentration – salinity' method are given in de Jong *et al.* (1999). The analysis in the 1999 and 1993 QSRs are based on winter concentrations normalized to standard salinities of 10 and 27. A decrease was observed for phosphate (PO_4, dissolved inorganic phosphorus or DIP), but no trend was observed for nitrogen nutrients. The QSR 1999 also stated that reductions in phosphate had not led to a reduction of biological phenomena which may be related to nutrient loading, notably average chlorophyll concentrations, the duration of *Phaeocystis* blooms in the Marsdiep and growth of macrozoobenthos.

1.2 Findings of the QSR 2004

In contrast to the 1999 QSR, the QSR 2004 (van Beusekom *et al.*, 2005) could demonstrate a decrease in riverine nutrient input. The effect on the eutrophication status was shown by two indicators: autumn NH_4+NO_2 concentrations (developed as a Wadden Sea Specific Eutrophication Criterion, [van Beusekom *et al.*, 2001] and applied in the 2004 QSR) and mean summer chlorophyll (developed for the QSR 2004).

Category I: Nutrients.

Riverine nutrient input showed a gradual decrease during the period 1997-2002. This was reflected by the phosphate concentrations in winter in the Wadden Sea that decreased since the mid 1980s 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 was detectable yet.

Category II: Direct effects on primary producers

Decreasing riverine TN loads had a significant effect on the phytoplankton biomass (as chlorophyll) in summer in most of the Southern Wadden Sea. In the Northern Wadden, a less clear picture emerges. Only in the List Tidal Basin, (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. The most conspicuous blooms were observed in 1998 and 2000 along the Danish west coast, with large, ichthyotoxic *Chattonella* blooms. 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 1990s.

Category III: Direct effects on organic matter

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 were a good indicator of organic matter turnover in the Southern Wadden Sea, but not for the central and Northern Wadden Sea.

The OSPAR Common Procedure

In 1997, the OSPAR Commission adopted the so-called Common Procedure for the identification of the eutrophication status of the Maritime Area of the OSPAR Convention (OSPAR, 1997). The Common Procedure distinguishes three areas:

- Problem Areas are those areas for which evidence of an undesirable disturbance to the marine ecosystem due to anthropogenic enrichment by nutrients exists
- Potential Problem Areas are those areas for which there are reasonable grounds for concern that undesirable disturbance may occur
- Non-Problem Areas are those for which such concerns do not exist.

The Common Procedure consists of two steps, the Screening Procedure and the Comprehensive Procedure (COMP). The Screening Procedure identifies with a "broad brush" approach those areas that are likely to be eutrophication Non-Problem Areas. It was not applied to the Wadden Sea because it was claimed to be at least a Potential-Problem Area. The Comprehensive Procedure identifies Problem Areas and Potential Problem Areas based on parameters from a "holistic checklist" and if necessary based on region-specific criteria. The latter were developed for the Wadden Sea by van Beusekom et al., (2001) and are grouped according to the Comprehensive Procedure below:

Causative Factors (Cat. I) are atmospheric and riverine nutrient input. The effect of the increased nutrient input is best seen in changes in the annual nutrient cycle.

Supporting Factor (Cat. II) for Wadden Sea eutrophication is the import of organic matter from the adjacent North Sea.

Direct Effects (Cat. III) of eutrophication could be observed in all biota of the Wadden Sea. However, no clear dose-response relation could be identified. Other factors like weather, temperature or more complex interactions also play important roles in the proliferation of eutrophication effects.

Indirect Effects such as changes in zoobenthos biomass and species composition were observed, but no clear dose-response relation could be identified.

Regional differences

The data analysis highlighted 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 were about two times higher than in the Northern Wadden Sea, suggesting a more intense eutrophication of the Southern Wadden Sea.

Background values

Compared to background TN concentrations in rivers entering the North Sea, mean TN values of 4-5 mg/l (~1990 – 2000) were about 7-8 times higher. The organic matter turnover rates in the Wadden Sea were estimated to be about 3-5 times compared to pristine conditions (van Beusekom, 2005).

1.2 OSPAR Eutrophication Assessment 2008 according to the Comprehensive Procedure

The OSPAR convention area was assessed with the Comprehensive Procedure for the period 2000 – 2005 (OSPAR 2008). The Wadden Sea was classified as a eutrophication problem area by Denmark, Germany and The Netherlands. As criteria, deviations from background levels were used. All three countries used nutrient enrichment, elevated chlorophyll levels, problems with nuisance algae and algal toxins/toxic algae as criteria. Differences and uncertainties in the assessment of the eutrophication effects on macroalgae, macrobenthos and oxygen dynamics are apparent (Table 1).

Table 1: Summary of the Wadden Sea Eutrophication Assessment by OSPAR (OSPAR 2008). All three Wadden Sea countries assessed the Wadden Sea as a Problem Area. Key to the table: **–**: Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters **+**: Increased trends, elevated levels, shifts or changes in the respective assessment parameters **?**: Not enough data for an assessment or the data available is not fit for the purpose **Nr**: Not relevant.

		The Netherlands	Germany	Denmark
Cat I:	Riverine Input	+	?	-
	Winter Concentrations	+	+	+
	N/P ratios	+	+	-
Cat II:	Chlorophyll levels (Max. and Mean)	+	+	+
	Area specific Phytoplankton Indicator Species	+	+	-
	Macrophytes	?	?	-
Cat III:	Oxygen Problems	-	Nr	-
	Changes/Kills of Macrobenthos	?	?	(+)
	Organic matter/Organic Carbon	-	+	-
Cat IV:	Algal toxins	-		-

2. Data analysis

Data analysis focussed on long (>15 years) time series covering the entire seasonal cycle with a temporal resolution of at least once a month. All available data were summarized to monthly means. We extended the approach adopted in the QSR 2004. In short, we analysed the riverine input and the responses of the different Wadden Sea regions to the riverine input levels. As proxies, we used the autumn levels of ammonium and nitrite (based on Wadden Specific Eutrophication Criteria, van Beusekom *et al.*, 2001) and summer chlorophyll levels (QSR 2004). As in the previous assessments, we focussed on nitrogen but acknowledge the conflicting views as to whether nitrogen or phosphorus ultimately limits the production levels in the Wadden Sea in some areas like the Western Dutch Wadden Sea (*e.g.*, Philippart *et al.*, 2007).

2.1 Causative factors

River Input

Riverine input data are based on monitoring data that were interpolated to daily loads (Lenhart and Pätsch, 2001; updated until 2006). The major sources influencing the Southern Wadden Sea are Haringvliet, Maassluis, Noordzeekanaal, IJsselmeer and Ems. The first four sources are in a wider sense part of the Rhine-Meuse delta. Major sources for the Central Wadden Sea (Jade-Eiderstedt) are the rivers Weser and Elbe. The latter rivers are also major nutrient sources for the Northern Wadden Sea, where small rivers (Eider, Danish rivers) contribute about 6-7%. The relative contributions of the above mentioned river sources are compiled in QSR 2004.

The high inter-annual variability of riverine nutrient input is largely due to two factors: differences in inter-annual freshwater discharge and a general decrease in nutrient concentrations. Figures 1 and 2 show that peaks in freshwater discharge coincide with peaks in nutrient loads: in general, the annual nutrient loads correlate significantly with the annual freshwater discharge. Specific (normalized) nutrient loads (annual nutrient load divided by annual discharge) show a steadily decreasing trend for TN and TP for the major rivers entering the Wadden Sea (Figure 3). Since 1985, the specific TN load to the Southern and Central Wadden Sea decreased on average each year by 2.1%. The specific TP load decreased more strongly than the specific TN load, but during recent years the rate of decrease slows down. It now amounts to 2.9% per year for the Southern Wadden Sea and 2.1% per year for the Central Wadden Sea. Note that during the period 1985-2002 the rates were about 0.4% higher. Especially for the Elbe and Weser, a slow-down in the decrease in specific TP load is evident since about 1990.

Atmospheric Input

In the QSR 2004, a total (wet) nitrogen deposition in the Wadden Sea of about 0.8 g N m^{-2} y^{-1} was estimated (wet + dry deposition: 1.2 g N m^{-2} y^{-1}). Recent estimates in the framework of OSPAR (Bartnicki and Fagerli, 2006) support this estimate. Total annual wet deposition at the OSPAR monitoring station in the Southern Wadden Sea area ranged during 1990 and 2004 between ~700 and ~1200 mg N m^{-2} and in the northern

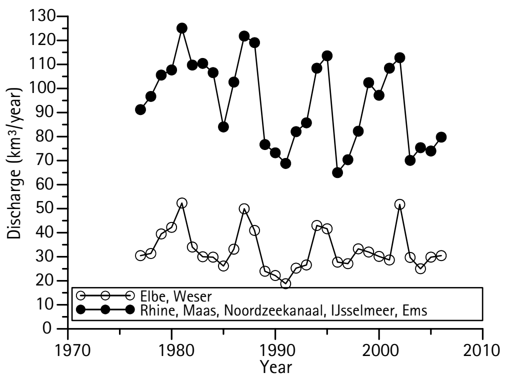


Figure 1: Major annual freshwater discharges influencing the Southern Wadden Sea (Rhine, Meuse, Noordzeekanaal, IJsselmeer and Ems) and the Central and Northern Wadden Sea (Weser, Elbe). Data source: DONAR, Lenhart & Pätsch (2001), updated to 2006.

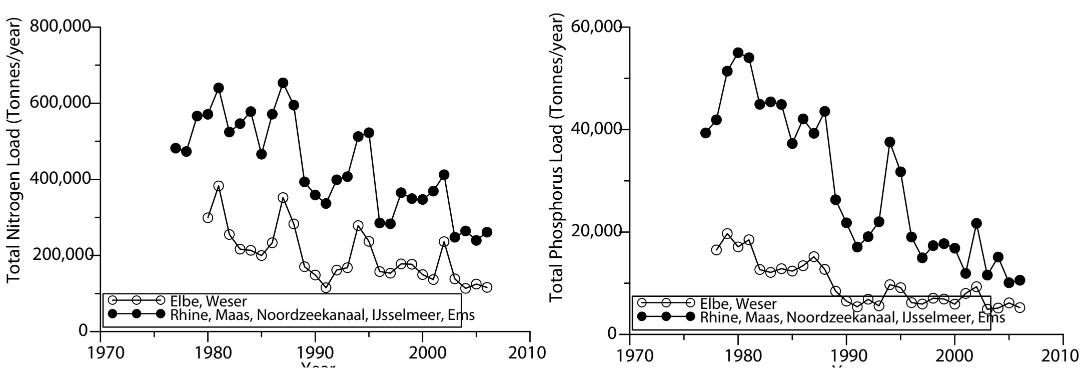


Figure 2: Major riverine TP and TN loads to the Southern Wadden Sea (Rhine, Meuse, Noordzeekanaal, IJsselmeer and Ems) and to the Central and Northern Wadden Sea (Weser, Elbe). Data source: DONAR, NLWKN, Lenhart and Pätsch (2001), updated to 2006.

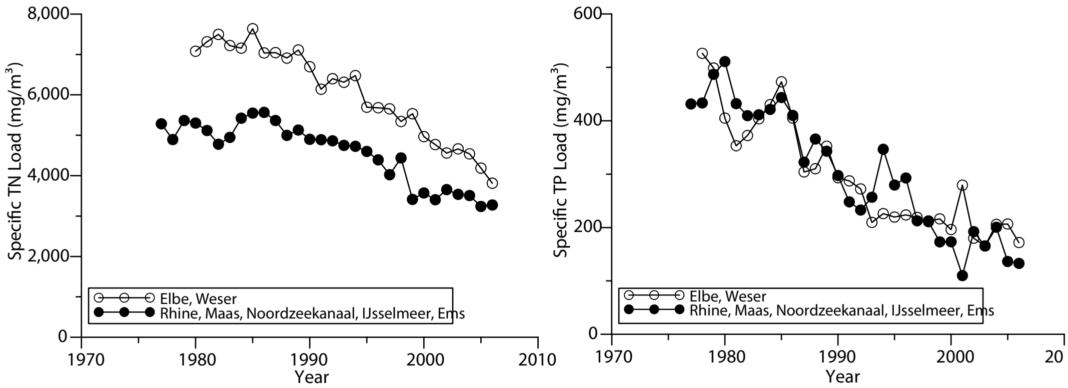


Figure 3: Specific nitrogen and phosphorus load (mean annual load / mean annual discharge) to the Southern Wadden Sea (Rhine, Meuse, Noordzeekanaal, IJsselmeer and Ems) and to the Central and Northern Wadden Sea (Weser, Elbe). Data source: DONAR, NLWKN, Lenhart and Pätsch (2001), updated to 2006.

area between ~550 and ~1000 N m^{-2}. Between 1990 and 2004 no significant reduction in Area 8 (off-shore Wadden Sea and German Bight) occurred. Carstensen *et al.* (2008) analyzed the input data for the Danish Wadden Sea and observed a downward trend between 1990 and 2006.

Winter concentrations

Winter concentrations in the North Sea depend strongly on salinity (*e.g.*, van Bennekom and Wetsteyn, 1990; Körner and Weichart, 1992). Monitoring data by the BSH reflect the gradual decrease in riverine nutrient input (Weigelt-Krenz *et al.*, 2010) and show a decrease of DIN (dissolved inorganic nitrogen) at a salinity of 30 from ~60 µM in 1985 to ~45 µM in 2006. Phosphate decreased in that period from ~2.5 µM to ~1.0 µM.

Also in the Wadden Sea, winter nutrient concentrations correlate with salinity. In order to describe trends and to compare the different areas, the winter concentrations were normalized to a salinity of 27. This estimate was only made if a significant correlation between nutrient concentrations and salinity was present. If not, the mean winter concentration was calculated. In case of significant correlations, the concentration at a salinity of 10 was also estimated. Details of this method are given in the QSR 1999.

Figures 4 and 5 present updates of the QSR 2004 for nitrate and phosphate. The salinity normalized winter nitrate data (at salinity 27) now show a downward trend in some areas since the early 1990s. In the Dutch Wadden Sea, a slight decrease from around 50 µM (early 1990s) dropped to around 40 µM (since 2002). In the Ems river district (Ems estuary and Lower Saxony), winter nitrate decreased from 80 µM (early 1990s) to around 60 µM (since 2002). In Dithmarschen (Eider district), winter nitrate decreased from 70-80 µM (early 1990s) to around 50-60 µM (since 2002). In the North Frisian Wadden Sea and in the Danish Wadden Sea, no clear trends were observed. Salinity normalized concentrations were around 44-49 µM.

Two other studies indicate downward trends in the North Frisian and Danish Wadden Sea. Carstensen (2008) analyzed long-term monitoring data from the Danish Wadden Sea and also observed a decrease in TN levels in the Danish Wadden Sea. Van Beusekom *et al.* (2008) observed a downward long-term trend in winter nitrate concentrations in the List Tidal Basin of about 2% per year. The downward rate compares favourably with a similar riverine trend. The authors observed that, at a given salinity, the nitrate concentrations were always lower than in the adjacent German Bight and concluded that denitrification plays an important role in winter nitrate dynamics.

Salinity-normalized winter phosphate concentrations showed the strongest decrease between 1985 and 1995 (QSR 2004). Since then, no further changes are apparent for most areas and salinity normalized concentrations range between ~0.9 µM in the western Dutch Wadden Sea, and ~1.1 µM in the Danish Wadden Sea to around 1.8 µM near the Ems and Elbe estuaries. Only in the western Dutch Wadden Sea was a further decrease, of 1.4 µM during the early 1990s to about 0.9µM since 2002, observed.

2.2 Direct effects

Phytoplankton

Phytoplankton biomass and productivity

The analysis of chlorophyll data (an indicator of phytoplankton biomass) focuses on summer chlorophyll means (May-September) instead of annual means. We excluded data from March-April because at least in the North Frisian Wadden Sea the spring phytoplankton dynamics are related to winter temperatures (van Beusekom *et al.*, 2009).

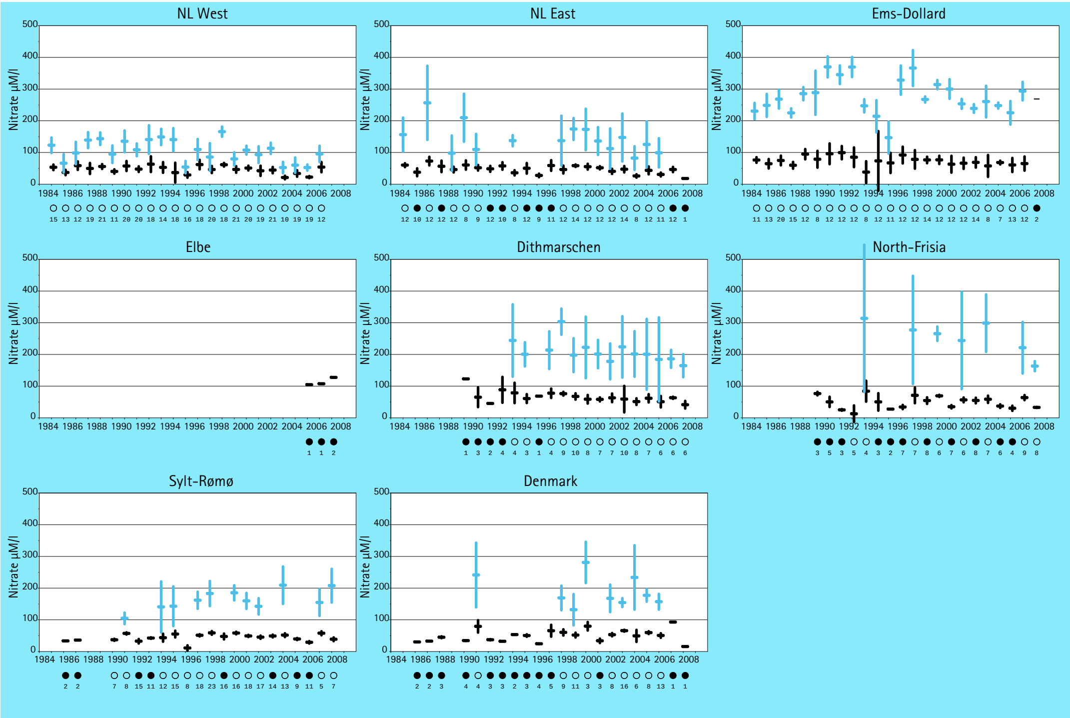


Figure 4: Trends in winter nitrate+nitrite concentrations (µM/l) (December–February) in the river basin districts of the Wadden Sea. The concentrations and standard deviations are normalized to a salinity of 30 (black symbols) and 27 (black symbols). Open dots below indicate a significant correlation with salinity. In this case, the concentration at salinity 27 was estimated. Solid dots indicate no significant correlation with salinity. Data source: TMAP Data Units.

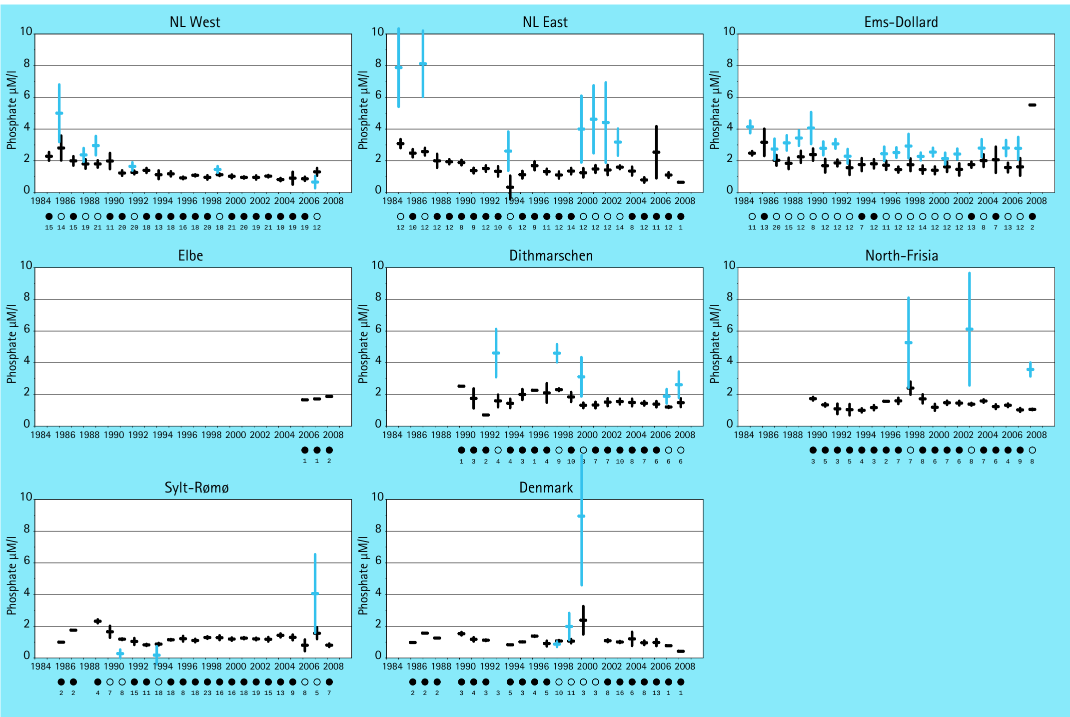


Figure 5: Trends in winter phosphate concentrations (µM/l) (December–February) in the river basin districts of the Wadden Sea. The concentrations and standard deviations are normalized to a salinity of 30 (black symbols) and 27 (black symbols). Open dots below indicate a significant correlation with salinity. In this case, the concentration at salinity 27 was estimated. Solid dots indicate no significant correlation with salinity. Data source: TMAP Data Units

Table 2:
Comparison of summer chlorophyll levels (µg/l; May-September) in different parts of the Wadden Sea (2000-2006) and their correlation with TN input (December-August) via Rhine and Meuse (Dutch Wadden Sea, Norderney) or via Weser and Elbe (Schleswig-Holstein, List Tidal Basin, Gradyb). For comparison, background values are included that were taken from the national reports prepared for the Second OSPAR Eutrophication Integrated Report on Eutrophication.
Data source: TMAP Data Units, DONAR (P. Bot), LANU (T. Petenati, J. Goebels), NLWKN (M. Hanslik), AWI (J. van Beusekom), Lenhart & Pätsch (2001, updated until 2006), DMU (J. Carstensen).

Area	Period	Trend	Correlation	Summer mean (2000-2006)	Background
Western Dutch Wadden Sea	1976-2006	Yes	r^2=0.59; n=30; p<0.0001	9.7 µg Chl/l	8 µg Chl/l
Eastern Dutch Wadden Sea	1976-2006	No	r^2=0.00; n=30; p=0.87	19.9 µg Chl/l	8 µg Chl/l
Lower Saxon Wadden Sea (Norderney)	1988-2006	Yes	r^2=0.450; n=22; p=0.0006	11.5 µg Chl/l	2-3 µg Chl/l
Southern Schleswig-Holstein	1998-2006	No*	r^2=0.00; n=9; p=0.98	12.8 µg Chl/l	2-3 µg Chl/l
Northern Schleswig-Holstein	1998-2006	No*	r^2=0.07; n=9; p=0.478	5.4 µg Chl/l	2-3 µg Chl/l
List Tidal Basin[1]	1984-2006	Yes**	r^2=0.31; n=23; p=0.0056	5.9 µg Chl/l	2-3 µg Chl/l
Gradyb[2]	1990-2006	Yes*	r^2=0.36; n=17; p=0.01	12.5 µg Chl/l	2 µg Chl/l

* Elbe/Weser Input (Jan.–Aug.).
** Also a significant trend with Rhine Meuse Input (Dec.-Aug.: r^2=0.345; n=23; p=0.003).
[1] Only German Data (AWI)
[2] Outlier: 2004.

The data analysis in the QSR 2005 was already based on this time window. The available data are summarized in Table 2. Long time series (18-30 years: Dutch Wadden Sea, Norderney, Sylt, Grådyb) that cover the entire seasonal cycle are shown in Figures 6 a-d. Recently, doubts arose whether the chlorophyll measurements by the different agencies and research institutes were comparable. We summarized the applied techniques in Table 3.

Western Dutch Wadden Sea

Cadée and Hegeman (2002) summarized trends in phytoplankton biomass and productivity at the NIOZ time series station in the Marsdiep area (Western Dutch Wadden Sea). They observed an increase in primary production from about 100-150 gC m^{-2} y^{-1} in 1965 to about 400 gC m^{-2} y^{-1} in 1994. Since then a decrease to values of about 200 gC m^{-2} y^{-1} was observed. Mean annual chlorophyll levels decreased slightly.

The analysis of long-term phytoplankton composition in combination with nutrient budget data (Philippart *et al.*, 2000) suggested that the time series could be divided into three periods: a nutrient-rich but phosphorus-controlled period (1974 - 1977), a more eutrophic, nitrogen-limited period (1978 - 1987) and a phosphate-limited period (1988-1993).

Philippart *et al.* (2007) re-analyzed primary production data by Cadée and Hegeman (2002) and reported lower primary production levels decreasing from a maximum of about 200 gC m^{-2} y^{-1} around 1990 to 150 gC m^{-2} y^{-1} since 2000. They observed a weak correlation between phytoplankton biomass and the limiting nutrients phosphate and silicon.

The present analysis (based on Dutch monitoring data) shows that mean summer chlorophyll levels (May-September) decreased from about 20 µg Chl-*a*/l in1976-1985 to about 11 µg Chl-*a*/l in 1996-2002 and 9.7 µg/l in the period 2000-2006.

Eastern Dutch Wadden Sea

Mean summer chlorophyll levels (May-September; Dutch Monitoring programme) amount to about 20 µg Chl-*a*/l and are the highest in the Wadden Sea. They show no decreasing trend. The mean for the period 2000-2006 is 19.9 µg Chl-*a*/l.

Table 3:
Methods used for determining Chlorophyll-*a*

Area	Period	Apparatus	Methods
Dutch Wadden Sea	1976-1988	Spectrophotometry	
Dutch Wadden Sea	1989-2006	HPLC	
Lower Saxon Wadden Sea (Norderney)	1988-2006	Spectrophotometry	Strickland and Parson
Southern Schleswig-Holstein	1998-2006	Spectrophotometry	Jeffrey & Humphrey (1975)
Northern Schleswig-Holstein	1998-2006	Spectrophotometry	Jeffrey & Humphrey (1975)
List Tidal Basin	1984-2006	Spectrophotometry	Jeffrey & Humphrey (1975)
Danish Wadden Sea	1990-2006	Spectrophotometry	

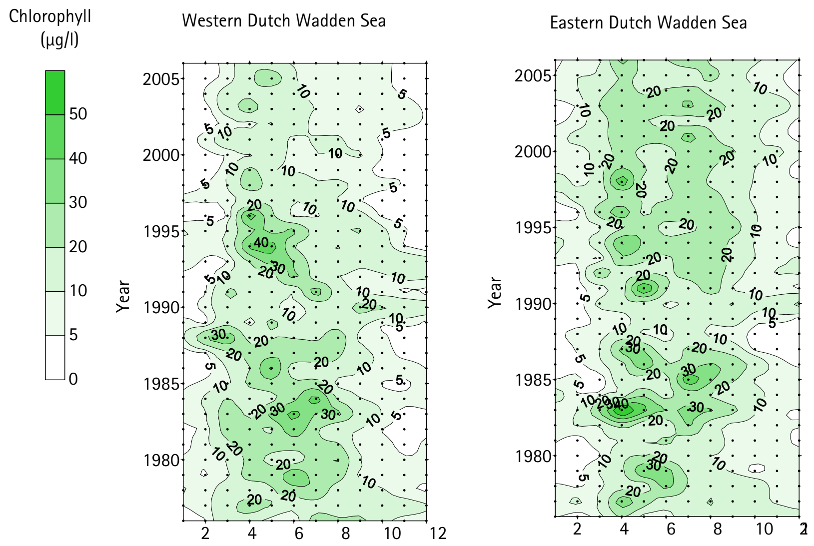


Figure 6a: Seasonal cycle of chlorophyll *a* in the Western and Eastern Dutch Wadden Sea, 1976-2006 Data source: TMAP Data Units and DONAR.

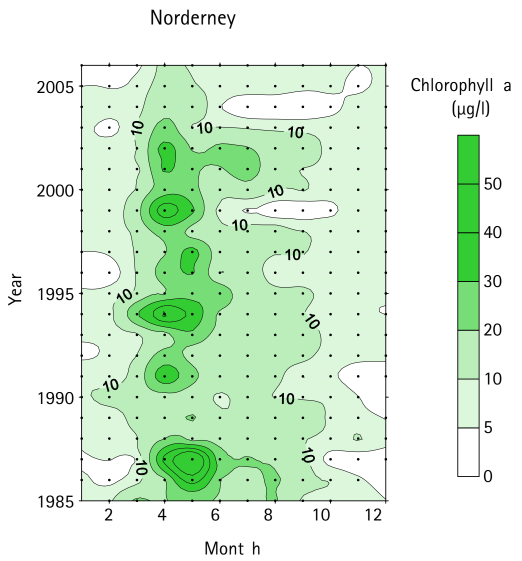


Figure 6b (left): Seasonal cycle of chlorophyll *a* in the Lower Saxonian Wadden Sea (Norderney), 1985-2006. Data source: TMAP Data Units and NLWKN (M. Hanslik).

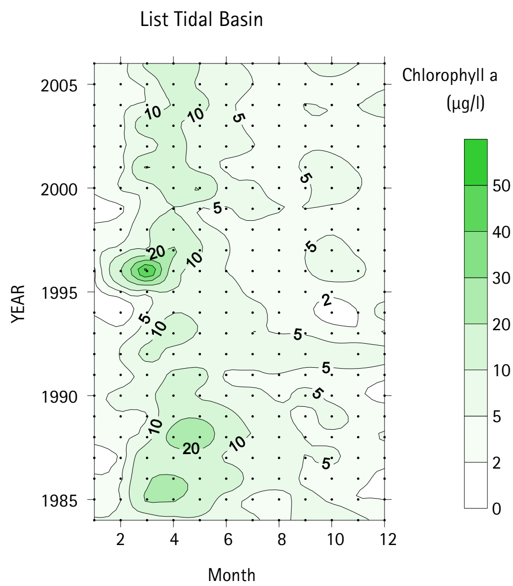


Figure 6c (right): Seasonal cycle of chlorophyll *a* in the Northfrisian Wadden Sea (List Tidal Basin), 1984-2006. Data source: AWI (J. van Beusekom).

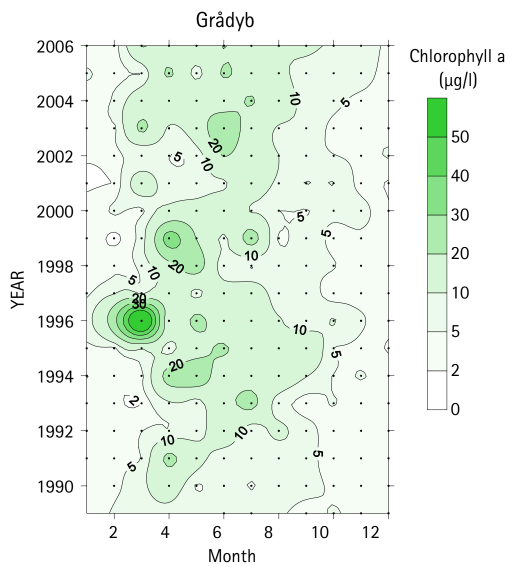


Figure 6d: Seasonal cycle of chlorophyll *a* in the Gradyb (Danish Wadden Sea), 1985-2006. Data source: DMU (J Carstensen)

Lower Saxon Wadden Sea

Mean summer chlorophyll concentrations at Norderney are similar to the Western Dutch Wadden Sea but lower than in the Eastern Dutch Wadden Sea. We observe a decreasing trend from about 20 µg Chl-*a*/l around 1990 to 11.5 µg during 2000-2006.

Schleswig-Holstein Wadden Sea

Primary production is not generally measured in the Schleswig-Holstein Wadden Sea. Loebl *et al.* (2007) reported an annual production of about 150 gC m^{-2} y^{-1} for the List Tidal Basin. Summer chlorophyll concentrations in the Northern Wadden Sea are generally lower than in the Southern Wadden Sea (J. Goebel, *pers. comm.*). Also, during the years 2000-2006, highest values prevailed south of the peninsula Eiderstedt in the vicinity of the estuaries of the rivers Weser and Elbe (12.8 µg Chl-*a*/l), decreasing to 5.4 µg Chl-*a*/l south of the island Amrum and 5.9 µg Chl-*a*/l in the List Tidal Basin (aka Sylt Rømø Bight). It should be noted that at a station in the Elbe Estuary (salinity ~25), a high mean value of about 20 µg Chl-*a*/l was found, but levels rapidly declined towards the German Bight.

Danish Wadden Sea

For the Lister Dyb (List Tidal Basin) and the Grådyb, continuous observations are present since the end of the 1980s. Chlorophyll estimates of two stations in the List Dyb area from the Danish monitoring programme of 6.0 and 8.2 µg/l (2000-2006) are in good agreement with the above mentioned German (AWI) data. Scattered summer chlorophyll data from the Juvre and Knude Dyb also indicated low summer chlorophyll levels, between 5 and 7 µg Chl-*a*/l. In the Grådyb – the northern edge of the Wadden Sea – higher mean summer values of about 12.5 µg Chl-*a*/l were observed.

Spatial Trends

Figure 7 summarizes the mean summer levels found during the period 2000-2006. In general, levels in the Southern Wadden Sea (about 10-20 µg Chl-*a*/l) are higher than in the Central and Northern Wadden Sea (5-13 µg Chl-*a*/l), but locally high values are also found in the Elbe estuary.

Relation with riverine Total Nitrogen input

To investigate the role of riverine nitrogen input on the summer chlorophyll levels, we distinguished

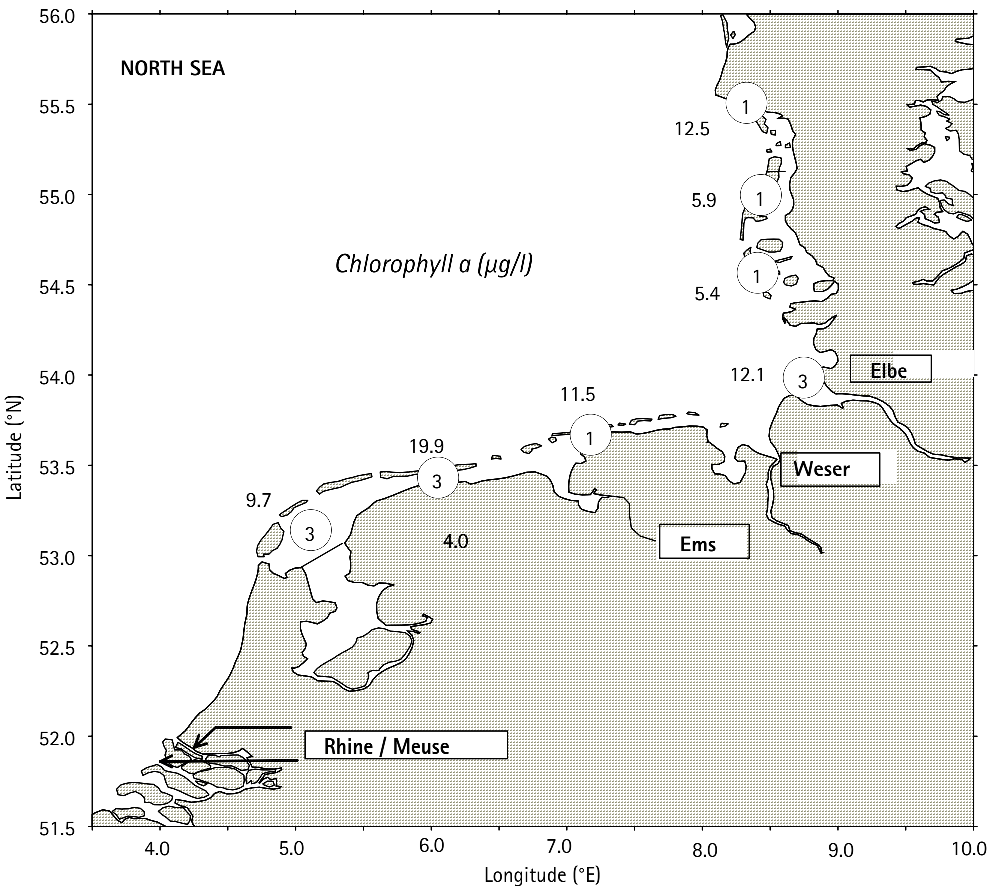


Figure 7: Spatial distribution of summer chlorophyll *a* (May-September) in the Wadden Sea during 2000-2006. Circles indicate the area considered and numbers inside indicate the number of stations used for the mean.

two areas. For the Southern Wadden Sea we used the Total Nitrogen load by the rivers Rhine and Meuse; for the Northern Wadden Sea we used the Total Nitrogen load by the rivers Weser and Elbe. We used the Total Nitrogen Input from December until August for the southern Wadden Sea and January-August for the Weser/Elbe. We did not use input data after August, as they cannot have a significant effect on the summer chlorophyll levels. These time windows were already used for the development of the Wadden Sea Eutrophication Criteria (van Beusekom *et al.*, 2001).

Significant correlations between chlorophyll summer means and riverine Total Nitrogen input via Rhine and Meuse were identified for the Western Dutch Wadden Sea and for Norderney (Lower Saxonian Wadden Sea). Significant correlations with riverine Total Nitrogen input via Weser and Elbe were identified in the Northern Wadden Sea for the List Tidal Basin (AWI-Sylt) and for the Grådyb (one outlier). In the Southern Wadden Sea, a larger part of the variability was explained by TN input (45-59%) than in the Northern Wadden Sea (31-36%). In all cases where a significant correlation with riverine TN input was found, summer chlorophyll levels significantly decreased with time. It is interesting to note that the inter-annual variability of summer chlorophyll levels in the list Tidal Basin could be explained by both the riverine TN input via Elbe and Weser and via the Rhine/Meuse. 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. It should be noted that the temporal patterns in the Rhine-Meuse system are very similar to the patterns in the Weser-Elbe-system (Figure 1-3) and significantly correlate (QSR 2004). The above analysis confirms the results of the chlorophyll analysis in the QSR 2004. In addition, a significant correlation is now also observed for the Grådyb (Danish Wadden Sea). Based on the above results, we conclude that summer chlorophyll levels are a good indicator of the eutrophication status of the Wadden Sea.

Toxic and nuisance blooms

Dutch Wadden Sea

In general, no relation between toxic or nuisance species and nutrients was found (van Duren, 2006). Between 2000 and 2005, *Chrysochromulina* exceed reverence levels (10^6/l) six times, *Dinophysis* spec. exceeded reverence levels (10^2/l) six times and *Phaeocystis* exceeded reverence levels (10^7/l) seven times.

Lower Saxon Wadden Sea

Dinophysis is regularly found at numbers near the reference level (10^2/l), but in 2002 and 2005 this threshold was clearly exceeded. *Pseudonitzschia* sp. bloomed abundantly in 2005 with cell numbers exceeding $2*10^6$/l. *Phaeocystis* remains a major bloomer each year especially during 2004 and 2005. However, in general, the situation was regarded as non problematic.

Schleswig-Holstein Wadden Sea

Phaeocystis dominates the spring phytoplankton bloom each year after the demise of the diatom bloom, with cell numbers well above (10^6/l). In 2002 and 2003 *Dinophysis* exceeded the reference level (10^2/l) near the Danish border and near the Elbe estuary. *Alexandrium* reached elevated numbers only in 2001 and 2004.

Danish Wadden Sea

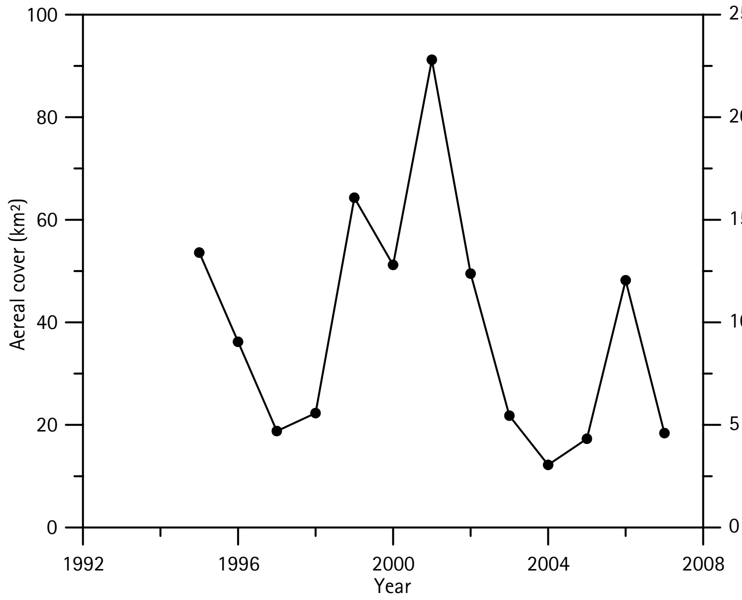
Blooms of *Phaeocystis* are observed almost every year in Grådyb (May-July) following the spring diatom bloom that is typically dominated by *Skeletonema costatum*. These blooms in Grådyb typically coincide with high *Phaeocystis* concentrations in the North Sea off the Danish Wadden Sea, suggesting that blooms in Grådyb could be imported. In List Dyb, blooms of *Phaeocystis* have not been recorded. In May 2004, a bloom of *Chatonella* (~100 µg C l^{-1}) was observed in Grådyb. Other toxic species are occasionally observed, but most commonly in small numbers.

Macroalgae

Compared to rocky shores, macroalgae used to cover sediments only to a minor extent. However, since the late 1970s to 1980s, green algae started to occur in thick mats covering vast areas of tidal sediments in the Wadden Sea (Reise, 1983; De Jonge *et al.*, 1993; Reise and Siebert 1994; Kolbe *et al.*, 1995) as well as in coastal areas elsewhere in the world (Fletcher, 1996). This development peaked in 1990-1993 with algal mats covering up to 20% of the intertidal area of the Schleswig-Holstein Wadden Sea. Since then, green algae remained abundant and thick mats occurred locally but never regained the massive proportions of the early 1990s. The summer of 2004 was the first one with green algae returning back to their marginal occurrences prior to the 1980s.

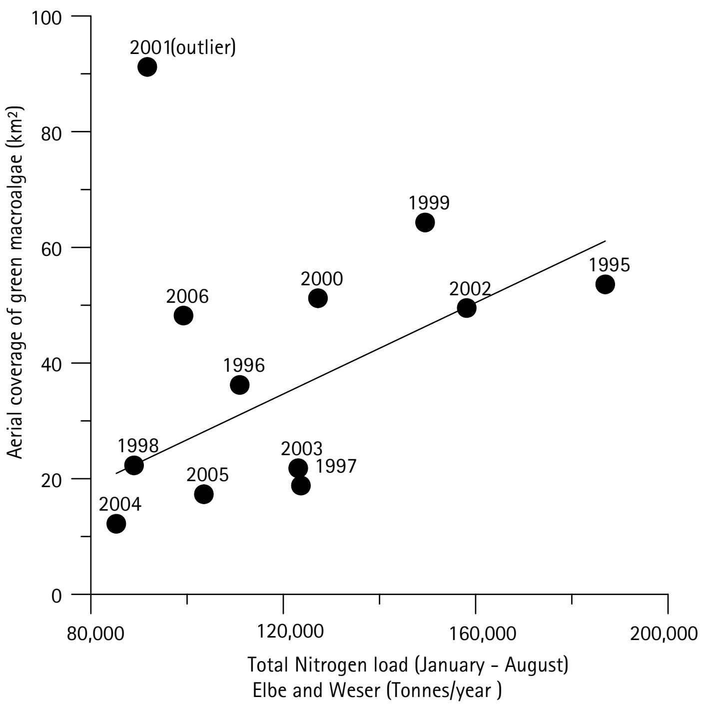
Based on aerial surveys, Reise (2008) estimated the areal coverage of green macroalgae in the entire Schleswig-Holstein Wadden Sea since

Figure 8a:
Time series of area covered with green macroalgae (cover >20%) in the Northern Wadden Sea based on aerial surveys from 1995 until 2007. (Reise, *unpubl.*).



1995. The time series are presented in Figure 8a. Large interannual differences are apparent. The highest coverage was observed in 2001, the lowest in 2004. We investigated a possible relation between riverine TN input and coverage and used the same riverine TN input data used above for the analysis of summer chlorophyll levels in the Northern Wadden Sea (Figure 8b). Using all data, no significant correlation was found. One outlier (2001, year with highest coverage) could be identified. Omitting this year gave a significant correlation with TN input via Weser and Elbe. These results support that in the Wadden Sea, green macroalgae coverage is related to nutrient enrichment via rivers. However, the outlier 2001 and large variability not explained by riverine TN input indicate that other factors are involved in regulating the algae coverage.

Figure 8b:
Relation between area covered with green macroalgae and TN load via Weser and Elbe (total of Jan.-Aug.). One outlier (2001) was identified and excluded from the linear fit.



2.3 Indirect effects

Autumn NH_4+NO_2 as indicator of organic matter turn-over

In the report on Wadden Sea eutrophication criteria (van Beusekom *et al.*, 2001) it was suggested that the intensity of the seasonal cycle of NH_4+NO_2 (more specifically, the autumn values) should be used as an indicator of the organic matter turnover in the Wadden Sea. The seasonal cycles of the major component NH_4 are shown in Figures 9a-9d for the Dutch Wadden Sea, the Lower Saxon Wadden Sea (Norderney), the North Frisian Wadden Sea (List Tidal Basin) and the Grådyb (Danish Wadden Sea). In the Western Dutch Wadden Sea and in the Lower Saxon Wadden Sea (Norderney), a decreasing trend is present during summer and autumn. In the Grådyb, a decrease in summer values is evident.

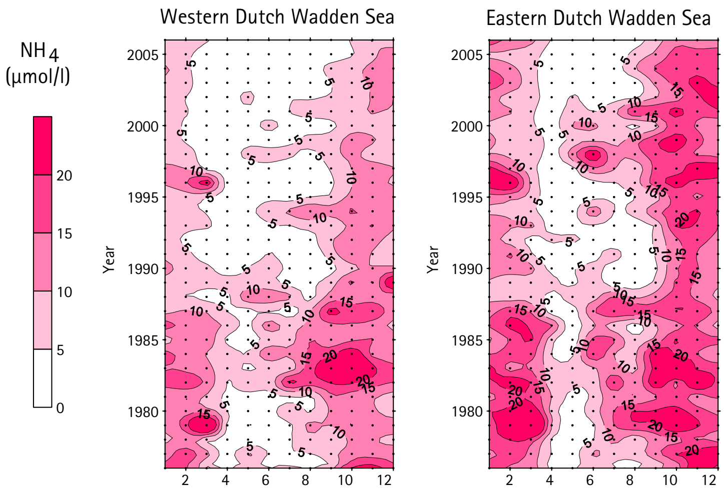
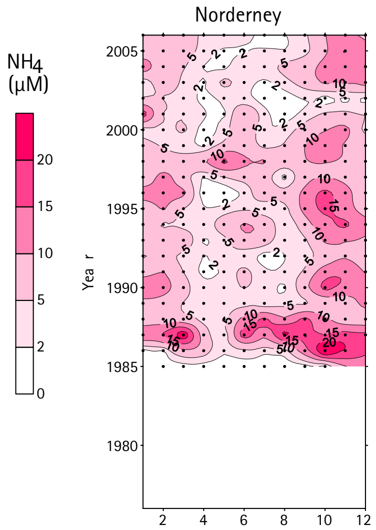


Figure 9a: Annual and seasonal ammonium cycle in the Dutch Wadden Sea. Data source: TMAP Data Units and DONAR.



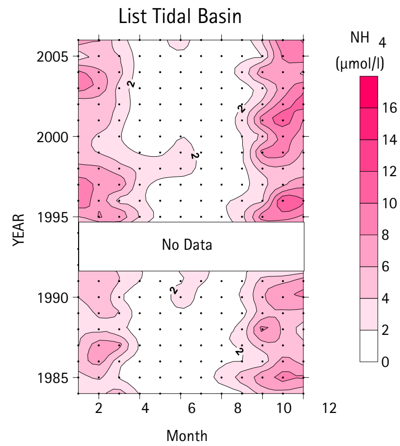


Figure 9b (left): Annual and seasonal ammonium cycle in the Lower Saxonian Wadden Sea/Norderney. Data source: TMAP Data Units and NLWKN (M. Hanslik).

Figure 9c (right): Annual and seasonal ammonium cycle in the North Frisian Wadden Sea (List Tidal Basin). Data source: AWI (J. van Beusekom).

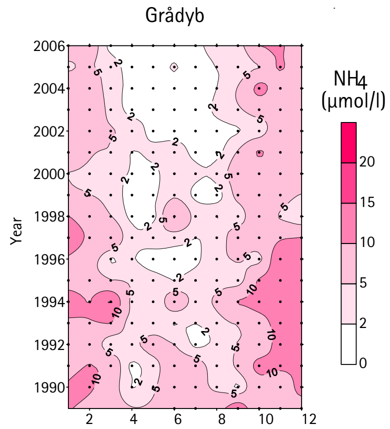


Figure 9d: Annual and seasonal ammonium cycle in the Grådyb (Danish Wadden Sea). Data source: TMAP Data Units and NERI (J. Carstensen).

Table 4:
Results of a multiple regression analysis between TN input via Rhine and Meuse and the autumn N remineralisation in the Wadden Sea.

Western Dutch Wadden Sea (1977-2006)

Dependent: Sum of NH_4 and NO_2 (Month 9-11)
Independent Rhine/Meuse TN load (Month 12-8)
Co-variable: Chlorophyll (Month 9-11), Temperature (Month 9-11)

Results:

N=30	p=0.00003	R^2=0.59	Outlier: none
Variable	Beta	B	P
TN load	0.77	0.00005	0.000002
Chl a	-0.08	-0.12	0.53
Temp	0.04	0.76	0.78

One outlier could be identified. Omission would increase R^2 from 0.53 to 0.56

Eastern Dutch Wadden Sea (1977-2006)

Dependent: Sum of NH_4 and NO_2 (Month 9-11)
Independent: Rhine/Meuse TN load (Month 12-8)
Co-variable: Chlorophyll (Month 9-11), Temperature (Month 9-11)

Results:

N=30	p=0.0034	R^2=0.403	Outlier: none
Variable	Beta	B	P
TN load	0.44	0.00003	0.010
Chl a	-0.36	-0.54	0.033
Temp	0.05	-0.22	0.76

No outliers could be identified.

Lower Saxonian Wadden Sea (1987-2006)

Dependent: Sum of NH_4 and NO_2 (Month 9-11)
Independent: Rhine/Meuse TN load (Month 12-8)
Co-variable: Chlorophyll (Month 9-11), , Temperature (Month 9-11)

Results:

N=20	P=0.042	R^2=0.393	Outlier: none
Variable	Beta	B	P
TN load	0.45	0.00002	0.044
Chl a	-0.51	-0.96	0.031
Temp	-0.24	-0.80	0.30

Period: 1987-2006

The analysis is based on a multiple regression with mean autumn NH_4+NO_2 concentrations as the dependent variable and riverine TN input, autumn chlorophyll levels and temperature as independent variables. In the QSR 2004, we noted that significant correlations were only found for the Southern Wadden Sea. The present analysis confirms that the autumn values are good eutrophication indicators for the Southern Wadden Sea (Table 4). Chlorophyll did not significantly influence the relation in the Western Dutch Wadden Sea, but had a significant impact in the Eastern Dutch Wadden Sea and Norderney.

The mean autumn values of NH_4+NO_2 during 2000-2006 are presented in Figure 10. Highest concentrations are found in the southern Wadden. The spatial pattern strongly resembles the summer chlorophyll pattern and a significant correlation exists between both indices (Figure 11). Such a correlation is expected if both parameters are independent eutrophication proxies.

2.4 Effects of decreased nutrient input

The decreased riverine nutrient input since the mid-1980s has led to a lower eutrophication status in the Wadden Sea. We observe decreasing summer chlorophyll levels in the entire Wadden Sea and in the Southern Wadden Sea also a significant decrease in autumn NH_4+NO_2 levels (as a proxy for organic matter turnover). The increase in seagrass and a moderate green macroalgal cover may also be due to a decreasing eutrophication level.

Little information exists on a Wadden Sea-wide scale on the effects of the nutrient reductions on

Table 5:
Classification of the Wadden Sea into Non-Problem, Potential Problem and Problem areas based on autumn concentrations of NH_4+NO_2 (µM) as proposed by van Beusekom *et al.* (2001) and modified with data from the recent study. The division in sub-regions is based on the availability of seasonal data. The present autumn values refer to values during the period 2000-2006. Non-problem conditions were based on background values for the Western Dutch Wadden Sea. Values for the other areas proportionally assigned on the basis of present day values (Beusekom *et al.*, 2001). All threshold values were formally derived and an uncertainty range of ±1 µM should be added.

Area	Non-Problem conditions	Potential Problem conditions	Problem conditions	„Present" values (2000-2006)
Western Dutch Wadden Sea	<3.0 µM	3.0 µM <> 8.3 µM	> 8.3 µM	8.2µM
Eastern Dutch Wadden Sea	<4.0 µM	4.0 µM <> 10.2 µM	> 10.2 µM	16.8µM
Lower Sax. Wadden Sea	<3.2 µM	3.2 µM <> 8.2 µM	> 8.2 µM	9.9µM
List Tidal Basin	<1.9 µM	1.9 µM <> 4.2 µM	> 4.2 µM	5.9µM
Danish Wadden Sea	<2.5 µM	2.5 µM <> 6.5 µM	> 6.5 µM	8.3µM

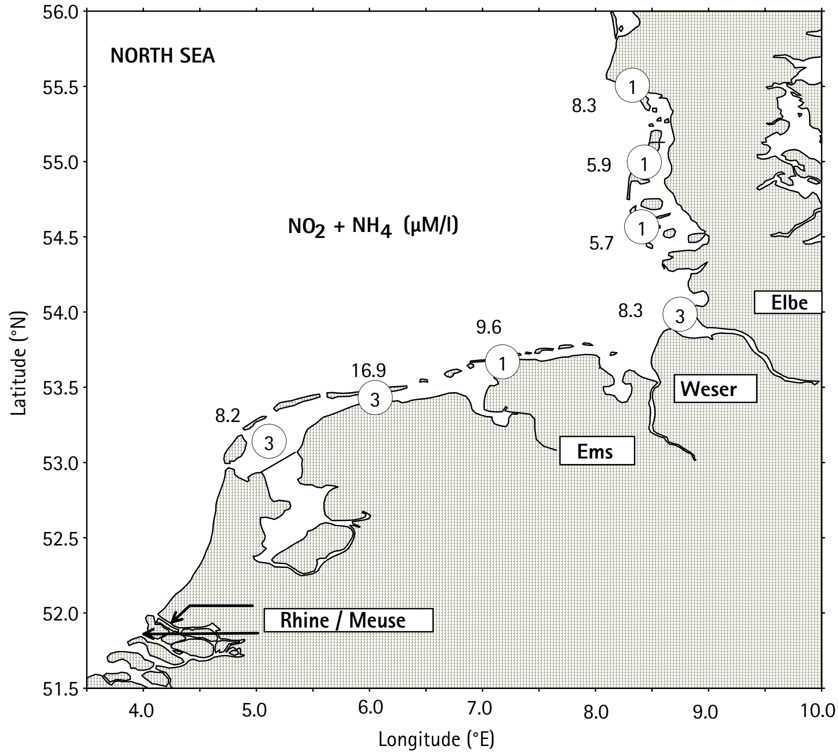


Figure 10: Spatial distribution of Autumn NH_4+NO_2 in the Wadden Sea during 2000-2006. Dots indicate the area considered. Circles indicate the area considered and numbers inside indicate the number of stations used for the mean. No NO_2 data were available for the Grådyb area and we added Wadden Sea average mean of 1.5 µM to an NH_4 value of 6.8 µM.

higher trophic levels. Based on time-series from the Western Dutch Wadden Sea, Philippart *et al.* (2007) also observed reduced primary production in the western Dutch Wadden Sea. The authors concluded that the decrease had repercussions for the entire ecosystem including macrobenthos and birds (Philippart *et al.*, 2007). The authors highlighted especially the limiting role of phosphorus and silicon.

2.5 Target evaluation

Nutrients

Targets on the chemical quality of the Wadden Sea ecosystem were adopted at the Leeuwarden Conference and aim at natural levels of nutrient concentrations and nutrient input. They are prerequisite for a naturally developing phytoplankton and phytobenthos. Background values of winter concentrations are used for the OSPAR assessments (*e.g.*, OSPAR 2008). For the Dutch Wadden Sea, background DIN levels of 6.5 µM were used (Baretta-Bekker *et al.*, 2008); for the German Wadden Sea, Brockmann *et al.* (2008) proposed DIN values of about 7-9 µM; and Andersen and Kaas (2008) used 11.5 µM for the Danish Wadden Sea. Compared to the present salinity-normalized DIN winter concentrations of about 40-60 µM, we conclude that background DIN concentrations have not been reached yet.

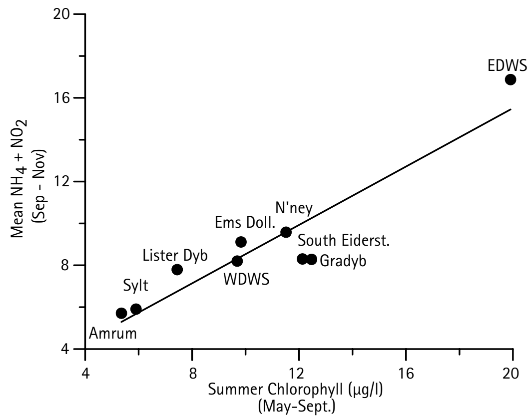


Figure 11: Correlation between mean summer chlorophyll *a* (µg/l) for 2000-2006 and mean autumn values of NH_4+NO_2 for 2000-2006 shown in Figures 7 and 10. Abbreviations: WDWS: Western Dutch Wadden Sea, EDWS: Eastern Dutch Wadden Sea, N'ney: Norderney.

For the Dutch Wadden Sea, background PO_4 levels of 0.5 µM were used by Baretta-Bekker *et al.* (2008); for the German Wadden Sea, Brockmann *et al.* (2007) proposed PO_4 values of about 0.4 µM; and Andersen and Kaas (2008) used 0.4 µM for the Danish Wadden Sea. Compared to the present salinity-normalized PO_4 winter concentrations of about 1.0-1.8 µM, we conclude that natural PO_4 concentrations have not been reached yet.

Background concentrations of NH_4+NO_2 in autumn as a proxy of organic matter turnover in the Wadden Sea have been estimated at about 1.5-4 µM (van Beusekom *et al.*, 2001; van Beusekom, 2005) and present levels are clearly above this level (Table 5).

Riverine background concentrations for European rivers were estimated at about 20-71 µM N (~0.6 mg/l N) and 0.7 - 4.5 µM P by Laane (1992). Brockmann *et al.* (2007) reported lower TN values of about 20 µM (~0.3 mg/l N) and TP values of values of about 0.5 µM P. Despite the large uncertainty in the riverine background estimates, the present values of about 250 µM N and 5 µM P are clearly above the background estimates.

Chlorophyll

The data analysis confirms that enhanced riverine nutrient input led to higher phytoplankton stocks. The recent decrease in riverine nutrient loads has led to reduced phytoplankton standing stocks. The evaluation of present levels against background estimates is difficult because the three Wadden Sea countries use different estimates. Also, different time windows and different statistics are used. As a rule of thumb, the following conversions can be used. In general, annual mean chlorophyll levels are about 20% lower than summer chlorophyll levels (May-September; this study). 90 percentile values are about 2 times higher than mean values (*e.g.*, Baretta-Bekker *et al.*, 2008).

Background mean chlorophyll levels during the growth season (March-September) for the Dutch Wadden Sea are estimated at 8 µg Chl-*a*/l (Baretta-Bekker *et al.*, 2008). German estimates are almost two times lower and amount to 2-3 µg Chl-*a*/l. Danish background estimates of 1.9 µg Chl-*a*/l (May-September; Andersen and Kaas, 2008) and 4.0 µg Chl-*a*/l (May-September; Carstensen *et al.*, 2008) are in the same range as the German estimates. In all areas, present values are clearly higher than background values (Table 2).

3. Conclusions

3.1 Main Results

The main results are grouped according to the categories used in the OSPAR *Comprehensive Procedure*.

Category I: Nutrients.

Riverine nutrient input showed a gradual decrease during the period 1985-2006, with a rate of about 2% for TN and 2-3% for TP. This is reflected by the phosphate concentrations in winter in the Wadden Sea that decreased since the mid 1980s to winter levels of about 1.0-1.8 µM. Salinity normalized nitrate+nitrite concentrations in the German Bight in winter reflect the decreasing TN load, and in some Wadden Sea areas a decreasing trend is now apparent.

Background values

Compared to background estimates of winter nutrient concentrations, present values are clearly elevated.

Category II: Direct effects on primary producers

The decreasing nutrient input (TN loads by Rhine and Meuse or Weser and Elbe) had a significant effect on the phytoplankton biomass (as chlorophyll) in summer in the Southern Wadden Sea (Western Dutch Wadden Sea, Lower Saxonian Wadden Sea (Norderney). In the Northern Wadden Sea, decreasing TN loads by the rivers Weser and Elbe had a significant effect on the summer chlorophyll levels in the List Tidal Basin and in the Grådyb.

Toxic blooms are observed in all parts of the Wadden Sea, but no decreasing or increasing trend in relation to nutrient input is evident. 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 in the Northern Wadden Sea correlates with riverine TN input and is below the maximum levels observed during the early 1990s.

Regional differences

In general, summer chlorophyll levels are higher in the Southern Wadden Sea than in the Northern Wadden Sea and are in line with the previous conclusion in QSR 2004 of a higher eutrophication status in the Southern Wadden Sea. However, within both Wadden Sea regions, large differences exist: hotspots are the Eastern Dutch Wadden Sea, the Elbe estuary and Gradyb. Lowest values are found in the Danish and North Frisian Wadden Sea (between Eiderstedt and Gradyb).

Background values

Compared to background estimates of summer chlorophyll levels, present values are clearly elevated.

Category III: Direct effects on organic matter

The autumn NH_4+NO_2 values are a good indicator of organic matter turnover in the Southern Wadden Sea. The decreasing nutrient input (TN loads by Rhine and Meuse) lead to decreasing autumn NH_4+NO_2 values in the Southern Wadden Sea. In the Northern Wadden Sea, a less clear picture emerges and no correlation with riverine TN input is observed.

Regional differences

The recent distribution patterns of autumn NH_4+NO_2 values show a similar pattern as summer chlorophyll and both proxies are strongly correlated ($r^2 = 0.87$; $N = 7$; $p < 0.00021$; compare van Beusekom, 2006). This supports that the observed regional differences are real. Autumn values identify the same eutrophication hotspots and low eutrophication regions as summer chlorophyll.

Background values

Compared to background estimates of autumn NH_4+NO_2 values, present values are clearly elevated.

4. Assessment according to the WFD

The Water Framework Directive (EU) is an EU Directive adopted in 2000. It aims to (1) prevent further deterioration, protect and enhance the environmental status of aquatic systems and (2) promote the sustainable use of water, while progressively reducing or eliminating discharges, losses and emissions of pollutants and other pressures for the long-term protection and enhancement of the aquatic environment. Good ecological status, defined as a slight deviation from an undisturbed condition, should be reached by 2015. Depending on the water body being assessed, the Directive prescribes the use of certain biological quality indicators. For most of the Wadden Sea, they comprise phytoplankton, macrophytes and macrobenthos. Fish are additional quality indicators in transitional waters.

Based on a certain reference condition representing the high ecological status, metrics have to be developed that scale the status in five steps (high, good, moderate, poor, bad). The Directive is explicit in the prime use of biological indicators, but chemical indicators may support the assessment. Each country can develop its own metrics that are inter-calibrated in so-called GIGs (Geographical Intercalibration Groups). For the assessment of the phytoplankton eutrophication status in the Wadden Sea, two metrics are presently discussed: 1) the percentage of observations with *Phaeocystis* bloom conditions (>10^7 cells/l); and 2) deviations from a reference phytoplankton biomass. In the latter case the 90-percentile of chlorophyll-a during the period March-October is used as indicator. In the Wadden Sea area, no agreement has been reached yet on the reference conditions and boundaries between good and moderate for phytoplankton biomass.

5. Recommendations

5.1 Management

Current policies to reduce nutrient input have been successful with regard to phosphorus and nitrogen compounds. The decreasing nutrient loads into the coastal North Sea and directly into the Wadden Sea have led to a decreasing eutrophication status in the entire Wadden Sea. The target of a Wadden Sea without eutrophication problems has not been reached yet. Therefore it is recommended continuing policies to reduce nutrient input.

5.2 Monitoring and research

Regional differences within the Wadden Sea

The present study confirms the previous conclusion (QSR 2004) on regional differences within the international Wadden Sea. The reasons for these differences have to be revealed in order to be able to formulate region-specific standards for a good ecological status, as for instance demanded by the Water Framework Directive.

Interacting effects of regional change

During the past decade, the warming trend in the Wadden Sea area has become evident. Especially invading species seem to have taken advantage of this trend (Nehring *et al.*, 2009). Future research will have to tackle the question of how present trends (de-eutrophication, warming, proliferation of invading species, sea level rise) interact (Reise and van Beusekom, 2008). Monitoring and assessment strategies have to adapt at an early stage to account for changes ahead as previous assessment strategies may not be appropriate any more.

Importance of coverage of the entire seasonal cycle

The present study was largely based on nutrient and chlorophyll data that cover the entire annual cycle with a resolution of at least once a month and preferably more frequent during the growth season in order not to miss peaks in chlorophyll abundance. Not all monitoring programmes have the necessary spatial and temporal resolution. Care should be taken that such data should be available in the future and that temporal and spatial resolution of monitoring programmes is extended.

New automated monitoring techniques

At present, techniques and strategies are developed in The Netherlands and Germany to implement automated monitoring stations. We suggest to stimulate international exchange of information and methods and in order to establish a coherent Wadden Sea-wide automated monitoring network. Care should be taken that the "classical time" series are continued.

Phosphorus versus Nitrogen limitation

In the present study, the temporal dynamics in eutrophication proxies were significantly correlated with riverine TN input. However, evidence suggests that at least part of the Wadden Sea (*e.g.*, Western Dutch Wadden Sea) is limited by phosphorus (*e.g.*, Philippart *et al.*, 2007) whereas at least for the Northern Wadden Sea nitrogen limitation is assumed (*e.g.*, Carstensen, 2008; van Beusekom *et al.*, 2009). Research is needed to understand the regional differences in nutrient limitation patterns and their implications for the coastal ecosystem.

Chlorophyll intercalibration

The different monitoring and research institutes in the Wadden sea area use different methods for assessing chlorophyll. This may hamper the areal comparison. Intercalibration exercises are needed to demonstrate the comparability of the methods used. Comparability of data is of utmost importance in the light of, *e.g.*, defining a good ecological status for the Water Framework Directive.

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1. Introduction

The dispersal of organisms is a natural process limited by multiple barriers, among which geographical barriers are the most evident. However, for centuries, alien species have been introduced to new areas in which they were previously absent and to which they have been introduced by humans as mediator. With increasing global trade the introduction of alien species, both intentional and unintentional, has increased concomitantly and has increased in complexity. Next to global habitat loss and climate change, this biological globalization has become a key process in altering the biosphere.

Alien species bring both costs and benefits which may accrue to different sectors of society. Benefits are wide-ranging and examples in the aquatic environment include stocking and re-stocking operations, new aquaculture opportunities and tools in coastal protection and reclamation schemes (*a.o.* Minchin and Rosenthal, 2002). By contrast, viewed on a global basis, alien species are one of the key threats to native species and ecosystems and other aspects of biodiversity (Rabitsch *et al.*, 2008). Furthermore, biological invasions may turn into serious threats to humans, their health and economical possibilities. In Germany for example, the economic losses caused by only 20 analysed terrestrial and aquatic alien species are estimated to a level of 156 million Euro annually (Reinhardt *et al.*, 2003). We here consider the effects of alien species on the environmental quality of the Wadden Sea, and thus adopt a nature protection perspective.

The worldwide implications of alien species have been identified by both non-governmental and governmental organizations, and have been emphasized in numerous international conventions and other legally binding and non-binding instruments (Shine, 2006). On the basis of the Convention on Biological Diversity (CBD, 1992), the European Strategy on Invasive Alien Species was finalized in 2003 (Council of Europe, 2003) to combine existing regulations established under the Bern Convention in 1979 and its subsequent agreements, and to offer the signatory states possibilities to deal with alien species. However, until now, most of these measures have so far only been declarations of intentions which lack the extensive detailed planning necessary to prevent alien introductions. Therefore, the implementation of sound strategies and instruments to deal with biological invasions must be an urgent conservation priority.

Especially in the Wadden Sea area, a diverse range of alien species has established permanent populations (Reise *et al.*, 2005). The rate of alien introductions is continuously increasing and no change is as yet in sight. Many of the introduced species have become abundant and several can be regarded as invasive in the sense of having a significant effect on the recipient ecosystem (Jensen and Knudsen, 2005; Wolff, 2005; Gollasch and Nehring, 2006). The guiding principle of the trilateral Wadden Sea policy *"is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way".* Invasive alien species pose a particularly serious threat to such nature conservation interests. Moreover, as concluded in the Quality Status Report 2004, species introductions are irreversible and accumulating over time. This issue may be considered to be more important than reversible effects of overfishing, eutrophication and contaminants. For the Wadden Sea, the net effect of unhampered introductions would be a regional increase in species richness and a growing biotic similarity with other coasts. The unique character of the Wadden Sea would still be manifest in the physical environment but not any more in its living component (Reise *et al.*, 2005). However, up to now a purposeful strategy on how to deal with alien species introduced into the Wadden Sea is lacking (Nehring and Klingenstein, 2005). To respond effectively to threats by alien species, the trilateral policy and management should take the issue of alien species into account to a greater extent.

2. Instruments and impact assessment

More than fifty international and regional conventions, codes of conduct and other instruments now deal directly or indirectly with the spreading of alien species (SCBD, 2001; Shine, 2006). Nearly all of them have their own institutional mechanisms and decision-making procedures. These binding or voluntary instruments often provide the baseline from which domestic legislatures develop policy, legislation and management frameworks to address alien species issues (Council of Europe, 2003). The main international instruments for nature conservation that specifically address alien species includes the Convention on Biological Diversity (Rio de Janeiro, 1992), the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention, Bonn, 1980), the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention, Bern, 1979), and the Convention on Wetlands of International Importance as Waterfowl Habitat (Ramsar Convention, Paris, 1994). However, instruments at all levels use variable terminology, sometimes inconsistently or without adequate definitions. On the other hand, a consensual set of definitions regarding alien species is essential in order to facilitate discourse among the science, policy and management communities dealing with the issue. Thus we propose a set of key terms and definitions as an operating tool (see box below) that does not lead to further confusion. The set is based on terms and definitions mainly used in work done under the Convention on Biological Diversity (CBD, www.biodiv.org).

The aims of the Convention on Biological Diversity, which was adopted in 1992 and enforced in 1993, are the conservation of biological diversity, the sustainable usage of biological resources, and the fair and equitable sharing of benefits arising from the use of genetic resources. Article 8 of the Convention requires all Contracting Parties "*as far as possible and as appropriate, to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species*". This statement was specified by the decision VI/23 *"Guiding Principles on Invasive Alien Species"* by the 6th Conference of the Parties to the Convention in 2002. Its adoption suggests comprehensive national strategies on the basis of a hierarchical approach (prevention, early detection, measures).

The Bonn Convention highlights in Article III.4.c that the Contracting Parties agree *"to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely*

Definitions

Native species

A species, including genetically distinct populations, occurring within its natural range (past or present) and dispersal potential (i.e. within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans).

Alien species

A species, including genetically distinct populations, occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans); includes any part, gametes or propagules of such species that might survive and subsequently reproduce.

Invasive alien species

An alien species which is known or expected to exert effects on native populations and species, natural habitats and ecosystems beyond of which can be considered to be within the range of average regional conditions.

Introduction

The transfer, by direct or indirect human agency, of a species or genetically distinct population outside of its natural range (past or present) and dispersal potential; this movement can be either within a country or between countries or areas beyond national jurisdiction. Human involvement here does not include habitat changes, global warming, eutrophication, etc.

Intentional introduction

Deliberate transfer and/or release by humans of a species or genetically distinct population outside its natural range (past or present) and dispersal potential (such introductions may be authorised or unauthorised); this includes also species which subsequently escape or which are released into the environment.

Unintentional introduction

All other introductions which are not intentional; this also includes parasites, symbionts etc. of intentionally introduced species.

to further endanger [migratory] species, including strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species." Article V.5.e of this Convention states that Contracting Parties should protect *"habitats [of migratory species] from disturbances, including strict control of the introduction of, or control of already introduced exotic species detrimental to the migratory species".*

The Bern Convention, to which 39 European states and the EC are party, provides a regional framework for implementation of the Convention on Biological Diversity in Europe (Council of Europe, 2003). Article 11.2.b of the Bern Convention states, that Contracting Parties should *"strictly control the introduction of non-native species".* Bern Convention Parties should also inform governments of neighbouring countries if accidental introductions have occurred (Recommendation No. R (84) 14, 1984) and set up mechanisms for inter-State co-operation, notification and consultation in order to co-ordinate precautionary and control measures for invasive species (Recommendation No. 77, 1999).

In 2000, the Bern Convention's expert group on invasive alien species began developing elements for a European Strategy on Invasive Alien Species. The finalized European Strategy, approved by the Bern Convention Standing Committee in 2003 (Recommendation No. 99), is a comprehensive document addressed to nature conservation agencies and all other sectoral agencies with responsibility for activities relevant to the prevention or management of invasive alien species (Council of Europe, 2003). The European Strategy promotes the development and implementation of national strategies, coordinated measures and cooperative efforts throughout Europe to prevent or minimise adverse impacts of invasive alien species on Europe's biodiversity, as well as their consequences for the economy and human health and well-being (Council of Europe, 2003).

The recent Marine Strategy Framework Directive (European Parliament and Council, 2008) extends EU water legislation to the marine environment and follows an approach similar to that of the Water Framework Directive (European Parliament and Council, 2000). It came into force on 15 July 2008 and establishes a comprehensive structure within which Member States are required to develop and implement cost effective measures, necessary to achieve or maintain Good Environmental Status (GES) in the marine environment. GES must be achieved by the year 2020 at the latest. Within the Directive, GES is defined by eleven qualitative descriptors, one of them being "Non-indigenous species". In Annex 1 of the Directive it is mentioned as: "Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems".

For coastal and inland wetlands, the Ramsar Convention has recognized the threat to their ecological character and to terrestrial and marine wetland species if alien species become invasive. In Resolution VII.14 (1999) on invasive species and wetlands Contracting Parties are urged, where necessary, to adopt legislation or programmes to prevent introduction of *"new and environmentally dangerous alien species"* into their jurisdiction and to develop capacity for identifying such alien species. In Resolution VIII.18 (2002) the Conference of the Parties to the Ramsar Convention urged Contracting Parties to address the problems posed by invasive species in wetland ecosystems in a decisive and holistic manner. Further, Contracting Parties are urged to identify the presence of invasive alien species in Ramsar sites and other wetlands in their territory, the threats they pose to the ecological character of these wetlands, and to undertake risk assessments of alien species that may pose a threat to the ecological character of wetlands.

Despite these and other efforts, alien species in the Wadden Sea are still perceived only at a descriptive level. To mitigate present, and avoid future, negative impacts of aliens in the Wadden Sea, legal and organisational implementation in the three bordering countries, Denmark, Germany and The Netherlands are of utmost importance. However, invasion processes ignore political boundaries between countries. Consistent with the ecosystem approach as developed under the Convention of Biological Diversity, inter- and intra-regional cooperation is essential for effective frameworks and development of an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea. Efficiency can be increased by sharing information and intensifying cooperation, ensuring basic consistency in policies, legislation and practice.

The impacts of alien species on ecosystems vary significantly depending upon the invading species, the extent of the invasion, and the vulnerability of the ecosystem being invaded. An initial step towards an alien management plan is to assess and present the evidence that invasive alien species are a major threat to natural biodiversity in that area and that action is mandatory to be taken. The preparation of a preliminary assessment is a crucial step and should be based on existing information, which can be accessed from various sources (literature, databases, *etc.*). Loss and degradation of native biodiversity due to alien species can occur throughout all levels of biological organization from the genetic and population levels to the species, community, and ecosystem levels, and may involve major alterations to physical habitat, water quality, essential resources and ecological processes. These impacts can vary in terms of the lapse of time between the initial introduction and subsequent spread of an alien species, its severity of impact, the likelihood of synergistic interactions with other threatening processes, and the potential for initiation of a cascade of effects ramifying throughout an entire ecosystem (Mooney and Hobbs, 2000; Kowarik, 2003; Reise *et al.*, 2006).

Up to now, concern has been mainly confined to the species level and introductions from outside the Northeast Atlantic biogeographic province. This may be too narrow in perspective. Particularly, benthic species may show considerable genetic structure variation within that region (*i.e.* Luttikhuizen *et al.*, 2003a; Olsen *et al.*, 2004). This may not be surprising for benthic organisms lacking pelagic means of dispersal, but it also seems to occur in species with pelagic larvae, such as the European cockle *Cerastoderma edule* (Krakau *et al.*, submitted) and *Macoma balthica* which even shows genetic differences between the Wadden Sea and adjacent North Sea coastal regions (Luttikhuizen *et al.*, 2003b). Obviously, shifting organisms from one coast to another, a common practice in aquaculture with mussels and oysters, may dilute the adaptations evolved within local populations. It is probable that this practice has contributed to the collapse in many local populations of the European oyster in the 19th and early 20th centuries. We usually lack sufficient genetic information and the knowledge to anticipate the effects of lost subspecific adaptations. This is urgently needed, as is evident from recent transfers of mussels from British coasts into the northern Wadden Sea which may entail the introduction of alien genes. In order to protect intraspecific genetic diversity, alien proveniences of native species (*"gebietsfremde Herkünfte heimischer Arten"*) should be taken more into consideration in authorization procedures in future.

The European Strategy on Invasive Alien Species (Council of Europe, 2003) recommends that all aliens have to be sorted into three categories: (1) a white list of species which are harmless and might even be of use or benefit; (2) a grey list of species which impact is unclear; (3) a black list of species which cause serious harm. However, species lists and the according decision-making needs to be based on transparent scientific criteria that are regularly reviewed and on accurate, precise, generally applicable, and widely accepted assessment protocols. Various methods of performing risk analyses on specific groups of alien species have been employed (*e.g.* Morse *et al.*, 2004; Copp *et al.*, 2005; Hewitt *et al.*, 2006), but there is still no international standardised methodology.

For German nature conservation activities, criteria based risk assessment for evaluating the ecological threat of both alien plants and animals in aquatic (freshwater, brackish and marine waters) and terrestrial habitats are now being developed (Essl *et al.*, 2008). The method allows allocating species (or infraspecific taxa, as appropriate) in one of the three following impacts categories: invasive (Black List), potential invasive (Grey List), and non-invasive (White List). The main focus is on threats imposed by alien species on native species which can be summarized into five general categories:

- Hybridisation with native and other alien species, producing reproductive offspring;
- Competition;
- Predation and herbivory;
- Introduction of parasites and disease agents which affect indigenous species;
- Habitat alteration, resulting in changes of biological structures and water budget.

These threats have to be considered in the context and in conjunction with other effects in the ecosystem such as the provision of a novel and beneficial food supply, a more efficient coastal filter function, diversion of parasites from native to introduced species or the provision of complex habitat structures where none have been before.

The basis for assessment is the net endangerment of native species by alien species, *e.g.* verified by listing in a Red List. Distribution in the assessment area, the applicability of control measures and specific bio-ecologically traits (*e.g.* occurrence in protected areas, reproduction and spreading potentials, facilitation by climate change) serve as additional classification criteria. The German assessment method allows for (1) identifying those species that threaten natural biodiversity and other ecological functions and values, and (2) prioritizing species for management efforts (e.g. mitigation, control, monitoring). While designed for use in Germany and Austria, the protocol can be applied to any other region, and may also be applicable to assess the impact in the non-native range of a species that is also present elsewhere in a region as a native.

On basis of the routine outlined above, a preliminary assessment of alien species occurring in the Wadden Sea shows that presently most of the alien species cause no, or only minor, impacts on the natural biodiversity of the Wadden Sea, but it is also clear that several of them involve far-reaching ecological consequences (in detail see chapter 7.3). However, it should be noted that the impact of alien species, even those that may be invasive, is often insufficiently known because appropriate studies have not been attempted; effects often develop over many years and it is often difficult to distinguish the effects of alien species from those of many other simultaneous, natural, and anthropogenic effects on ecosystems (Reise and van Beusekom, 2008). Apart from ecological consequences by invasive alien species, any alien species invasion constitutes a biological contamination of natural aquatic ecosystems. In coastal waters the macrozoobenthic communities of the mesohaline zone in estuaries are characterized by the highest number of alien species as well as by the highest percentage of alien species compared to the respective total indigenous species numbers (Wolff, 1999; Nehring, 2006) (Fig. 1). The high sum total of aliens may be more significant than the effects of the individual alien species. Also, the interactions between aliens may give rise to an 'invasional meltdown' in the sense that already-established aliens facilitate the establishment of others. The conclusion is that the assessment of ecological quality status needs to be undertaken in an ecosystem context. Specific indices should be established to aid identification of invasive species, as recommended by Arbaicauskas *et al.*, (2008) and Panov *et al.*, (2009) for inland and coastal waters.

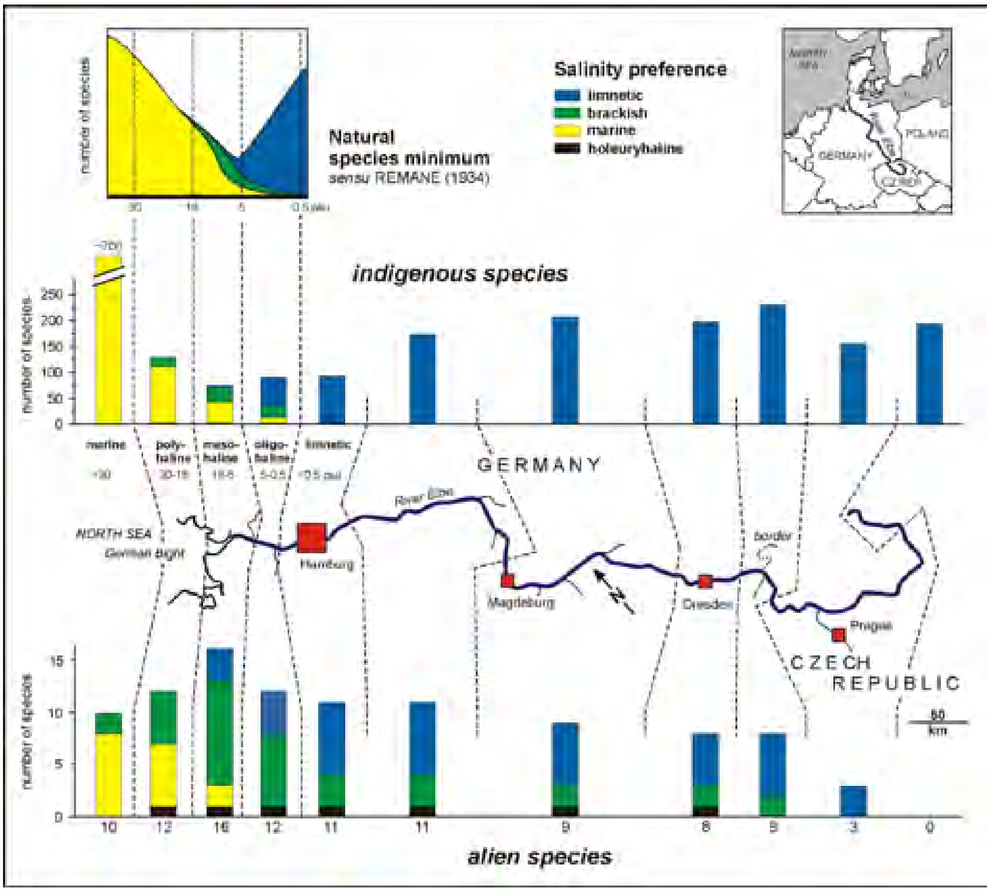


Figure 1: Estuaries – one hotspot of invasion. It seems that the combination of brackish water with its unsaturated ecological niches and intensive international ship traffic is responsible for the observed high infection rate with alien macrozoobenthic species in the Elbe estuary (after Nehring, 2006).

3. Hotspots of invasion in the Wadden Sea

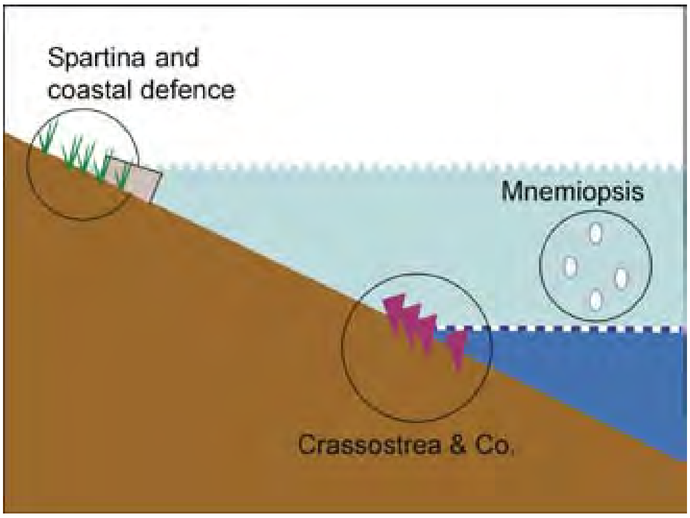


Figure 2: Hotspots of bioinvasions at the vertical habitat gradient in the Wadden Sea. *Spartina* and artificial hard structures around high tide level, *Crassostrea* and other alien suspension feeders with epibionts around low tide level, and alien plankton.

In the Wadden Sea, invasive alien species have not spread randomly across the depth gradient from the upper beaches and salt marshes to the deepest bottoms of the tidal inlets. Instead, there are three hotspots of alien impacts (Fig. 2): The first is encountered around high tide level on sheltered shores. Either the invasive *Spartina* grass dominates the vegetation or introduced hard substrates prevail as a coastal defence or harbour walls. *Spartina* is dealt with in detail below. The artificial hard substrates host rocky shore species which otherwise would be absent from the Wadden Sea but are native to the region (*i.e.* the common sea slater *Ligia oceanica*). These boulder walls may also serve as gateways for alien species which arrived by ship from overseas (Reise and Buschbaum, 2007). Examples are the Asian shore crabs *Hemigrapsus sanguineus* and *H. takanoi* which hide underneath boulders and may potentially interfere with juveniles of the native shore crabs. Since 2007 both crabs are spread throughout the entire Wadden Sea.

Extensive habitats in the Wadden Sea, the vast mud and sand flats around mean tide level, with or without seagrass, are almost devoid of alien species. Only in the estuarine parts the invasive polychaetes *Marenzelleria neglecta* and *M. viridis* temporarily achieved high densities (Fig. 3) (Nehring and Leuchs, 2001; Essink and Dekker, 2002). Also sandy beaches are virtually free of alien invaders. By contrast, the transition from the lower intertidal into the upper subtidal zone alongside tidal channels is again a hotspot where the benthos is becoming dominated by alien species,

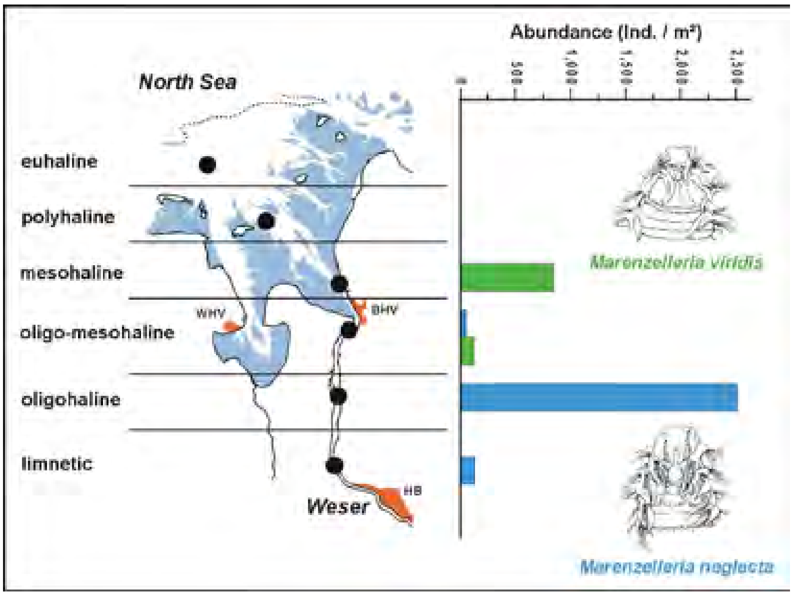


Figure 3: High abundance of two American spionid polychaetes, *Marenzelleria neglecta* and *M. viridis* in the sublittoral of the Weser estuary, differentiated by the salinity gradient (BfG Estuary Monitoring Programme 1999, modified after Nehring and Leuchs, 2001).

above all by the Pacific oyster *Crassostrea gigas, Ensis americanus*, locally *Crepidula fornicata* and others. This is an invasional meltdown where aliens facilitate each other. At greater depth of channels and in the adjacent offshore zone, the share of aliens is again quite low up to now.

Potentially, a third hotspot may be in the coastal waters flowing in and out of the Wadden Sea with the tides. Some alien holoplanktonic species at times abound including the ctenophore invader *Mnemiopsis leidyi* and larvae of introduced aliens. As well as these three hotspots, one could also regard specific localities as potential hotspots of alien species, where they can be expected to show up first after arrival in the Wadden Sea. These localities include ports, marinas, on buoys and in inner estuaries where the species are introduced with ships and are expected to arrive and have a good chance to get off board or reproduce. Other hotspots are around oyster and mussel cultures. Such localities should be particularly surveyed for early detection of alien invaders (see chapter 4).

3.1 *Spartina* – the most important invasive plant in the Wadden Sea

Already intentionally introduced eight decades ago to aid in land claims and now well rooted with extensive populations along the sheltered shores of the Wadden Sea and adjacent coasts, the *Spartina* grass has become a characteristic feature of the transition zone between marsh and tidal flats (Fig. 4). Nevertheless, it is still not generally known that this conspicuous grass does not belong to the native flora and constitutes an artificial element in the Wadden Sea, just as dikes and revetments, linear ditches and brushwood groins. What is the history and what are the prospects, what the effects on the ecosystem and biodiversity, and what could be done about it?

Grasses of the genus *Spartina* are indigenous to the Americas and the species *S. maritima* to Africa and southwest Europe or possibly has been introduced a long time ago into the latter region. Along other coasts in the world, including the Wadden Sea, various other plants such as species of the genera *Salicornia* and *Puccinellia* used to dominate the pioneer zone of salt marshes. However, this has changed. Today *Spartina* grasses abound at most sheltered shores of temperate climate zones because of deliberate introductions which aimed to enhance salt marsh development. *Spartina* species hybridized, natural vegetation became displaced and coastal landscapes transformed. *Spartina* is a classic example of global biological homogenization through its mixing with once-distinct coastal vegetations.

Particularly widespread are *S. alterniflora* and *S. anglica.* The latter originates from accidental hybridization between *S. maritima* and introduced *S. alterniflora* in southern England. In the sterile hybrid, a doubling of chromosomes happened to occur and a fertile species was born, named *S. anglica* in 1892. This new species turned out to be a more vigorous pioneer of salt marsh vegetation than its parents, strongly facilitating sediment accretion and thereby transforming tidal flats into salt marshes. This has attracted coastal engineers and systematic planting of *S. anglica* commenced in the 1920s, including the introduction at various sites in the Wadden Sea between 1925 and 1944 (Nehring and Hesse, 2008). These plantings were partly successful and *Spartina* spread further on its own. However, disillusionment soon followed the initial euphoria. König (1948) concluded that *Spartina* cannot protect any coast but grows well only where it is protected by the coast itself. Also die-backs occurred, marshes with *Spartina* became water-logged and unsuitable for grazing, and ditching for irrigation increasingly cumbersome. Finally, in the 1960s, even tests with herbicides were conducted in the German Wadden Sea to eradicate *Spartina*, in the end without success.

Figure 4: A belt of *Spartina anglica* between native salt marsh vegetation (*Halimione*) and bare tidal flats with some seagrass (*Zostera noltii*) on the island of Sylt (July 2008).

On vegetation maps for the Wadden Sea, salt marshes were generally categorized into pioneer, low and high salt marsh zones but did not provide information on the areal share of *Spartina*. Only for salt marshes along the Schleswig-Holstein coast, the areal share of a "*Spartina anglica* Typy" was given as 18% for the mainland and 13% for the islands in 2001 (see Stock *et al*., 2005). However, this does not comprise *Spartina* growing outside that type in the unspecified pioneer and lower salt marsh zone. Thus, there are no data on the areal extent of *Spartina* in the Wadden Sea. Knowledge is confined to a few selected sites showing how this invader spread initially, and that it is still spreading (*i.e.* Vinther *et al*., 2001; Stock *et al*., 2005; Loebl *et al*., 2006). It has been suggested that reductions in domestic grazing and in irrigation works (Stock *et al*., 2005), climate change in the form of mild winters (Vinther *et al*., 2001), and warmer and earlier spring times since 1988 (Loebl *et al*., 2006) have contributed to a renewed acceleration in the spread of *Spartina*.

Global warming may prolong the growth season of *Spartina* in the Wadden Sea because it belongs to plants with a C_4 pathway with physiological thresholds of 4°C for germination and 7°C for effective photosynthesis. Loebl *et al.* (2006) assume that the improved temperature conditions may have helped the grass to grow also on more exposed sandy tidal shores where it has been absent before. However, interactive effects between warmer temperature and increasing hydrodynamics in the wake of accelerating sea level rise may ultimately set a limit to the further spread of *Spartina* in response to global warming, relegating its distribution in the Wadden Sea to the sheltered locations in the upper tidal zone. Thus, a general cover of bare sediment by *Spartina* down to mid tide level, as it commonly occurs at the more sheltered Atlantic shores of North America, may never happen in the Wadden Sea.

Patches and swards of *Spartina* are a strong habitat transformer or ecosystem engineer by accreting sediment, accumulating organic material, penetrating the ground with a dense mesh of roots and rhizomes, and offering a complex habitat structure above the ground which also shades the bottom and calms down hydrodynamics. A multitude of effects has been recorded, varying with the phase of succession, the physical environment and the organisms considered (Table 1).

The role of *Spartina* as food to herbivores is minor compared to being a source of detritus and physically changing the habitat structure. Effects on biodiversity depend on location, the organisms and the scale which is considered. *Spartina* tends to grow in monospecific stands which displace more diverse native vegetation but on a larger scale it adds one more type of habitat patch to the dynamic mosaic of the salt marsh vegetation (Fig. 5). The diversity and complexity of effects of *Spartina* on the environment precludes any

Table 1: Effects of *Spartina* on the habitat and other organisms

Effects	Habitat/Organisms	References
Shoots and roots are food	for foraging geese	Esselink *et al*., 2000
Shoots provide shelter	for ducks and other birds	Zedler, 1993
Shoots provide habitat	*Littorina, Hydrobia*	Armbrecht, 2008; Bouma *et al*., 2009
Dense swards prevent	edge erosion of old marsh	see Fig. 7.4
Dense swards accrete sediment	more than other vegetation	Gray *et al*., 1991
Shade out native plants	*Puccinellia, Salicornia*	Scholten and Rozema, 1990; Gray *et al*., 1991
Raise the ground too high for	*Zostera noltii*	Reise *et al*., 2005
Culms increase	abundance of macrobenthos	Rader, 1984
Roots inhibit burrowing fauna	*Arenicola* and other infauna	Armbrecht, 2008; Bouma *et al*., 2009
Growth phases have different effects	in infauna	Neira *et al*., 2007
Patch edge and center differ in effects	on bivalves	Dumbauld *et al*., 1994 in Daehler and Strong, 1996
Inhibit suspension feeders	*Cerastoderma edule*	Armbrecht, 2008
Roots create oxic microhabitats	nematodes	Osenga and Coull, 1983
Accumulation of detritus creates	anoxia and die-back	Nehring and Hesse, 2008
Sediment accretion eventually	facilitates native plants	Dijkema, 1983
Invasion of bare tidal flats reduces	feeding area for shorebirds	Evans, 1986; Goss-Custard and Moser, 1988
Monospecific swards	may be susceptible to epidemics	Thompson, 1991

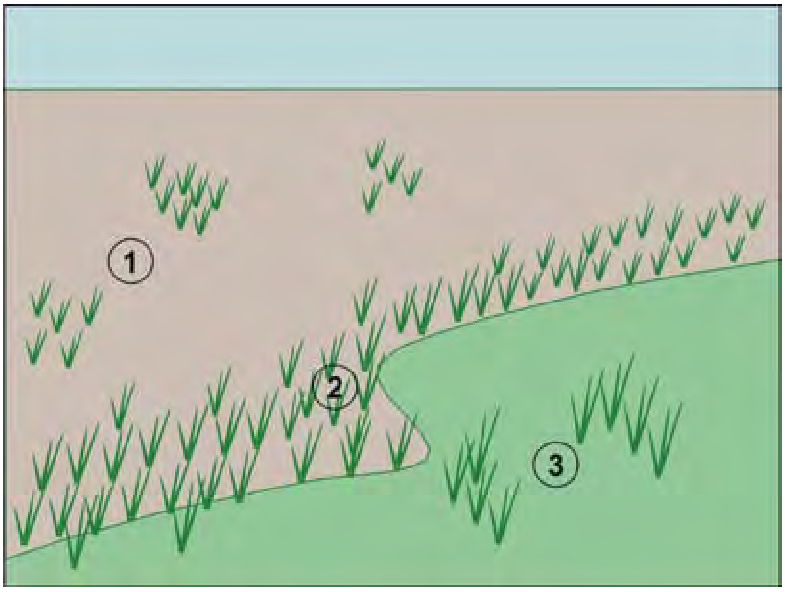


Figure 5: *Spartina anglica* invades (1) upper tidal flats in patches, (2) dominates in swards the seaward edge of salt marshes, and invades (3) the high marsh with dynamic patches. Effects on habitat structures and other species differ at these sites.

simple normative statement whether it is good or bad, and the net balance will vary with time and location. From a nature conservation point of view, however, the magnitude of deviation from natural conditions caused by the *Spartina* invasion is relevant and could justify measures of eradication or control (see chapter 4).

Nehring and Hesse (2008) have reviewed mechanical, chemical and biological methods which have been employed or have been suggested to control *Spartina*. To restore natural processes in the upper tidal zone of the Wadden Sea, it would be desirable to have shores again without *Spartina*. However, methods to eliminate established *Spartina* should fulfil the following requirements:

1. Mechanical elimination must not have disturbing effects on other organisms and natural habitat structures lasting longer than a few years.
2. Applied chemicals must not poison other organisms.
3. Biological agents such as diseases or herbivores must be specific to *Spartina* and not spread to regions where these are not wanted.
4. Must be successful in the long run, be cost-effective and acceptable to the public.

In addition, any management measures should be avoided which promote *Spartina* in the Wadden Sea. The Natura 2000 programme ought to be corrected. The invasive alien *S. anglica* should not fall any more into the natural habitat type *Spartinion maritimae* code 1320.

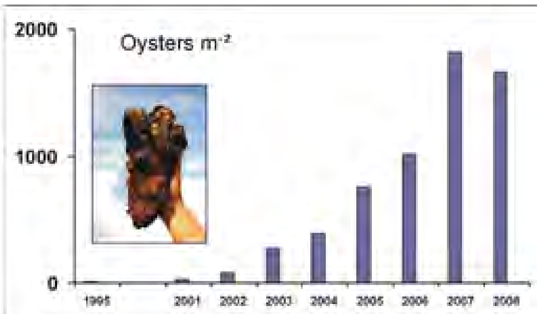
3.2 Invasional meltdown around low tide level

Similar to *Spartina*, also the Pacific oyster *Crassostrea gigas* is a universal habitat transformer of temperate shores, regardless whether muddy, sandy or rocky (Ruesink *et al.*, 2005). Different from *Spartina*, the invasion of *Crassostrea* began only two decades ago and it is still too early to venture a sound projection on the final outcome. So far, there is hardly any other invaded region which happened to be so readily invasible for this alien oyster as the Wadden Sea. How could that happen, what is the impact like and is there anything which could be done about it? *C. gigas* is spreading above and below low tide level where it is not the only successful alien invader. The interactive effects with other aliens exacerbate the situation. The benthic community around low tide level is often dominated by alien species.

Without the depletion of natural beds and subsequent extinction of the European oyster *Ostrea edulis* in the Wadden Sea and adjacent waters, there would not have been an incentive to introduce alien oysters (Reise, 2007). Early attempts failed to introduce *O. edulis* from elsewhere in Europe, *C.virginica* from Atlantic America and various strains of *C. gigas* from the western Pacific. However, the *C. gigas* introduced into the Oosterschelde estuary in 1964 spread into the wild from 1976 onwards. In the Western Wadden Sea specimens probably originating from seed oysters imported from a French hatchery (Smaal *et al.* 2009) were introduced in the cooling basin of the electricity plant in Texel in the late 1970s (Tyde-

Figure 6: Pacific oysters growing adjacent to an oyster farm at the island of Sylt (August 2007).

man, 2008) and adult specimen were encountered outside that basin in 1983. Spread from there was rather slow at first but since the late 1990s the invasion progressed rapidly throughout the Wadden Sea (for details see Dankers *et al.*, 2004; Reise *et al.*, 2005; Nehls and Büttger 2007; Fey *et al.* in press). Another source of this species was regular farming of *C. gigas* with spat from British and Irish hatcheries near Sylt since 1986. A wild population, started close to that farm in 1991, invaded the Danish Wadden Sea and also spread to the south (Fig. 6).



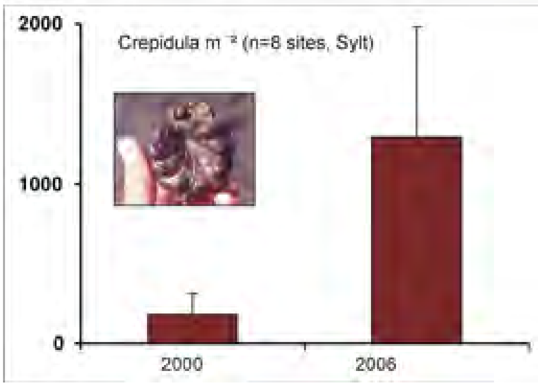


Figure 7: Above: mean abundance of the Pacific oyster *Crassostrea gigas* on mussel beds which since 2005 appeared to be all oysters reefs near Munkmarsch harbour on Sylt. Below: mean abundances of the American slipper limpet *Crepidula fornicata* adjacent to mussel beds in 2000 and to oyster reefs in 2006 at about spring low tide level near the island of Sylt (Reise, unpubl.).

The reproductive success in *C. gigas* has been linked to mean water temperatures >18°C during July and August (Diederich *et al.*, 2005), and particularly strong recruitment was observed in summers between 2002 and 2006. A representative course of oyster reef development on former mussel beds is given in Fig. 7. Oysters settle on any hard substrate but are most common on mussel beds or where these had been before. The vertical distribution ranges from below mid tide level down into the shallow subtidal with a maximum found around low tide level, copying the pattern of mussel beds. Abundances generally attain densities up to 1,000 to 2,000 oysters m^{-2} with a total weight of 30 to 50 kg m^{-2}, but on established reefs they may go as high as 140 kg m^{-2} (Fey *et al.* in press). In 2006, the oyster mass including shells was estimated to be at least 61,000 t in the Wadden Sea (Nehls and Büttger, 2007).

Ecologically, the spread in the Wadden Sea started with a paradox. In spite of strong crowding between *Mytilus edulis* on mussel beds, oyster larvae successfully attached to individual mussels, grew faster and larger, soon smothered their basibionts and began to dominate the beds (Fig. 8). Mussels have not reversed this hostile takeover by settling on top of the oysters and smothering them in turn. Instead, mussels settled in the understory between the much larger oysters, escaping predators. Oyster larvae, by contrast, settled preferentially on top of their older conspecifics which gives rise to reef formation (Diederich, 2005). There are also wide areas with scattered clusters of oysters. These are mostly dislodged from the reefs, continue to grow and may serve as nuclei for new beds where bare sediment had been before.

There are probably no more mussel beds without any oysters in the entire Wadden Sea. Will the Pacific oysters eventually displace the native mussels? Up to now, the observations are inconclusive (Nehls *et al.*, 2006; Nehls and Büttger, 2007). Within and between mussel beds, all combinations of high and low abundances have been encountered. Also the temporal development provides no clue. Since 1998, mussels increased in the Dutch and decreased in the German and Danish Wadden Sea, while oysters proliferated everywhere. The decrease in mussels commenced already before the oysters began to increase significantly. The area of mussel beds in Dutch Wadden Sea has remained relatively stable over the last years while oyster reefs and mixed beds are increasing (Fig 9).

Long-term experience with mussels indicates that severe winters have regularly resulted in population expansion in the subsequent summer (Nehls *et al.*, 2006). This has been linked to a gap in predation pressure caused by high predator mortality and/or their retarded development. However, such gaps may also occur for other reasons as the development of the mussel population in the Dutch Wadden Sea shows. Thus, the climatic trend alone, with no more severe winters since 1996, will not suffice to predict the future proportions of mussels to oysters in the Wadden Sea. The microspatial pattern suggests that mussels have a chance to coexist under the dominance of oysters (Fig. 8).

The spectrum of species associated with mussel beds and oyster reefs is roughly the same but strongly varies with location (Markert *et al.*, 2009).

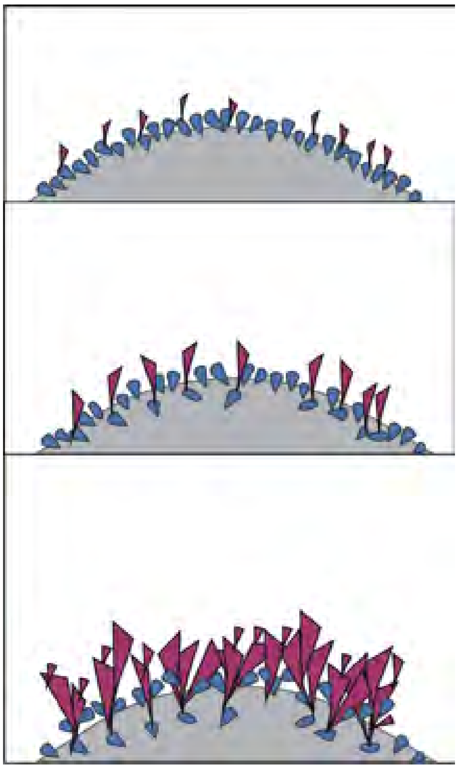


Figure 8: Succession of the conversion of a mussel bed into an oyster reef in the Wadden Sea within 3 to 5 years. First, Pacific oysters settle upon mussels. Then new mussels settle in the understory, while settling oysters attach to the tops of live and dead oysters, creating an oyster reef.

A field experiment with mussels and oysters revealed that differences in the habitat matrix generated by these two bivalve aggregates entailed different abundances of associated infauna and epifauna (Kochmann *et al.*, 2008). Further, a cover with fucoid algae common on sheltered mussel beds rarely develops where oysters prevail. As a coastal filter the oyster reefs may be a functional analogue to the mussel beds but the structural

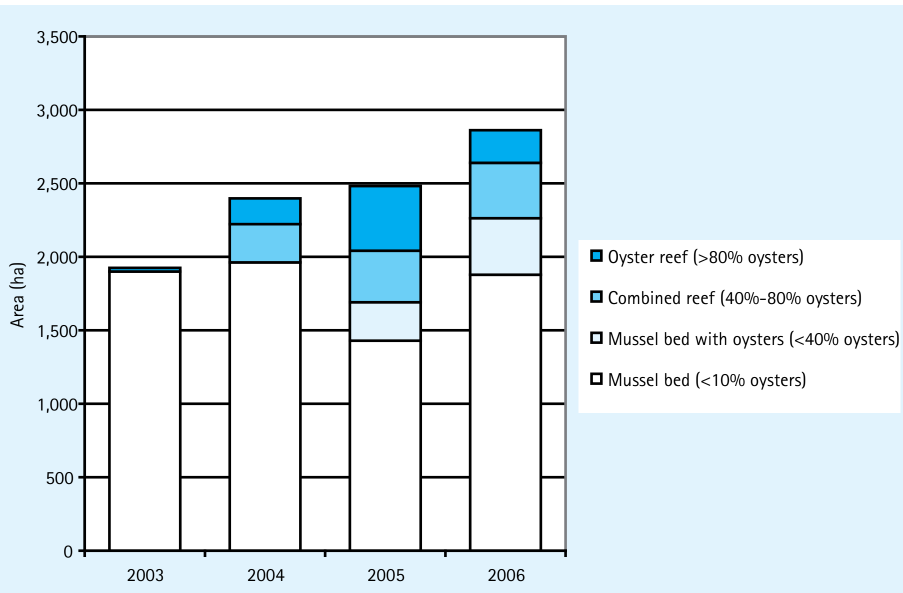


Figure 9: Area of intertidal mussel beds and the "takeover" by the Pacific oyster in the Dutch Wadden Sea (Fey *et al.* 2009).

Figure 10: Stack of the American slipper limpet *Crepidula fornicata* (left) and stacks scattered on shallow subtidal bottom forming a dense bed of limpets (Sylt, September 2008).

effects differ. In particular, the Pacific oysters are still poorly integrated into the food web of the Wadden Sea. Birds like eider, oystercatcher and herring gull which particularly feed on mussels may run into a shortage of food because most oysters are too large for consumption or fused into clusters, and shells are too strong for the birds to break them open (Blew and Südbeck, 2005; but see also Cadée, 2008 a,b).

May the Pacific oysters cause food shortage in native suspension feeders by competition? In line with such a process, native bivalves did decrease over the last decade (Beukema and Dekker, 2005; Nehls *et al.*, 2006). As pointed out above, the trend of warming is more likely to be the cause. This entails an increasing predation by shrimp and shore crabs on bivalve spat rather than competition with the alien suspension feeders. Further, one should note that *C. gigas* is not the only suspension feeder that invaded the Wadden Sea. Concurrently with the increase in oysters, the American slipper limpet *Crepidula fornicata* increased in abundance (Fig. 7). It was already introduced into the northern Wadden Sea seven decades ago with *O. edulis* imported from the Oosterschelde, and switched from the fading oyster grounds to subtidal mussel beds near Sylt (Thieltges *et al.*, 2003). There it now abounds in the shelter of mussel beds or oyster reefs, forming a halo virtually paved with stacks of individuals attached to each other (Fig.10) (Nehls *et al.*, 2006; Thieltges *et al.*, 2009). Also around low tide line, the razor clam *Ensis (directus) americanus* attains its highest densities since the 1980s (Armonies and Reise, 1999). Attached to the empty shells protruding out of the sediment as well as to oysters and slipper limpets, the Asian ascidian *Styela clava* frequently occurs in bunches of individuals with up to 232 m^{-2} just below mean low tide level (Fig. 11) (Liebich, 2007).

Altogether, *Crassostrea, Crepidula, Ensis, Styela* and a few others have launched a striking invasion of alien suspension feeders in the zone around low tide line. The level of primary production may be still high enough to supply them all (Brinkman and Jansen 2007; Reise and van Beusekom, 2008). In addition to competition and predation, parasitism has to be considered as an important biotic interaction altered through alien bioinvasions.

Figure 11: Aggregate of the invasive ascidian *Styela clava* on shallow subtidal bottom (Sylt, June 2007)

Alien molluscs generally have arrived without their parasites, but parasites of native molluscs also infected the alien hosts (Krakau *et al.*, 2006). Experiments have shown that Pacific oysters and American slipper limpets actually mitigate the parasite burden of the native mussels (Thieltges *et al.*, 2009). From the oysters as intermediate hosts, trematodes cannot reach their final hosts because oysters are not (yet) consumed by the birds. Slipper limpets actually prey on cercarial stages and do not get infected. In recent years massive mortality occurred locally in late summer (Dankers *et al.*, 2004). From the French Atlantic coast there are reports of very high summer mortalities in *Crassostrea gigas* (Samain *et al.* 2004). In the Wadden Sea, oyster beds do not disappear after mortality events. The shells remain and new spat fall even solidifies the bed as a whole (Fig. 12)

Slipper limpets attached to mussels have been shown to reduce growth and increase mortality in their basibionts, while they provide protection against predator attacks by shore crabs and starfish (Thieltges *et al.*, 2006). The web of interactions becomes even more complex when the large invasive kelp *Sargassum muticum* is considered (Fig. 13). It forms dense canopies in the shallow subtidal of Sylt with positive effects on the diversity of native species which attach or roam between the manifold branched thalli (Buschbaum *et al.*, 2006; Polte and Buschbaum, 2008). Usually, clusters of oysters and stacks of slipper limpets provide the main anchorage at the bottom for this invasive macroalgae. However, this is often not perfect because the algae attain lengths of up to 3 m in July and the resulting drag lifts the anchorage off the bottom, and both together end up in the wash line on the beach.

Figure 12: Dead Pacific oysters serve as substrate to subsequent settlement which may glue together the empty shells (Photo: N. Dankers).

In conclusion, the Pacific oyster has established firmly in the Wadden Sea. Neither the final population size nor the impacts on native species can be clearly projected but it may cause a change in the ecosystem which may surpass that of *Spartina*. Together with several other alien invaders parallel to or interacting with *C. gigas*, the benthos around low tide level has already been overturned with cascading effects on foraging birds and the functioning of the ecosystem. Thus, efforts to protect *Crassostrea* reefs in the Natura 2000 programme as natural habitat type of community interest (Reefs, code 1170) have not to be put into action.

Figure13: The invasive *Sargassum muticum* forms a dense kelp forest adjacent to the oyster farm at the island of Sylt (July 2007).

Apparently, the spread of *C. gigas* into the wild was not considered to be a problem until the late 1990s. Although *Crassostrea* successfully reproduced in the Oosterschelde since the mid 1970s, it was still assured in 1986 that starting a *Crassostrea* farm near Sylt is not violating National Park law because it was assumed that the Pacific oysters were unable to breed under our latitude and would not spread into the wild. Concern has arisen only after the invading population had passed the line of no return. In view of the sheer number already present, together with its enormous potential of reproduction and dispersal, no mechanical control of this invader is conceivable. Wild aggregates of *C. gigas* may not be commercially harvestable for consumption, and large scale dredging for low quality meat, manure or chalk production would be devastating for the environment. Thus, fishery on oysters would be no sensitive option for the Wadden Sea ecosystem. Seed oysters might be collected but very few are suitable for further culturing because most are attached firmly to clusters and cumbersome to detach. Removal of entire reefs with bulldozers or by dredging from a ship is not feasible on the large scale required for control without harming all other organisms including natives, and the success is likely to be only short term. Other means of control could be the introduction of potent predators or diseases. However, such biocontrols are difficult to keep under control (Hoddle, 2004; Thomas and Reid, 2007). Potential collateral damage to non-target species as well as to cultured oysters is usually impossible to rule out.

However, as a partial reparation for the over-exploitation of the native oysters and the introduction of alien ones, attempts could be made to re-introduce the native oyster *O. edulis*. Other than the mainly intertidal *C. gigas*, this species had occurred subtidally and so may not suffer from spatial competition with *C. gigas* if re-introduced. The maintenance of dense commercial stocks of *O. edulis* may provide the key to a redevelopment of native oyster beds by providing initial brood stock nuclei from which larvae can spread. A problem might be to obtain a genotype similar to the one which once thrived in the Wadden Sea before over-exploitation led to its extinction. Care should also be taken not to introduce the *Bonamia*-disease. Presumably, *O. edulis* living today in Limfjorden (Kristensen, 1997) could be a proper source for the re-introduction. An unintended re-introduction of *O. edulis* has turned into a success in Strangford Lough, Northern Ireland (D. Roberts, *pers. comm.*). However care should be taken as these oysters might be susceptible for Bonamia disease or if resistant they might carry the disease and might form a stepping stone between infected regions (Dutch Delta) and non-infected regions such as Limfjorden.

3.3 Alien invaders in the plankton

In drifting planktonic organisms, an occurrence in the North Sea cannot be set apart from the Wadden Sea. These organisms are largely at the mercy of currents and thus their abundance in the Wadden Sea is highly variable. What evidence is known that aliens in the plankton exert effects on natives or on the ecosystem in the Wadden Sea?

At least nine taxa in the phytoplankton are likely to have been introduced with ballast water or oysters, and of these the diatoms *Odontella sinensis*, *Coscinodiscus wailesii* (Fig. 14) and *Thalassiosira punctigera,* the frequently re-named dinophyte *Karenia (=Gymnodinium) mikimotoi (=aureolum)* and *Fibrocapsa japonica* belonging to the Rhaphidophyceae have been occasionally reported as abundant (Gollasch *et al.*, 2008). To what extent these introduced alien species have effects on other phytoplankton or on consumers has not yet been shown.

As a corollary of the many alien invaders in the benthos, there are times when their larvae are abundan in the coastal waters. As an extreme example, larvae of the American razor clam *Ensis americanus* dominated with 92% all identified bivalve larvae in the plankton samples taken in summer 2004 near Sylt (M. Strasser, *pers. comm.*). As with phytoplankton, the cascading effects in the food web are not known.

In the warm summer of 2006, the lobate ctenophore *Mnemiopsis leidyi* was sighted at several coasts in northern Europe including the Wadden Sea, but may have been introduced several years earlier with ballast water (Faase and Bayha, 2006; Boersma *et al.*, 2007; Tendal *et al.*, 2007). Normally, only specialists care about such comb jellies. However, *M. leidyi* had already a bad name from the Black and Caspian seas. This American ctenophore found ideal conditions after first encounters in 1982, spread massively and was blamed for having caused the collapse of the Black Sea fishery on anchovy by competing for planktonic food (Bilio and Niermann, 2004). After 1995 the same ctenophore also invaded the Caspian Sea, and again this was associated with a dramatic decrease in other zooplankton and fish, in this case kilka, the most common anchovy there. Similar effects were suspected in North European waters.

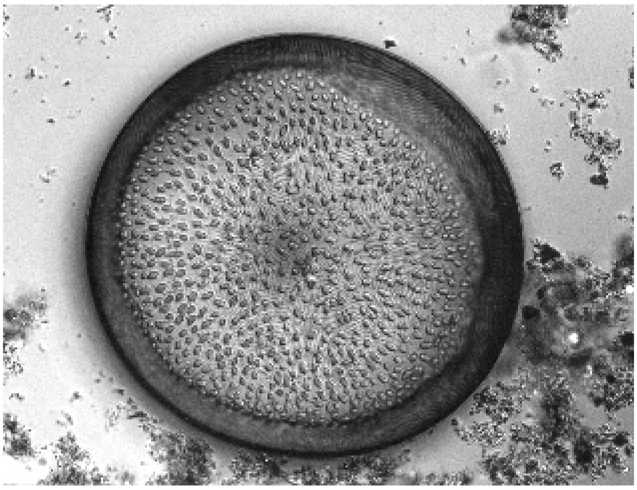


Figure14: The invasive diatom *Coscinodiscus wailesii* forms dense blooms, up to 90 % total algal biomass (Photo: K. Hesse).

However, *M. leidyi* on average remained smaller than in southern waters, mostly <40 mm in length and only a few were found in the Wadden Sea, sized up to 80 mm. From winter to early summer densities were rather low, and then increased up to 60 m^{-3} in August when temperatures were above 17°C (Fischer, 2008). Small size may limit both, reproductive potential as well as predatory impact. Mainly small sized prey is taken such as copepods and barnacle larvae (Müller, 2008). With high abundance only in late summer, effects on larvae of most fish and benthic macrofauna may remain weak, while larvae of species like *C. gigas* which spawn later may become potentially decimated.

It is obvious that no control of pelagic invaders is possible once these have arrived. Prevention of such species from entering the Wadden Sea with their vectors is the only way to keep them out. Treatment of ballast water and careful quarantines with imports for aquaculture must ensure that no life organisms with the potential to survive and reproduce in the Wadden Sea find their way into the North Sea. Such measures need to include benthic organisms or benthic stages as well and therefore the hulls of ships should receive special treatment.

3.4 What next do we have to expect?

Watching at the gate to prevent aliens from entering the Wadden Sea and getting established inside the Conservation Area is essential. This is the most effective precaution against the rising tide of alien invaders. It requires sound knowledge of what is native and what is not. When the Egyptian ibis, which has escaped from zoos into French coastal wetlands, is attempting to nest on a Wadden Sea island, this will be readily noticed and swift action could be taken to prevent breeding. The American horseshoe crab *Limulus polyphemus* is another likely candidate to become established, but is conspicuous and strange enough not to be overlooked. However, there are many other cases which will pass unnoticed without specifically focused surveys.

On the Pacific coast of North America, a vigorous hybrid between the introduced *Spartina alterniflora* and the native *S. foliosa* emerged (Ayres *et al.*, 2004). Detecting such a hybrid introduction into the Wadden Sea may require genetic screening. The same may apply to the native small eelgrass *Zostera noltii* and *Z. japonica*. These are morphologically very similar, and the latter is already spreading in coastal America. No alien species is known from the weedy green algae categorized as *Ulva* or formerly *Enteromorpha*. This may simply reflect the current confusion in the taxonomy of this group. Genetic screening will be necessary to unravel to what extent globalization already has proceeded and then to detect newly invading taxa or genotypes.

Such an effort may seem exaggerated at first sight. However, eelgrass and green algae are used as monitoring parameters to evaluate environmental quality for the European water framework directive. If the taxonomic basis of such parameters is not well controlled, serious misinterpretations could be the result. At present, seed mussels are imported into the northern Wadden Sea from the British Isles which entails the possibility that, in addition to *Mytilus edulis,* the southern sister species *M. galloprovincialis* or a hybrid between the two is imported unnoticed. It

Figure 5: Mature female of *Callinectes sapidus* Rathbun caught in German Weser estuary on 20 July 2007 (Photo: J. Albersmeyer).

is not known what the consequences for survival and for species interactions may arise from such genetic mixing. The invasion of *Crassostrea gigas* is already severe but it could become even worse if in addition other Pacific species such as *C. sikamea* and *C.ariakensis* are introduced. Morphologically these are almost indistinguishable from *C. gigas*. Nevertheless, there are important ecological differences with respect to vertical range and exposure to hydrodynamics.

Some invaders are almost certainly about to invade the Wadden Sea if they are not already present before this volume is published. Some have an impressive career as successful invaders elsewhere, i.e. the Pontocaspian fish *Neogobius melanostomus*, the Pacific whelks *Rapana venosa* and *Ocinebrellus inornatus*, the Asian clam *Tapes philippinarum*, the small mussel *Musculista senhousiana* and the sizable blue crab *Callinectes sapidus* (Fig. 15). Decisions whether these should be met with resistance to prevent establishment should be based on experiments testing the interactions with native species as well as on models predicting the invasional pressure and thus the chances to keep particular invaders out. Thus, in addition to regular surveys by experts, a considerable research effort is needed.

4. Conditions and measures

The significant effects of alien species on aquatic ecosystems require that efforts should be made to prevent and control their further spread. The strategies to minimize impacts caused by alien species are known. However, the countries' abilities to address issues on alien species varies.

Alien policy in the Dutch Wadden Sea

There is no specific alien policy for the Wadden Sea. In October 2007 the Ministry of Agriculture, Nature and Food Quality send a policy statement (Beleidsnota Invasieve Soorten) to the Dutch parliament. It mentions several of the above indicated international agreements and also the IMO ballast water agreement (to be ratified in 2009) but not the RAMSAR convention which is specifically important for the Wadden Sea.

A general conclusion of the statement is that preventing introductions of invasive alien species is the most important and (cost) effective policy option. Possible management options that contribute to prevention are creating public awareness of this problem and making agreements with stakeholders, such as companies that import plants, plant products or animals.

The Ministry of Agriculture, Nature and Food Quality set up an *Invasive Species Team,* consisting of several civil servants. The formal starting date for this team was January 2009. In co-operation with an expert network this Invasive Species Team will work on: a) gathering information on (new) alien species, b) setting up monitoring programs (early detection of new alien species), c) risk analysis (carried out by experts), d) advising the Ministry on invasive species (risks and possible management options), e) informing the public on invasive species (raising awareness). The Invasive Species Team mainly focuses on alien species that (potentially) impact biodiversity. Most of the (alien) organisms that threaten human health or the economy (agriculture) are dealt with in other organizations and ministries. When an initial analysis indicates possible impacts on biodiversity and more information is needed, a risk analysis will be carried out by experts. If needed, further monitoring will be carried out to determine the spread of the alien species. Based on this information the Invasive Species Team advises the Ministry on the possible impacts of the alien species and possible management actions.

Alien policy in the Danish Wadden Sea

In 2008 Denmark prepared a National Action Plan for Alien Invasive Species. The Action Plan gives a number of recommendations on prevention, eradication, control and research on alien species. Regarding the marine environment, prevention is much preferred as eradication most often is impossible. Therefore one of the recommendations is implementation of the Ballast Water Convention.

The Action Plan also includes the first Danish "black list" of species regarded as the "worst" alien invasive species in Denmark. Furthermore there is an "observation list" of species either not yet present in Denmark but known to be invasive in neighbouring countries or present in Denmark but still rare.

Alien policy in the German Wadden Sea

In accordance with the CBD's guiding principles (CBD, 2000), Germany has recently been preparing a national strategy on invasive alien species (Hubo *et al.*, 2007). The overall strategy for alien species comprises two main components: dealing with the problem of alien species already present, and the prevention of further introductions including the response if prevention should fail. Depending on the species, efforts should target one of the five categories: (a) prevention of introductions through education and regulations; (b) monitoring and early detection by effective monitoring programs; (c) rapid measures to eliminate newly introduced invasive alien species; (d) minimization of impacts of established invasive alien species by eradication and control; and (e) acceptance of established non-invasive species.

a. Prevention

Prevention is the first line of defence. In aquatic environments, alien species can be hard to detect and organisms disperse rapidly. It is a well-known fact that the eradication of an introduced species, once it has established in our waters, will be very difficult (and expensive), or even impossible. Therefore, the prevention of introductions (at best at source) is the most effective and least costly management strategy. Moreover, prevention is the only option where different measures for intended and unintended introductions have to be applied (Nehring and Klingenstein, 2008).

As far as intended introductions are concerned, many releases of alien organisms have been undertaken without taking into account the possibility of detrimental effects. Some organizations have developed guidelines and codes of practice (*e.g.* the ICES Code of Practice on introductions and transfer of marine organisms, the EIFAC Code of Practice and Manual of Procedures for consideration of introductions and transfers of marine and freshwater organisms). These instruments should assist key authorities (*e.g.* government agencies, regional authorities, professional associations for fishing) in determining whether an introduction is justified, and advise them on what to do after an introduction has been approved. However, these voluntary rules have lacked efficiency up to now.

As a legal instrument, the European Council enacted in 2007 a council regulation concerning the use of alien and locally absent species in the European aquaculture industry (Council of Europe, 2007). This is a first step in the right direction. However, up to now this directive is not transferred in national legislation in the three Wadden Sea countries. Under the proposed measures, all projects to introduce an alien species, or a native species which is locally absent from an area, would have to be submitted for approval to a national advisory committee which would determine whether the proposed introduction was 'routine' (i.e. from a known source of aquatic organisms classified as low risk) or not. In the case of non-routine introductions, an environmental risk assessment would have to be carried out. Only movements which are assessed as low risk (or reduced to low risk by application of mitigation procedures or technologies) would be granted a permit which can cover a five year period. The proposal requires quarantine procedures for non-routine introductions and also sets out a number of requirements concerning pilot release, contingency plans, monitoring and the keeping of national registers.

An important example of preventing unintended introductions is the International Convention for the Control and Management of Ships' Ballast Water and Sediments, adopted by member States of the International Maritime Organization in 2004 (IMO, 2004). It will enter into force 12 months after its ratification by 30 States, representing 35% of the world's merchant shipping tonnage. Under the Convention, ballast water management will become mandatory in order to minimize the introduction of harmful aquatic organisms and pathogens by this vector. Implementation of the Convention will prove difficult as it involves many legal, biological and technical aspects, including changing the design, construction and operation of ships. Expediently, parties (port or flag state administrations) are given the right to take more stringent measures than prescribed by the convention when consistent with international law. However, up to now this convention is not in force because as of 26 October 2008 sixteen States representing 14.24% of world tonnage had ratified. The sixteen states include just three from Europe: France, Norway and Spain.

The Ballast Water Convention does not prevent all unintended introductions associated with shipping since it only covers ballast water management. But solutions with environmentally acceptable methods for the control of hull fouling are also urgently needed now that effective but ecologically risky TBT based antifoulants have been banned in many countries (Nehring, 2001). And up to now there have been no activities focusing on shipping canals, although this pathway is of highest relevance for alien invasions in aquatic ecosystems, especially in Germany and its estuaries (Nehring, 2006; Galil *et al.*, 2007).

An important additional aspect of preventing unintended and intended introductions is the raising of awareness/enlightenment of politicians, management authorities, companies, scientists as well as the public about alien species, their risks and the possibilities to prevent further introductions. Among presentations in the scientific world and for the public, web-based information platforms offer a great chance to enhance awareness of the alien problem continuously (e.g. the German web-sites www.aquatic-aliens.de, www.neophyten.de). In particular, the many nature guides in the Wadden Sea should attend special courses on alien species. As in the case of oil spills or other environmental hazards, we recommend establishing a trilateral working group of experts, sufficiently funded to specify specific preventative conditions and measures to prevent efficient alien invasions in the Conservation area of the Wadden Sea.

b. Monitoring and early detection

The second line of defence, and high priority, against biological invasion into protected areas, is the monitoring and early detection of alien species (De Poorter, 2007).

Monitoring is of special relevance to obtain information about the invasibility of habitats, and the spreading and establishment of alien species, or about the efficiency of measures (see below).

However, a purposeful monitoring scheme for aquatic alien species is still missing. Such schemes should be based on existing data and instruments (*e.g.* TMAP) as well as the development of new mechanisms such as expert consultation and early detection systems (see below). The European Water Framework Directive (European Parliament and Council, 2000) requires that an integrated monitoring programme be established within each river basin district, including coastal waters. In many cases, these monitoring programmes will be extensions or modifications of existing programmes and will enable collections of the physical, chemical and biological data necessary to assess the status of water bodies. Alien species should be a key parameter in the monitoring design.

Within surveillance and monitoring efforts, the development of an effective early detection system is necessary to detect and to determine the status of newly occurring alien species in the wild. By rapid measures (see below) any potential invasion can be "nipped in the bud" – avoiding impacts on biodiversity and livelihoods, and saving large amounts of management resources. Invasive alien species which are listed on 'black lists' elsewhere should receive special attention. However, in aquatic environments, new introduced species are much more difficult to detect than in terrestrial habitats. Therefore an early detection system and rapid assessment strategy could focus in short time intervals 1) on areas that are likely to be hot spots of entry, such as large estuaries (*e.g.* Ems, Elbe, Weser; see Nehring, 2006), ports (*e.g.* Bremerhaven, and in the near future Wilhelmshaven after the opening of the Jade-Weser-Port; see Gollasch and Leppäkoski, 2001), marinas and aquaculture plots (*e.g.* Pacific oyster farm near the island of Sylt; see Wolff and Reise, 2002), and 2) as the need arises on particularly valuable habitats within protected area sites. And apart from this, an important component of an aquatic early detection system should be the integration of fishermen because many first discoveries of aquatic alien species are made by them (Nehring *et al.*, 2008). We recommend that in the trilateral group of experts (see above) an alien monitoring scheme inclusive early warning system and need of alien research in the Wadden Sea should be specified.

In general, every measure, pronounced in the following categories, should be based on a case-by-case decision depending on the local conditions or situation in accordance with legal codes and regulations. In order to evaluate the success or failure of a management programme, it is necessary to monitor and, if necessary, adapt the efforts undertaken.

c. Rapid measures

Due to the key actions of the European Strategy on Invasive Alien Species, rapid measures are the third line of defence (Council of Europe, 2003). Once an alien species becomes established within a location in an aquatic system, it poses a threat to an entire region due to its rapid dispersal via coastal water currents, shipping canals and rivers (Nehring, 2005). Therefore time is limited during which rapid measures are a practicable option. Its realization and choice of methods will be influenced by ecological, financial, legal and political considerations. Especially for newly introduced alien species, which are defined as invasive after a risk assessment, eradication is the most coherent solution in terms of biodiversity conservation (Genovesi, 2005). However, a basic requirement is the availability of at least one efficient eradication method. If rapid measures are not initiated or do not result in species eradication, the further establishment of the species in the immediate environs can be very costly (Gren, 2008).

To our knowledge, no rapid measures on newly introduced alien species have been carried out in the Wadden Sea to date, although it is conceivable that with the establishment of an early detection system (see above) newly introduced invasive species can be eradicated more promptly and successfully. This has been achieved with *Caulerpa taxifolia* in Californian lagoons (Anderson, 2005). From the Mediterranean Sea, the invasive potential of this algae was already well known. Rapid eradication was made possible because of an early detection by a monitoring programme, freeing up emergency money originally set aside for the case of an oil spill, a public campaign to prevent further introductions from private seawater aquaria, and the engagement of many volunteer divers. In the Wadden Sea, on the other hand, we feel a 'hurrah attitude' of being the first discoverer and the curiosity of how the invader proceeds still dominates over rushing for immediate eradication. We recommend that in the trilateral group of experts (see above) possibilities concerning rapid measures should be considered and recommended.

d. Eradication and control

If an alien species is defined as invasive after a risk assessment and if rapid measures fail or are not practicable, the competent authorities may be able to prevent further proliferation and/or minimize harmful impacts by taking mitigation/control measures – the fourth line of defence. Where it is ecologically feasible and socially acceptable, eradication should be the preferred option over long-term control, because eradication is usually more cost effective and less risky for the environment than control. However, especially in the aquatic environment, it is almost hopeless to eradicate widespread invasive alien species.

Once the establishment of an alien species is deemed irreversible, unwanted species can be controlled, for example by preventing propagation, preventing establishment in new sites or fixing the population size at a certain level to keep their impact within limits. As mitigation measures, control methods should also be selected, while taking into consideration the conservation value of the habitat as well as the efficiency, selectivity and the undesired effects these methods may cause. In the area of the Wadden Sea, only one control activity has so far been carried out to reduce the wild stock of the invasive cord-grass *Spartina anglica*. In the early 1960s, an experiment was initiated to eradicate *Spartina* locally in the Wadden Sea of Schleswig-Holstein (Meyer, 1964). Several herbicides were tested, but the results showed that single treatments were ineffective in the long run. Randløv (2007) advocated a combination of sheep and cattle grazing, and in case these were not possible, the use of a brush cutter to control *S. anglica* in Danish coastal waters was suggested.

It will, for instance, not always be possible to eradicate or control the worst invader, if there are insoluble conflicts with other conservation targets, insufficient resources, or the available techniques are unreliable. In that case, it may be better to focus on several other invasive species that are not as far into the invasion cycle and where there is a good chance of success. We recommend that in the trilateral group of experts (see above) possibilities concerning eradication and control measures should be considered and recommended.

e. Acceptance

The impacts from alien species can be direct, indirect, cumulative and/or complex, unexpected, surprising and counter-intuitive, and they often only show after a considerable time lag. Therefore, from a management perspective, every alien species needs to be managed as if it is potentially invasive, until convincing evidence indicates that it presents no such threat.

Many aquatic alien species which are already introduced and established in the Wadden Sea are innocuous and have obviously no relevant ecological effects (see Chapter 7.2 and 7.3). Such species should be accepted as a new component of our flora and fauna after a critical re-assessment of their effects. Where a species is assessed as harmless it can be included on a 'white list' to simplify management efforts. However, risk assessment may become outdated when conditions change. This may be due to other aliens altering habitat properties, to a change in climate, or to a change in the invader population itself. This requires periodical re-evaluations (Nehring and Klingenstein, 2008).

5. Conclusions

Although our present knowledge about the extent, patterns and mechanisms of aquatic bioinvasions is still in its infancy, it is clear that aliens are a significant force of change in aquatic communities globally. In the highly protected Wadden Sea a multitude of alien species have established permanent populations, several with an invasive or potentially invasive nature. These species pose a serious impact to native biodiversity because they have the potential to alter the natural state of an ecosystem into which they were introduced and may enhance the trend of global homogenization of flora and fauna. Further, alien invasions in aquatic systems tend to be irreversible, and it is certain that in the near future more alien species will arrive and establish permanent populations in the Wadden Sea. Such changes constitute a serious challenge to nature conservation. Who will be moved to protect a habitat entirely dominated by a fortuitous and growing assemblage of alien species? Therefore management of alien species is a priority issue and must be mainstreamed into all aspects of protected area management. This also needs to include the potential genetic mixing by aquaculture practices within genetically structured populations of species native to the Northeast Atlantic coasts.

Up to now no management plan exists in which way the preservation or restoration of the Wadden Sea ecosystem in relation to alien species could be guaranteed. Legal and organisational implementation in the three bordering countries, Denmark, Germany and The Netherlands, lags behind other regions that have developed strategic frameworks to address alien species in a holistic way. In each bordering country, multiple agencies have responsibility for different aspects of the alien species issue. Moreover the various sectors relevant to the management of aliens have vastly different management needs and policy processes associated with them. On the other hand management of alien species needs to be put in an ecosystem context.

The need for an effective coordination and cooperation in the issues of alien species within the Wadden Sea region to conserve the unique Wadden Sea ecosystem has never been greater. Priority should be given to developing an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea, consistent and harmonised with the European Strategy on Invasive Alien Species, with the Natura 2000 programme and with other legally binding and non-binding instruments. This pressing issue will be even more imperative considering that *Spartina anglica* and other invasive alien species will benefit from global warming, thus resulting in further spreading and radial expansion in the near future.

6. Target evaluation

In the Trilateral Wadden Sea Plan (1997) no specific targets were formulated with respect to alien species issues. However, in recent years, invasive alien species have become a high-profile policy topic for the international community which has emphasised the need for cross-sectoral coordination between competent institutions and stakeholders at all levels (Council of Europe, 2003). In the Evaluation Report about the Trilateral Wadden Sea Cooperation, invasive alien species are specified as one emerging challenge which needs an effective Cooperation in the future to conserve the unique Wadden Sea ecosystem (Moser and Brown, 2007). Therefore the object of efforts should be the developing of an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea in which specific targets and measures are formulated.

7. Recommendations

There is a need to consider the development of a trilateral policy on how to deal with alien species in the Wadden Sea. Therefore, the development of a trilateral alien management plan is recommended, which should take into account the following:

- Trilateral targets concerning alien species issues must be specified, consistent and harmonised with the European Strategy on Invasive Alien Species and other legally binding and non-binding instruments.
- The Natura 2000 programme ought to be corrected. The invasive alien *Spartina anglica* should not fall any more into the natural habitat type *Spartinion maritimae* code 1320. Efforts to protect reefs of the invasive alien *Crassostrea gigas* in the Natura 2000 programme (Reefs, code 1170) have not to be put into action.
- An inventory should be made of occurrence and distribution of alien species in the Wadden Sea.
- A criteria based risk assessment for evaluating the ecological impacts of alien species in the Wadden Sea should be realized. Subsequently alien species should be classified equivalent to the 'Black, Grey and White List' of the European Strategy on Invasive Alien Species.
- The potential genetic mixing by aquaculture practices within genetically structured populations of species native to the Northeast Atlantic coasts should be a concern in protected area management.
- The knowledge about economic and socio-economic benefits and damages of alien species in the Wadden Sea should be improved.
- A trilateral working group of experts needs to be established, sufficiently funded to help in alien species identifications, to assist in ad hoc risk assessments, and to specify alien monitoring schemes which include an early warning system and need of alien research in the Wadden Sea. Possibilities concerning preventative, eradication and control measures should be considered and recommended.
- A common portal should be installed with searchable lists of alien species occurring in the Wadden Sea, species accounts, species distributions, species fact sheets, a catalogue of experts on alien species and recommended preventative, eradication and control measures.
- To enhance awareness of the alien problem, the many nature guides in the Wadden Sea should attend special courses on alien species.

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1. Introduction

Salt marsh on the island of Juist (Photo: N. Hecker).

Coastal salt marshes may broadly be defined as areas, vegetated by herbs, grasses or low shrubs, which are subject to periodic flooding (tidal or non-tidal) as a result of fluctuations in the level of the adjacent saline-water bodies (Adam 1990), and where saline water is defined as not being fresh, when the annual average salinity is greater than 0.5 g of solutes per kg of water (Odum 1988). In tidal systems, salt marshes form the upper parts of the intertidal zone, i.e. the interface between land and sea. They may extend vertically from well below the mean high-tide level up to the highest water mark. Salt marshes reach their greatest extent along low-energy coasts where wave action is limited and mud can accumulate (Allen & Pye 1992). Salt marshes of the Wadden Sea make up about 20% of the total area of salt marshes along the European Atlantic and Baltic coasts.

Although the number of species per unit area may be relatively low, coastal salt marshes constitute precious and irreplaceable habitat for a wide range of organisms. For Europe, van der Maarel & van der Maarel-Versluijs (1996) presented a list of 1068 plant species and subspecies that are bound to coastal habitats, of which nearly 200 are restricted to salt marshes. The highest species diversity in coastal salt marshes is found among the invertebrate fauna: European salt marshes are inhabited by approximately 1500 arthropod species, of which a considerable number are restricted to this habitat (Heydemann 1981; Niedringhaus *et al.* 2008). Additionally, salt marshes may be essential habitats to species that use the marshes only part of the time, such as coastal waders, which feed on the intertidal mudflats, but use the salt marshes as their roost during high tide (Meltofte *et al.* 1994; van de Kam *et al.* 1999). Some waterfowl species use salt marshes during spring migration to replenish their body reserves in order to reach their northern breeding grounds (in temperate Europe, especially the brent goose (*Branta bernicla*) and the barnacle goose (*B. leucopsis*); Madsen *et al.* 1999; Koffijberg *et al.* 2003; Blew *et al.* 2005).

Various human activities have or may have a direct or indirect impact on salt marshes. These activities include coastal defence measures, land use (grazing, fisheries, hunting, recreation, nature conservation), management, as well as pollution and eutrophication.

1.1 Trilateral Policy and Management

Mainland salt marshes have been embanked for centuries and today's extent is only the relic of a former widespread transition zone between fresh, brackish and saline habitats. Nowadays, all salt marshes in the Wadden Sea area are under national nature protection. In addition to the national legislation and nature protection regulations in the Netherlands, Germany and Denmark, the trilateral Wadden Sea Plan with specific targets for the salt marshes provides the framework for the management for the entire area (Trilateral Wadden Sea Plan 1997). The aim of the Wadden Sea Plan (WSP) is to maintain, and where possible, to extend the area of salt marshes. In general, it is the aim to reduce human interference with salt marshes and to enhance natural development by reducing the intensity of drainage and grazing in order to gain a high biodiversity in the entire Wadden Sea Area. Coastal protection activities, such as protection of salt-marsh edges or seawall reinforcement, are carried out in coordination with nature protection needs, *e.g.* by applying Best Environmental Practice (see also QSR Chapter 3.1 Coastal Defence).

European Directives

Salt marshes are also protected within the EU Habitats Directive (Annex I habitat types 1310 *Salicornia* and other annuals colonising mud and sand, 1320 *Spartina* swards, 1330 Atlantic salt meadows). The Habitats Directive (HD) provides an European network of special areas of conservation (Natura 2000 (Balzer *et al.* 2002)). The aim of the HD is to achieve a favourable conservation status for habitats and species across Europe, including birds (Birds Directive).

In addition, within the Water Framework Directive (WFD), salt marshes are considered as part of the quality element "angiosperms" which is one element to assess the ecological status of water bodies. The aim of the WFD is to achieve a good ecological status for all water bodies until 2015.

The status assessment and conservation objectives for salt-marsh habitat types are to a large extent comparable among the two above-mentioned EU directives and the WSP. In the framework of the Marine Strategy Framework Directive (MSFD), it has to be discussed at a later stage how salt-marsh habitat types can be incorporated to assess the good environmental status.

1.2 Outcome of the 2004 QSR

The main achievement of the QSR-2004 was the incorporation of the TMAP vegetation typology in order to monitor the status of Wadden Sea salt marshes in a standardized way. With the aid of aerial photography and GIS tools, the area of different vegetation zones has been calculated. The geomorphological classification of salt-marsh types was adapted by subdividing mainland marshes into barrier-connected and foreland marsh (including estuarine marsh) and adding summerpolders and de-embanked summerpolders as new types (for island and mainland marshes). Because of differences in both classification and methodology, a direct comparison with the 1999 QSR was not feasible.

It was decided that grazing terminology should be based on the structure and heterogeneity of the vegetation instead of stocking density. A discussion on naturalness resulted in a distinction between landscape and vegetation level. The result of this hierarchical classification is that changes in land use and management cannot result in a transition from semi-natural to natural marsh (landscape level), but meanwhile the vegetation may develop towards a more natural state.

A new topic in the 2004 QSR was the so-called ageing of the salt marsh, i.e. the extension of late-succession salt-marsh communities, mostly with low species diversity, at the expense of young succession stages. Removal of artificial dune ridges, de-embankment of summerpolders and low-intensity grazing were suggested as management options in order to preserve young succession stages and high species diversity.

The following recommendations were formulated:

- In the Wadden Sea area, the common monitoring programme of the salt marshes according to the TMAP guidelines should be continued with a frequency of once in five years. The TMAP typology is sufficient to fulfil the requirements of the Habitats Directive.
- In addition, long-term annual recording of vegetation, surface elevation change and management at several permanent sites is required to gain insight into different processes and developments.
- Target No. 3 on 'natural vegetation structure' of artificial salt marshes should be specified as follows: "The aim is a vegetation diversity that reflects the geomorphological conditions of the habitat."
- The application of livestock grazing should be determined by the conservation targets per area.
- Future management should aim at:
  a) Preclusion of engineering measures in the geomorphology of both natural salt marshes and of intertidal flats in front of sedimentation fields,

  b) Restoration and increase of the total area of especially mainland salt marshes through de-embankments of summerpolders,

  c) Rejuvenation of salt marshes on barrier islands through removal of artificial dune ridges

d) Increase of the natural morphology and dynamics of artificial salt marshes through cessation of the upkeep of artificial drainage,

e) Enhancement of a natural vegetation structure through cessation and adaptation of grazing and drainage regimes.

1.3 Aim of the 2009 QSR

The aim of the current quality status report is at least twofold:

- The first aim is based on the common monitor programme, and is to give an overview of the present status the Wadden Sea salt marshes. This status review includes aspects of total extent, geomorphology, vegetation characteristics and management.
- The second aim is to highlight actual affairs in salt-marsh management and research. Following the outcome of the 2004 QSR, the following topics will be addressed:

(a) Vegetation succession and ageing of salt marshes;

(b) Success of restoration of salt marshes through de-embankments;

(c) Management of the artificial[1] foreland marshes (i.e. the so-called salt-marsh works);

(d) Influence of artificial dune ridges on back-barrier salt marshes.

[1] The term "artificial salt marsh" is used throughout this report for salt marshes that have been developed within sedimentation fields or by ditching of tidal flats. Their development has thus been enhanced anthropogenically.

2. Methods

In the framework of TMAP, a monitor programme for salt marshes has been developed. On a regular time base, the following salt-marsh parameters are monitored:

- Location and total area
- Vegetation composition on the base of the standardized TMAP vegetation typology (Appendix I)
- Land use and management
- Geomorphology and artificial drainage

A time frequency of once per five year has been recommended. The programme is functioning successfully in both the Netherlands and the various German sectors of the Wadden Sea (Table 1). In Denmark, monitoring of salt marshes is carried out on the basis of EU habitat types. Here, an assessment is performed at the level of the HD habitat types. The TMAP programme requires an aerial survey of the salt marshes, which is followed by the collection of ground truth. The exact procedures differ sector-wise across the Wadden Sea, and are documented in the TMAP salt-marsh monitoring guidelines. The programme forms the basis of much of the data presented in this QSR. Additional information has been provided by special programmes or projects.

In the 2004 QSR, salt-marsh vegetation zones were described for the first time with the standardized TMAP typology. Initially six different zones were distinguished, *viz.*: pioneer vegetation, low marsh, high marsh, green beach, brackish marsh and fresh grassland. In the present QSR, green-beaches have been redefined at the landscape level: green beaches may comprise a mosaic or complex of dune slack, dune and salt-marsh vegetation. From the transition from salt marshes to dunes, two vegetation zones with seawater influence have been added, *viz*: (1) a zone that comprises the zone of embryonic dunes and drift-line vegetation, and (2) a zone that comprises seepage vegetation (Appendix I).

Since the previous QSR of Wadden Sea salt marshes (Bakker *et al.* 2005), nearly all salt marshes in the Netherlands and German sectors have been re-surveyed, and new vegetation maps have become available. Hence, the present report is based on surveys from 2002 – 2007, whereas the 2004 QSR was based on salt-marsh surveys from the period 1995 – 2002 (Table 1).

In the Netherlands, the salt marshes of the Wadden Sea are mapped within the VEGWAD-programme. Since the introduction of the WFD, the programme has a mapping frequency of each area of once per six years. Vegetation maps are produced with a scale of 1:5,000 or 1:10,000. Input is from remote sensing (interpretation of stereo false-colour photographs) and fieldwork. The interpretation is improved by the use of a digital 3D-photogrammetric system. For the classification of the vegetation a detailed standard typology is used (SALT97, de Jong *et al.* 1998). This typology can easily be transformed into the TMAP typology.

In Lower Saxony the entire terrestrial area of the National Park was surveyed in 2004 with the use of the TMAP typology. This survey was carried out by a combination of remote sensing, GIS and extensive field verification (Petersen *et al.* 2008). The accurateness of the new maps in location and vegetation assignment was improved considerably compared to the previous survey. The latter had been based on mapping of biotopes, and was performed by air-picture analyses with limited effort on gathering ground truth. In the evaluation of monitoring results, the change of methodology must be considered.

In Schleswig-Holstein, a new salt-marsh survey was carried out in 2006/2007. The same method was used as in Lower Saxony in 2004. The TMAP-vegetation maps of Lower Saxony and Schleswig-Holstein are freely accessible at the homepages of the national parks.

In Denmark, In the framework of the National NOVANA programme, the EU habitat type 1330 (Atlantic salt meadows; cf. App. I) was surveyed in 2005/2006 within the Natura 2000 area in the Wadden Sea Area; surveys of the habitats H1310 and H1320 are planned for the period 5.

Table 1: Overview of available monitor data of salt marshes for salt marsh vegetation in the countries covering the whole area (GIS data, based on aerial photographs and ground truth covering the whole Wadden Sea area).

Country/Sector	Time / Frequency	Level
The Netherlands	Every 5-7 years[1]) since 1980	Vegetation, land use and management
Lower Saxony	1991, 1997, 2002 2003/2004	Biotope and land use Vegetation, land use and management
Hamburg	1995 – Neuwerk 1998 – Neuwerk (east), Scharhörn, Nigehörn 2004	Biotope and land use Vegetation, land use and management
Schleswig-Holstein	1988 [2]), 1996 [2]), 2001/2002, 2006/2007	Vegetation, land use and management
Denmark	2000 [3]), 2005/2006 [4,5]) Annual [5]) Every 6 years [5])	Area, state indictors, management Monitoring 40–60 permanent plots in H1330 Monitoring 9 permanent plots in H1330

1) Rotating monitoring schedule of sites with a frequency of 5–7 years (since 1980), VEGWAD-programme, Ministry of Transport, Public Works and Water Management. 2) Salt marshes on the Halligen and islands excluded. 3) Inventory of salt marshes: Ribe Amt, 2002: Strandenge i Ribe Amt – Status 2000. 4) Survey of salt marshes inside the Natura2000 site in the Wadden Sea area. 5) In the framework of the Danish NOVANA programme.

3. Status

3.1 Total area of salt-marsh types

Based on the most recent data, salt marshes in the Wadden Sea extend over slightly more than 400 km², summerpolders included (Table 2). The size of the Wadden Sea salt marshes represents about 20% of the total area of coastal salt marshes in Europe (Doody 2008). Although the size of salt marshes in the Wadden Sea is still considerable, it is worth remembering they have been much more extensive than they are today. The major cause for the decline of salt marshes has been land-claim in order to acquire new land for agriculture, and more recently, coastal protection measures. Loss of salt marsh through human intervention continued throughout the 20th century.

From a morphological view, four types of salt marsh may be distinguished in the Wadden Sea, *viz.* (Table 2): (a) back-barrier marshes, (b) green beaches, (c) foreland marshes and (d) Hallig salt marshes. Summerpolders have a risk to be flooded by seawater during extreme storm tides. Because they have a high potential for restoration of salt marshes, their 2,520 ha have been added to Table 2 and Figure 1.

Foreland salt marshes on the mainland make up approximately half of the salt-marsh area in the Wadden Sea. These salt marshes are largely of anthropogenic origin, because their development has been promoted by ditching and the construction of sedimentation fields. Despite their artificial origin, the mainland marshes are appreciated for their value for nature conservation. The most extensive foreland marshes may be found in Schleswig-Holstein with more than 40% of their total area.

Back-barrier marshes and green beaches are in principal natural salt marshes. Back-barrier marshes develop in the lee of a barrier beach, whereas green beaches are generally found more exposed in the foreshore area of the barrier beach. The construction of artificial dune ridges in the past has stimulated the development of back-barrier marshes, such as for instance the Boschplaat salt marsh on the island of Terschelling, Netherlands and the salt marsh of the Skallingen peninsula, Denmark. The presence of artificial dune ridges explain why in the Netherlands Wadden Sea the extent of back-barrier marshes today is much greater than their historic reference values (Dijkema 1987).

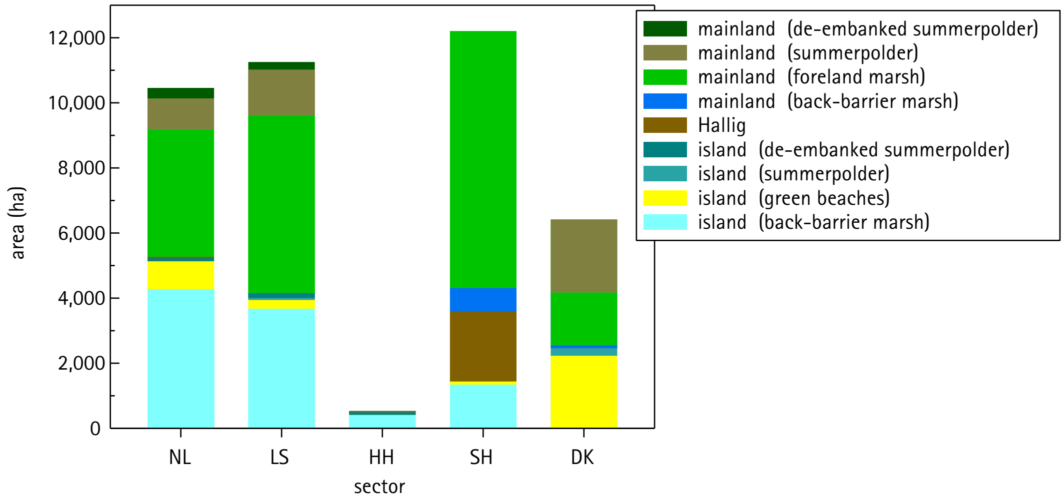
The distribution of the salt marshes shows some conspicuous variation across the Wadden Sea (Fig. 1). Back-barrier marshes on the mainland coast, for instance, are restricted to the northern part of the Wadden Sea. Here the principal coastline has a north to south orientation, whereas the western Wadden Sea has a west to east orientation. A hallig is a salt-marsh island, which in the past has been part of the mainland and which is not protected by a seawall. Hallig salt marshes thus accreted on low-lying old land. Hallig salt marshes are found almost only in Schleswig-Holstein, with the Punt van Reide salt marsh, the

Landform	**The Netherlands**	**Lower Saxony**	**Hamburg**	**Schleswig-Holstein**	**Denmark [1)]**	**Total**
Year of survey	2002-2006	2004	2004	2006/2007	2005	
Islands						
Back-barrier (foreland incl.)	4,280	3,660	260	1,250	2,230	11,770
Green beaches	850	280	4	100	320	1,550
De-embanked (summer)polder	90[2)]	150	40			280
Summerpolder	10	60	80			150
Mainland						
Back-barrier				720	1,620	2,340
Foreland-type	3,910	5,460		7,880	2,240	19,490
De-embanked summerpolder	320	240[3)]				560
Summerpolder	960	1,400			10	2,370
Hallig						
	50			2,160		2,210
Total	**10,470**	**11,250**	**380**	**12,200**	**6,320**	**40,620**

1) Habitat type 1330 only (cf. Appendix I)
2) Total de-embanked area
3) includes both de-embanked and opened summerpolder

Table 2: Recent extent (ha) of salt marshes in different parts of the Wadden Sea specified according to their geomorphology. The areas include the pioneer zone, except for Denmark. The pioneer zone has been defined as the area where pioneer vegetation cover ≥ 5%; in Schleswig Holstein, this threshold value was 10%. On the islands, de-embanked summerpolders may be added to the back-barrier marshes; on the mainland to the foreland-type salt marshes.

Figure 1: Overview of the total area of salt marshes and summerpolders in different parts of the Wadden Sea specified according to their morphology. Same data as Table 2. See this table for further explanation.



Netherlands, as an exception. Hallig salt marshes are often protected with revetments. They show a greater resemblance with the clayey foreland salt marshes than with the sandy back-barrier marshes.

3.2 Salt-marsh zones and vegetation composition

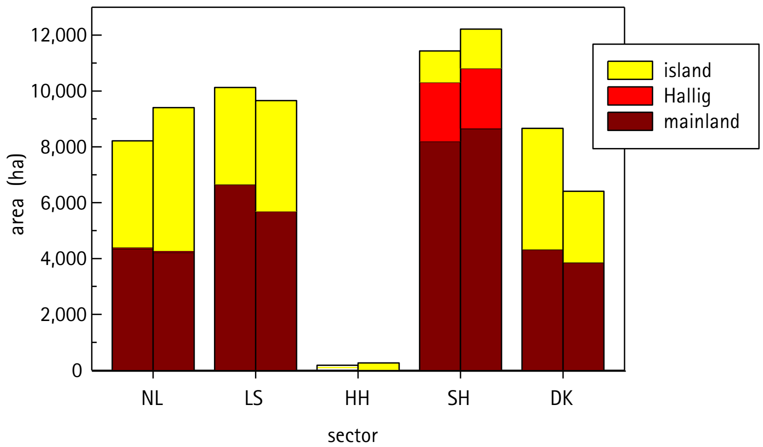
3.2.1 Current distribution

Between the 1995/2001 and 2002/07 surveys, changes in the total area of salt marshes differed markedly between islands and mainland marshes and among sections (Fig. 2). On the trilateral level, the data show a net loss of 650 ha of salt marsh between the two surveys. This development is largely caused by changes in the Danish Wadden Sea. The Danish salt marshes may well have been overestimated during the first survey, however. Leaving the Danish data aside, the total extent of salt marshes increased by nearly 1,600 ha.

This increase was found predominately on the islands (Fig. 3A). On the Netherlands islands, the area of all salt-marsh zones increased, especially the zone of embryonic dunes and drift-line vegetation. In Lower Saxony and Hamburg, island salt marshes grew with ca. 300 ha, but the high-marsh zone increased by almost 700 ha, and now covers over 50% of the entire salt-marsh area (Fig. 3B). The high marsh is to a limited degree covered with the climax community of *Elytrigia atherica* (Appendix II). In Schleswig-Holstein, the island salt marshes increased by almost 300 ha. The area of both the pioneer and the low-marsh zone remained more or less constant, which resulted in a lower relative weight of these two zones. On the island of Trischen, *Spartina anglica*-dominated vegetation took up a significant proportion (30%) of the entire salt marsh (Appendix II).

The size of the mainland marshes in both the Netherlands and Lower Saxony showed a minor decline, whereas in Schleswig-Holstein mainland marshes increased by 450 ha (Fig. 3C). In all three sectors, the area of the pioneer zone diminished, whereas that of high-marsh zone increased. In Lower Saxony, the high-marsh zone now occupies

Figure 2: Comparison of the areal extent of salt marshes in different parts of the Wadden Sea during the 1995/2001 (left bars) and the 2002/2007 (right bars) salt-marsh surveys. For Denmark, the values do not include pioneer salt marsh. Data of the 1995/2001 survey after Bakker et al. (2005).



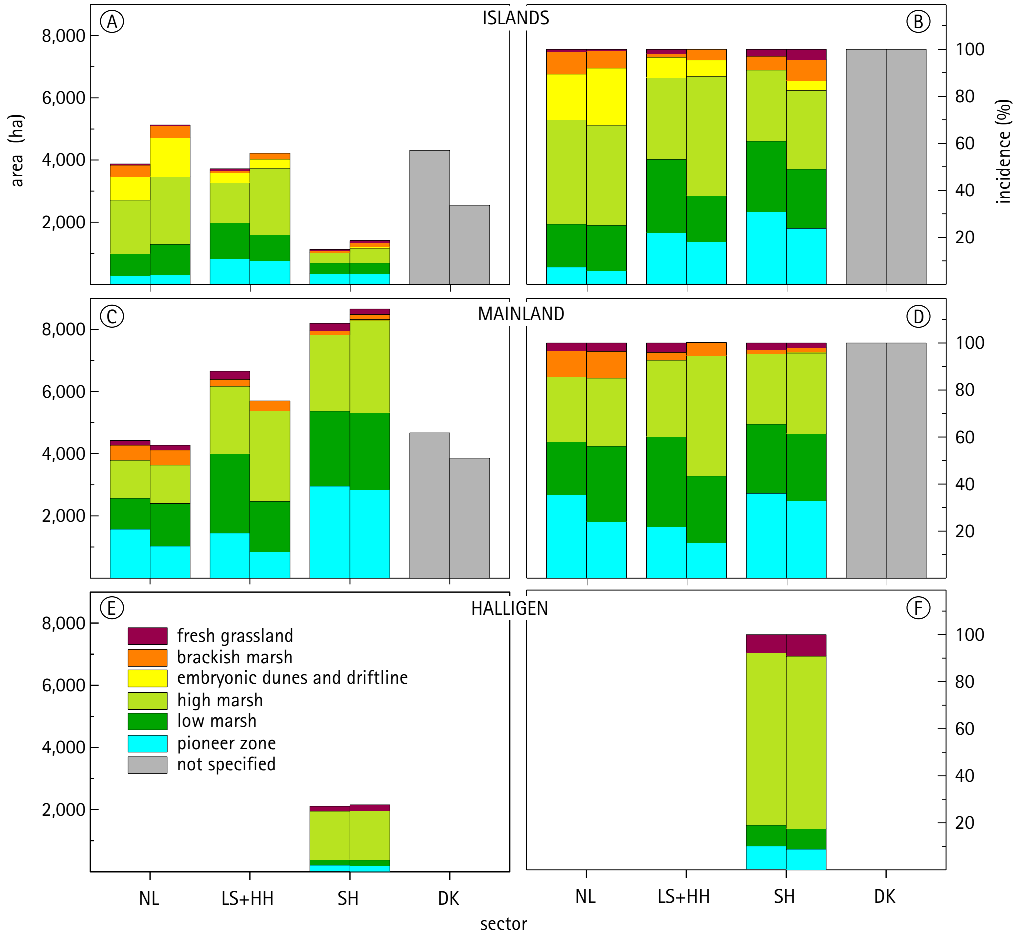


Figure 3: Comparison of the areal extent of the different vegetation zones between the 1995/2001 (left bars) and 2002/07 (right bars) salt-marsh surveys on the (AB) Wadden Sea islands, (CD) mainland coast and (EF) Halligen. Data of the 1995/2001 survey from Bakker *et al.* (2005). Right panels give the relative weight of different zones. For graphical reasons, salt marshes of Hamburg and Lower Saxony have been pooled.

over 50% of the area (Fig. 3D). In the mainland marshes, vegetation of *Elytrigia atherica* appears to be of greater importance than on the island marshes. During the last survey of several larger salt-marsh complexes (500 ha or more) in Lower Saxony, this vegetation type occupied over 40% of the area (Krummhörn, Ostfriesland, Jade and Budjadingen; Appendix II).

The area of Hallig salt marshes remained more or less constant (Fig. 3E). The Hallig salt marshes are for nearly 75% comprised of high salt marsh, but generally with a low incidence of *Elytrigia atherica* vegetation (Appendix II). The latter does not count for the two smallest Hallig salt marshes (Norderoog and Habel), which were for more than 40% covered by *Elytrigia* vegetation.

3.2.2 Vegetation change

Vegetation change Netherlands sector

On nearly all Netherlands mainland – and barrier-island salt marshes succession and ageing of the vegetation are the dominant processes. The distribution of different salt-marsh vegetation zones in the Dutch Wadden Sea is diverse from the early 1980s to the first years of the new millennium (Fig. 4). The largest area of pioneer vegetation is found in the mainland salt marshes of Groningen and Friesland. This can be explained by extensive engineering measures, the so-called salt-marsh works (Dijkema *et al.* 2001; Bakker *et al.* 2005). The area of pioneer zone shows high year-to-year variation which is not reflected in Figure 4. In most sites, the dominant change during this 25-year period has been a decrease of vegetation diversity because of the increase of a single vegetation type; to a lesser extent the same counts for the brackish salt-marsh zone as well. This loss of biodiversity is mainly caused by the increase of the climax vegetation types of *Elytrigia* spp and *Phragmites australis*. As a consequence, on the islands the other vegetation types of the high marsh decreased, and on the mainland the types of the low marsh decreased.

On the barrier islands, the incidence of the *Elytrigia* climax redoubled in the Schorren marshes at the island of Texel, and in the salt marshes of the islands of Terschelling, Schiermonnikoog and Rottumerplaat. In these marshes the increase was much higher than on the island of Ameland

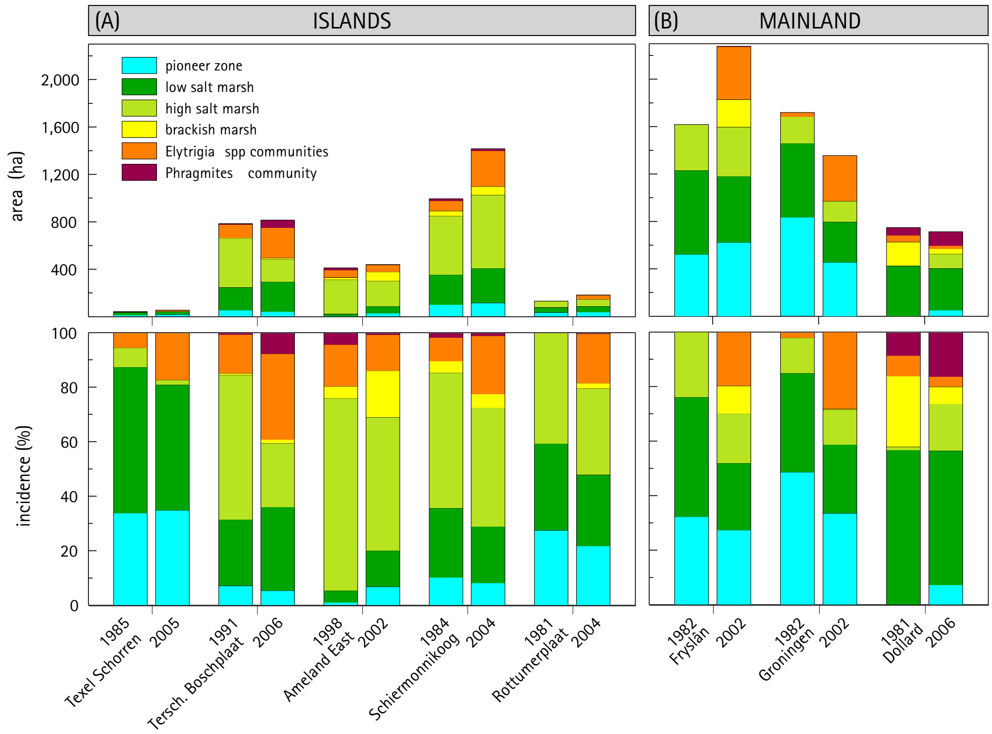


Figure 4: Vegetation change in three mainland salt marshes and on five barrier islands in the Netherlands Wadden Sea over an approximately 25-year period. The graphs present both area and incidence of the main vegetation zones and climax communities (Dijkema et al. 2007). Data from vegetation mapping 1978 – 2006 by RWS-DID.

where a high grazing intensity and soil subsidence arrested vegetation succession (Dijkema *et al.* 2007).

The incidence of the *Elytrigia* climax was highest on the Boschplaat salt marsh on Terschelling. This is the first back-barrier salt marsh that became protected by an artificial dune ridge, and where this dune ridge is still intact. In the Dollard, the climax[2] of *Elytrigia repens* decreased, because of the combined effect of grazing and an increased soil waterlogging. The latter was caused by the abandonment of the upkeep of the artificial drainage by 1984 (Esselink *et al.* 2000, 2002). The grazing intensity was not high enough to prevail a gradual increase of *Phragmites* (Esselink 2000; Esselink *et al.* 2000). Among the various salt-marsh sites, the highest increase of *Elytrigia* was found in the marshes on the Groningen and Friesland mainland coast (Fig. 5). This increase could be related to high sedimentation rates (Friesland) and a strong decrease in grazing intensity (Groningen).

Vegetation change Lower Saxon sector

The area of *Salicornia* pioneer marsh in particular has decreased, from 3200 ha in 1991 to 2260 ha in 1997 and to 970 ha in 2004. Whether this sharp declined might be explained by methodological differences among surveys is unknown and will be examined in the frame of the next survey. The area of the *Spartina* pioneer community, on the contrary, has increased from 124 ha in 1991 to 417 ha in 2004. The strongest increase of *Spartina* was observed in the mainland salt marshes. Only did *Spartina* decrease, where erosion of salt-marsh edges had already been registered since the 1960s.

The area of low salt marsh in Lower Saxony is squeezed by two opposite developments: the strongest development was succession to high salt marsh; the area of high salt marsh increased in Lower Saxony from 3790 ha in 1991 to 5050 ha in 2004. Between 1991 and 2004, the low salt marsh decreased from an area of 3640 ha to 1180 ha.

To a minor extent, *Spartina* facies encroached into the low salt marsh. The "Ostplate" on the island of Spiekeroog may illustrate the main development of the salt-marsh vegetation on the East Frisian barrier islands. The Ostplate has developed since the 1960s from a high sand into a dune-salt marsh complex. In 1991 and 1997, a great continuous *Salicornia* pioneer marsh was found on the south side of the island, which until today is extending in southwest direction. Between 1997 and 2004, this pioneer marsh developed to a great extent into a low salt marsh. Former low salt marsh developed into high salt marsh and the incidence of the *Elytrigia atherica* climax community also increased (Appendix III).

The Elisabeth-Außengroden salt marsh may serve as an example of the Lower Saxony mainland salt marshes (Appendix III). The vegetation maps

[2] The term "climax" is used throughout this report for the late succesional plant communites.

Figure 5: Vegetation change in the Netherlands salt-marsh works from 1960 to 2005. In permanent transects which were numbered from West to East, dominant plant groups are reproduced. Transects were grouped according to Province and grazing intensity.

illustrate that extensive parts of the low salt marsh developed into high salt marsh, especially into *Elytrigia* spp-dominated communities.

Vegetation change in the Wadden Sea of Hamburg

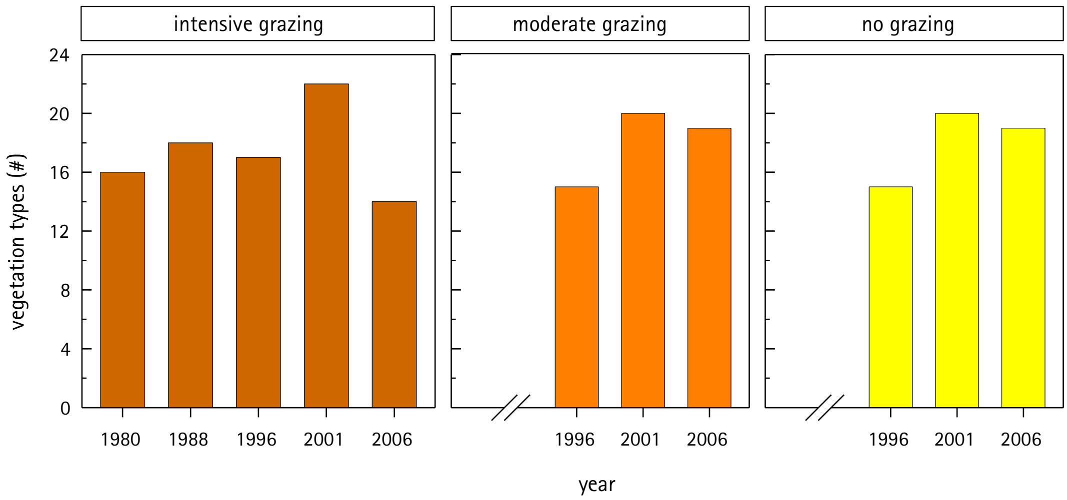
The salt marshes around the islands Scharhörn and Nigehörn showed a remarkable increase during the last couple of years. Both islands are now greater in size than historic references: Scharhörn 30 ha, Nigehörn 58 ha, and with additionally 109 ha of pioneer vegetation at the Scharhörnplate (2008). As a result both islands have merged together. Relatively new to the area is the pioneer vegetation of *Spartina anglica*. Up to recently, the species was confined to only one small stand. The increase of salt-marsh vegetation was accompanied by the development of a new tidal creek system.

On the island of Nigehörn, the salt-marsh vegetation appears more brackish with larger stands of *Bolboschoenus maritimus* and *Phragmites australis* within salt-marsh areas. Also small bushes and trees (*Salix* spp, *Alnus glutinosa*) have meanwhile settled on the island. It is not clear how this vegetation pattern on Nigehörn can be explained.

Vegetation change on the Schleswig-Holstein mainland salt marshes

The vegetation along the entire Wadden Sea mainland coast of Schleswig-Holstein was mapped for the first time in 1980. This survey was repeated in 1988. In retrospect, legend units of both mappings were transformed into the TMAP vegetation typology. Because of a technical reason (a colour-infrared flight too early in the season), *Salicornia* vegetation could not be mapped in 1988. During both surveys, the vast majority of the salt marsh was intensively grazed by sheep. This had a great impact on vegetation composition. In 1991 a reduction in grazing intensity was initiated, which resulted in a new management

Figure 6: Number of vegetation types in relation to grazing regime on the mainland salt marshes in Schleswig-Holstein. Note that until 1991 the whole area was grazed intensively.



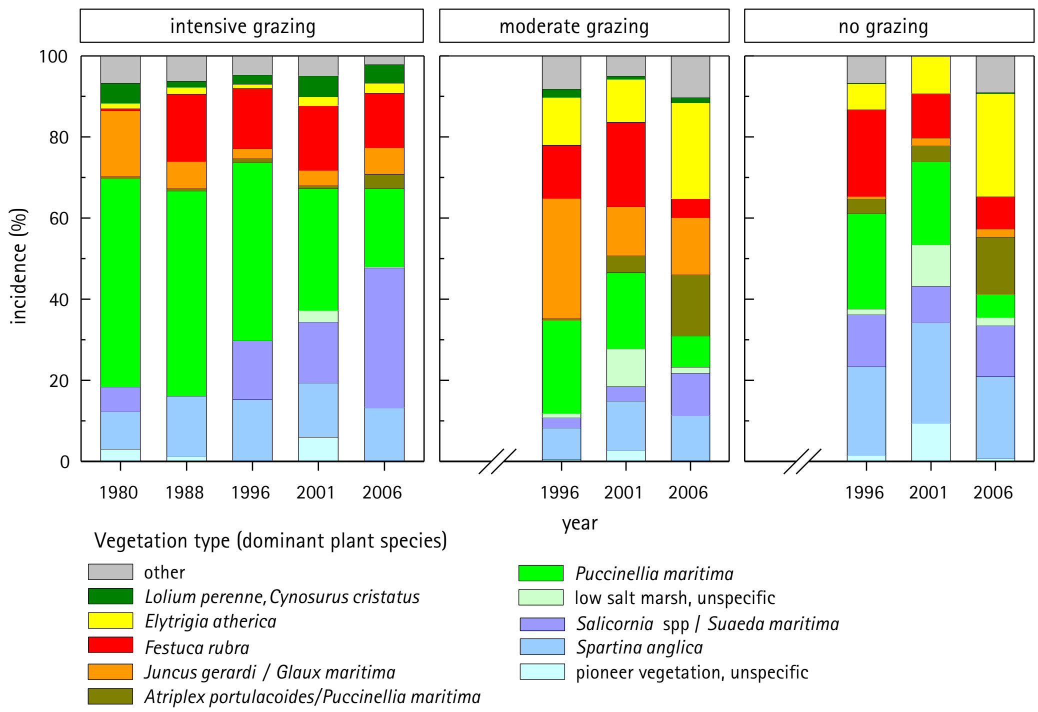
scheme with three levels of grazing: no grazing, moderate grazing, and high-intensity grazing. This scheme is valid until today. Subsequent surveys were carried out in 1996, 2001 and 2006. The last two surveys cover the entire salt marsh area in Schleswig-Holstein.

Except for the 2001 survey, the highest number of vegetation types or plant communities was found in the ungrazed parts of the salt marshes (Fig. 6). This may be explained by the large amount of vegetation complexes in the intermediate successional stage of the vegetation, which appeared in all management regimes.

Marked changes occurred in the intensively grazed parts of the mainland salt marshes (Fig. 7). The incidence of the *P. maritima* community decreased, whereas the incidence of the *Salicornia* community increased. For the 2006 survey, this is partly explained by the fact that *Puccinellia* swards that were codominated by *Salicornia ramosissima* (= *S. europaea*), have been classified according to the TMAP key as *Salicornia* plant community (see App. I).

In the intensively grazed salt marshes, the incidence of the *Spartina anglica* and *Festuca rubra* communities remained more or less constant during the period 1988–2006, whereas the *Juncus gerardi* community increased slightly. In 1980, most of the upper salt marsh has been classified as *Juncus gerardi* community. In the intensively grazed marshes, the *Elytrigia atherica* community increased only slightly over the whole period of

Figure 7: Vegetation development on the mainland salt marshes in Schleswig-Holstein in relation to grazing management. Note that until 1991 the whole area was grazed intensively with sheep. Vegetation types are according to TMAP typology (Appendix I). For graphical reasons, vegetation types with a limited distribution (incidence < 5% in all years) were merged into one rest group (other).



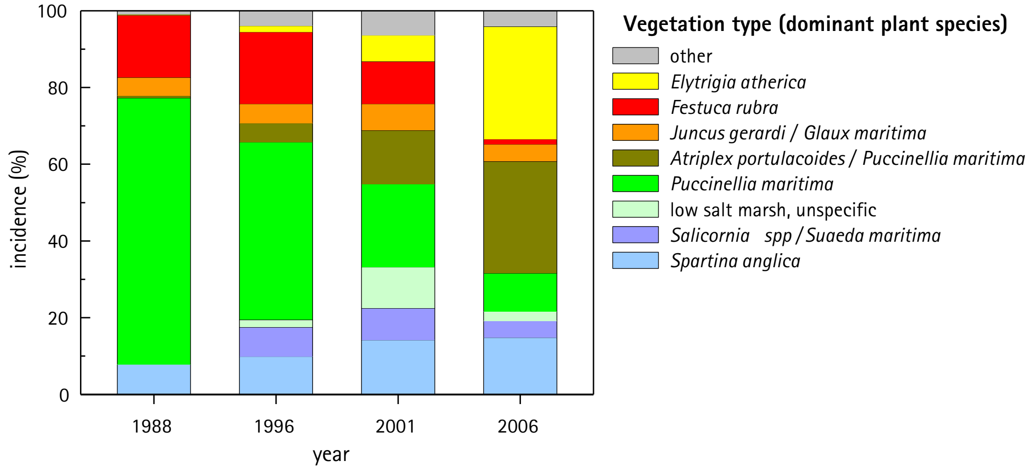


Figure 8: Vegetation development on the Hamburger Hallig from 1988 until 2006 based on vegetation surveys of the total area. Note that the whole area was grazed intensively with sheep until 1991, when three management regimes were introduced in different parts of the area. Vegetation types are according to TMAP typology (Appendix I). For graphical reasons, vegetation types with a limited distribution (incidence < 5% in all years) were merged into one rest group (other).

26 years of successive mapping, but did remain below 5 % of the area. *Atriplex portulacoides* and *Artemisia maritima* communities increased slightly only during the last 10 years; their occurrence stayed below 5%.

The overall trends in vegetation changes differed locally in relation to local grazing intensity, elevation and waterlogging of the specific site. The Hamburger Hallig, for example, was intensively grazed until 1990. Since 1991, however, about 53% of the site is ungrazed, 26% moderately and 20% intensively grazed. As a result of this decreased grazing intensity, the *Puccinellia maritima* community decreased steadily from more than 70% to less than 10% (Fig. 8). The *Festuca rubra* community showed the same trend, although its decrease was less pronounced. On the other hand, the incidence of *Atriplex portulacoides* and *Elytrigia atherica* types increased significantly (Seiberling & Stock 2009).

In summary, it may be concluded that the formerly intensively grazed marsh dominated by a short monotonous *Puccinellia* turf, now supports a variety of vegetation types. The spatial pattern of the vegetation is related to variation of abiotic factors (such as elevation, drainage pattern, waterlogging, and nutrient supply) and to biological interactions including successional change.

Vegetation changes in Danish Wadden Sea

The Danish salt-marsh surveys were almost confined to their areal extent with the exclusion of the pioneer zone. Because neither vegetation types nor salt-marsh zones have been distinguished, vegetation changes can not be evaluated on an areal base. Data from the NOVANA monitor programme have not yet been analysed, and it is therefore too early for any conclusion about changes in plant-species composition.

Methods of the two recent Danish surveys (Tables 1, 2) were not consistent, and the results can not be compared. In the recent years there has been an increase in the area of green beach on the islands of Fanø and Rømø, and an increase of salt-marsh vegetation on the high sand south of the island of Fanø (Keldssand).

3.2.3 Elytrigia atherica encroachment in back-barrier marshes

On the barrier island of Schiermonnikoog, the species *Elytrigia atherica* is expanding eastwards along with the eastward expansion of the island. At the same time, the species increases in abundance. In 1958, the area of the *E. atherica* community (TMAP vegetation type 3.7: *E. atherica* cover >25% and highest abundance among plant species) was less than 0.01% of the salt marsh (the area of creeks not included). By 1992, the area of the *E. atherica* community had increased to 20% of the salt marsh. In recent years, the expansion of this community levelled off (Fig. 9). Within the *E. atherica* community, however, the abundance of *E. atherica* continued to increase, from >25% to >50% cover. A similar levelling off in expansion, as a result of reaching equilibrium or simply because of limited space, has been found in old and well-established stands of *Phragmites australis* and *Spartina* alterniflora (Rice *et al.* 2000; Civille *et al.* 2005).

Recently, in the oldest part of the salt marsh at a great distance from the intertidal flats, a decrease of the *E. atherica* community has been observed.

The decrease of *E. atherica* community may be related to environmental changes. In the old marsh, soil compaction and a decrease of sediment input may have led to the formation of depressions with standing water. Here, former *E. atherica*

Figure 9: Distribution of the plant species *Elytrigia atherica* in the back-barrier salt marsh on the island of Schiermonnikoog during subsequent mappings in the period 1958 – 2004. Abundance of *E. atherica* is given as the percentage plant cover. The abundance has been estimated from the distribution of plant communities and their concurrent survey data. See Figure 10 for the location of the artificial dune ridge.

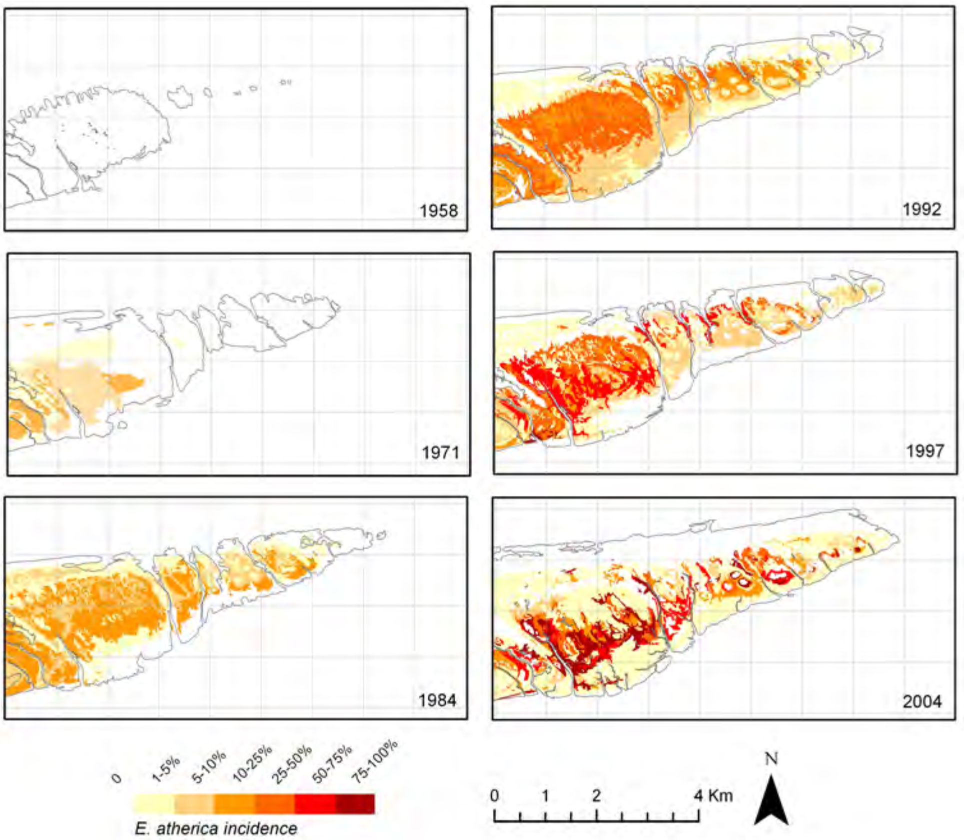
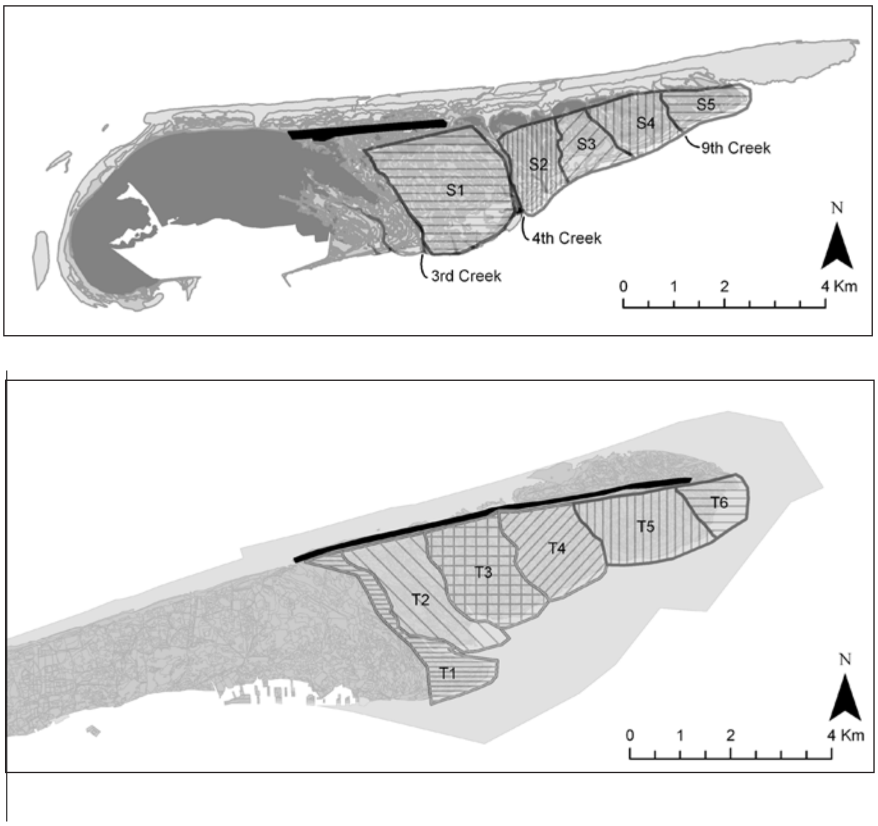


Figure 10: Maps of the back-barrier marshes on the islands of Schiermonnikoog (upper panel) and Terschelling (lower panel) with the defined salt-marsh sections and the location of the artificial dune ridge on each island (black bars).



stands have been replaced recently by stands of *Phragmites australis* and *Juncus gerardi*. Further research on soil conditions is required to support these ideas.

We compared the spread of *Elytrigia atherica* on four back-barrier salt marshes on the island tails of four islands with differences in human influence on the geomorphology of the islands tails, *viz*.

(1) Terschelling: artificial dune ridge along the entire island tail,

(2) Schiermonnikoog: artificial dune ridge partly present,

(3) Spiekeroog: artificial dune ridge not present,

(4) Norderney artificial dune ridge not present; artificial drainage of salt marsh.

On Schiermonnikoog, an artificial dune ridge was constructed in the late 1950s north of the sections S1–S3 (Fig. 10). This dune ridge breached every winter, however, and became only maintained north of section S1. Since the mid-1960s, the more eastern part of the island (sections S2–S5) has not been protected from the North Sea. The eastward part of the contemporary salt marsh thus developed in the absence of an artificial dune ridge (see Fig. 9). On Terschelling an artificial dune ridge was constructed in the early 1930s north of the sections T1–T6 (Fig. 10). This dune ridge was maintained successfully from the beginning. Hence, the salt marsh started to develop in the shelter of the artificial dune ridge in all sections simultaneously. Comparison of the two most recent vegetation maps revealed that the incidence of the *Elytrigia atherica* community was between 20–25 % of the vegetated salt marsh, and its increase was about 4% per year in all sections T1–T6 (Fig. 11A).

On the island of Schiermonnikoog, a gradient was found of a high incidence of the *Elytrigia atherica* community on the old salt marsh in the west to a low incidence on the youngest salt marsh in the east. The increase of *E. atherica* on the unprotected salt marsh was stronger (sections S2–S5) than at the old marsh (Section S1), protected by the artificial dune ridge (Fig. 11B), possibly because of a change in soil conditions in

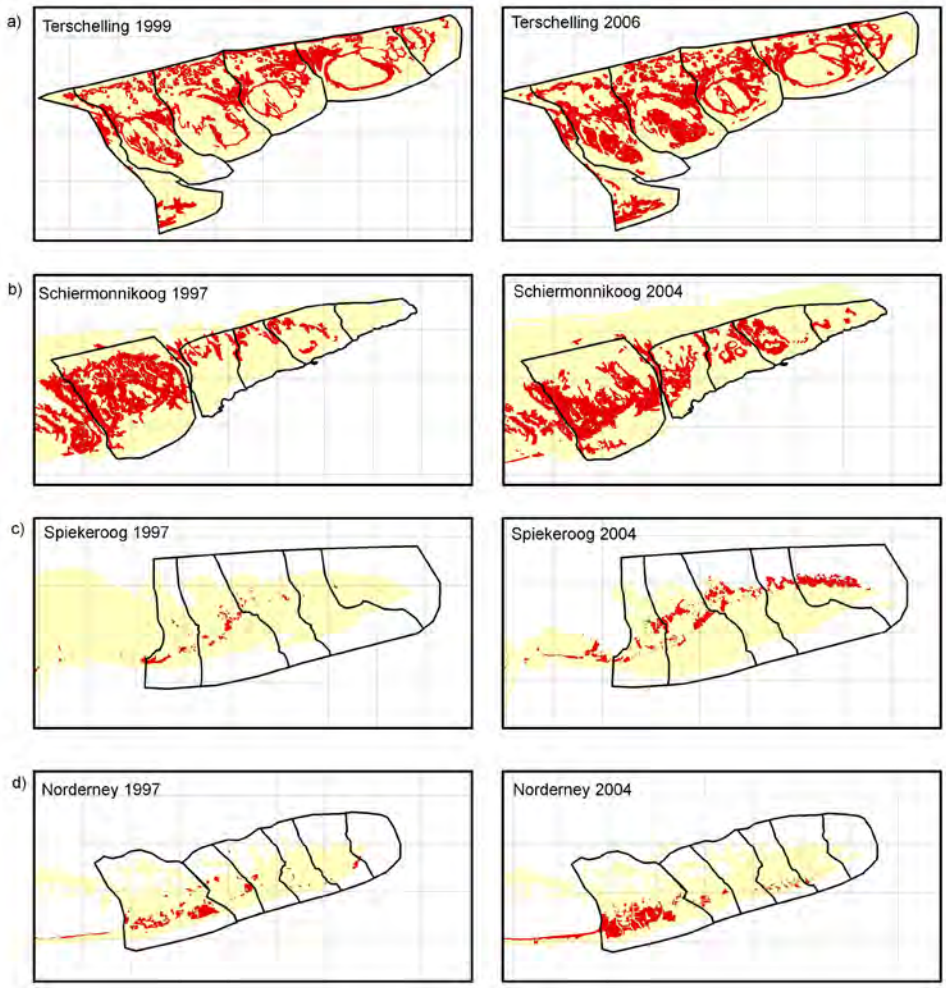


Figure 11: Distribution of *Elytrigia atherica* community (TMAP vegetation type S 3.7) during two subsequent mappings around the turn of the millennium in the back-barrier salt marshes of the islands of (A) Terschelling, (B) Schiermonnikoog, (C) Spiekeroog and (D) Norderney. The grid size in each panel is 1 km.

Box 1: Towards a New Geomorphological Concept of Wadden Sea Barrier Islands

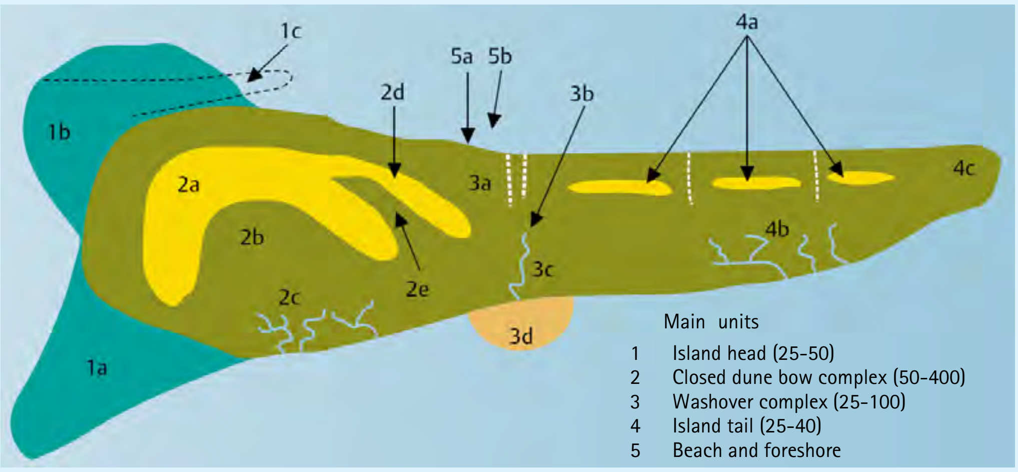


Figure 12: New geomorphological model of a barrier island with its characteristic main units and sub-units (after Löffler et al. 2008). Values between brackets refer to expected longevity of main units (years); Letter symbols refer to different sub-units. Salt marshes may be found in sub-units 2c, 3bc, 4b and 5a.

In response to questions about both climatic change and coastal safety on the one hand, and different scenarios for a nature-conservation strategy on the other hand, a new model on the geomorphological functioning of Wadden Sea barrier islands has been developed (ten Haaf & Buijs 2008; de Leeuw *et al.* 2008; Löffler *et al.* 2008). The model was developed specifically for the Netherlands islands, and hence applies to the west-east orientated barrier islands of the southern Wadden Sea only. The model identifies the most important geomorphic driving forces at different spatial and temporal scales. As a result, a barrier island in the model comprises five geomorphological main units with several sub-units (Fig. 12). Salt marshes may be found in all five main units of a model island. It is unclear yet to what extent these salt marshes differ ecologically.

The model is likely to influence coastal management, and our view on the functioning of island salt marshes. The model is therefore briefly introduced here by a characterization of the five main units of an ideal barrier island (cf. Fig. 12):

(1) Island heads

On the island heads, green beaches may develop in places where the beach plain is partly cut-off from the sea. This situation may be found on the islands of Terschelling, Ameland and Schiermonnikoog. The vegetation of green beaches is characterized by a combination of pioneer species from salt marshes and dune valleys. Salt marshes may also develop on the leeside of embryonic dunes or dune ridges.

(2) Dune-bow complexes

Extensive salt marshes have developed on the south side of dune-bow complexes under the influence of inundation by seawater from the Wadden Sea. These marshes are characterized by different vegetation zones from high to low salt marsh and pioneer vegetation. The low marsh and pioneer zone may be subject to erosion as well as accretion. Large parts of these salt marshes have been turned into agricultural area through embankment.

(3) Washover complexes

Washover complexes that are formed on the North Sea side of the island gradually merge with salt-marsh vegetation on the Wadden Sea side. The washover complex itself can either be bare, covered with algae or with pioneer salt-marsh or dune vegetation comparable to green beaches. A dynamic washover complex is subject to both the deposition and erosion of sand by wind, as well as to frequent inundation by seawater and sedimentation from the water column. These processes affect both succession and rejuvenation processes of the salt marsh that fringes the washover complex to the south.

(4) Island tails

Initially, island tails are bare sand flats that are periodically subject to erosion and accretion. On these sand flats, small embryonic dunes may be formed, which may grow into larger dune complexes that are separated from each other by washovers. On most of the Netherlands islands, these dune complexes have been connected by an artificial dune ridge, especially during the 20th century. On the leeside of these artificial dune ridges extensive salt marshes have developed, such as the Boschplaat on the island of Terschelling. The presence of the artificial dune ridges explains why in a quantitative sense, island tails are the most important units for salt-marsh vegetation, and why the actual extent of islands salt marshes is well above historic reference values (Dijkema 1987). In addition, the almost complete elimination of morphodynamic influences from the North Sea on both sedimentation and erosion explains that young succession stages are almost absent, and old succession stages generally predominate the northern fringe of these marshes.

(5) Beach and foreshore

The beach and foreshore can be found along the entire North Sea side of the barrier island. Periodically, extensive areas of green beach may develop, which may disappear quickly when large-scale dynamic processes are less favourable.

the old salt marsh (see above).

Though on Spiekeroog, the incidence of the *Elytrigia atherica* community was lower than on Schiermonnikoog, the expansion pattern appeared very similar (Fig. 11C). On Norderney, a significant expansion of the *E. atherica* community was only observed in the western part of the salt marsh (Fig. 11D). In this section, remains of artificial drainage furrows are still present, which may have stimulated the expansion of *E. atherica*.

The long time series of Schiermonnikoog, reveals that the increase of *Elytrigia atherica* on salt marshes is strongly related with the age of the vegetated marsh (Fig. 9). The comparison of the development of *E. atherica* on the four back-barrier marshes allows us to evaluate the effect of coastal management on vegetation succession on the back-barrier marshes. The well maintained artificial dune ridge on Terschelling enhanced the succession, and allowed *E. atherica* to develop rapidly to a climax vegetation type. Also the drainage works on Norderney enhanced the increase of *E. atherica* vegetation. On the unmanaged salt marshes, natural dynamics appear to prevent, or at least to hamper the succession to a climax vegetation of monostands of *E. atherica*.

3.3 Management

3.3.1 Salt-marsh works

From the current total of about 400 km^2 of salt marshes in the Wadden Sea, over 50% is formed by foreland-type salt marshes on the mainland (Table 1, Fig. 1). These mainland marshes have to a great extent been developed artificially from sedimentation works. In general, management aims have shifted over the past decades from agricultural exploitation and land claim to nature conservation. Concurrently, on parts of the coast artificial salt marshes have been developed and are managed for coastal protection. In this section, the major developments per sector are reviewed.

Netherlands

Mainland salt marshes in the Netherlands Wadden Sea are almost entirely of anthropogenic origin. Their development has been stimulated by a system of drainage ditches, and since the 1930s especially by a lay-out of sedimentation fields surrounded by brushwood groynes, which improved conditions both for sedimentation and plant establishment. The main aim of this construction was land reclamation for agricultural purposes. The sedimentation fields originally measured 400 m × 400 m and were arranged in three rows from the salt marsh onto the intertidal flat. Accretion works reached their greatest extent in the 1960s, when a turning point was reached. A study from 1965 concluded that developing salt marsh for land reclamation was not an economic enterprise, whereupon it was decided to downgrade the aim of the management of the accretion works to maintaining the status quo.

From about 1975, there has been a growing recognition that the remaining mainland salt marshes have an important value for nature conservation. In the framework of an integrated management plan for the Dutch Wadden Sea, a "no-net-loss" policy was developed during the 1980s for the existing mainland salt marshes. Since accretion works protect the existing salt marshes from erosion, this policy has become the main reason to maintain accretion works in the Netherlands. In order to enhance more natural development, human intervention gradually has been diminished from 1990 onwards by a more judicious maintenance of groynes and a reduction of artificial drainage systems. In summary, since 1990 the following changes in management have been introduced:

- Abandonment of the third, most seaward row of sedimentation fields, which did not contributed to the protection of the salt marsh.
- Cessation of all engineering measures on coastal stretches where either accretion rates were very high or where accretion rates were negligible and elevations stayed too low to allow salt marshes to develop.
- Run-down of all groundwork, i.e. a minimum-intervention management of the drainage system by 2000.
- The construction height of new groynes was restored to the original relative height of 0.30 m above MHT with an extra margin for future sea-level rise (groyne height had not been adapted to local sea-level rise for several decades).
- A flexible protection regime of the zone directly in front of the salt marsh which was realized by a reduction in size of sedimentation fields to 400 m × 200 m or 200 m × 200 m at sites where elevation development of the pioneer zone did not keep pace with the increase of MHT and where low salt marsh deteriorated.
- Constant monitoring and maintenance of a solid connection between brushwood groyne and salt marsh to prevent erosive water currents to occur in between.
- Use of more durable brushwood filling (*Picea abies, Pseudotsuga menziesii, Picea sitchensis*), which allowed a lower filling frequency,

and meant a cut in maintenance costs.

As a result of all changes, the area of both the pioneer and other salt-marsh zones started to increase again. The total groyne length along the Frisian and Groningen mainland coast decreased from 220 km to approximately 140 km in most recent years and 2,000 ha of intertidal flats have been returned to the influence of natural dynamics without that the extent of salt marshes was negatively affected.

Lower Saxony

Similar to the situation in the Netherlands, salt marshes on the mainland coast of Lower Saxony are mainly of anthropogenic origin. Land claim and shortening of the coastline for coastal-protection have reduced the formerly extended salt marshes into a narrow band of salt marshes in front of the seawall. The vast majority of the mainland salt marshes developed from accretion works.

The current focus of nature conservation is to improve the habitat quality of the salt marshes. A common concern of coastal defence and nature conservation in Lower Saxony is to preserve the present extent of salt marshes as far as possible. This implies that for areas with strong salt-marsh erosion, nature-conservation agencies support engineering measures to preserve the salt marsh. In concurrence with the establishment of the National Park, the appreciation of salt marshes as habitat for animals and plants improved greatly. The salt marshes in Lower Saxony, comprising a total of 8,600 hectares between the Dollard and Cuxhaven on the mainland and on the East Frisian islands, are located entirely within the national parks of the Lower Saxon Wadden Sea. The approach of the national parks is to preserve or restore the development of salt marshes under natural or nearly natural conditions as far as feasible:

- At present, sedimentation fields are constructed for coastal protection only. In order to create a buffer protection of the seawall against wave-energy, – contrary to the management in the Netherlands, – salt-marsh development is also stimulated on coastal stretches where the foreland is very small or absent.
- The development of salt marsh in front of a seawall by means of sedimentation fields will be implemented in special cases. The intention is to stimulate sedimentation in the sedimentation fields by periodic refurbishment of the ditches until a closed vegetation cover has developed.
- In agreement with the organisations for coastal protection, maintenance of the drainage system on the mainland marshes as well as on the islands has largely been abandoned, especially where agricultural exploitation has stopped. In order to ensure drainage of the foot of the seawall, the upkeep of the drainage system is continued in a restricted part of the marshes only.
- The opening of summer banks, the reactivation of former creek systems, the abandonment of the artificial drainage system and an enhanced salt-water influence have been realized successfully in accordance with coastal protection issues.
- In some areas, particularly in the Jadebusen, strengthening of the seawall is necessary. The required clay is primarily extracted from clay pits inland of the existing seawall or, in exceptional cases, from existing salt marshes. The site selection and design of the clay pits is done in accordance with the authorities for nature-conservation: clay pits are restricted to areas where in the new developed salt marsh in the medium term, an improved habitat structure and diversity is expected.
- The major concern of nature conservation in recent years was a further reduction of the agricultural use of salt marshes, which resulted in the current mosaic of exploited and especially unexploited salt marshes. On state-owned land, agricultural use is of a low intensity in accordance with strict guidelines about grazing intensity, date of mowing, *etc*.

In order to combine the various issues of coastal defence and nature conservation in relation to salt marshes, management plans will be formulated for all foreshore coastal sections separately by institutions that are either responsible for coastal defence or nature conservation.

Hamburg

In the past there were no regularly salt-marsh works on the island of Neuwerk for a long period. In the 1930s groynes were built in front of the eastern part of the island to support the sedimentation and the development of foreland. The experience of the following years indicated, however, that this did not have any effect. Therefore engineering measures were abandoned during the 1950s. The rest of the foreland on Neuwerk consists of natural-developed salt marshes. On the islands of Scharhörn and Nigehörn, the salt marshes have developed completely naturally without any human interference.

Schleswig-Holstein

The great majority of the salt marshes on the mainland coast of Schleswig-Holstein have been developed through accretion-enhancement techniques since about 1850. This has been achieved by the construction of sedimentation fields surrounded by brushwood groynes. Until the 1950s, the main purpose was to reclaim new land for agriculture. Later, the main objective became coastal defence. During the last few decades and with the implementation of the national park in Schleswig-Holstein (1985), a growing environmental concern led to a new appreciation of salt marshes. The guiding principle for salt-marsh management became to achieve a natural and sustainable ecosystem where ideally, natural processes should proceed without human interference. Consequently, a new concept for the management of the salt marshes in Schleswig-Holstein had to be prepared, and the following common principles for salt marsh management were established:

- The common goal of the coastal defence and the environmental administration is to preserve existing salt marshes.
- Salt marshes will only be created in front of the seawall where prevailing sedimentation processes allow it.
- The techniques that are used to reach these goals depend upon local circumstances. They must be carried out in an ecologically sound way as far as possible.
- Where local circumstances allow, technical measures are abandoned.
- A salt-marsh monitoring programme has been established to assess the success of these measures.

As a consequence of these management principles the main management techniques have been evaluated. Artificial drainage has been abandoned in the ungrazed marshes and was reduced in the grazed parts of the marshes. Brushwood groynes enhance salt marsh accretion and stabilise existing salt marsh edges. This traditional technique shall be maintained in most areas. The traditional set-up to create a salt marsh consists of three sedimentations fields in front of the seawall, each 200 m x 200 m large. For the protection of the marsh edge a simple field in front of it is sufficient. In sheltered locations and favourable sedimentation conditions, the maintenance of the groynes has been abandoned. Transport dams, perpendicular to the seawall, are only maintained in the grazed marshes and in the ungrazed where they are essential for coastal defence. Considering the common principles and the evaluation of the present salt-marsh techniques, regionally differentiated plans were developed, including ten reference areas where technical measures are abandoned.

Denmark

Also in Denmark, the foreland-type salt marshes are mainly artificial. They area confined to the mainland coast between Esbjerg and the Danish-German border, where they were developed in connection with 20th-century land claims.

Today, salt marshes in Denmark fall under the Danish Nature Conservation Law (1992) and the Wadden Sea Ministerial Order (1998). This legislation entails limitations to the use and management of the salt marshes. Neither new drainage works nor sedimentation fields with ditches and groynes are maintained any longer. The exception is along the low tide dam to the island of Mandø where these activities are carried out in order to secure the island passage.

In the framework of the elaboration of the Danish Wadden Sea Natura 2000 Management Plan, the following objectives and management measures for the future maintenance have been formulated:

The salt marshes have a favourable conservation status, which implies that:

- The area and the biological condition should be stabilized or being increased;
- The natural drainage and hydrology are secured;
- Optimal (low-intensity) maintenance is secured;
- Their function as breeding- and roosting ground for birdlife is secured.

3.3.2 Drainage

In the framework of the artificial enhancement of salt-marsh development in most of the foreland-type salt marshes of the Wadden Sea, the digging and the upkeep of drainage furrows has traditionally been an important management tool. The function of artificial drainage was to drain seawater after flooding and to improve soil conditions for plant growth. As an effect of drainage measures, the lower fringe of both the pioneer and the low-marsh zone could descend vertically by 0.2 metre (Dijkema *et al.* 1991; Bakker *et al.* 1997). The construction and upkeep of a dense artificial drainage system does generally not have any direct effect on vertical accretion rates (Dijkema *et al.* 1991; Arens & Götting 2008; Michaelis 2008). In traditionally exploited marshes, the upkeep of the artificial drainage was continued in order to enhance the carrying capacity for livestock

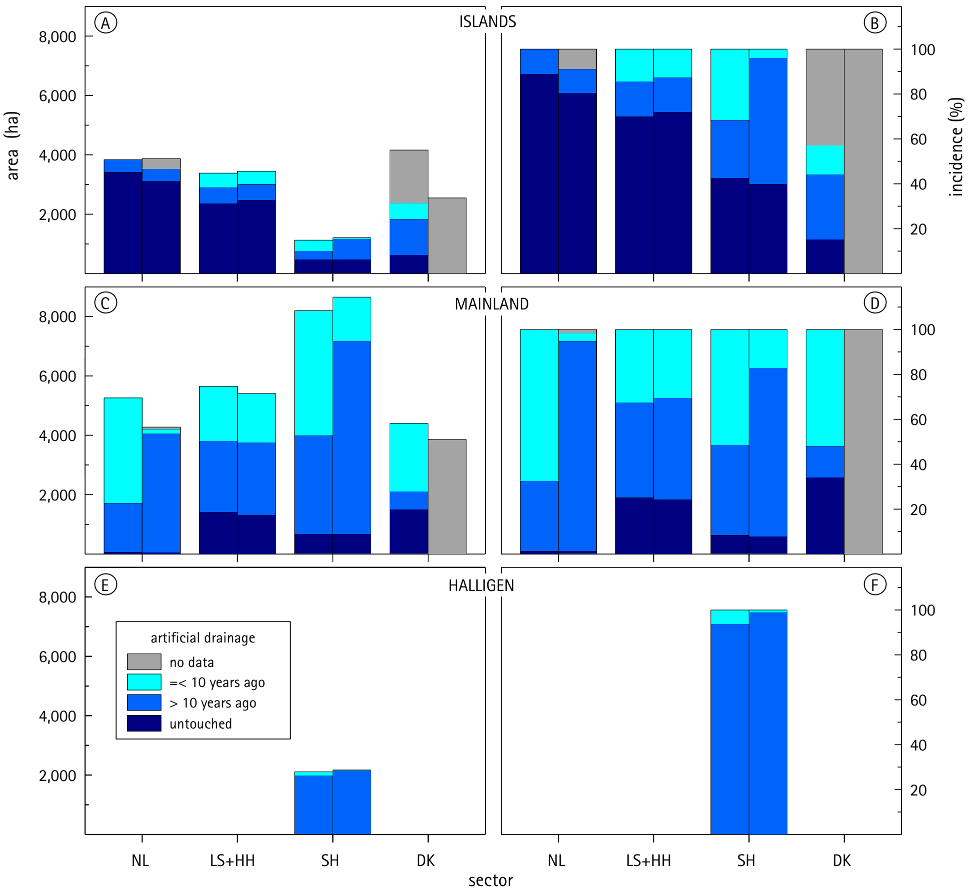


Figure 13: Development of the extent of artificial drainage in the Wadden Sea salt marshes. Figure compares the results of the 2002 survey (left bars; Bakker *et al.* 2005) with the 2008 survey. Right panels give the relative weight of the three drainage classes distinguished (refurbishment of the drainage system at least once during the last 10 years; last refurbishment more than 10 years ago, and salt marsh not disturbed by artificial drainage). For graphical reasons, salt marshes of Hamburg have been pooled with Lower Saxony; and Hallig-type salt marshes in the Netherlands have been included in the mainland marshes. Summerpolders were excluded from the figure. Information about the elapsed time since the last upkeep of the drainage system is not available for the salt marshes in Denmark.

grazing.

Parallel with the shift away from agricultural exploitation towards the recognition of conservation values of salt marshes, the view on drainage measures has changed dramatically over the last decades. In order to increase the natural morphology of artificial salt marshes (Wadden Sea Plan Target), the maintenance of artificial drainage systems has ceased completely over extensive marsh areas (Fig. 13). In Germany, this development has been stimulated with the creation of the national parks during the 1980s. A few years earlier, the upkeep of the artificial drainage was stopped already in the larger part of the Netherlands salt marshes in the Dollard (Esselink 2000). Maintenance of the ditches in the salt-marsh works on the north coast of the provinces of Fryslân and Groningen was stopped by 2001 (Dijkema *et al.* 2001). In the Netherlands, ditching is continued locally by farmers in order to facilitate livestock grazing. This small-scale practice contributes to the local diversity of the salt marshes.

In the western part of the Wadden Sea (i.e. Netherlands up to and including Hamburg), islands salt marshes have been disturbed by ditching in the past to a minor extent, whereas in Schleswig-Holstein more than 60 % of islands marshes have been touched (Fig. 13AB). During the past 10 years, however, ditching has virtually not been practiced here anymore. To restore the natural morphology and drainage in a back-barrier marsh that had been disturbed by ditching in the past, a 9-ha pilot project has been carried in 2008 on the island of Norderney (Bunje, unpubl.).

For the Danish salt marshes, recent data on the development of drainage management over time are not available (Fig. 13). Ditching is licence-restricted. During the most recent survey (2008), 43% of the Danish salt marshes were classified as "undrained", 39% as "moderately drained" and 18% as "intensively drained" on the average with only minor differences between island and mainland marshes.

In the artificial foreland salt marshes, it may be virtually impossible to develop a full natural drainage system. Natural creeks develop during a certain time window in the process of salt-marsh initiation. Once the salt marsh has been formed, creeks remain relatively stable. In the artificial salt marshes, the presence of an artificial drainage system precludes the formation of natural creeks and the time window of creek formation has passed (Esselink 2000; Dijkema *et al.* 2007).

Neglect of the artificial drainage system results in silting of most ditches, whereas the remaining ditches will increase in size. Elevated levees may develop along the ditches as long as the latter are functioning as creeks. Behind the levees, depressions develop. In the Dollard salt marshes, the process of silting up of ditches lasted more than 20 years (Esselink 2007). Once ditches were completely silted up in these marshes, elevation differences between depressions and levees faded in time. Also in the Paezemerlannen, a developing pattern of levees and depressions seemed only transitory after this salt marsh became de-embanked 35 years ago (van Duin *et al.* 1997, 2007a). Based on the developments in the Dollard marshes and a comparison with salt marshes elsewhere, it may be assumed that a distinct pattern of levees and depressions will have the longest life expectancy in salt marshes where vertical accretion rates are relatively low, for instance in the back area of broad marshes.

Salt-marsh creeks are, in general, spatially stable. This implies that a straight ditch will not change easily in a meandering creek. Such creeks are more likely to develop in artificial salt marshes by headward erosion of creeks. This is normally a very long-lasting process.

Opposite to ditching, neglect of the artificial drainage will cause increased soil waterlogging or rewetting of the salt marsh. This may partially reset or at least retard vegetation succession.

3.3.3 Livestock grazing

The main land use of salt marshes is either agricultural use or nature conservation. Similar to the 2004-QSR data, the respective areas have still not been quantified. In principal, within each land-use type, management practices such as livestock grazing, mowing, and abandonment are distinguished and these have been quantified in the TMAP surveys.

Agricultural exploitation of salt marshes is not a modern phenomenon. Already during the mid Holocene, salt marshes in western Europe were used for livestock grazing, especially where the vicinity of higher grounds or peat domes permitted permanent dwelling (Allen 2000). In the Netherlands, the oldest archaeological evidence for salt-marsh exploitation, leaving hunting aside, originated from cattle grazing during the Late-Neolithic (about 2,600 B.C.; Bakels & Zeiler 2005). After the construction of seawalls during the Middle Ages, grazing soon became mentioned in local regulations on management of the foreland for coastal defence (*e.g.* for the Netherlands: Rustinger Law first half of 12th century (Acker Stratingh 1886, cited by Oost 1995)).

Firstly, grazing should provide the possibility to cut salt-marsh sods for seawall repair. Secondly, grazing was thought to have a positive effect on the shear strength of the marsh bed, thus to prevent erosion, and hence to contribute to the stability of salt marshes. Because salt marshes have a positive effect on the safety of seawalls, grazing became advocated, at least regionally, for reasons of coastal defence. This has proven to be a fallacy. Leaving out the pioneer zone, there is ample evidence meanwhile that surface erosion from a vegetated salt marsh can be ignored (Erchinger *et al.* 1996; Zhang & Horn 1996).

Among the three Wadden Sea countries, the starting point of the management for nature conservation differs. In the German national parks, the undisturbed course of natural processes is by law the declared prime objective. This implies a ban on livestock grazing in a considerable part of the salt marshes. In the Netherlands and Denmark, objectives of management for nature conservation are more centred on the preservation of biodiversity. In order to halt vegetation succession, livestock grazing is advocated in these countries, especially in the semi-natural foreland salt marshes.

Between the 1995/2001 and 2002/2007 surveys, the status of livestock grazing, including mowing over limited areas, has approximately been stable in the Netherlands and German sectors over the last ten years (Fig. 14). In Denmark, survey methods evolved from livestock counting from the air to assessment of the grazing status during fieldwork for the EU habitat survey more recently (see Table 1). Data may therefore not be fully comparable. In the Danish sector, the area of minimum-intervention management seemed to have more than doubled on both island and mainland marshes.

During the surveys, grazing has been subdivided in two classes of intensity which have been defined on the basis of appearance of the vegetation:

- 'intensive grazing' is indicated by a uniform short sward,
- 'moderate grazing' is indicated by a heterogeneous sward of with short and tall canopies.

Mainland salt marshes were more frequently grazed than island marshes, especially in the western Wadden Sea (i.e. west of the Elbe estuary). North of the Elbe, island salt marshes seem more frequently and more intensively grazed than in the western Wadden Sea. The foundation of National Parks in the German Wadden Sea in the 1980s signified cessation of the agricultural

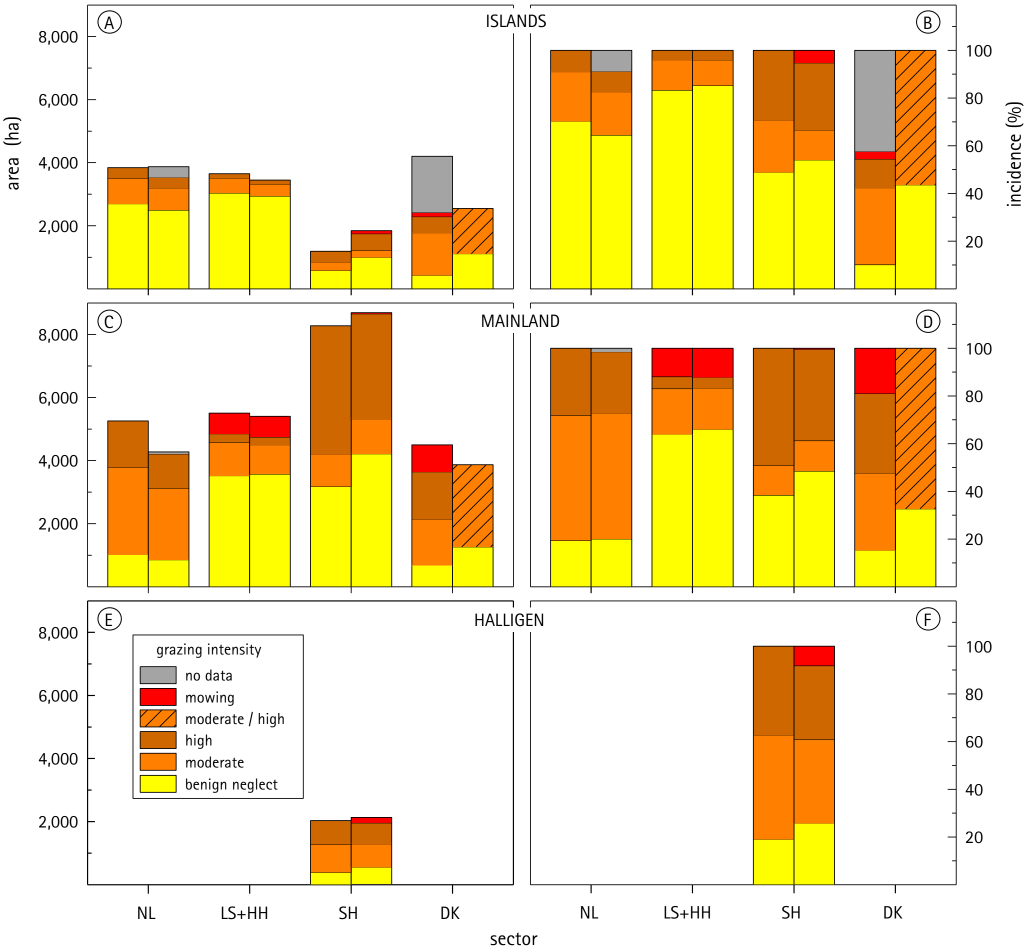


Figure 14: Development of the extent of livestock grazing, mowing and minimum-intervention management in the Wadden Sea salt marshes between 1997/2001 (left bars) and the recent survey of 2002/2008 (right bars). Livestock grazing includes both agricultural exploitation and livestock grazing as management tool for nature conservation. Right panels give the relative weight of the different management types. The most recent Danish figures do not distinguish between moderate and high-intensity grazing. For graphical reasons, salt marshes of Hamburg have been pooled with Lower Saxony; and Hallig-type salt marshes in the Netherlands have been included in the mainland marshes. Summerpolders were excluded from the figure.

use of extensive areas of salt marsh. Before these national parks affected the use of the salt marshes, the situation on the mainland marshes in Lower Saxony differed from that Schleswig Holstein, however: in 1986, 42% of the mainland marshes of Lower Saxony were managed already with a policy of minimum intervention in comparison with only 3% in Schleswig Holstein.

- The major changes in livestock grazing of the salt marshes over the 20-year period that is covered by Figure 15, may be summarized as follows:
- Island salt marshes Schleswig-Holstein: an increase in the incidence of the area that was managed with minimum intervention from 30% to 54% at the expense of the area with a high grazing intensity.
- Island salt marshes Denmark: a sharp increase in the incidence of minimum-intervention management from 5% to over 40%.
- Mainland marshes Netherlands: redoubling in the incidence of moderate grazing from nearly 25% to just over 50% of the marsh area.
- Mainland salt marshes Lower Saxony: if mowing is ignored, a cut in the incidence of intensive use from over 25% to less than 5%, followed by an increase of minimum-intervention management.
- Mainland salt marshes Schleswig-Holstein: A sharp drop of intensive sheep grazing from almost 90% of the area in 1986 to 38% by 2008 with a similar increase in the incidence of minimum-intervention management (Stock *et al.* 2005). In order to guarantee the possibility for sod cutting for seawall repair, intensive grazing is continued in a restricted area that fringes the seawall.
- Mainland salt marshes Denmark: A fourfold increase from 8% to 33% in the incidence of ungrazed marshes.

Data presented by Kempf *et al.* (1987) on the management of the Hallig salt marshes cannot be compared with the two TMAP surveys: data of Kempf *et al.* concern only the foreland marshes of the Halligen, whereas the data of the TMAP surveys refer the Halligen proper. The comparison with the data of Kempf *et al.* can only be performed on a percentage base because of data incompatibility. Small changes in grazing management on a percentage base, for instance of the islands marshes in the western Wadden Sea may be the result of

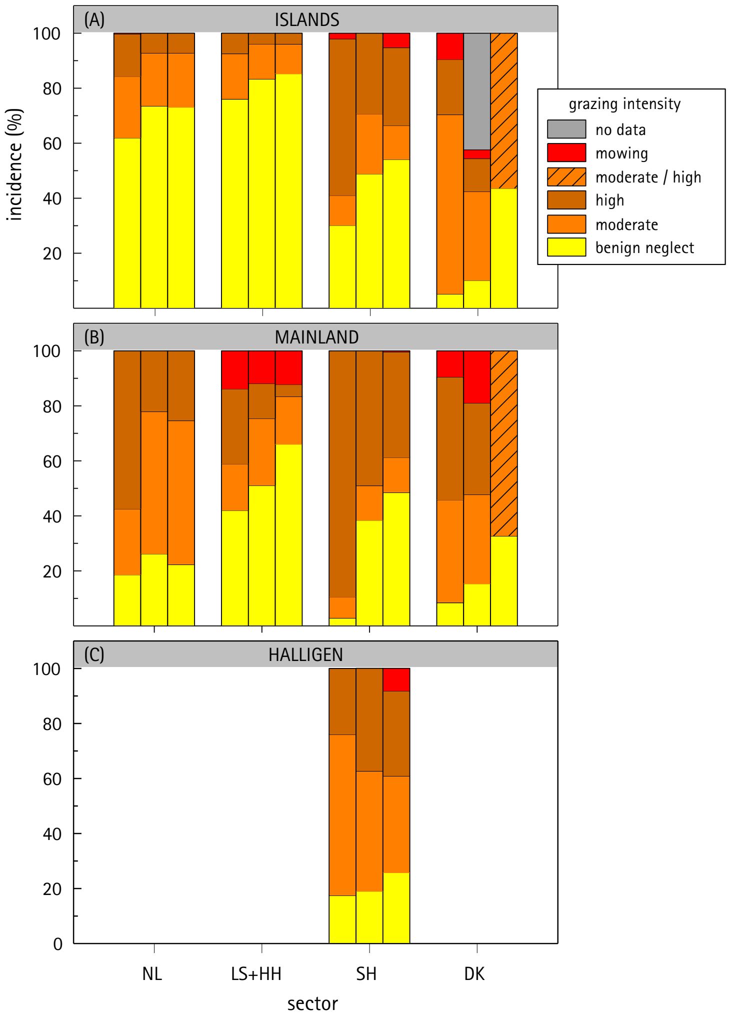


Figure 15: Development of livestock grazing, mowing and minimum-intervention management in the Wadden Sea salt marshes from 1986/1987 (left bars) to 2002/2008 (right bars). The centre bars present the results of the 1997/2001 survey (Fig. 14; Bakker *et al.* 2005). Data of the 1980s have been modified after Kempf *et al.* (1987). Data of the three surveys can be compared on a relative scale only. See Figure 14 and text for further explanation.

changes in the total marsh area.

3.4 Vertical accretion and vegetation succession in broad marshes: the Hamburger Hallig case

Most of the Wadden Sea salt marshes in Schleswig-Holstein have been grazed intensively by sheep for centuries. Because nothing was known about natural succession of the vegetation in the area, an enclosure of 0.8 ha was established in the central part of the Hamburger Hallig in 1978. In one half of this enclosure, different management regimes (grazing, mowing) were applied for three years. The other half of the enclosure was managed with non-intervention. This management was extended to the entire enclosure when the management experiment stopped after 1980. Artificial drainage of the area was also abandoned.

Detailed elevation data of the enclosure are available from 1979. Elevation measurements have been repeated yearly from 2001 onwards. These data show an average accretion rate of 3.9 mm/yr for the last seven years. Over the entire time span since 1979, the net accretion rate was not more than 1.5 mm/yr.

A detailed vegetation map from 1980 is missing, but according to a vegetation map of the entire area in 1980, the vegetation was dominated by *Juncus gerardi*. 15 Years after the cessation of grazing in the enclosure, a first vegetation map was drawn in 1995 (Fig 16). Mapping was repeated in 2007 with the same methodology. Over the last 27 years, the vegetation developed from a J. gerardi-dominated sward in 1980 into ungrazed, species-rich *Festuca rubra*-dominated vegetation. In 1995, large parts of the enclosure were also covered by *Aster tripolium* and to a lesser extent by *Artemisia maritima*. *Aster tripolium* decreased again afterwards. The high incidence of this grazing-sensitive species in 1995 can be seen as an effect of the cessation of grazing 15

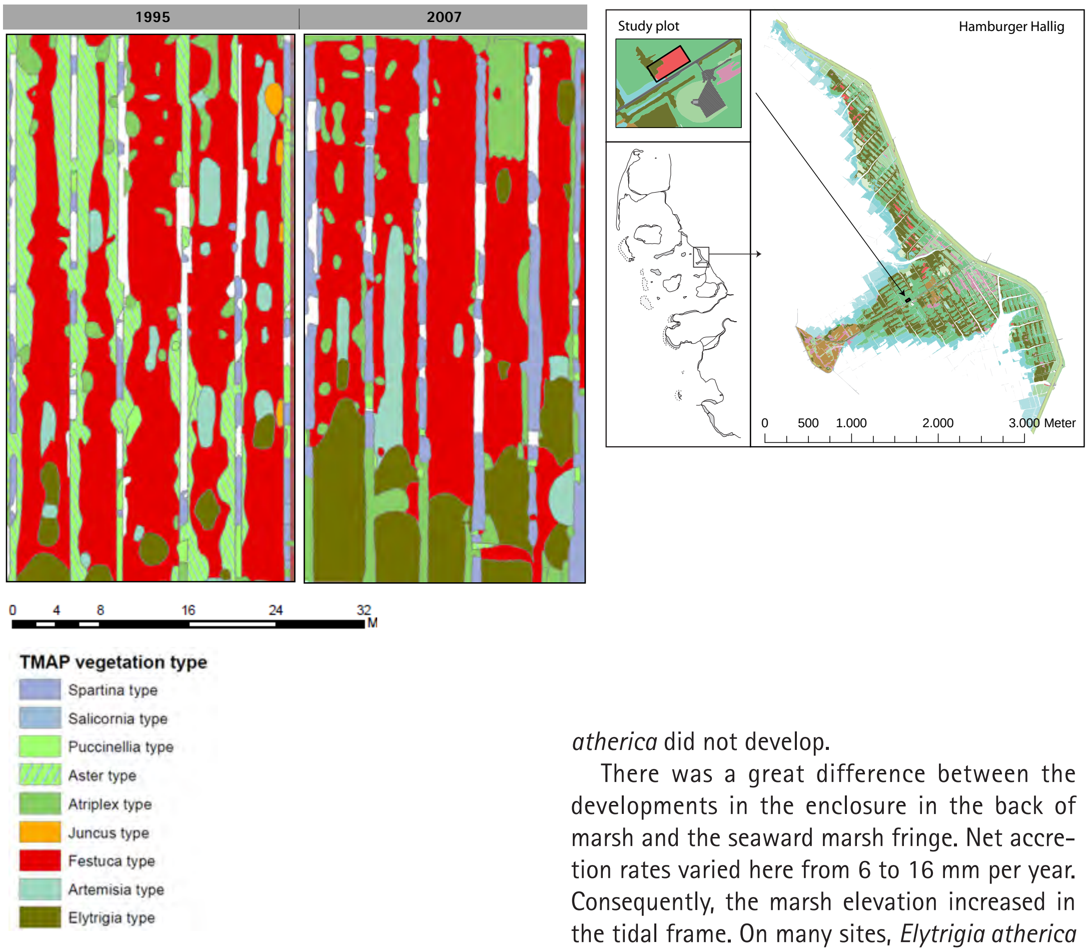


Figure 16: Comparison of the 1995 and 2007 vegetation map of the enclosure in the central part of the Hamburger Hallig, after a period of 15 years and 27 years of minimum-intervention management, respectively. Vegetation types are according to the TMAP typology (Appendix I).

years before. Following the neglect of the drainage system, *Spartina anglica* is now found in former ditches. *Atriplex portulacoides* has increased from 5% in 1995 to 12% in 2007. The latter species was growing on lower and well aerated parts of the salt marsh. *Elytrigia atherica* had already established between 1978 and 1980. In 1995, it covered 3 % of the vegetation. In 2007, 27 years after the abandonment, it covered 17 % of the enclosure, but was limited to the highest parts (Fig. 16).

Within the last 27 years, the elevation of the enclosure in relation to mean high tide has not increased. On the contrary, because the rise of the mean high tide level exceeded the average net accretion rates, the elevation of the plot in the tidal frame is even slightly lower today than it was in 1978 (Table 3). Thus, soil waterlogging of the site has been constant or slightly increased. We conclude that these circumstances form an important factor that may control both the rate and the direction of vegetation succession in an ungrazed situation (Schröder *et al.* 2002). Until today, the vegetation is dominated by a species-rich *Festuca* community and a dominance of *E. atherica* did not develop.

There was a great difference between the developments in the enclosure in the back of marsh and the seaward marsh fringe. Net accretion rates varied here from 6 to 16 mm per year. Consequently, the marsh elevation increased in the tidal frame. On many sites, *Elytrigia atherica* increased in the highest parts, and *Atriplex portulacoides* on the less elevated parts, irrespective of whether these parts of the marsh were moderately grazed or ungrazed.

3.5 Restoration

Salt-marsh restoration has received increasing attention during the last two decades. Since 1973 some 16 restoration projects have been implemented in the Wadden Sea Region or are planned for the near future, including 567 ha for the Netherlands, 385 ha for Lower Saxony and 40 ha for Hamburg (Table 4; Textboxes 2 – 4).

Key factor in these projects is the re-introduction of tidal influence to areas that have been embanked for decades to centuries. These areas are mainly summerpolders which have been reclaimed from artificial salt marshes, but also include beach plains and former dune slacks. Tidal influence is completely restored by bank removal from the marsh bed, or partly by the installation of sluices, culverts or dams. The success rate varies from low to high with different salt-marsh plant species establishing, but with ageing, low tidal amplitude and silting up of the sublittoral

Elevation above NN	Year	MHT	Elevation above MHT	Reference
(m)		(m)	(m)	
1.92	1979	1.48	0.44	Hansen (1982)
1.90 – 1.95	1995	1.55	0.35 – 0.40	Heinze (1997)
1.96	2007	1.55	0.41	Stock unpubl.

Table 3: Average elevation of the enclosure in the central part of the Hamburger Hallig in different years, the concurrent level of MHT and the average elevation relative to the level of MHT.

zone as limiting factors for species diversity. Especially sites with regulated tidal access (Polder Breebaart and Lütetsburger Sommerpolder) have a low success rate. In case, the aim of restoration is to develop a characteristic salt-marsh vegetation with different vegetation zones, ageing appears to be a constraint mainly in sites with a laissez faire policy, whereas the implementation of unrestricted tidal access and a moderate grazing regime are the best ingredients for success.

It is important that restoration sites are monitored annually from one year prior to at least 10 years after de-embankment, with sedimentation rate, vegetation development and elevation change as the most important variables. This will increase our understanding of the processes involved in salt-marsh establishment and allows adaptation of management regimes (grazing, drainage) or engineering (removal of sediment blockades, changing tidal inlet). It is also important to state clear and objective targets that can be easily measured in the field. Not only is the setting of targets indispensable for the assessment of restoration success, it is also of crucial importance in the process of gaining and retaining the necessary support from policy makers and society.

Location	**Site**	**Year of de-embankment**	**Polder period (yr)**	**Total area (ha)**	**Tidal exchange**	**Nature management**	**Restoration success**	**Ref.**
Netherlands								
mainland Friesland	Paezemerlannen	1973	40	100	U	LF	moderate	1,2,6
mainland Friesland	Holwert West	<1990	NA	51	U	G	good	10
mainland Friesland	Holwerder zomerpolder	1989/1995	33	37	R	LF	good	2,3,5
mainland Friesland	Noarderleech	2001	91	123	U	G	good	5,7
mainland Friesland	Biltpollen	2009	NA	70	NA	G	NA	
mainland Groningen	Polder Breebaart	2001	22	63	Rg	G	low	8
Island of Vlieland	Kroon's Polders	1996	76	85	R	M	good	2,3,5
I. of Terschelling	Groene Strand	1996	NA	23	T	G	low	2,3,5
Island of Texel	De Slufter	2002	NA	15	T	?	?	4
Lower Saxony*)								
Leybucht	Hauener Hooge	1994	50	80	U	LF	moderate	11,12
Norderland	Lütetsburger Sommerpolder, embanked part	1986	?	c. 15	U	LF	moderate	11
Norderland	Lütetsburger Sommerpolder	2007	25	50	Rg	G	low	11
Island of Langeoog	Sommerpolder Langeoog	2003	70	150	U	LF/G	good	9,11
Wurster Küste	North of Cappel Neufeld	2008	> 100	47	U	LF/G	NA	11
Wurster Küste	North of Dorum Neufeld	2008	> 100	43	U	LF/G	NA	11
Hamburg								
Neuwerk	Ostvorland	2004	79	40	U	LF	good	12

*) The project in the summerpolder "Spieka-Neufelder Sommergroden" has been omitted. The decision-making process allowed only a regulated saltwater exchange via the construction of a small sluice. Because of the restricted saltwater influence, no salt marsh did develop in the summerpolder as result of the project (Kinder *et al.* 2003).

References: 1) van Duin *et al.* 1997, 2) www.zoetzout.nl; 3) Esselink *et al.* 2003; 4) de Leeuw & Meijer 2004; 5) Wolters *et al.* 2005; 6) van Duin *et al.* 2007a; 7) van Duin *et al.* 2007b; 8) Esselink & Berg 2007; 9) Barkowski *et al.* 2009; 10) Esselink pers. obs. 11) Bunje, pers. obs; 12) this report.

Table 4: Overview of de-embankment sites in the Wadden Sea region. NA = no information available. The success rate is based on observations of the extent and diversity of salt-marsh vegetation. Tidal exchange is unrestricted (U), reduced (R), regulated (Rg) or unrestricted only above an elevated threshold (T). Nature management varies from a laissez faire policy (LF) to a (partly) grazing (G) or mowing (M) regime.

Box 2: From summerpolder to salt marsh: salt-marsh restoration in Noarderleech, Netherlands

An extensive 970-ha complex of summerpolders is located on the mainland coast of the Province of Fryslân, Netherlands. These summerpolders were developed from artificial salt marshes, but have a high potential for salt-marsh restoration. In 1996 an ambitious restoration project, financially supported by the EU-life programme, was launched to create one of the largest continuous salt-marsh areas in Europe. In 2001, a pilot project was carried out by de-embankment of a 123-ha summerpolder.

Restoration included the construction of three 30 to 40-metre wide breaches in the summer bank, digging of three artificial creeks in the summerpolder, and continuation of livestock grazing. The pilot included a 5-year monitor programme and evaluation (van Duin *et al.* 2007b).

In the third year after de-embankment up to 100% of the target species were recorded in 100-m wide permanent transects (Fig. 17). It should be noted that 80 % of the target species were already present before de-embankment as a result of import of seeds by seawater, either via intrusion through culverts or by overtopping of the summer bank and inundation of the area during severe storms. Nevertheless, breaching the summer bank caused a rapid spread of salt-marsh species in the area within the first year. *Puccinellia maritima*, for example, occurred with at least 10 % coverage in almost the entire Transect 2 in the first year after de-embankment (Fig. 18).

Elevation of the restoration site in relation to the tidal frame, an unrestrained tidal exchange, drainage, the presence of a fronting salt marsh as source area for target species, and the grazing management were all considered to be important factors for the rapid development of a halophytic vegetation and the success of the restoration efforts.

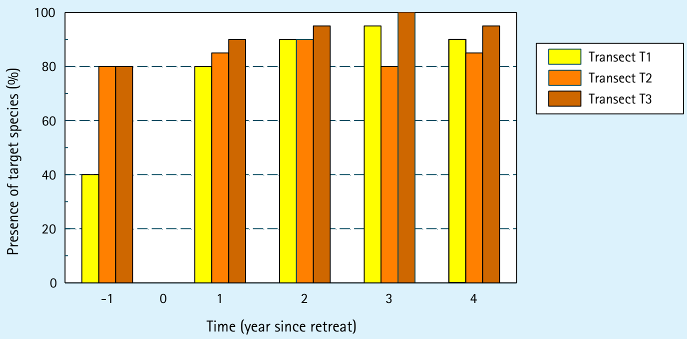


Figure 17: The percentage of target species (n = 21) that were found in three 100-m wide permanent transects in the former summerpolder of Noarderleegh form one year before until four years after the summer bank was breached. The transects all crossed the entire de-embanked area perpendicularly to the coastline. The selection of target species was based on Wolters *et al.* (2005) and plant communities expected to develop (van Duin *et al.* 2007b).

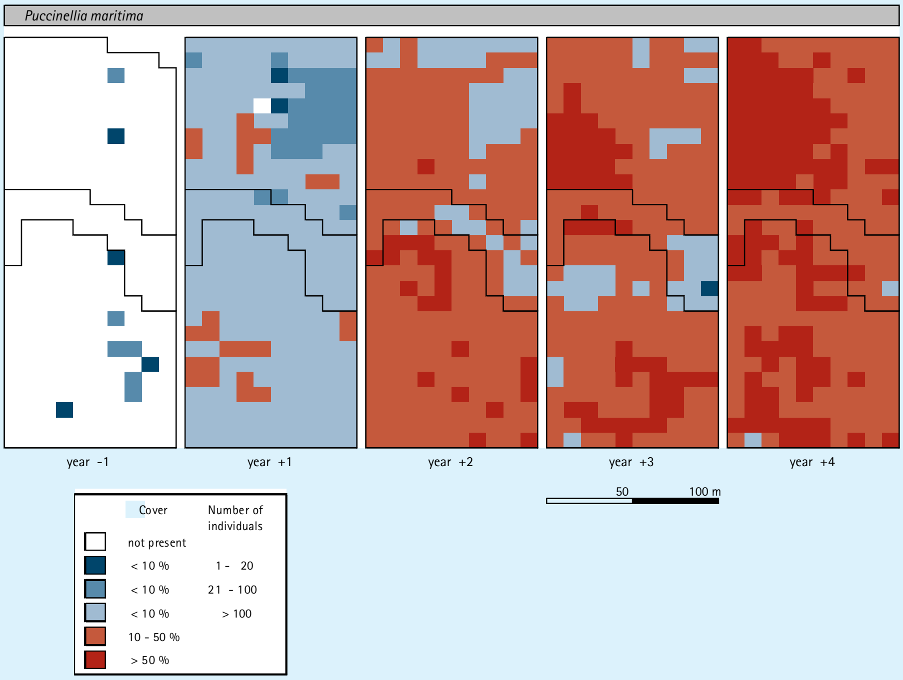


Figure 18: Changes in distribution of *Puccinellia maritima* in Transect 2 in the former summerpolder of Noarderleech, Netherlands, in the year before – until four years after the summer bank was breached (from van Duin *et al.* 2007b).

Box: 3 Vegetation change in a restored salt marsh in the Leybucht

In 1994 a summerbank was breached to allow free entrance of seawater to the summerpolder of the Hauener Hooge in the Leybucht. Over a period of 12 years the vegetation development has been monitored by successive mapping of the area and by permanent-plot recording (Arens 2005, 2007).

Before the breach was created, the area was predominantly covered by a Lolium perenne community. In the year after the opening, this community was invaded by halophytes, but still covered more than 50% of the area (Fig. 19). A fresh *Elytrigia repens*-dominated community covered 13% of the area, whereas other parts were covered by halophytic vegetation, especially by communities of *Aster tripolium* (13%), of Salicornia spp (5%) and of *Puccinellia distans - Spergularia salina* (5%). Areas without vegetation comprised shallow depressions and dug clay pits (8% in total).

Ten years after the breach, the incidence of the *Elytrigia atherica* community augmented nearly 40%. The *Festuca rubra* community had almost disappeared. The clay pits and the eastern part of the Hauener Hooge were dominated by the *Puccinellia maritima* type. In the northern part, bare depressions developed.

In 10 years time, all glycophytic and brackish plant species had disappeared from the permanent plots, and as a result, the total number of species diminished (Tables 5, 6). The current number of plant species is comparable to other salt marshes in the Leybucht that are not grazed (Arens 2007).

The investigations at the former Hauener Hooge summer polder have shown that in most of the areas salt-marsh vegetation could develop within a few years after breaching the summer bank. Because of the increasing salt-water influence, a rapid decrease of most fresh-grassland species was observed during the first years. At the same time different salt-marsh species increased or invaded the area.

The investigations at the former Hauener Hooge summerpolder have shown that the opening of summerbanks is a successful measure in order to restore salt-marsh habitat. Therefore the opening of summerbanks should be integrated in future management plans of the Wadden Sea Area.

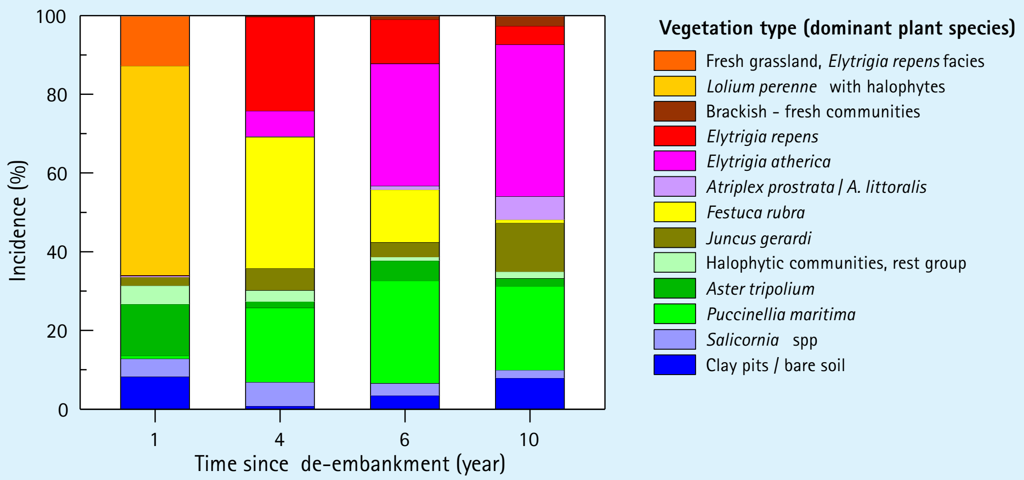


Figure 19: Vegetation change in the former summerpolder Hauener Hooge during the first 10 years after the polder was de-embanked in 1994. Vegetation types according to TMAP typology. For graphical reasons, vegetation types with a limited distribution (incidence < 5% in all years) were merged into two rest groups, *viz.*: (a) halophytic communities and (b) brackish – fresh communities.

Table 5: Average presence (%) of plant species in permanent plots (N = 12) in the former Hauener Hooge summerpolder during the first 13 years after the summer bank was breached in 1994 in order to restore salt-marsh habitat. Plant species are sorted according salt indicator values for species of the coast after Ellenberg *et al.* (2001).

Salt indicator value*	Plant species	Presence (%)								
	Time after breach (yr)	1	2	3	4	5	6	8	10	13
	Pioneer zone									
8-9	*Salicornia spp*	8	8			17	8	8	50	58
8	*Spartina anglica*								8	25
8	*Suaeda maritima*	58	8	100	8	25	17	33	42	75
	Salt marsh									
8	*Aster tripolium*	100	100	100	75	100	67	92	50	100
8	*Spergularia media*	8		8	8	8	8	8		
8	*Cochlearia anglica*		8							
8	*Triglochin maritima*					8	8			17
8	*Puccinellia maritima*	8	17	8	8	17	17	25	25	42
8	*Atriplex portulacoides*								8	17
7	*Atriplex littoralis*								42	8
7	*Atriplex prostrata*	92	100	100	92	100	100	100	92	83
7	*Plantago maritima*	25	50	50	33	42	17	8	8	8
7	*Glaux maritima*	33	75	67	75	75	75	58	67	42
7	*Festuca rubra*	100	100	100	100	100	100	92	92	42
7	*Juncus gerardi*	17	17	17	8			17	17	17
6	*Agrostis stolonifera*	100	83	83	92	75	75	58	42	
6	*Elytrigia atherica*	42	42	100	92	92	100	92	92	92
5	*Artemisia maritima*	17	25	25	25	33	58	25	25	25
5	*Elytrigia repens*	50	58	50	58	67	58	83	58	17
5	*Parapholis strigosa*								8	
5	*Potentilla anserina*	83	67	50	58	42	42	25		
4	*Hordeum secalinum*	92	75	42	33	17	8	8		
4	*Trifolium fragiferum*	17								
	Grassland/brackish marsh									
3	*Cirsium arvense*	100	83	50	25	17	17	8		
3	*Leontodon autumnalis*	100	67	17						
3	*Taraxacum officinale*	50	50	17						
3	*Lolium perenne*	25		8				8		
3	*Sonchus arvensis*		17							
3	*Triglochin palustre*		8							
2	*Plantago major*	100	67	50						
1	*Trifolium repens*	50	8							
1	*Poa trivialis*							8		
1	*Ranunculus repens*		8							

Table 6: Species richness of permanent plots (average number of plant species per plot; N = 12) in the former Hauener Hooge summerpolder during the first 13 years after the summer bank was breached in 1994 to restore salt marsh. The plant species have been separated into two groups according to Table 5, *viz.*: salt-marsh halophytes or target species and plant species of fresh grassland and brackish marsh.

Time after breach (year)	Species richness (no. of plant species / plot)		
	Total	Salt-marsh species	Fresh / brackish species
1	12.8	8.5	4.3
2	11.4	8.3	3.1
3	10.4	9.0	1.4
4	7.9	7.7	0.3
5	8.3	8.2	0.2
6	7.8	7.6	0.2
8	7.6	7.3	0.3
10	7.3	7.3	0.0
13	6.7	6.7	0.0

Box 4: Salt-marsh restoration on the island of Neuwerk

This salt-marsh restoration project was a great success within a couple of years after tidal influence had been re-introduced after almost 80 years in a 40-ha summerpolder. After the sluice of the summerpolder was set out of function in September 2004, vegetation development led to the whole range of the vegetation types that were expected to develop. The opening width of the sluice was sufficient to allow almost natural tidal dynamics in the whole restoration site. Within the few years, fresh and brackish vegetation were replaced by more salt-tolerant salt-marsh communities, Vegetation change was most rapid at lower elevations, i.e. in the lower salt marsh and pioneer zone. Also morphological changes of the natural tidal creeks started again. Birdlife responded positively on the restoration: breeding birds (especially Redshank) increased, whereas the area was also more frequently used as feeding ground.

Restoration of salt marshes in the eastern part of Neuwerk (Photo: Armin Jess)

4. Discussion and conclusions

4.1 Vegetation development

4.1.1 Vegetation development and ageing

The main result that follows from the comparison of vegetation changes in the present QSR is a decrease of the pioneer zone and an extension of late successional and climax stages in many salt marshes across the Wadden Sea region. The characteristic climax stages comprise two or three plant communities, namely *Elytrigia atherica* community on the high salt marshes, *Phragmites australis* community in brackish marshes, and *Atriplex portulacoides* community in low salt marshes. These climax communities are usually formed by almost monospecific stands of the dominant plant species, and hence have a low species and structural diversity.

Not only does ageing affect the floristic diversity on the salt marsh, but that of the entire salt-marsh community. About one third of the invertebrate fauna is phytophagous, among which a considerable number are highly specialised monophagous species. Host plants that accommodate the highest number of monophagous invertebrates are *Aster tripolium*, *Plantago maritima*, *Artemisia maritima*, *Juncus gerardi*, at greater distance followed by *Limonium vulgare*, *Triglochin maritima* and *Bulboschoenus maritimus* (Meyer & Reinke 1995). It follows that there is likely to be a good invertebrate fauna where these plant species are present (Doody 1992). Except for *A. maritima*, these host plants all belong to early and mid-succession plant communities. Thus extension of climax plant communities at the expense of early succession communities will inevitably lead to a decline also of the specific invertebrate diversity in a salt marsh. This conclusion is sustained by Andresen *et al.* (1990), who documented that succession to an *Elytrigia atherica* community was accompanied by disappearance of invertebrate communities characteristic for salt marshes.

Is ageing to be considered as the natural fate of all salt marshes? To answer this question, it seems relevant to realize that salt-marsh succession may be driven by two factors, namely: (1) an increase in marsh elevation by sedimentation, and (2) an increase in availability of plant nutrients, especially nitrogen. In the Wadden Sea in general, the first factor dominates in the mainland foreland-type salt marshes, whereas the increase of nutrient availability appears the prime driving factor of the succession in sandy back-barrier marshes (de Leeuw *et al.* 1993; Olff *et al.* 1997).

For mainland salt marshes, vertical accretion rates are generally described to be in the order of 1 cm per year, i.e. well above the current rate of sea-level rise of about 0.2 cm per year (*e.g.* Erchinger *et al.* 1996; Stock & Kiehl 2000; Dijkema *et al.* 2001; 2009; Esselink 2007). The resulting raising of the salt marshes in the tidal frame will enhance vegetation succession. Vertical accretion, is not constant over an entire marsh, however, but varies within a salt marsh as result of elevation differences, vegetation structure and hydrodynamic gradients (stream velocities and distance from sediment sources; Esselink *et al.* 1998; Allen 2000; Esselink 2000). In wide salt marshes (*i.e.* marshes with great distance between seaward marsh edge and landward boundary), vertical accretion rates decrease landward, and marsh elevations in these inner parts lag behind the outer parts. Consequently, the inner parts or wide salt marshes are less inclined to develop to climax communities than the outer seaward parts. This is sustained for instance, by the vegetation development in the enclosure at the Hamburger Hallig (section 3.4).

The current shape of the mainland salt marshes in the Wadden Sea has strongly been determined by a history of successive land claims and sedimentation works. Consequently, the grand majority of the mainland marshes are not more than a narrow fringe along the seawalls. It follows that in very few situations these marshes feature a complete hydrodynamic gradient of natural wide salt marshes. Nature conservancy should give priority to conserve and restore wide salt marshes wherever this is attainable.

The pattern of vegetation succession in back-barrier marshes differs greatly from the foreland marshes on the mainland. Back-barrier marshes initiate on different elevations of a sand flat in the lee of the barrier. The low and high marsh part each follow their own succession path ways. It follows that the observed zonation along the vertical gradient in these marshes does not reflect succession. At both high and low elevation, succession is primarily driven by the accumulation of nutrients in the clayey toplayer of the marsh (Olff *et al.* 1997). High marshes generally develop towards a dominance of *Elytrigia atherica*; lower parts develop first to a dominance of *Atriplex portulacoides*, and may become invaded eventually by *E. atherica* too. Soil drainage generally influences nutrient availability positively and this may well explain the observed increase of *E. atherica* on the salt marsh of Norderney after ditching (section 3.2). At the same time, however, at naturally poorly drained sites, succession may be impeded by a low nutrient availability. This may be illustrated by the occurrence of the *Limonium vulgare/Juncus gerardi* community in the inner parts of the Boschplaat salt marsh on the island of Terschelling (de Leeuw *et al.* 2008; App. III). Environmental variation provided by a pristine natural drainage of a barrier marsh may preclude a total dominance of late-succession plant communities.

4.1.2 Spatial fixation and ageing

A lack of natural spatial dynamics may form an second important factor for the observed overall trend of ageing. Salt marshes normally are spatial dynamic: they either protrude or erode. The contemporary Wadden Sea salt marshes have to a large extent been fixated by anthropogenic influences. On the mainland, the landward boundary is fixed by the seawall, whereas on many coastal stretches the seaward boundary is fixed by sedimentation works. In the sedimentation fields, the sheltered environment enhances the expansion of pioneer salt marsh, and the succession of the pioneer salt marsh to low salt marsh. Within the sedimentation fields space is limited, however. Inevitably, in many locations the extension of the pioneer salt marsh will eventually be squeezed between the protruding low salt marsh and the fixed seaward boundary of the sedimentation fields. There are areas, however, that form an exception. For instance, in the southern parts of the west-coast of Schleswig-Holstein, an increase of pioneer salt marsh may be found seaward far outside the sedimentation fields. In the Netherlands, currently there seems ample space for growth of pioneer salt marsh within the sedimentation fields. In the long run, primary pioneer salt marsh might be preserved if spatial dynamics become integrated in the management of the sedimentation fields (Esselink 2000). Whether this is a realistic option has been questioned, however, by van Duin *et al.* (2007c).

A secondary pioneer community may be preserved in poorly drained depressions. This community is generally dominated by *Salicornia europaea* and *Suaeda maritima* in contrast with the primary pioneer community in front of a salt marsh which is dominated by *Salicornia procumbens.* It follows that these two pioneer communities are not equivalent ecologically. Because of the ecological differences, the mergence of both communities into one TMAP-type may be reconsidered.

The construction of artificial dune ridges on some islands limited erosion processes but enhanced the sedimentation of clayey material from the Wadden Sea and thereby enhanced both the extension and ageing of the affected back-barrier marshes. A second effect was that in the lee of the dune ridge, vegetation succession was more or less synchronized, which has further decreased the spatial variation in these marshes.

4.2 Management

4.2.1 Artificial dune ridges and salt marshes

The presence of the artificial dune ridges restricts to a great extent the natural geomorphological processes of island salt marshes, especially in the washover complexes and island tails (Box 1; see above). Artificial dune ridges have been constructed especially on the islands in the Netherlands and on the Skallingen peninsula in Denmark. In order to bend ageing, and to restore spatial diverse salt marshes, the removal, at least partially, of these dune ridges seems a prerequisite. Although the artificial dune ridges have been constructed for in the framework of coastal defence, coastal safety is generally not at risk, because the removal has been proposed for uninhabited parts of the islands only.

On coastal stretches where the barrier system does not hold any direct human or economic interest in the Netherlands, the regular upkeep of the artificial dune ridges has been abandoned recently (Lammerts & Petersen 2009). This can be seen as a first step to achieve greater dynamics. De Leeuw *et al.* (2008) go one step further and review the potential ecological outcome of different scenarios for the partial active removal of the artificial dune ridge. The latter authors argue that restoration of a washover should preferably be located on the divide between the catchment areas of two salt-marsh creeks. A washover channel which is directly connected to an existing salt-marsh creek might result in enhancement of the ageing of the salt marsh by an improved drainage. In order to fill up gaps in the existing knowledge, any restoration effort should be accompanied with research.

4.2.2 Future of salt-marsh works

The majority of mainland marshes originated as a result of salt-marsh works. From a geological perspective thereby are man-made or artificially. From an ecological point of view, however, because the vegetation carpet was self-established, the salt marshes may be considered as semi-natural, and are of high conservation value. The construction of sedimentation fields would change highly valued habitats – the intertidal flats or Zostera beds – into another one. Therefore, the restoration of a continuous band of salt marshes along the entire Wadden Sea mainland coast is not demanded. The exception might be for future coastal defence, i.e. the development of artificial marshes in order to protect the seawall under the condition of an increased sea-level rise.

The extension of the artificial salt marshes by the establishment of new sedimentation fields has ensured the presence of an extensive pioneer zone. The pioneer zone itself protects the salt marsh higher up. The construction of brushwood groynes is enough to fulfil the requirements of protection. Additional engineering (*e.g.* drainage and groundwork) in the pioneer zone and the growing marsh is neither recommended nor required.

The edge of naturally-growing salt marshes should not be disturbed. Sedimentation fields should therefore not be planned in front of natural salt marshes or where natural salt-marsh growth is expected.

Cliff erosion is a natural process, in both natural and artificial salt marshes. Cliff erosion therefore should not be automatically interrupted by counter measures. In an extended salt marsh, natural processes should be given space, and one should refrain from the construction of sedimentation fields. In case, cliff erosion has to be stopped, the counter measure should be adapted to the local circumstances (Adnitt *et al.* 2007). The least negative solution is the construction of new sedimentation field in front of the cliff. Sedimentation fields do not function everywhere, however, they fail for instance where high stream velocities prevail. In such circumstances, a gradual transition between salt marsh and intertidal flats may successfully be preserved by the construction of offshore breakwaters (Storm 1999). Stone revetments should only be considered under very stressful conditions, as for instance around the Halligen.

Sediment recharge is a relative new technique for salt-marsh creation or as protection measure for in front of salt marshes. The authors consider this technique as too conflicting with the Guiding Principle and strongly advice not to apply this technique in the Wadden Sea.

4.2.3 Drainage

Barrier-connected salt marshes

The natural drainage system in these marshes may be restored successfully after disturbance by ditching. The aim of restoration is to increase both the natural dynamics and the abiotic diversity of the salt marsh, and to retard ageing by the rewetting process. A pilot project has been conducted on the island of Norderney recently (section 3.3.2).

Mainland salt marshes

In comparison with natural salt marshes, drainage systems of artificial salt marshes are generally oversized (Reents *et al.* 1999). In order to increase the naturalness of existing mainland salt marshes, it is necessary to rewet the salt marsh by a reduction of the artificial drainage. Aim is an increase of the abiotic variation and a retardation of the ageing process. The effect of rewetting can be reinforced by moderate grazing with cattle that is adapted to wet circumstances. Ditching of salt marshes should be restricted to the purpose of draining the seawall.

Neglect of the artificial drainage increases the naturalness of the salt marsh and its creek system, but does not result in the development of a fully natural creek system. Ditching during the (pre)pioneer phase of salt-marsh formation precludes the development of a natural drainage system (Section 3.3.2). It is sometimes believed that ditching enhances the vertical growth of a salt marsh (*e.g.* Nottage & Robertson 2005). This is probably a wrong-footed assumption. In several field studies, not any positive effect of ditching on vertical accretion was found (section 3.2.2; Dijkema *et al.* 1991, Arens & Götting 2008, Michaelis 2008). It follows that it is recommended to refrain from any groundwork both in natural extending salt marshes, and in sedimentation fields that are maintained to create new salt marshes for coastal defence. One exception might be stretches of the coastline where without ditching a salt marsh would not develop.

4.2.4 Salt-marsh restoration

In the 2004 QSR, an increase of the area of semi-natural and natural salt marshes was assessed as management target. In order to achieve this target, de-embankment of summerpolders was considered as an appropriate measure. This policy has been quite successful and over 800 ha of salt marsh has been restored so far. In addition to the total area, de-embankment of summerpolders may improve the quality of the salt marshes, because de-embankment creates the possibility to restore wide salt marshes with a more complete hydrodynamic gradient than most of the existing salt marshes.

Salt-marsh restoration by de-embankment should be preceded by the assessment of clear restoration targets (section 3.5), and be accompanied with an integrated package of restoration measures. In order to increase the naturalness and abiotic variety of the de-embanked area, former creeks and depressions may be restored, and ditches may be filled up. In order to prevent the dominance of one vegetation type, moderate grazing may be considered.

Through de-embankment, sedimentation gives the area the possibility to adapt to the expected sea level rise and climate change.

5. Target evaluation

In the 2004 QSR four different targets were assessed four salt marshes (Essink *et al.* 2005). These targets were related to:

1) Total area
2) Geomorphology
3) Vegetation structure
4) Provision of favourable habitat for migrating and breeding birds

Similar to the 2004 QSR, the fourth target will not be discussed in this report, but will be addressed in the thematic report on birds [ref].

5.1 Total area of salt marshes

Natural salt marshes by definition have not been affected by anthropogenic influences (Bakker *et al.* 2005). This means that the geomorphology has not been influenced by any engineering practices: neither by erosion-protection measures, nor accretion enhancement and not by ditching. Natural processes are here still in place. In the Wadden Sea, natural salt marshes occur mainly as barrier-connected marshes, whereas most of the mainland salt marshes are artificial because their geomorphology is strongly affected by anthropogenic influences.

In comparison with the data presented in the 2004 QSR, the total extent of salt marshes in the Netherlands and German sector of the Wadden Sea increased by nearly 1,600 ha (= 5%). This increase occurred predominantly on both the islands and the mainland coast of Schleswig-Holstein. The new marshes will comprise mainly young natural salt marsh including embryonic dunes and driftline vegetation (Section 3.2.1). The Danish salt-marsh data have been left aside, because the consecutive surveys were not comparable. Natural and semi-natural salt marshes in the Wadden Sea cannot be fully discriminated in the data-analysis, because geomorphology and vegetation have not yet been integrated in a common GIS database. A further point that is not cleared is whether salt marshes which developed in the lee of artificial dune ridges should be classified either as natural or semi-natural.

In the Netherlands sector, today the total size of island salt marshes is well above any historic reference value. This is mainly due to the presence of artificial dune ridges (Box 1; Section 3.2.3; Dijkema 1987; Dijkema *et al.* 2005). Efforts that aim to restore geomorphological processes on the islands at a greater scale including the restoration of washover complexes may yield in a more diverse salt marsh with greater spatial dynamics, and counterbalance ageing, but will probably be accompanied with a diminished size of island salt marshes. For the Netherlands islands, this would imply that the target has been reached.

In the mean time on the mainland of the Netherlands, the size of clayey foreland marshes has diminished to an historic minimum due to the long history of land claims, whereas the development of new salt marsh and the preservation of existing salt marsh largely depend on engineering measures (Dijkema 1987). This situation differs greatly from that in Schleswig-Holstein, where naturally developing foreland salt marsh may be found at several sites.

An increase in the area of salt marshes may be achieved by de-embankment of summerpolders. Currently, a total of nearly 1,000 ha have been de-embanked compared to 780 ha by 2004 (Table 4; Section 3.5). These values include also restoration sites with regulated tidal regime.

Natural salt marshes that have been disturbed by ditching may be restored by the filling of ditching and restoration of the former creeks (Section 4.2.4).

Target

- An increased area of natural salt marshes

Target evaluation

In comparison with the 2004 QSR, the total extent of natural plus semi-natural salt marshes in the Netherlands and German sector increased by 1,600 ha (5%). For the Danish sector, a sound comparison is not available, because of shortcomings in the figures from the 2004 QSR. An evaluation of the target in quantitative terms is, however, currently not feasible, because geomorphology and vegetation have not yet been distinguished.

Conclusions

- Natural salt marshes in the Wadden Sea are mainly found as sandy barrier-connected island marshes. At least in some sectors, the size of these marshes is much greater today than ever before due to the presence of artificial dune ridges. There is currently greater concern about the quality than the areal extent of these salt marshes.
- The construction of artificial dune ridges on some islands and on the Skallingen Peninsula in the north did not only facilitate the extension of barrier-connected salt marshes, but also resulted in spatial fixation and ageing of these marshes.
- Re-introduction or restoration of geomorphological processes, including the restoration of washover complexes may yield in a more diverse salt marsh with greater spatial dynamics, and counterbalance ageing, but will

probably be accompanied with a diminished size of island salt marshes.

- On the mainland coast, the size of clayey foreland salt marshes is below historic reference values. The fast majority of these marshes are named artificial salt marsh, since they developed from salt-marsh works (see above); natural foreland salt marshes are relatively rare. Artificial salt marshes can be regarded as semi-natural, which cannot be restored to natural salt marsh. There is concern on both the extent and the quality of the mainland salt marshes.
- Barrier-connected salt marshes that have been disturbed by ditching can successfully be restored to natural salt marsh by filling up the ditches and excavating former creeks and depressions.
- The size of mainland salt marshes can be increased by de-embankment of summerpolders in the Netherlands and Lower Saxony. If restoration is aimed at the development of a characteristic salt-marsh with different vegetation types, the implementation of unrestricted tidal access and moderate grazing may be the best ingredients for success.

5.2 Increased natural morphology and dynamics of artificial salt marshes

For historic reasons, artificial salt marshes represent approximately 50% of the total salt-marsh area in the Wadden Sea (Fig. 1; Section 3.1). Typical aspects of the artificial marshes were an evenly distributed dense drainage network and a very flat topography. With some exceptions, the mainland marshes form a narrow band between fixed borders: the seawall and the groyne system of the sedimentation fields which have to protect the salt marsh from erosion. Traditionally, the artificial drainage system was refurbished very regular in order to (1) enhance vegetation establishment high on the intertidal flats, (2) increase the carrying capacity for livestock grazing and (3) prevent the formation of depressions.

In order to enhance a more natural morphology of the mainland salt marshes, maintenance of artificial drainage systems has ceased over extensive areas (Fig. 13CD; Section 3.3.2): in the Netherlands-German sectors the area where the drainage system had not been refurbished in the foregoing 10 years increased from nearly 7,400 ha (39%) during the surveys for the 2004 QSR to almost 13,000 ha (71%) for this QSR. In the two sectors, the drainage system in an area of 3,300 ha (18%) had been refurbished within a ten-year period prior to the most recent survey. There is probably also an increase neglect of the artificial drainage in the Danish sector, but the drainage data from this sector do not allow a comparison in time (Section 3.3.2).

Neglect of the artificial drainage system results in silting up of part of the ditches and an increased variation of the topography due to the formation of depressions and the building up of levees along ditches that remain open. It further leads to rewetting of the salt marsh, which may result in retardation of the succession and an increase of the vegetation diversity (Section 4.2.3).

Abandonment of the artificial drainage thus increases the naturalness of the salt marsh and its creek system, but the development a fully natural creek system may not be expected in the foreseeable future (Sections 3.3.2; 4.2.3). Once a salt marsh has been formed, the phase for creek formation has passed, and creeks stay relatively stable.

The morphology of mainland salt marshes may further be improved when wide marshes can be restored by de-embankment of summerpolders. Wide salt marshes have a more complete hydrodynamic gradient than most of the existing salt marshes (Sections 3.4; 4.2.4).

Whereas natural salt marshes are generally spatial dynamic, artificial salt marshes are relatively fixed. Cliff erosion is a natural process, in both natural and artificial salt marshes. It follows that cliff erosion should not automatically be interrupted by counter measures, but natural processes should be given space, especially in extended marshes (Section 4.2.2). If cliff erosion has to stopped, any counter measure should be adapted to the local circumstances.

Target

- An increased natural morphology and dynamics, including natural drainage patterns, of artificial salt marshes, under the condition that their present size is not reduced.

Target evaluation

- In order to create a more natural morphology and to increase natural dynamics in the artificial salt marshes, the area where the maintenance of the artificial drainage has ceased in the Netherlands-German sector, has risen further from 7,400 ha during the surveys for the 2004 QSR to almost 13,000 ha (71%) for this QSR. Cessation of artificial drainage results in increased naturalness of the marshes, which includes both their morphology and vegetation dynamics. The remaining ditches that do not silt up, will not easily develop into natural-like creeks.

Conclusions

- In the Netherlands and German sector, the area where the artificial drainage is now neglected, has increased significantly recently, and includes now over 70% of the mainland salt marshes.
- Neglect of the artificial drainage leads a more diverse topography in the artificial salt marshes, which include the formation of levees along the remaining ditches and the development of depressions.
- Neglect of the artificial drainage also leads rewetting of the salt marsh, which will retard ageing, and enhance vegetation diversity.
- Natural creeks normally develop in a very early stage of salt-marsh formation. Cessation of ditching in an existing salt marsh therefore does not automatically lead to the development of a natural creek system.
- The morphology of a salt marsh also includes size. In comparison with narrow salt marshes, wide marshes have a greater, more complete internal hydrodynamic gradient which enhances internal variation in both vertical accretion rates and vegetation development.
- The anthropogenic impact on the coastal landscape explains why wide salt marshes have become an exception.
- In comparison with natural salt marshes, artificial salt marshes lack spatial dynamics.

5.3 Improved natural vegetation structure, including the pioneer zone, of artificial salt marshes

In the 2004 QSR it was concluded that Target 3 requires specification. Bakker *et al.* (2005) therefore reformulated the target as follows:

- The aim is a salt-marsh vegetation diversity reflecting the geomorphological conditions of the habitat

An important question that has not been addressed on the trilateral level, however, is how the target should be evaluated. For the German sector, an evaluation has been formulated in the framework of the HD. From a geomorphological perspective, most artificial salt marshes are relatively uniform, also after rewetting. If these marshes are not grazed, they may be very susceptible to ageing, which will result in a dominance of *Elytrigia atherica* vegetation over extensive areas. This is for instance, currently the case in some large salt marshes in Lower Saxony (Section 3.2.1). The development towards a dominance of *E. atherica* may be retarded or even prevented in salt marshes where the target of an increased natural morphology of artificial salt marshes has been fulfilled.

Management objectives are diverging among the three countries and areas. In the German national parks, minimization of anthropogenic influences has been formulated as guiding principle of salt-marsh management. The objective is a vegetation development in relation to the geomorphological conditions. A definite aim for a certain composition of flora or fauna has not been formulated. Outside the national parks, management objectives may be more distinct, for instance favourable conditions for migrating and breeding birds. In order to realize such goals, livestock grazing may be used here as management instrument.

In the Netherlands, the main aim of nature conservation of the mainland salt marshes is the preservation and enhancement of the current biodiversity. Livestock grazing is considered an indispensable tool for nature management to prevent dominance of a few late-successional stages. This implies that a vegetation diversity is aimed at which is the outcome of the interaction between geomorphological conditions and livestock grazing. Also in Denmark, livestock grazing is seen as indispensable management tool to prevent dominance of late successional vegetation stages.

In conclusion, in order to do justice to both approaches in the management of the artificial salt marshes, Target 3 may require revision. Secondly, evaluation tools based on vegetation parameters should be developed on a trilateral level.

From the evaluation of Target 2 (Section 5.2), it follows that an increased natural morphology is a pre-requisite in order to achieve improved vegetation diversity. For instance at low elevations, i.e. in sedimentation fields around MHT, improved vegetation diversity may be reached by cessation of artificial drainage. On existing salt marshes in the absence of grazing, high sedimentation rates will result in monotonous climax vegetation due to ageing. Differences in geomorphology will be masked by such homogeneous vegetation. In such marshes moderate grazing may result in high vegetation diversity. In wide salt marshes with low sedimentation rates (1–3 mm/year) in the inner parts, high vegetation diversity may develop autonomously (Section 3.4).

Artificial salt marshes often have two fixed boundaries: the seawall at the landward side and a groyne system at the seaward side. Where this situation prevails, the position of primary pioneer vegetation will ultimately become delicate after the available space has been consumed by salt-marsh development (Section 4.1.2). Since livestock grazing does not affect the fate of the pioneer zone, primary pioneer salt marsh may only be preserved if spatial dynamics become integrated in the management of sedimentation fields.

Long-term studies had already indicated that Wadden Sea salt-marsh vegetation may succeed relatively quickly towards species-poor late-successional communities. This so-called ageing was a new topic in the 2004 QSR. Except for wide salt marshes, where inner parts of the marsh may be characterized as low-sedimentation areas, the majority of the artificial salt marshes may be susceptible to ageing, due to their low geomorphological variation and high sedimentation rates. This is sustained by the results presented in this QSR. In the Netherlands-German sector, out of the 34 TMAP types, the climax community of *Elytrigia atherica* was the most common community with an almost 20% incidence (App. II). The community was clearly more common in the clayey mainland salt marshes than in the barrier-connected salt marshes (Section 3.2.2). The increase of *E. atherica* community was clearly related with cessation of livestock grazing (Figs 5, 7). In ungrazed mainland salt marshes of Lower Saxony, the incidence of the *E. atherica* community reached values of over 40% without an indication that the community has reached its maximum extent.

Target

- An improved natural vegetation structure, including the pioneer zone, of artificial salt marshes.

or (2004 QSR)

- The aim is a salt marsh vegetation diversity reflecting the geomorphological conditions of the habitat

Target evaluation

- In some artificial marshes, increased vegetation diversity has been observed as a result of management changes and an increased natural morphology.
- Ageing is a common process in most artificial salt marshes, especially in the absence of grazing. In salt marshes with improved morphology (Target 2), the ageing process may be retarded or stopped.
- For the evaluation and assessment of vegetation diversity data from longer time periods are required. Therefore an evaluation of the target can not be given yet. On the trilateral level, an evaluation method has still to be developed.

Conclusions

- On the trilateral level, management objectives of the artificial salt marshes are diverging. One approach is to aim at a vegetation development in relation to the geomorphological conditions with a minimum of anthropogenic influences. In the second approach, the aim is to prevent dominance by species-poor climax vegetation, and to preserve and enhance vegetation diversity in a semi-natural landscape with livestock grazing as indispensable tool for nature management. In this approach vegetation diversity is thus the outcome of the interaction between geomorphological conditions and grazing.
- In order to integrate the two management approaches, the target may require revision.

6. Recommendations

6.1 Recommendations for monitoring and research

a) The monitoring according to the TMAP guidelines should be fully implemented.

In order to assess the "favourable conservation status" of the HD and the "good ecological status" of the WFD on the trilateral level, the TMAP Salt-Marsh Working Group (SMWG) concluded that the TMAP monitoring according to TMAP guidelines is a pre-requisite (Bakker *et al.* 2005). Therefore, in order to allow of a trilateral assessment, implementation of the TMAP salt-marsh monitoring programme by Denmark is awaited.

b) Distinction of secondary pioneer vegetation in the TMAP typology.

The primary pioneer zone and the secondary pioneer plant community in the inner salt marsh are not equivalent ecologically. In order to assess both communities separately, it is advised to consider a subdivision of the TMAP type vegetation of *Salicornia* spp / *Suaeda maritima* (type S.1.2; App. I).

c) The monitoring according to the TMAP guidelines should be extended with monitoring of marsh elevation.

Elevation is a basic measure for all salt marshes. Changes of elevation are an essential parameter for the evaluation of salt-marsh development. Monitoring of elevation on selected permanent transects or monitor stations is therefore recommended.

d) The monitoring according to the TMAP guidelines should be extended by monitoring plant species of the TMAP vegetation types.

At present, the TMAP monitor programme does not provide monitor data at the level of plant species, but on the level of plant communities only. Data on the level of individual plant species, however, are required by the WFD. In order to assess processes of salt-marsh change, Bakker *et al.* (2005) recommended the annual monitoring of vegetation types at selected permanent sites on in relation with elevation changes and management data. It follows that this recommendation can be specified as the monitoring of plant species in permanent plots, ideally in relation with marsh elevation and management.

e) Addition of geomorphological layers.

In order to analyse vegetation maps or vegetation changes, data on substrate or salt-marsh type may be very relevant. So far such information is not available at the trilateral level. Additionally, the WFD requires data on geomorphological elements. There are also some gaps in the habitat typology data (*e.g.* lagoons). The SMWG therefore recommends the addition of standardized geomorphological map layers to the TMAP vegetation maps.

f) Harmonisation with data of other TMAP monitoring programmes.

In the framework of the Trilateral Monitoring and Assessment Programme, spatial data are al so being assessed by other working groups (*e.g.* dunes, birds). Harmonisation of the different datasets would allow of studying interrelationships among different ecosystem compartments.

g) Every 6 yrs TMAP shall be used.

The HB and WFD both prescribe an evaluation cycle with a time interval of 6 years. The SMWG advises to harmonize the mapping frequency with this evaluation cycle, and to adapt to a 6-year time interval for the next vegetation mappings. This is currently being incorporated in the TMAP guidelines.

h) Integration of additional relevant available data in relation to salt marshes, especially legal protection status, ownership and land use.

Land use of Wadden Sea salt marshes can be subdivided into agricultural exploitation and nature conservation. These two land-use types cannot be separated and quantified with the available data. In order to separate, for instance, agricultural exploitation by livestock grazing, grazing as management tool in nature management, the land-use types should be available in a harmonized GIS-dataset. The SMWG recommends therefore the addition of a harmonized dataset on legal protection status, ownership and land use.

- Study of the possible interrelationship between ageing towards climax vegetation, rate of sedimentation and cessation of grazing;
- Continuation of long-term study sites and incorporation of these sites into the International Long-Term Ecological Research sites (ILTER).
- Study the significance of the new geomorphological concept of the W-E orientated barrier islands for the S-N orientated barrier islands in the northern part of the Wadden Sea.

6.2 Recommendations for management

- The development of naturally protruding salt marshes is best guaranteed by leaving the geomorphology of both the growing marsh and the adjacent intertidal mudflats undisturbed.
- In order to allow natural creek systems to develop in sedimentation fields which are

maintained to create new salt marsh for coastal defence, it is advised to refrain from any groundwork in these sites.

- The size of mainland salt marshes can be restored by de-embankment of summer-polders.
- Wide salt marshes have a higher conservation value than narrow marshes (Section 4.1.1). A priority should be given to the preservation and restoration of wide salt marshes wherever this is attainable.
- A further diminishment of ditching in the artificial marshes is recommended.
- In order to prevent waterlogging at the foot of the seawall, ditching of salt marshes should be confined to this purpose only.
- Cliff erosion should be considered as a natural process in both natural and artificial salt marshes. It follows that cliff erosion should not automatically be interrupted by counter measures, but natural processes should be given space, especially in extended marshes.

Future management should aim at:

- Rejuvenation of salt marshes and restoration of washover complexes on barrier islands through removal of artificial dune ridges.

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Appendix I: TMAP Typology

TMAP legend and typology of salt and brackish vegetation

Table I.1: Description of the TMAP salt-marsh vegetation typology (version 1.61) with the corresponding habitat type of the EU Habitats Directive (HD). a) The Netherlands, b) locally in Schleswig-Holstein only.

TMAP unit		Description	HD habitat type
Code (alphan.)	Code (letter)		
S	S	Salt marsh (Haloserie)	
S.0	**Su**	**No vegetation**	
S.0.0	Su*	Vegetation not present, unspecific (anthropogenic disturbed, *etc.*)	
S.0.1	Sw	open water	
S.0.2	Ss	bare soil: sand & shells (beaches etc.) = dune type X.1	
S.0.3	Sm	bare soil: mudflat	1140
S.1	**SP**	**Pioneer salt-marsh vegetation**	
S.1.0	SP*	Pionier salt marsh, unspecific	1310
S.1.1	SPs	Spartina anglica type	1320
S.1.2	SPq	Salicornia spp / Suaeda maritima type	1310
S.2	SL	Low salt-marsh vegetation	1330
S.2.0	SL*	Low salt marsh, unspecific	1330
S.2.1	SLp	Puccinellia maritima type	1330
S.2.2	SLl	Limonium vulgare / Puccinellia maritima type	1330
S.2.3	SLa	Aster tripolium / Puccinellia maritima type	1330
S.2.4	SLh	Atriplex portulacoides / Puccinellia maritima type	1330
S.3	**SH**	**High salt-marsh vegetation**	**1330**
S.3.0	SH*	High salt marsh, unspecific	1330
S.3.1	SHl	Limonium vulgare / Juncus gerardi type	1330
S.3.2	SHj	Juncus gerardi / Glaux maritima type	1330
S.3.3	SHf	Festuca rubra type	1330
S.3.4	SHh	Atriplex portulacoides / Artemisia maritima type	1330
S.3.5	SHz	Artemisia maritima / Festuca rubra type	1330
S.3.6	SHm	Juncus maritimus / Festuca rubra / Juncus gerardi type	1330
S.3.7	SHy	Elytrigia atherica type	1330
S.3.8	SHe	Carex extensa type	1330
S.3.9	SHx	Atriplex prostrata / Atriplex littoralis type	1330
S.3.10	SHg	Agrostis stolonifera / Trifolium fragiferum type	1330
S.3.11	SHc	Plantago coronopus / Centaurium littorale type	1310[a)] /1330
S.3.12	SHo	Ononis spinosa / Carex distans type	1330
S.3.13	SHr	Elytrigia repens type	1330
S.5	**SB**	**Brackish marsh vegetation**	**1330**
S.5.0	SB*	Brackish marsh, unspecific	1330
S.5.1	SBb	Bolboschoenus + Schoenoplectus type	1330
S.5.2	SBp	Phragmites australis type	1330
S.5.3	SBg	Brackish flooded grassland type	1330
S.5.4	SBm	Juncus maritimus / Oenanthe lachenalii type	1330
S.6	**SF**	**Fresh (anthropogenic) grassland**	**-**
S.6.0	SF*	Fresh (anthropogenic) vegetation, unspecific	-
S.6.1	SFl	Lolium perenne, Cynosurus cristatus and other fresh species type	-
X2/3	**XE**	**Embryonic dunes & driftline vegetation**	**-**
X.2.0/3.0	XE*	Embryonic dunes & driftline, unspecific	-
X.2.1	XEd	Cakile maritima / Salsola kali / Honckenya peploides type (=Cakile maritima type in Dune typology (Petersen & Lammerts 2005))	- /1210[b)]
X.3.1	XEf	Elytrigia juncea ssp boreoatlantica type (= Elymus farctus type)	2110
H1/2	**HS**	**Seepage vegetation**	**2190**
H.1.0/1.1	HS*	Seepage vegetation, unspecific; Centaurio Saginetum inclusive	2190
H.2.2	HSc	Schoenus nigricans type	2190

Table I.2: Classification key to the TMAP salt-marsh vegetation typology. The key is based on the following assignment process: Start to read the top row; if the description does not match, then move to the following row; *etc*. The first match gives the vegetation type that is searched for.

TMAP unit		Classification key
Code (alphan.)	Code (letter)	
S.0.1	Sw	vegetation abundance < 5%: bare water (in SH < 10%)
S.0.2	Ss	vegetation abundance < 5%: bare soil, sand (beaches etc.) (in SH < 10%)
S.0.3	Sm	vegetation abundance < 5%: bare soil, mudflat (in SH < 10%)
		Rest zone types:
S.5.2	SBp	Phrag aus > 50%
S.2.4	SLh	Atrip por > 50%
S.2.3	SLa	Aster tri > 50%
S.3.7	SHy	Elytr ath > 50%
S.3.9	SHx	Atrip pro > 50%
S.1.1	SPs	Spart ang > 50%
S.5.1	SBb	(Bolbo mar + Schoe tab + Schoe tri) > 50%
S.2.2	SLl	Limon vul > 25% and grasses[1)] < 25%
S.1.2	SPq	Suaed mar > 25%, and Suaed mar highest abundance of GROUP 1
S.3.7	SHy	(Elytr ath + Atrip pro) > 25%[e)], and Elytri ath highest abundance of GROUP 1
S.3.9	SHx	Atrip lit > 25%, and Atrip lit highest abundance of GROUP 1
S.2.1	SLp	(Pucci dis + Sperg sal) ≥ 10%, and both species present
S.3.8	SHe	Carex ext > 5%
S.5.3	SBg	Blysm ruf ≥ 10% or Blysm ruf > 5% and Carex ext > 1% & Centm pul + Odont ver are both present
S.3.11	SHc	(Sagin mar + Cochl dan + Buple ten + Plant cor) > 5% and > 2 species present or (Centm lit + Sagin nod + Leont sax) > 2 species present
X.3.1	XEf	Glaux mar > 5 % and neither P species and L species present (on sandy places, salty embryonic dunes)
S.3.12	SHo	(Ononi spi + Carex dis) ≥ 5% and Ononi spi is present
S.5.3	SBg	Agros sto ≥ 5% and GROUP 2[2)] ≥ 4 species present
S.2.3	SLa	Aster tri > 25% and grasses < 15% and Aster tri highest abundance of GROUP 3[4)]
S.5.3	SBg	Trigl mar > 25% and grasses < 15% and Trigl mar highest abundance of GROUP 3[4)]
S.5.1	SBb	(Bolbo mar + Schoe tab + Schoe tri) > 25% and Bolbo mar + Schoe tab + Schoe tri highest abundance of GROUP 3[4)]
S.5.2	SBp	Phrag aus > 25% and Phrag aus highest abundance of GROUP 3[4)]
S.5.3	SBg	Agros sto > 25% and Juncu ger < 5% and Festu rub <= 15% and Pucci mar < 25% and (GROUP H (high salt marsh) + Ranun sce + Alope gen + Cotul cor) ≥ 1 present and GROUP H < 50%
		Zonation types:
S.1	SP	Pioneer salt marsh (cover > 5% [a)]; P SPECIES > (A + L + higher species)
S.1.1	SPs	Spart ang + Spart mar > Salicornia spp + Suaed mar + Bassi hir
S.1.2	SPq	Salicornia spp + Suaed mar + Bassi hir > Spart ang + Spart mar[b)]
S.1.0	SP*	rest
S.2	SL	Low marsh (A + P SPECIES) < L1 SPECIES > (M + higher species)
S.2.2	SLl	Limon vul > 15% and highest abundance of GROUP 4[5)]
S.2.4	SLh	Atrip por > 20% [c)] and highest abundance of GROUP 4[5)]
S.2.3	SLa	Aster tri > 15% and highest abundance of GROUP 4[5)]
S.2.1	SLp	Pucci mar > 5%
S.2.0	SL*	rest = low marsh, unspecific
S.3	SH	High marsh (A + P + L1 + L2 + X + B + F + S SPECIES < M (- Agros sto & Festu rub + H SPECIES)
S.3.5	SHz	Artem mar > 15% and Artem mar > Festu rub
S.3.4	SHh	Atrip por > 15% and highest abundance of GROUP 4[5)]
S.3.6	SHm	Juncu mar > 15%
S.3.1	SHl	Limon vul > 10% and Limon vul > Armer mar
S.3.2	SHj	Juncu ger > 35%[d)] and Juncu ger > Festu rub
S.3.3	SHf	Festu rub > 35% and Festu rub > Juncu ger
S.3.2	SHj	Glaux mar > 25% and grasses < 15%

Table I.2 (cont.)

TMAP unit		Classification key
Code (alphan.)	Code (letter)	
S.3.13	SHr	Elytr rep > 25% and H SPECIES > 0 and H SPECIES ≥ (L2 SPECIES + M SPECIES)
S.3.10	SHg	Festu rub > 15% and Agros sto + Poten ans present and H SPECIES > 0 and H SPECIES ≥ (L2 SPECIES + M SPECIES)
S.3.0	SH*	rest = high marsh, unspecific
X2/3	XE	Embryonic dunes & driftline vegetation (X SPECIES > 2 and X SPECIES ≥ 5%, or X SPECIES ≥ 1 and X SPECIES 1-5% and other species not present)
X.2.1	XEd	(Honck pep + Salso kal + Cakil mar) ≥ 5%, or 1-5% and only one species present, or Cakil mar ≥ 20%
X.3.1	XEf	(Elytr b-a + Cakil mar ≥ 5% or Elytr b-a + Cakil mar) < 5% and other species are not present, or (Agros sto + Glaux mar) > 5%
X.2.0/3.0	XE*	rest = embryonic dunes & beach driftline, unspecific
S.5	SB	Brackish marsh (B SPECIES ≥ 2 and B SPECIES > 5%)
S.5.4	SBm	(Juncu mar + Oenan lac ≥ 10% and Juncu mar present
S.5.3	SBg	Festu aru > 10% or Poten ans > 25% or Elytr rep > 25% and GROUP 3 present
S.5.0	SB*	rest = brackish marsh, unspecific
S.6	SF	Fresh (anthropogenic grassland of the other zones)
S.6.1	SFl	(Loliu per + Cynos cri + Belli per + Poa annua + Poa triv + Plant maj + Polyg avi) > 25%
S.6.0	SF*	rest = fresh (anthropogenic vegetation, unspecific
H1/2	HS	Seepage vegetation (S SPECIES > 2 and S SPECIES > 5%)
H.2.2	HSc	(Schoe nig + Lipar loe +Epipa pal + Parna pal + Pelli end + Genti ama ≥ 1 species
H.1.0/1.1	HS*	rest = seepage vegetation, unspecific, Centario saginetum inclusive
S	S	Haloserie
S	S	No information about vegetation composition; neither zone nor type

Explanation of species groups and footnotes

Species group	Plant species
[1] grasses	Pucci mar, Festu rub, Agros sto, Elytr ath, Juncu ger
[2] GROUP 1	Elytr ath, Suaed mar, Atrip lit, Atrip pro, high salt marsh / fresh species
[3] GROUP 2	Eleoc uni, Trifo fra, Juncu ger, Carex dis, Centm pul, Odont v-s, Poten ans
[4] GROUP 3	Aster tri, Trigl mar, Bolbo mar, Schoe tab, Schoe tri, Phrag aus
[5] GROUP 4	Limon vul, Aster tri, Atrip por
A SPECIES	Zoste mar, Zoste nol, Ruppi mar, Ruppi cir, Zanic pal s.l., Potam pec
P SPECIES	Spart ang, Spart mar, Salic spp, Suaed mar, Bassi hir
L1 SPECIES	Pucci mar, Atrip por, Cochl ang, Atrip ped
L2 SPECIES	Aster tri, Spergl mar, Trigl mar, Limon vul, Plant mar, Parap str
M SPECIES	Artem mar, Armer mar, Juncu ger, Glaux mar, Carex dis, Festu rub, Agros sto
H SPECIES	Carex ext, Ononi spi, Centm lit, Elytr rep, Leont aut, Trifo fra, Trifo rep, Rumex cri, Lotus ten, Loliu per, Tarax off, Poa pra, Poa tri, Ranun rep, Horde sec
X SPECIES	Elytr b-a, Honck pep, Salso k-k, Cakil mar, Glauc fla, Atrip lac, Atrip gla, Cramb mar, Beta vul
B SPECIES	Phrag aus, Bolbo mar, Schoe tab, Schoe tri, Eleoc uni, Trigl pal, Blysm ruf, Centm pul, Potenans, Cotul cor, Ranun sce, Oenan lac, Festu aru, Juncu art, Juncu buf, Juncu amb, Cheno rub, Cheno gla
F SPECIES	Loliu per, Poa ann, Cynos cri, Belli per, Tarax off, Plant maj, Poa tri, Elytr rep, Capse bur, Polyn avi, Cirsi arv, Rumex obt
S SPECIES	Carex fla, Carex o-o, Centa lit, Dacty inc, Eleoc qui, Epipa pal, Equis var, Eupat can, Euphr stri, Genti ama, Gymna con, Juncu a-a, Juncu a-b, Linum cat, Lipar loe, Parna pal, Pedic pal, Pyrol rot, Sagin nod, Schoe nig, Tarax pal *Bryophytes*: Aneur pin, Bryum pse, Campu pol, Campu ste, Fissi adi, Moerc hib, Pelli end, Preis qua
[a]	in SH > 10 % cover
[b]	in SH Salicornia ramosissimae *with* Pucci mar = low salt marsh
[c]	in SH > 35 % cover
[d]	in SH > 5 % cover
[e]	in SH > 30 % cover

Saline-brackish aquatic plant species (A)
Zostera marina, *Zostera noltii*, *Ruppia maritima*, *Ruppia cirrhosa*, *Zanichellia palustris s.l.*, *Potamogeton pectinatus.*

Pioneer plant species (P)
Spartina anglica & S. maritima, *Salicornia europaea*, *S. procumbens & S. stricta*, *Suaeda maritima*, *Bassia hirsuta.*

Plant species of the low salt marsh (L)
Puccinellia maritima, *Atriplex portulacoides*, *Cochlearia anglica*, *Aster tripolium*, *Spergularia maritima & salina*, *Triglochin maritima*, *Limonium vulgare*, *Plantago maritima*, *Parapholis strigosa*, *Atriplex pedunculata.*

Plant species of the high salt marsh (H)
Artemisia maritima, *Armeria maritima*, *Juncus gerardi*, *Glaux maritima*, *Agrostis stolonifera*, *Festuca rubra*, *Elytrigia atherica*, *Juncus maritimus*, *Potentilla anserina*, *Trifolium fragiferum*, *T. pratense & T. repens*, *Poa pratensis*, *Lolium perenne*, *Plantago coronopus*, *Sagina maritima & S. nodosa*, *Carex extensa & C. distans*, *Ononis spinosa*, *Hordeum secalinum*, *Leontodon autumnalis & L. saxatilis*, *Lotus corniculatus & L. glaber*, *Centaurium pulchellum & C. littorale*, *Cochlearia danica*, *Odontites vernus* ssp *serotinus*, *Cerastium fontanum* ssp *vulgare*, *Bupleurum tenuissimum*, *Hordeum marinum*, *Elytrigia repens.*

Plant species of the brackish marsh (B)
Phragmites australis, *Bolboschoenus maritimus*, *Schoenoplectus tabernaemontani*, *Blysmus rufus*, *Agrostis stolonifera*, *Eleocharis uniglumis*, *Triglochin palustris*, *Cotula coronopifolia*, *Potentilla anserina*, *Juncus maritimus*, *Oenanthe lachenalii*, *Trifolium repens & T. fragiferum*, *Festuca arundinacea*, *Elytrigia repens*, *Leontodon autumnalis*, *Alopecurus geniculatus*, *Ranunculus sceleratus*, *Centaurium pulchellum*, *Juncus ambiguus*, *J. articulatus & J. bufonius*, *Chenopodium rubrum & C. glaucum*, *Apium graveolens.*

Plant species of embryonic dunes & driftlines (X)
Elytrigia juncea ssp *boreoatlantica (= Elymus farctus)*, *Glaux maritima*, *Agrostis stolonifera*, *Honckenya peploides*, *Salsola kali* ssp *kali*, *Cakile maritima*, *Glaucium flavum*, *Atriplex laciniata*, *Atriplex glabriuscula*, *Crambe maritima*, *Beta vulgaris.*

Plant species of fresh anthropogenic grasslands (F)
Lolium perenne, *Poa annua*, *Cynosurus cristatus*, *Bellis perennis*, *Taraxacum sect. Vulgaria*, *Plantago major*, *Poa trivialis*, *Elytrigia repens*, *Capsella bursa-pastoris*, *Polygonum aviculare*, *Cirsium arvense*, *Rumex obtusifolius.*

Plant species of seepage vegetation (S)
Carex flacca, *Carex oederi* ssp *oederi*, *Centaurium littorale*, *Dactylhoriza incarnata*, *Eleocharis quinqueflora*, *Epipactis palustris*, *Equisetum variegatum*, *Eupatorium cannabinum*, *Euphrasia stricta*, *Gentianella amarella*, *Gymnadenia conopsea*, *Juncus alpinoarticulatus* ssp *atricapillus*, *Juncus arcticus ssp. balticus*, *Linum catharticum*, *Liparis loeseli*, *Parnassia palustris*, *Pedicularis palustris*, *Pyrola rotundifolia*, *Sagina nodosa*, *Schoenus nigricans*, *Taraxacum palustre*
Bryophytes*: Aneura pinguis*, *Bryum pseudotriquetrum*, *Campylium polygamum & C. stellatum*, *Fissidens adianthoides*, *Moerckia hibernica*, *Pellia endiviifolia*, *Preissia quadrata.*

Vegetation complexes and assignment of polygons

Vegetation mappings are mostly carried out with a scale 1:5,000 or 1:10,000. Input is given by remote sensing (digital images or stereo false-colour photographs) and fieldwork.

The TMAP vegetation types can be presented either alphanumerical or letter codes. The codes start with an "S" (salt marsh), "X" (dry dunes) or "H" (moist dunes), followed by a number or character for vegetation zone (e.g. "P" for pioneer zone) and a character for the dominant or characteristic species (e.g. "s" for Spartina).

For the presentation of vegetation complexes (polygons that include more than one vegetation type), only the dominant type is presented on a map. A vegetation complex that consists of two vegetation types with a 50% share each, is assigned to the vegetation type that would appear earliest in succession. When a complex includes three or more vegetation, the polygon is assigned to the vegetation type where the centre of gravity is located. The first step is to determine the vegetation zone where the centre of gravity is located; the second and final step is to determine the vegetation type (Table I.3).

Matrix legend of all polygons											
TMAP a.-code	S.0.3	S.1.1	S.1.2	S.2.1	S.2.2	S.2.3	S.2.4	S.3.8	S.3.11		
TMAP l.-code	Sm	SPs	SPq	SLp	SLl	SLa	SLh	SHe	SHc		
Polygons										**Code (& colour) on the map**	**Explanation**
Bare soil (S)											
Sm1	100									Sm	Type Sm is dominant
Sm2	90	10								Sm	Sm is dominant
Pioneer zone (SP)											
SP1		100								SPs	Sps is dominant
SP2	10	90								SPs	Sps is dominant
SP3		80	10						10	SPs	Sps is dominant
SP4		50						50		SPs	Both types are 50%, SPs is the type of the earliest succession stage.
SP5		30	**30**				40			SPq	60% is pioneer zone, both types are 30%, SPq is the centre of gravity
Low marsh											
SP10		20		40			40			SLp	80% is low marsh, both types are 40%, SLp is the centre of gravity

Table I.3: Examples of the assignment of TMAP codes to polygons.

Appendix II: Incidence of TMAP types

Table II.1: Incidence (%) of vegetation types across the Netherlands and German sections of the Wadden Sea specified per island and region or site on the mainland coast.

Zone	Pioneer marsh			Low marsh					High marsh														Brackish marsh					Fr. grassl		Embr. dunes / driftline			Seepage vegetation		Total Area (ha)
Vegetation type: alphan. code	S.1.0	S.1.1	S.1.2	S.2.0	S.2.1	S.2.2	S.2.3	S.2.4	S.3.0	S.3.1	S.3.2	S.3.3	S.3.4	S.3.5	S.3.6	S.3.7	S.3.8	S.3.9	S.3.10	S.3.11	S.3.12	S.3.13	S.5.0	S.5.1	S.5.2	S.5.3	S.5.4	S.6.0	S.6.1	X.2.0	X.3.1	X.2.1	H.1.0	H.2.2	
letter code	SP*	SPs	SPq	SL*	SLp	SLl	SLa	SLh	SH*	SHl	SHj	SHf	SHh	SHz	SHm	SHy	SHe	SHx	SHg	SHc	SHo	SHr	SB*	SBb	SBp	SBg	SBm	SF*	SFl	XE*	XEf	XEd	HS*	HSc	
THE NETHERLANDS		**3.0**	**9.9**		**11.1**	**3.4**	**3.3**	**5.0**		**0.9**	**3.4**	**5.6**	**0.1**	**1.8**	**0.2**	**14.2**	**0.6**	**3.3**	**2.0**	**0.5**	**0.0**	**2.0**		**0.2**	**1.8**	**6.3**	**0.4**		**8.8**	**9.3**	**2.8**			**0.0**	**10,352**
Texel		2.2	9.5		4.4	6.9	0.3	11.7		7.2	2.5	10.1	0.5	12.1	1.7	13.1	0.0	0.6	0.7	0.3	0.0	0.0		0.0	0.7	0.7	5.7		0.0	0.1	9.1				381
Vlieland		0.7	13.8		21.5	2.1	6.2	4.3		0.8	5.1	7.9	0.0	0.0	0.0	1.7	1.6	1.1	2.4	0.1	0.0	0.0		0.3	3.7	7.7	0.0		1.6	6.1	11.2				188
Terschelling		0.4	2.9		0.7	9.1	0.3	10.4		1.1	4.1	2.9	0.2	0.6	0.6	16.7	0.8	3.1	4.0	0.2	0.0	0.2		0.2	1.3	3.6	0.2		0.9	33.9	1.5			0.0	2,299
Griend		0.1	10.4		7.5	15.8	0.3	4.3		0.0	0.2	0.1	0.0	0.4	0.0	22.0	0.0	32.6	0.2	0.0	0.0	1.2		0.1	0.8	2.4	0.0		0.0	0.0	1.4				37
Ameland		0.1	4.2		9.1	0.4	0.0	2.3		1.0	19.6	16.1	0.0	4.1	0.1	11.6	0.0	1.8	8.8	0.2	0.1	0.1		0.6	0.5	16.5	0.3		0.9	0.0	1.7				471
Schiermonnikoog		0.2	5.7		3.2	4.1	2.4	7.1		1.7	9.0	9.1	0.0	3.7	0.2	17.3	2.1	0.7	3.2	2.7	0.1	0.0		0.1	1.1	6.0	0.7		0.0	11.7	8.2				1,450
Rottum		1.4	14.0		1.8	5.1	0.5	10.6		3.3	1.0	6.3	0.0	4.3	0.6	17.6	2.5	0.9	2.7	1.9	0.0	0.0		0.3	0.2	2.5	0.0		0.0	0.0	22.5				301
North-Holland mainland coast		7.1	27.1		4.6	0.0	7.9	0.1		0.0	0.1	0.1	0.0	2.0	0.0	31.0	0.0	4.4	0.0	0.0	0.0	0.0		0.0	15.1	0.1	0.0		0.0	0.5	0.0				86
Friesland mainland coast		1.2	22.5		23.5	0.0	5.8	0.0		0.0	0.0	7.3	0.0	0.3	0.0	13.0	0.0	7.8	0.0	0.0	0.0	1.0		0.1	0.1	11.4	0.0		5.9	0.0	0.0				2,089
Groningen mainland		18.3	15.7		9.6	0.0	11.1	5.7		0.0	0.0	5.0	0.0	2.2	0.0	26.7	0.0	3.2	0.0	0.0	0.0	0.4		0.0	0.0	0.3	0.0		1.9	0.0	0.0				1,350
Dollard		1.1	5.2		48.6	4.3	1.7	0.0		0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.6	0.0	0.0	3.9		1.4	16.5	12.5	0.0		0.7	0.0	0.0				702
Punt van Reide		0.3	0.0		16.8	0.0	0.0	0.0		0.0	19.7	3.8	0.0	0.1	0.0	5.7	0.0	0.0	25.1	0.0	0.0	0.0		0.0	0.0	28.3	0.0		0.3	0.0	0.0				49
Lower Saxony	**0.2**	**4.3**	**10.1**		**22.3**			**3.1**	**24.0**							**28.5**							**0.5**	**0.5**	**3.5**						**3.0**				**9,648**
Borkum	0.2	4.7	6.9		17.1			14.1	37.2							8.3							0.0	1.1	5.1						5.4				480
Memmert	0.0	0.3	37.1		20.5			5.2	17.5							15.3							0.0	2.6	0.7						0.8				366
Juist	0.0	4.0	6.4		15.4			3.7	45.1							18.4							0.0	0.2	0.9						5.8				386
Norderney	3.5	3.0	4.5		4.8			4.5	50.5							13.0							0.0	0.5	0.1						15.7				609
Baltrum	0.0	3.1	6.4		10.4			3.2	36.1							28.6							0.1	1.7	2.6						8.0				220
Langeoog	0.0	4.7	7.7		1.1			9.5	45.4							15.2							3.8	0.0	0.0						12.5				464
Spiekeroog	0.0	1.5	21.3		18.5			5.9	36.3							10.7							0.0	0.4	0.5						4.9				919
Wangerooge	0.0	6.8	15.1		26.0			5.5	24.1							20.0							0.4	0.2	1.0						0.9				163
Lüttje Horn	0.0	0.0	14.4		10.2			0.0	8.9							0.0							0.0	0.0	0.0						66.6				5
Minsener Oog	0.0	2.6	71.1		3.4			0.0	14.3							0.0							0.0	0.0	0.3						8.3				13
Mellum	0.0	0.8	14.7		11.9			11.6	22.2							34.2							0.0	0.0	0.3						4.4				334
Dollart	0.0	0.4	0.9		18.2			0.0	34.2							22.8							0.0	0.9	22.6										225
Krummhörn	0.0	0.9	4.8		13.0			0.0	26.0							47.4							0.0	1.4	6.4										280
Leybucht	0.1	4.1	8.7		45.9			0.0	10.3							30.5							0.0	0.2	0.3										1,025
Ostfriesland	0.0	6.0	8.4		20.7			0.3	16.1							45.3							1.2	0.4	1.6										1,148
Jade	0.0	2.1	9.5		35.3			0.9	8.6							42.7							0.0	0.0	0.9										1,794
Budjadingen	0.0	2.8	4.4		10.1			0.1	8.2							43.9							1.1	0.0	29.3										560

Zone	Pioneer marsh			Low marsh					High marsh														Brackish marsh					Fr. grassl		Embr. dunes / driftline			Seepage vegetation		Total Area (ha)
Vegetation type: alphan. code	S.1.0	S.1.1	S.1.2	S.2.0	S.2.1	S.2.2	S.2.3	S.2.4	S.3.0	S.3.1	S.3.2	S.3.3	S.3.4	S.3.5	S.3.6	S.3.7	S.3.8	S.3.9	S.3.10	S.3.11	S.3.12	S.3.13	S.5.0	S.5.1	S.5.2	S.5.3	S.5.4	S.6.0	S.6.1	X.2.0	X.3.1	X.2.1	H.1.0	H.2.2	
letter code	SP*	SPs	SPq	SL*	SLp	SLl	SLa	SLh	SH*	SHl	SHj	SHf	SHh	SHz	SHm	SHy	SHe	SHx	SHg	SHc	SHo	SHr	SB*	SBb	SBp	SBg	SBm	SF*	SFl	XE*	XEf	XEd	HS*	HSc	
Wurster Küste	0.0	20.7	3.5		23.1			0.0	32.1							14.9							1.7	0.9	3.0										657
Hamburg		**3.1**	**28.1**		**6.3**		**0.7**	**0.1**		**0.2**	**0.7**	**7.7**	**0.0**	**0.4**		**3.8**	**0.0**	**2.1**	**0.7**		**0.6**	**4.5**		**0.2**	**0.5**	**38.9**					**1.4**				**261**
Neuwerk		5.1	0.7		4.6		0.2	0.1		0.1	1.1	12.4	0.0	0.6		1.8		3.3			1.0	7.3		0.3		61.4									161
Scharhörn			88.4		1.3		2.0			0.8						2.5		0.5													4.5				37
Nigehörn			63.2		13.5		1.5									9.7	0.2		2.7						2.2	4.0					3.0				63
Schleswig-Holstein	**0.4**	**13.8**	**13.4**	**1.3**	**13.1**		**1.4**	**9.0**	**0.2**		**13.2**	**8.5**	**0.0**	**1.8**	**0.0**	**14.8**	**0.1**	**2.0**	**0.2**	**0.0**	**0.1**	**0.0**		**0.2**	**2.0**	**0.1**		**0.5**	**3.0**		**0.8**				**12,218**
Trischen	0.0	30.0	5.8	5.1	2.0		0.0	26.4	0.0		0.2	0.0	0.0	0.6	0.1	16.8	1.8	4.2	0.1	0.0	0.0	0.0		0.0	0.3	0.0		0.0	0.0		6.4				126
Pellworm	0.0	17.3	30.6	0.0	30.4		0.0	0.4	0.0		12.4	4.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	4.4		0.0				155
Föhr-Godelniederung	0.0	2.0	9.4	1.4	14.7		0.0	15.4	0.8		11.9	10.2	0.0	2.4	0.0	17.0	0.0	0.2	0.9	0.0	0.0	0.0		0.0	3.9	0.0		0.1	9.2		0.2				326
Amrum	5.6	6.9	9.2	0.0	4.7		0.0	6.9	0.3		11.6	4.6	0.0	0.6	0.2	3.3	0.6	1.0	1.9	0.0	0.0	0.0		0.7	7.9	0.2		0.0	7.0		29.3				166
Sylt	0.0	13.1	10.3	0.1	14.1		0.6	7.6	0.0		15.9	2.5	0.0	1.1	0.0	12.3	0.0	3.4	0.9	0.0	0.1	0.0		0.1	15.5	0.0		0.4	1.8		0.3				640
Dithmarschen	0.7	15.8	10.5	1.1	12.1		2.8	3.2	0.2		4.2	22.0	0.0	1.1	0.0	18.0	0.0	1.0	0.1	0.0	0.0	0.0		0.7	2.0	0.4		0.3	3.7		0.0				3,039
Eiderstedt	0.3	19.8	17.8	1.3	15.3		0.8	14.2	0.4		7.7	2.0	0.0	0.7	0.0	13.4	0.3	0.4	0.2	0.0	0.5	0.1		0.2	1.8	0.0		0.6	0.9		1.1				3,253
Nordfriesland	0.4	11.7	21.1	1.8	19.7		2.2	13.0	0.3		2.9	4.0	0.0	1.7	0.0	19.2	0.0	1.6	0.0	0.0	0.0	0.0		0.0	0.1	0.0		0.0	0.2		0.0				2,355
Nordmarsch-Langeness	0.0	4.2	1.1	1.2	2.6		0.0	4.2	0.0		59.1	5.9	0.0	1.0	0.0	9.7	0.0	5.2	0.0	0.0	0.0	0.1		0.1	0.1	0.0		1.4	4.1		0.0				949
Südfall	0.0	5.4	21.1	10.2	6.4		0.0	5.1	0.0		2.9	11.0	0.0	11.4	0.0	23.1	0.0	2.6	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.7	0.0		0.0				37
Süderoog	0.0	1.4	16.2	0.6	13.1		0.0	10.7	0.0		10.1	8.1	0.0	19.9	0.0	10.0	0.0	9.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.5	0.4		0.0				57
Nordstrandischmoor	0.0	13.7	4.9	0.4	10.9		0.4	0.2	0.0		13.4	32.1	0.0	7.8	0.0	11.0	0.0	3.4	0.0	0.0	0.0	0.0		0.0	0.0	0.0		1.9	0.0		0.0				188
Norderoog	0.2	11.4	3.5	0.0	0.2		0.0	35.1	0.0		0.0	0.0	0.0	0.7	0.0	41.6	0.0	1.6	0.0	0.0	0.0	0.0		0.0	5.8	0.0		0.0	0.0		0.0				9
Hooge	0.0	0.5	0.1	0.0	0.9		0.0	0.4	0.0		61.3	0.6	0.0	2.6	0.0	2.7	0.0	4.5	0.1	0.0	0.0	0.0		0.1	0.7	0.0		1.3	24.2		0.0				493
Habel	0.0	3.3	5.0	0.9	5.8		0.0	8.4	0.0		0.0	6.0	0.0	11.0	0.0	53.3	0.0	2.3	0.0	0.0	0.0	0.0		0.0	0.0	0.0		4.0	0.0		0.0				6
Gröde-Appelland	0.1	3.2	3.5	1.3	6.1		0.0	7.3	0.0		17.5	7.2	0.0	27.9	0.0	13.8	0.0	10.5	0.0	0.0	0.0	0.0		0.0	0.0	0.0		1.0	0.6		0.0				188
Oland	1.2	16.1	11.5	0.7	1.2		0.4	10.9	0.0		24.7	1.2	0.0	0.0	0.0	19.9	0.0	9.9	0.0	0.0	0.0	0.0		0.0	0.0	0.0		1.0	1.3		0.0				230
NL-GER WADDEN SEA	**0.2**	**7.7**	**11.7**	**1.0**	**15.6**	**1.1**	**1.6**	**6.0**	**7.4**	**0.3**	**6.0**	**5.2**	**0.0**	**1.3**	**0.1**	**19.0**	**0.2**	**1.8**	**0.7**	**0.2**	**0.1**	**0.3**	**0.2**	**0.3**	**2.5**	**2.3**	**0.1**	**0.2**	**1.7**	**2.9**	**2.1**			**0.0**	**31,520**

Appendix III: Vegatation changes

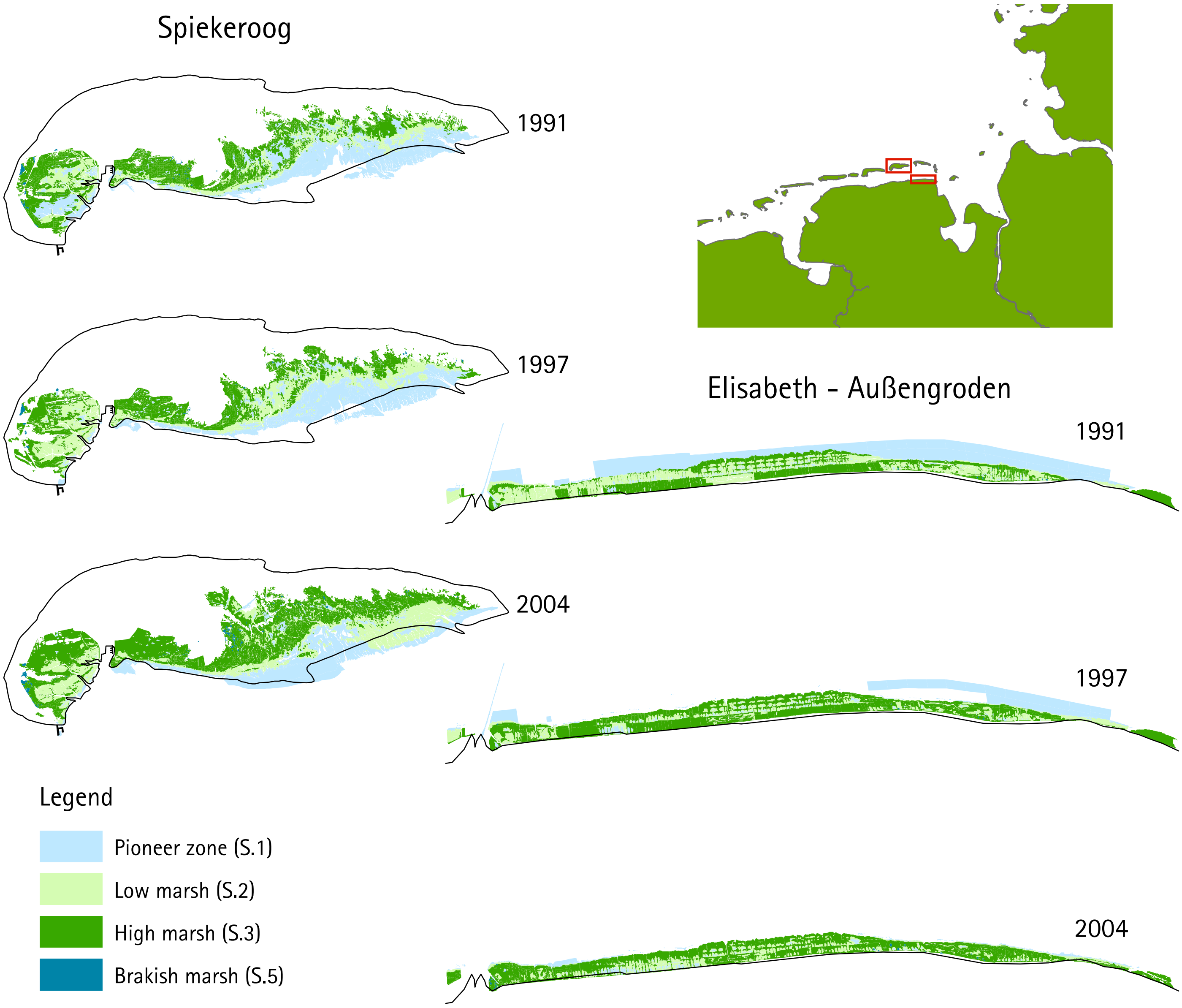

Figure III.1: Changes of salt marsh vegetation zones on the island of Spiekeroog and at the Elisbeth-Außengroen, National Park Lower Saxon Wadden Sea (1991 - 2004).

Appendix IV: GIS Data Sets

Table IV.1: Inventory of salt marsh GIS data sets.

Title	Alternate Title	Abstract	Language	Topic Category	Keywords	Date	Contact	Spatial Extent	Period	Online Source	Source
Salt marsh areas in the trilateral Wadden Sea	Saltmarsh GIS data for QSR 2004	Salt marsh GIS data set with harmonized data on zonation, vegetation typology, drainage and land use based on national GIS from the years 1997-2002 data. The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	English	Salt marsh TMAP typology, zonation, grazing, drainage	salt marsh, TMAP typology, Wadden Sea	2004	G. Lüerßen, Common Wadden Sea Secretariat (CWSS), Wilhelmshaven, Germany	04,700° W 08,717° E 52,883° S 55,617° N	1997-2002	www.waddensea-secretariat.org (provider)	CWSS
Habitats of the Netherlands, German and Danish Wadden Sea	Habitats in the Wadden Sea 1976 (K. S. Dijkema)	Historical trilateral maps: The maps of Dijkema (around 1976) have been digitized, georeferenced, translated into the TMAP typology. This work was carried out by J. Petersen and K. S. Dijkema as a joint project of IMARES Texel (former Alterra) and the CWSS. It covered 3 types of maps: habitat maps of the tidal flats and transition zone (24 maps, scale 1:100,00), vegetation maps of dunes, salt marshes and grassland (42 maps, scale 1:100,000), and some maps of selected areas with a higher resolution (different scales).	English	Abiotic (sand, muddy sand) and biotic features (mussel beds, zostera, salt marsh)	salt marsh, habitats, trilateral	2006	K. S. Dijkema, Institute for Marine Resources & Ecosystem Studies, Wageningen IMARES, Ecologie, Texel, NL; CWSS Wilhelmshaven	04,700° W 08,717° E 52,883° S 55,617° N	1970-1976?	www.waddensea-secretariat.org (provider)	CWSS
Salt marsh areas in the National Park Wadden Sea of Hamburg	Saltmarsh GIS data 2004	Salt marsh GIS data set with harmonized data on zonation, vegetation typology, drainage and land use based on national GIS from the year 2004 data. The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	German	Salt marsh TMAP typology, zonation, grazing, drainage	salt marsh, TMAP typology, Wadden Sea, Hamburg	2004	P. Körber, National Park Administration Wadden Sea of Hamburg, Hamburg, Germany	8°12,77' W 8°33,6399' E 53°51,6987' S 53°59,02' N Koordinaten nach World Geodetic System (WGS 84)	2004		P. Körber
Salt marsh areas in the trilateral Wadden Sea	Saltmarsh GIS data for QSR 2004	Salt marsh GIS data set with harmonized data on zonation, vegetation typology, drainage and land use based on national GIS from the years 1997-2002 data. The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	English	Salt marsh TMAP typology, zonation, grazing, drainage	salt marsh, TMAP typology, Wadden Sea	2004	G. Lüerßen, Common Wadden Sea Secretariat (CWSS), Wilhelmshaven, Germany	04,700° W 08,717° E 52,883° S 55,617° N	1997-2002	www.waddensea-secretariat.org (provider)	M. Stock
Habitats of the Netherlands, German and Danish Wadden Sea	Habitats in the Wadden Sea 1976 (K. S. Dijkema)	Historical trilateral maps: The maps of Dijkema (around 1976) have been digitized, georeferenced, translated into the TMAP typology. This work was carried out by J. Petersen and K. S. Dijkema as a joint project of IMARES Texel (former Alterra) and the CWSS. It covered 3 types of maps: habitat maps of the tidal flats and transition zone (24 maps, scale 1:100,00), vegetation maps of dunes, salt marshes and grassland (42 maps, scale 1:100,000), and some maps of selected areas with a higher resolution (different scales).	English	Abiotic (sand, muddy sand) and biotic features (mussel beds, zostera, salt marsh)	salt marsh, habitats, trilateral	2006	K. S. Dijkema, Institute for Marine Resources & Ecosystem Studies, Wageningen IMARES, Ecologie, Texel, NL; CWSS Wilhelmshaven	04,700° W 08,717° E 52,883° S 55,617° N	1970-1976?	www.waddensea-secretariat.org (provider)	M. Stock

Title	Alternate Title	Abstract	Language	Topic Category	Keywords	Date	Contact	Spatial Extent	Period	Online Source	Source
Salt marsh vegetation along the Wadden Sea coast of Schleswig-Holstein	Salt marsh vegetation - Wadden Sea area of Schleswig-Holstein	Salt marsh GIS data set with harmonized data on zonation and vegetation typology according to TMAP based on national GIS. Surveys in 1988, 1996, 2001, 2006. Data from 2001 and 2006 cover the entire salt marsh area along the westcoast of Schleswig-Holstein.	German	Salt marsh TMAP typology, zonation, grazing,	salt marsh, TMAP typology, Wadden Sea, Schleswig-Holstein	2007	M. Stock, LKN-SH, Nationalpark Office, Tönning, Germany		1989-2006	---	M. Stock
Salt marsh vegetation along the Wadden Sea coast of Schleswig-Holstein	Salt marsh vegetation - Wadden Sea area of Schleswig-Holstein	Salt marsh GIS data set with harmonized data on zonation and vegetation typology according to TMAP based on national GIS. Surveys from 1980 - 1984 cover the mainlan salt-marsh area along the westcoast of Schleswig-Holstein.	German	Salt marsh TMAP typology, zonation,	salt marsh, TMAP typology, Wadden Sea, Schleswig-Holstein	2007	M. Stock, LKN-SH, Nationalpark Office, Tönning, Germany		1980-1984	---	M. Stock
Salt marsh use in the National Park Wadden Sea of Lower Saxony	Use data 2008	Salt marsh use-data with data on drainage and land use based on national GIS from the year 2008 data. The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	German	Salt marsh mowing, grazing, drainage	salt marsh, TMAP typology, Wadden Sea, Lower Saxony	2008	J. Bunje, National Park Administration Wadden Sea of Lower Saxony, Germany	3342717 5898782 3478000 5973385	2008		J. Bunje
Salt marsh vegetation in the National Park Wadden Sea of Lower Saxony 1991	Saltmarsh GIS data 1991	Salt marsh vegetation GIS data set from 1991 with data on zonation and vegetation according to the TMAP typologie The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	German	Salt marsh TMAP typology, zonation,	Salt marsh, TMAP typology, Wadden Sea, Lower Saxony	1995	N. Hecker, National Park Administration Wadden Sea of Lower Saxony, Germany	3342717 5898782 3478000 5973385	1991		N. Hecker
Salt marsh vegetation in the National Park Wadden Sea of Lower Saxony 1997	Saltmarsh GIS data 1997	Salt marsh vegetation GIS data set from 1997 with data on zonation and vegetation according to the TMAP typologie The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	German	Salt marsh TMAP typology, zonation,	Salt marsh, TMAP typology, Wadden Sea, Lower Saxony	1999	N. Hecker, National Park Administration Wadden Sea of Lower Saxony, Germany	3342717 5898782 3478000 5973385	1997		N. Hecker
Salt marsh vegetation in the National Park Wadden Sea of Lower Saxony 2004	Saltmarsh GIS data 2004	Salt marsh vegetation GIS data set from 2003 / 2004 with data on zonation and vegetation according to the TMAP typologie The data has been compiled on basis of the harmonisation efforts and results of the trilateral salt marsh working group (2000-2004).	German	Salt marsh TMAP typology, zonation,	Salt marsh, TMAP typology, Wadden Sea, Lower Saxony	2006	N. Hecker, National Park Administration Wadden Sea of Lower Saxony, Germany	3342717 5898782 3478000 5973385	2003-2004	www.nationalpark-wattenmeer.niedersachsen.de	N. Hecker

Appendix V: Vertical accretion projets

Table V.1: Inventory of salt marsh projects and data sets with vertical accretion measurements.

Title of project	Content of project	Context of project	Method	Method description	Country	Location	Salt marsh type	Geom.
					D (LS)	mainland Niedersachen	foreland	clay
Ecological development in the Leybucht	Development of salt marsh area and vegetation	costal protection measure Leybucht	Sedimentation (levelling)	Measuring changes in surface level and vegetation development in 100 permanent plots in different vegetation zones	D (LS)	mainland Niedersachen	foreland	clay
Regeneration of former clay pits	Development of salt marsh area and vegetation	clay pit project	Sedimentation (levelling)	Measuring changes in surface level and vegetation development in 110 permanent plots in different vegetation zones	D (LS)	mainland Niedersachen	foreland	clay
ecological development of sedimentation fields	Development of salt marsh area and vegetation	Development of sedimentation fields at the Wurster Küste	Sedimentation (levelling)	Measuring changes in surface level and vegetation development in 55 permanent plots in different vegetation zones	D (LS)	mainland Niedersachen	foreland	clay
Simulierte Transgression als Folge der Rückdeichung des Langeooger Sommerpolders: Sukzession und Dynamik im litoralen Faziesraum (DFG BR 775/19)	Vegetation, sedimentation and geochemical monitoring after de-embankment of the Langeooger Sommerpolder	Salt-marsh restoration	SEB (sed./eros. Bar); sedimentation traps (self constructed)	Measuring changes in surface level, seasonal sediment fluxes (organic/inorganic) and vegetation development in 20 pq's in different salt marsh zones;	D (LS)	Langeooger Sommerpolder, Langeoog Island	restored marsh; (former summer polder)	silt and clay
			SET (sed./eros. Table)	Schoot, P.M. & J.E.A. de Jong (1982): Sedimentetie en reosie metingen met behulp van de Sedi-Erosi-tafel. - Rijkawaterstaat. Notitie DDMI-82.401, 12 p. ; Boumans, R.M.J. & J.W. Day (1991): Measurements of small elevation changes in shallow coastal areas using a sedimentation-erosion-table. - Dept. of Oceanography and Coastal Science, Coastal Ecology Institute, Louisiana State University, 17 p.	D (SH)	Friedrichskoog	foreland	clay
Sedimentation measurement in Wadden Sea salt marshes	Continuous measurements of sedimentation in the framework of the "Vorlandmanagementprogramm"; Supplementary parameter in the framework of the TMAP.	Vorlandmonitoringprogramm; TMAP	SEB (sed./eros. Bar)	van Duin, W. E., K.S. Dijkema & J. Zegers (1997): Verandering in bodemhoogte (opslipping. erosie en inklink) in de Peazemerlaan. - IBN-Rapport 326, 104 p.	D (SH)	mainland coast	foreland	clay
Sedimentation measurement in Wadden Sea salt marshes	Continuous measurements of sedimentation in the framework of the "Vorlandmanagementprogramm"; Supplementary parameter in the framework of the TMAP.	Vorlandmonitoringprogramm; TMAP	SEB (sed./eros. Bar)	van Duin, W. E., K.S. Dijkema & J. Zegers (1997): Verandering in bodemhoogte (opslipping. erosie en inklink) in de Peazemerlaan. - IBN-Rapport 326, 104 p.	D (SH)	Hamburger Hallig	foreland	clay
Halligprogramm	Control of management success within the Halligprogramm	Concomitant investigation in the framework of the Halligprogramm	FAR (Frequenzanalyserahmen; similar to SEB)	not known	D (SH)	Hallig Nordstran-dischmoor, Hooge, Gröde	hallig salt marsh	clay/silt

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Geomorphology

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1. Introduction

North Frisian islands, Halligen and sand banks (Satellite image, Brock-mann Consult

In 1994, the countries bordering the Wadden Sea agreed upon striving towards protecting and restoring nature in the Wadden Sea area as far as possible. This implies that large-scale interventions in the Wadden Sea system should be avoided. For a good appreciation of the quality of the present day Wadden Sea system, a clear understanding of its development through time is essential. This chapter provides an overview of the geomorphological development of the Wadden Sea over the past 1,200 years, illustrated by four paleogeographical reconstructions. During this period, human influence on the development of the Wadden Sea increased steadily, for instance through the construction of dikes and the extraction of peat. The paleogeographical reconstructions place the current human impact in a historical context and provide a reference for the trilateral Wadden Sea countries to strive towards their goal of a near-to-natural situation. Recent interventions such as gas extraction causing land subsidence, enclosure and reclamation of intertidal basins, the construction of artificial sand dikes and coastal defense structures will be discussed in this context.

2. Current geomorphological situation

The Wadden Sea consists of tidal flats and tidal channels, and is separated from the North Sea by a chain of barrier islands and ebb-tidal deltas over 75% of its length. It extends from Den Helder in The Netherlands in the west, along the coast of Niedersachsen and Schleswig Holstein in Germany, to the peninsula of Skallingen in Denmark in the north. Its existence and long life span hinge on a delicate balance of the relative sea-level rise and the availability of sediment. A sediment surplus caused by an increase in sediment input or slower relative sea-level rise would silt up the Wadden Sea. On the other hand, a sediment deficit caused by a decrease in sediment input or faster relative sea-level rise would result in a gradual loss of intertidal area of the Wadden Sea.

2.1 Natural preconditions

The general outline of the present day Wadden Sea can be largely attributed to a combination of the pre-existing relief in the area, variations in the tidal volume and storm surge frequency and wave climate.

The pre-existing relief of the Pleistocene surface influences the general position of the present-day Wadden Sea because of its position with respect to the present-day sea level: firstly, the steepness of the slope of the Pleistocene surface underlying the Wadden Sea is of influence on the morphological development of the Wadden Sea and the availability of sediment: a gentle slope is inundated faster during periods of sea-level rise than a steeper slope, and generally results in a higher availability of sediment. Secondly, the position of paleo-valleys in the Pleistocene surface that formed during sea-level lowstands determines the position of the tidal basins reaching inland, such as the Lauwersmeer, Ems-Dollard estuary, Jadebusen and the Elbe estuary. Thirdly, several of the barrier islands developed around a core of Pleistocene or older age, for instance Texel, Amrum and Sylt. Finally, sub-marine Pleistocene ridges can influence currents and wave impacts. For example, Blåvandshuk is a cuspate foreland which is formed on the lee-side of the sub-marine ridge of Horns Rev (Kingo Jacobsen, 1992).

In the Wadden Sea, between Den Helder and Esbjerg, the continuous shoreline is replaced by barrier islands separated from each other by tidal inlets (Ehlers, 1988). The general morphology of the barrier islands is governed by wave and tidal forces (Hayes, 1979). The tidal forces are determined by tidal basin size and height (and hence paleorelief) and tidal range. Along the Wadden Sea, there is variation in tidal range (Figure 1)

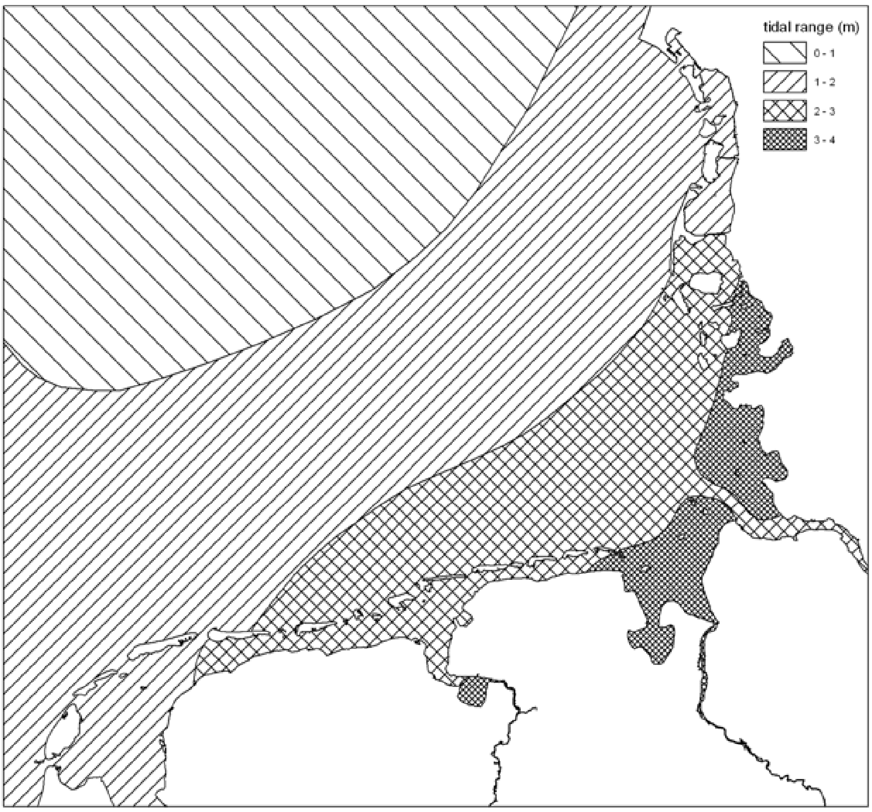

Figure 1: Tidal ranges in the Southern North Sea at spring tide (after Reineck, 1978; Postma, 1982; Ehlers, 1988).

and in significant wave height (1.3 to 1.6 m), both influencing the coastal morphology of the barrier islands. Between Wangerooge and the peninsula of Eiderstedt, only shoals are present with temporary primary dunes. In this area tidal ranges exceed ~2.9 m. From the German Bight up to the north, again barrier islands stretch from Eiderstedt up to Skallingen, the northern end of the Wadden Sea.

Under the influence of strong winds, water levels of the North Sea can reach extreme heights. Such storm surges can have a considerable effect on the morphology of barrier coasts and large land areas can be flooded and sometimes eroded. Channels created during storm surges can gradually develop into large tidal channels. For instance, it has been suggested that a breach of a relatively low and narrow dune belt between Den Helder and Texel during the storm surges of AD 1164 and 1170 eventually triggered the development of a large tidal inlet (Marsdiep) and helped change the freshwater Lake Flevo into a body of brackish water, the Zuiderzee (Oost et al., 2004). In addition, the Halligen in the German Bight were probably part of a larger salt marsh area that was eroded during storm surges in the Middle Ages. Specifically, one devastating storm in AD 1362, "die Grosse Mandränke" (great drowning), is often mentioned in this context, but the alleged impact of this legendary storm is questioned in historical studies (Buisman, 1996).

Through an interplay of the above-mentioned mechanisms, the present day Wadden Sea can be largely subdivided into three areas. First, a chain of barrier islands in front of a tidal basin extending from the western island of Texel, near Den Helder, up to the island of Wangerooge characterizes the western and eastern Frisian Wadden Sea. A notable feature is the decreasing length of the barrier islands towards the east, reflecting the increasing tidal range towards the east. Second, the area between the Jadebusen and the Eiderstedt peninsula is characterized by a series of mobile shoals and several large tidal inlets. The large tidal inlets are associated with a deeper Pleistocene surface representing the valley of the glacial Elbe and Weser rivers. Barrier islands are unable to develop in this area because of the macrotidal conditions. A third area encompasses the area from the Eiderstedt peninsula up to the Skallingen Peninsula in the upper north. This area consists of a chain of barrier islands, several of which enclose a core of Pleistocene or older age. The Halligen islands north of the Eiderstedt peninsula represent the remnants of a formerly extensive peat marsh and salt marsh environment.

3. Morphological development

3. Morphological development during the Holocene

1.1 Introduction

In the next chapter the morphological development of the Wadden Sea after the last Ice Age will be discussed. First in some broad steps, but in more detail for the period from 1000 AD until now, when humans exceedingly influenced the development of the area.

1.2 Holocene development

The early Holocene

During the last glacial, most of the North Sea was land and the nearest shoreline was off Bretagne in the south and near the Shetland Islands in the northwest. The rivers Ems, Weser, Elbe and Eider drained northward in a broad valley (Figge, 1980). When the continental ice-sheets started melting, sea level rose rapidly, forcing the shoreline to recede and flooding the present-day North Sea.

In The Netherlands and Niedersachsen, the deepest river valleys of the Pleistocene land surface underneath the present land area flooded around 8000 BP (Beets and Van der Spek, 2000). Sea-level was still some 20 m below its present level (Figure 2) and the coastline was much further offshore than its present position, 10 to 15 km for the Dutch coast (Vos and Van Kesteren, 2000). Smaller barrier islands or beach ridges were probably present in front of the coast as relicts of Pleistocene headlands (Flemming and Davis, 1994). Because sedimentation rates were insufficient to fill the accommodation space created by the rapidly rising sea (1.0 m/century), much of the inundated surface evolved into subtidal environments, fringed at the landward side by a narrow zone intertidal sand and mud flats and pioneer salt marshes. In the course of the Holocene, the barrier islands and tidal basins shifted landward as sea level continued to rise rapidly. An increase in tidal ranges (Figure 2) resulted in stronger tidal currents which might have led to increased net sediment transport into the tidal basins (Vos and Van Kesteren, 2000). At about 5000 BP, sediment accumulation rates began to exceed the rate of sea-level rise. Thus, intertidal sand flats grew at the expense of subtidal environments, which ultimately disappeared (Van Heteren and Van der Spek, 2003). At this time, the Dutch and Niedersachsen chain of barrier islands were still situated several kilometers seaward from the present position: in the case of Terschelling about 9.5 km more seaward (Sha, 1990).

From 5000 BP to present, the chain of barrier islands has been migrating landwards with an

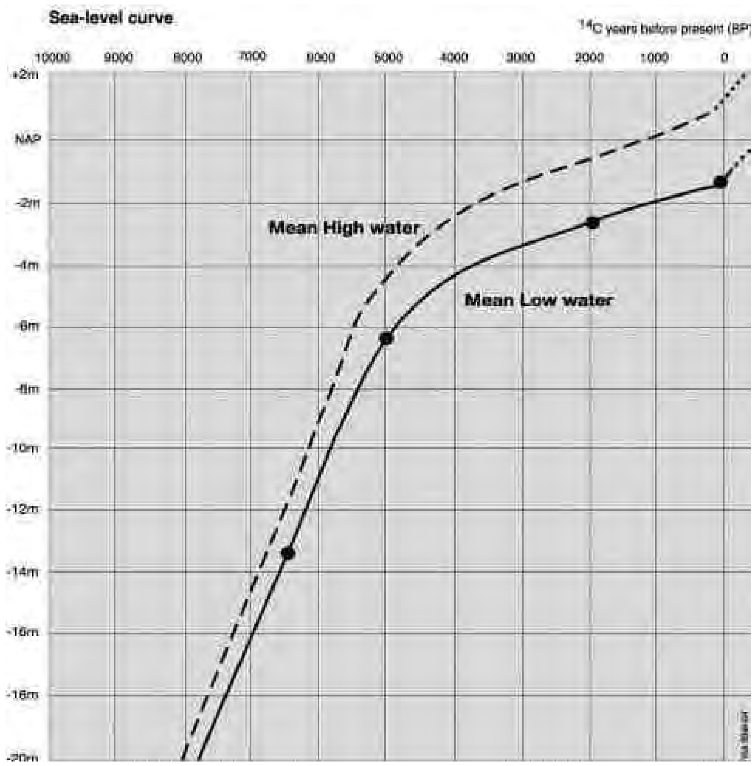

Figure 2: Sea-level trend curves of Mean High Water (MHW) and Mean Low Water (MLW) during the Holocene for the northern Netherlands (after Vos and Van Kesteren, 2000). The MHM was compiled after Jelgersma (1979), De Groot (1996) and Misdorp et al., (1990). MLW was reconstructed using computed palaeo-tidal ranges (Franken, 1987).

average landward migration rate in the order of almost 2 m/year. The landward migration of the barrier is caused by sand loss on the seaward side. This sand was largely transported into the intertidal basins of the Wadden Sea, and more or less balanced the ongoing sea-level rise (Van der Molen and De Swart, 2001). The situation in the German Bight was and is different. In this area, sediments were partially transported off-shore during storm surges (Aigner, 1985).

During the following millennia, sea-level rise decelerated, and the infilling of the available accommodation space tipped in favour of net sedimentation. As a consequence, the landward part of the basins silted up and the salt marshes at the landward fringe of the tidal basin could advance seawards (Vos and Van Kesteren, 2000). The landward shift of the barrier islands and the seaward progression of the salt-marshes resulted in a decrease of the intertidal area of the Wadden Sea (Vos and Van Kesteren, 2000). The clastic tidal sediments accumulated in and along the Wadden Sea are interspersed with a series of peat layers representing periods of terrestrification. Some of these peat layers reached a considerable extent (Behre, 2004). However, most of these fresh water marshes drowned again and clastic tidal sediments were deposited on top of them.

The Danish Wadden Sea formed about 5000 BP (Jacobsen and Madsen, 1993) in a similar way to the Dutch and Niedersachsen Wadden Sea. Once formed, the barrier islands retreated eastward with the relative sea-level rise. The difference with the Dutch and Niedersachsen situation is a slower relative sea-level rise (only ~12 m in the last 8400 years [Pedersen et al., 2009]) and a Pleistocene landscape consisting of Saalien moraines and gently sloping Weichselian outwash-plain deposits (Bartholdy and Pejrup, 1994). The gentle slope and slower sea-level rise may have resulted in the formation of a tidal basin with intertidal conditions since its formation, thereby skipping the period with subtidal conditions as has occurred in the Dutch and Niedersachsen Wadden Sea between about 8000 BP and 5000 BP.

In the area of Eiderstedt and North Frisia around 4500 BP the barriers and Pleistocene cores in the area formed an inlet-segmented coastline at the western part of the North Frisian tidal flat area (Meier, 2004). On the peninsula of Eiderstedt, the cores of present-day east-west trending sand-bars probably consist of eroded Pleistocene material and are a relict of this barrier system (Hoffmann, 2004). The sandy barrier system protected the hinterland and around 2500 years ago extensive marshes formed, consisting of thick sequences of clayey and peaty sediments with small scale relief due to differential compaction (Meier, 2004). Although a large part of these marshes eroded during storm surges in the Middle Ages, its remnants still dominate the morphology of the area.

The late Holocene: Human settlement

Dutch and Niedersachsen Wadden Sea

The first settlements on the marshes along this section of Wadden Sea date from the 9th/10th centuries BC in Niedersachsen (Behre, 2004) and from the 5th Century BC in The Netherlands (Vos and Knol, 2005). Around AD, there is a large increase in the number of settlements along most of these coasts. During this period, the settlers built their houses on naturally elevated levees and did not have to rely on artificial elevation of ground level. The distribution of these old settlements reflects the coastline and riversides during the initial settlement period. Shortly after AD 100, an increase in storm flood levels occurred, and until the late Middle Ages the inhabitants of the coastal marshes protected themselves against storm surges by the construction of dwelling mounds (Vos and Knol, 2005; reconstruction AD 800). Protection of the farmland, which was regularly inundated in winter, was carried out only in the close vicinity of the mounds and existed of small local dikes. The first large-scale dikes were built at the end of the 10th Century AD (Van der Spek, 1994) safeguarding arable fields and meadows from the occasional summer and spring floods. They were, however, not sufficient for protection against all winter storm surges. Gradually, these ring dikes were connected and raised, and by the 13th Century a continuous system of winter dikes had been created.

The consequence of the extensive embankments was that the storm-surge levels increased due to the reduction in space that could be inundated during storm floods, in particular in the funnel shaped estuaries of the Ems, Weser and Elbe rivers. This led to frequent dike breaches. In response to this, the dikes were elevated and new areas were reclaimed, thus leading to further rises in the levels of storm floods. During the dike breaches, the floodwaters invaded the low-lying back-swamp areas whose surfaces had subsided due to drainage and subsequent oxidation, burning of surface layers for growth of cereals, and compaction. This made it exceedingly difficult to drain the flooded areas, and dike breaches became irreversible, creating new bays (e.g., the Dollard and Jadebusen). Around AD 1500, many larger bays reached their maximum size. From this time onward, successful land reclamation started again, from time to time set back by severe storm surges.

Northern Frisia

The recovery of flint daggers and sickles dating from the Mesolithic proves the presence of people in the northern Frisian marshes at an early stage, but there is no continuity in the following periods. In the first centuries AD, the marshes were already densely populated, but later abandoned again, possibly in response to climate deterioration (Meier, 2004). Only since the 7th Century AD has the area been permanently occupied by humans (Meier, 2004). At this time, the first houses were erected on the marsh surface, indicating that the settlements were not seriously threatened by storm floods. In the 11th Century, storm-flood layers were deposited on top of the earliest cultural layers, indicating increased marine influence.

Later on, the northern Frisian marshes were protected by dikes, which required drainage resulting in compaction due to dewatering of the underlying sediments. In 1362 AD, a catastrophic storm surge inundated extensive areas protected by dikes. In particular, the areas consisting of thick clayey and peaty sediments that had experienced increased compaction could no longer be protected against the sea. Consequently, part of the former coastal marsh area was changed into a tidal flat area.

During the Middle Ages, people produced salt by burning the peat, which occurred in the coastal marshlands under a cover of clay. The area between Langness, Hooge and the mainland was most suitable for salt production because of the presence of a thick peat layer, and hence exploited. This peat extraction made the land especially vulnerable.

4. Morphological developments

Morphological development during the last 1200 years

The development of the Wadden Sea during the last 1200 years is illustrated in 4 maps. The first map represents the situation in AD 800 for the Dutch Wadden Sea only. The subsequent maps represent the situation for AD 1500, AD 1850 and AD 2000, for the entire Wadden Sea. For the reconstructions, we used a selection of historical, geological and geomorphological maps and previous reconstructions of parts of the Wadden Sea. The level of detail of the various areas on the maps reflects the confidence of the reconstructions. With respect to the mainland peat bogs, the extent in the Dutch part of the Wadden Sea is reconstructed based on soil maps, topography and land subdivision, whereas the peat bogs in Germany and Denmark reflect the current extent in a general reconstruction, because no detailed reconstructions are available. This is a first attempt to establish a comprehensive overview of the development of the whole Wadden Sea, from The Netherlands to Denmark; the authors would welcome additions and remarks.

Morphological situation of the Dutch Wadden Sea in AD 800 (Annex1)

The reconstruction of the Dutch Wadden Sea in AD 800 shows the situation before large scale human interference in the system. The situation in the Dutch part is thought to be representative for the most of the Wadden Sea in this time period. Clearly visible is the strong interconnectedness, showing rivers which debouche in the Wadden Sea and reach deep inland. In the direction of the mainland one could, at that time, go from the tidal flats via tidal marshes and extensive brackish areas towards the peats surrounding the higher sandy areas. Another striking feature is that the Holland coast was still partly open in the north and the area of Texel was still dissected by small inlets, with the northernmost island connected to Vlieland. Furthermore, the Marsdiep inlet, in between Texel and Den Helder, had not yet fully formed. The inter-tidal area consisting of tidal flats and salt marshes extended to the higher Pleistocene grounds. The settlements on the coastal marshes were built on dwelling mounds, having a negligible influence on the large-scale tidal dynamics.

Morphological changes between AD 800 and 1500 (Annex 2)

By AD 1500, a large area of salt marsh attached to the mainland had been embanked. Large areas of land bordering the inland bays along the Dutch and Niedersachsen coasts had been reclaimed in the period before AD 1500, following a devastating loss of land due to several dike breaches in the Middle Ages. The land reclamations also led to a decrease in tidal volume which resulted in smaller tidal inlets. The Halligen islands were still much larger than at present, although storm surges during Medieval times had already dramatically changed the landscape. The reconstruction also shows that small parts of the saltmarshes on several barrier islands had already been embanked. This might have happened as early as the 14th Century.

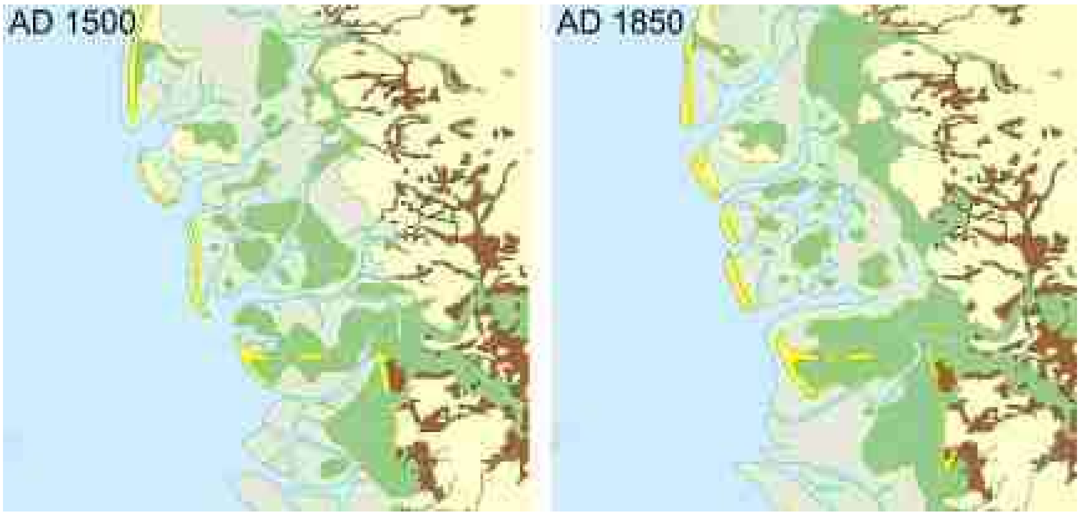

Figure 3: Reconstructed changes in the Halligen and Eiderstedt peninsula area between 1500 and 1850.

Morphological changes between AD 1500 and 1850 (Annex 3)

From 1500 AD onward, successful land reclamation continued. The area of embanked salt marshes gradually increased and the size of the inland bays consequently decreased. The tidal flat area has decreased with some 58% (Delafontaine et al., 2000) by the embankment of areas which rose above storm surge level due to sedimentation and due to the closure of embayments. This decrease also led to a marked decrease in muddy areas in the Wadden Sea. The Halligen area, which was especially vulnerable after peat extraction for the production of salt, was struck by catastrophic storm surges (e.g., 1634, 1825) and large areas of land were lost, largely shaping the present-day Halligen landscape (Figure 3). Only a small percentage of the inundated marsh could subsequently be reclaimed. In the early 17th Century the first large-scale attempts took place to protect dune belts on the barrier islands. The intended stimulation of a closed vegetation cover was inhibited, however, by extensive livestock grazing. In this period, extensive artificial sand dikes were erected and maintained by placing brushwood fences which trapped and stabilized wind-blown sand. As early as 1633, the islands of Eijerland and Texel were connected by an artificial dune dike.

On many maps from around AD 1650, large intertidal areas in front of the Danish barrier islands are indicated. These have disappeared by AD 1850.

Morphological changes after 1850 (Annex 4)

After 1850, land reclamation occurred as part of the industrial development. Parts of the Wadden Sea were changed into harbours, other parts (e.g., Zuiderzee and Lauwerszee) were simply diked and embanked affecting the shape and size of the associated tidal inlets for many decades after the closure. The changes in the landscape were quite significant. On the barrier islands, a series of notable morphological changes occurred, mainly between 1850 and 2000 (Ehlers, 1988). These changes concern primarily island growth and reflect excessive sand supply. During this period, the islands of Ameland, Schiermonnikoog, Juist, Norderney, Baltrum and Wangerooge, and the Ostplate of Spiekeroog started to grow rapidly eastward, and salt marshes began to develop behind dunes formed on Memmert and Mellum. On Trischen, vegetation developed on newly formed dunes. The Kniepsand began to merge with Amrum. In Denmark, the Havsand and Juvre Sand merged with Rømø, Fanø extended northwards with the formation of new dune ridges and the Skallingen spit grew thereby protecting a larger part of the back barrier basin leading to salt marsh development (Ehlers, 1988).

Some of these contemporary morphological changes may have been caused by local circumstances, but the striking coincidence of so many positive shoreline changes makes it very likely that some common processes may have caused them. Since the period discussed here marks the end of the Little Ice Age (~1450 - 1850), a change in circulation following this period has been suggested as a driving mechanism for the observed changes (Ehlers, 1988). Also an increased deposition of nitrogen associated with the industrial revolution could have enhanced vegetation development.

On the barrier islands, the increase in tourism in this period resulted in the development of first seaside resorts on the Wadden Sea coasts. These permanent structures were built in highly dynamic locations and were soon threatened by coastal retreat (Ehlers, 1988). In response, new coastal defense structures were developed, having an important impact on the morphological development of the islands. Most influential were the hard protection measures taken at the northwest and western heads of the islands Ameland, Borkum, Nordeney, Baltrum, Spiekeroog and Wangerooge. The constructions have halted the threatening migration of the tidal inlets. In some cases however, this caused extreme deepening of the inlets.

In addition to groynes, seawalls have been constructed to protect the barrier coast where vulnerable to erosion. The steep profile of these structures increases the power of the waves, and therefore they are often marked by a more smoothly sloping revetment. The earliest seawalls were built of basalt; later, asphalt mounted with stones was used in order to increase the roughness of the surface and decelerate the waves. In recent decades, there has been a growing tendency to use sand nourishment rather than hard structures to actively protect the coast. An advantage of nourishment is that the beach is maintained dynamically, keeping natural processes of erosion and sedimentation intact. A disadvantage is that the sand has to be dredged somewhere else, consequently introducing sand that is different from the sand native to the islands, and thus influencing the habitat.

Except for these smaller scale interventions stabilizing islands, several large scale construction works were built after AD 1850 influencing the remaining intertidal areas. The most notable interventions between AD 1850 and AD 2000 were the closure of the Zuiderzee by the construction of the Afsluitdijk in 1932, the construction of the dams connecting Rømø (1949) and Sylt (1927) to the mainland and the construction of the Eider barrier in 1973, protecting the mainland from storm surges. The influence of a selection of these interventions is discussed in the following section.

5. Recent interventions

Nowadays, humans influence the Wadden Sea to such an extent that the impact might be considered a "geomorphological force" in its own right. This influence causes the Wadden Sea area to deviate in its morphological structure and development from the natural situation. Two major groups of influence can be distinguished:

I. Influence on morphological development that is still exerted by large-scale interventions in the past, such as:

1) the diking of the higher tidal marshes, which effectively cut off the Wadden Sea from its hinterland that would be flooded during storm surges under natural conditions. The characteristic landscape existing of high supratidal mud-rich meadows, with occasional coast-parallel sandy/silty ridges and low-lying brackish areas has largely disappeared (Esselink, 2000).

2) The loss of land due to increasing vulnerability to flooding by peat excavation (inner and outer dikes) and drainage (e.g., Jade, Dollard, Lauwersmeer, North Frisian area (Kühn, 1997), but probably perhaps also in parts of the western Wadden Sea (Oost and Kleine Punte, 2004)). Several of the largest muddy embayments of the Wadden Sea are to some extent artifacts of flooding caused by peat extraction.

3) The loss of connectivity between the mainland, especially its rivers, and the Wadden Sea, following the closure and damming of many of the estuaries in the area. This loss resulted in the loss of many characteristic estuarine environments and species specialized in colonizing and occupying these brackish conditions.

4) The large-scale changes by humans in the Wadden Sea after 1900 still have their effect on the morphological developments in the Wadden Sea and the adjacent North Sea coasts. A well studied case is the closure of the Zuiderzee area in 1932. Since then the westernmost Wadden Sea in front of it has been adapting to the new hydrodynamic conditions and over the period 1927-1997 (Berger et al., 1987) nearly 400 Mm3 of sediments have accumulated in the backbarrier, especially in the tidal channels, a large part of it being derived from the North Sea coastal zone, causing strong retreat of the coastline and size reduction of the ebb-tidal deltas. From the developments, it can be judged that the effects of the damming will continue to influence the area for many decades (Elias, 2006).

5) A fifth large-scale change is brought about by all kinds of other protection works along the North Sea coasts, such as dikes and eolian dikes (probably since at least the 13th Century), groins (since at least the 18th Century), seawalls (since the 18th Century), harbour moles (since at least the 19th Century) and massive discharge sluices (since the 19th Century). Such defences have resulted in the fixation of inlets (e.g., Norderney) and sandy coasts (e.g., northern Texel), which effectively limits the possibility of inlets to shift. One effect is that longshore barrier-island dynamics have become more limited than before. As a result, opportunities for pioneer vegetation have dwindled and dune belts have experienced an uninterrupted succession of the vegetation cover (Löffler et al., 2008). The range of protection measures is also known to have influenced the development of complete inlet systems (Elias, 2006).

II. Influence that is exerted by current interventions, such as:

1) The dredging of harbours and channels, leading to a higher rate of trapping of fine sediments during a large part of the year, short periods of intense turbulence during dredging activities and re-suspension from the dumping sites. The exact cumulative effects are not exactly known.

2) The deepening of channels, leading to higher tidal amplitudes, larger tidal volumes and sometimes higher current velocities (e.g., the Ems estuary).

3) The stimulation of tidal marsh formation, leading to silting up of the inner edges of backbarrier basins in particular (e.g., the mainland coasts of Niedersachsen; Ehlers, 1988; Dijkema et al., 2007).

4) Beam trawling of the sea-bed to catch demersal fish, but especially shrimp and mussel (seed). Several morphological influences are possible. Firstly, it disturbs the internal structure and layering of the sediment, with its flora and fauna. As such sediments can be considered to form an underwater soil profile that builds up over a given amount of time, this might have far reaching effects, such as a shift to more opportunistic infauna which was also observed as an effect of mechanical cockle-dredging (e.g., Piersma et al., 2001; Zwarts, 2004). Furthermore, some grades of sedimentary particles, such as shells or silts, are removed as part of the exploitation, leading to different grain size and hence to different developments.

5) The enhancement of dikes leading to prolonged morphological inactivity in the area cut off from the Wadden Sea.

6) The discharge through sluices leading to irregular brackish situations which have their effects on biota and sedimentation and small scale estuarine circulation patterns.

7) The cultivation of mussels in the Wadden Sea, leading to locally enhanced deposition of fines during quiet weather conditions (mainly during spring and summer). On the other hand, during rough weather conditions (mainly during autumn and winter) they may act as point sources and lead to enhanced turbidity of the water.

8) The import of exotic species that change the sediment characteristics. A good example is the Pacific Oyster (Crassostrea gigas), which nowadays is omnipresent in the Wadden Sea. It influences the sedimentation of fines because it is a filter feeder. It also influences the local morphological development by forming shells and reefs. However, at the same time, many of the oyster beds have displaced mussel beds, which thus have to a large extent disappeared. Another example is the introduction of Spartina anglica grass, which enhances sedimentation at the edges of salt-marshes.

9) The nourishment of sand on the coasts of the barrier islands is currently subject to debate. Locally it influences the morphological development, by preventing net coastal erosion. Any influence on the morphological development of the Wadden area as a whole at present-day volumes has not yet been proven.

10) Subsidence caused by oil and gas extraction (Niedersachsen and The Netherlands). Although the subsidence at the surface is limited in the vertical sense, it extends over large areas. Hence volumes involved are large (Mm3). As a reaction extra sedimentation compensates for the subsidence in these areas, which is mainly derived from the North Sea coasts of the barrier islands (Oost et al., 1998).

The relative importance and cumulative effects of all these short- and long-term influences will remain subject to debate in the years to come. Comparison between the countries bordering the Wadden Sea and learning from past reconstructions might strongly enhance the understanding of process-response relationships and of measures needed to minimize negative impact of existing and future actions.

6. Towards a more natural Wadden Sea

In 2009, much of the Dutch and German Wadden Sea and its barrier islands became a World Heritage Site as a tribute of its geomorphological and ecological values. This designation brings an obligation for the responsible countries to keep natural values at the present level. Since the larger part of the Wadden Sea already is highly protected, this obligation will be met by enforcing existing laws. Within the Wadden Sea, some areas are entirely protected, such as Hörnum Deep, where no exploitation is allowed, and the islands Rottumerplaat en Rottumeroog, where all coastal protection measures were terminated. Here, the natural dynamics prevail.

Nowadays, for a number of interventions, mitigation measures are taken. For instance the velocity of subsidence of new gas fields is limited to what is considered a safe limit in The Netherlands, thus minimizing the effects on the morphological development (NAM, 2006). Furthermore, studies are carried out to minimize the effects of nourishments, channel maintenance (Hartsuiker and Grasmeijer, 2008) and trawling fisheries. Also studies are carried out to increase natural dynamics on a larger scale on the barrier islands.

In the previous overview, we made a first attempt to reconstruct the development of the Wadden Sea from AD 1500 onwards. We are well aware of the shortcomings which are still present and welcome any suggestions. But even from this first attempt some general conclusions can be drawn. Summarizing:

1) The earliest reconstructions of the Dutch Wadden Sea of AD 800 and the entire Wadden Sea of AD 1500 reflect a situation of a natural and largely natural Wadden Sea, respectively. The following maps of AD 1850 and AD 2000 illustrate the increasing human interference with the Wadden Sea system.

2) In its main characteristics, the Wadden Sea coastal configuration has, by and large, remained much the same over the past 500 years as is apparent from the similarity between the reconstructions. For example, the area of tidal flats and island size is largely comparable in the reconstructions of AD 1500, 1850 and 2000. This suggests that the Wadden Sea system as a whole seems to be largely in a kind of dynamical equilibrium over this period, morphologically speaking.

3) However, if one looks more closely, it shows that all the mainland coasts have become straighter and therefore shorter, partly due to natural sedimentation and erosion, and partly due to human interference, which became very significant in the 20th Century.

4) Also, all the mainly sandy, barrier islands have changed to some extent in form and some (e.g., Buise) have disappeared. The coast is clearly receiving the full brunt of the North Sea hydrodynamics and will continue to do so. Comparison of the changes on all the barrier islands through time might provide clues as to what to expect in the future when climate is expected to change.

5) Also, there is a marked difference between the development of the east-west trending Wadden Sea of The Netherlands and Niedersachsen and the north-south trending Wadden Sea of Schleswig-Holstein and Denmark. Whereas the first Wadden area is rather stable, the northern Wadden Sea area has undergone significant drowning and land-loss (e.g., the Halligen and intertidal areas in front of the Danish barrier islands). It is not completely clear why these differences occur.

These reconstructions of the entire Wadden Sea provide a first overview of the various morphological developments occurring in the Wadden Sea system through time: from a fully natural system around AD 800 to a human influenced system by AD 2000. Hence, we suggest they are used as a "morphological reference guide" when striving towards a near-to-natural situation. We hope that these reconstructions will further discussions on which situation is natural. We propose to produce more extensive reconstructions of the morphological development, both in spatial resolution and in time, preferably going back all the way to 5000 BP, when the Wadden Sea started to form.

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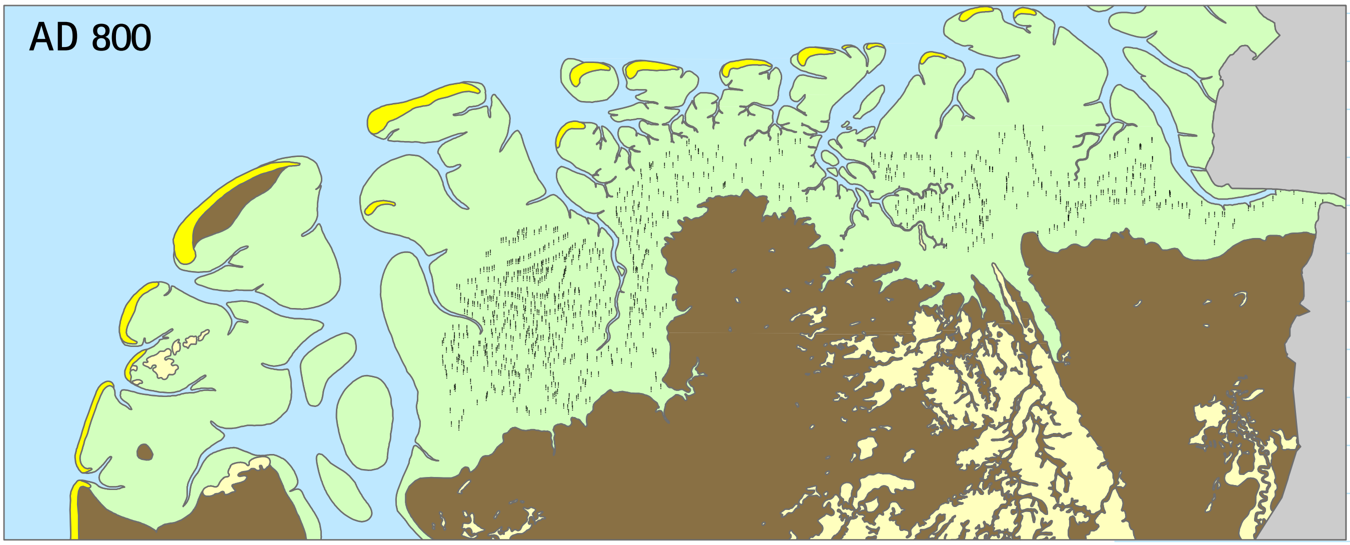
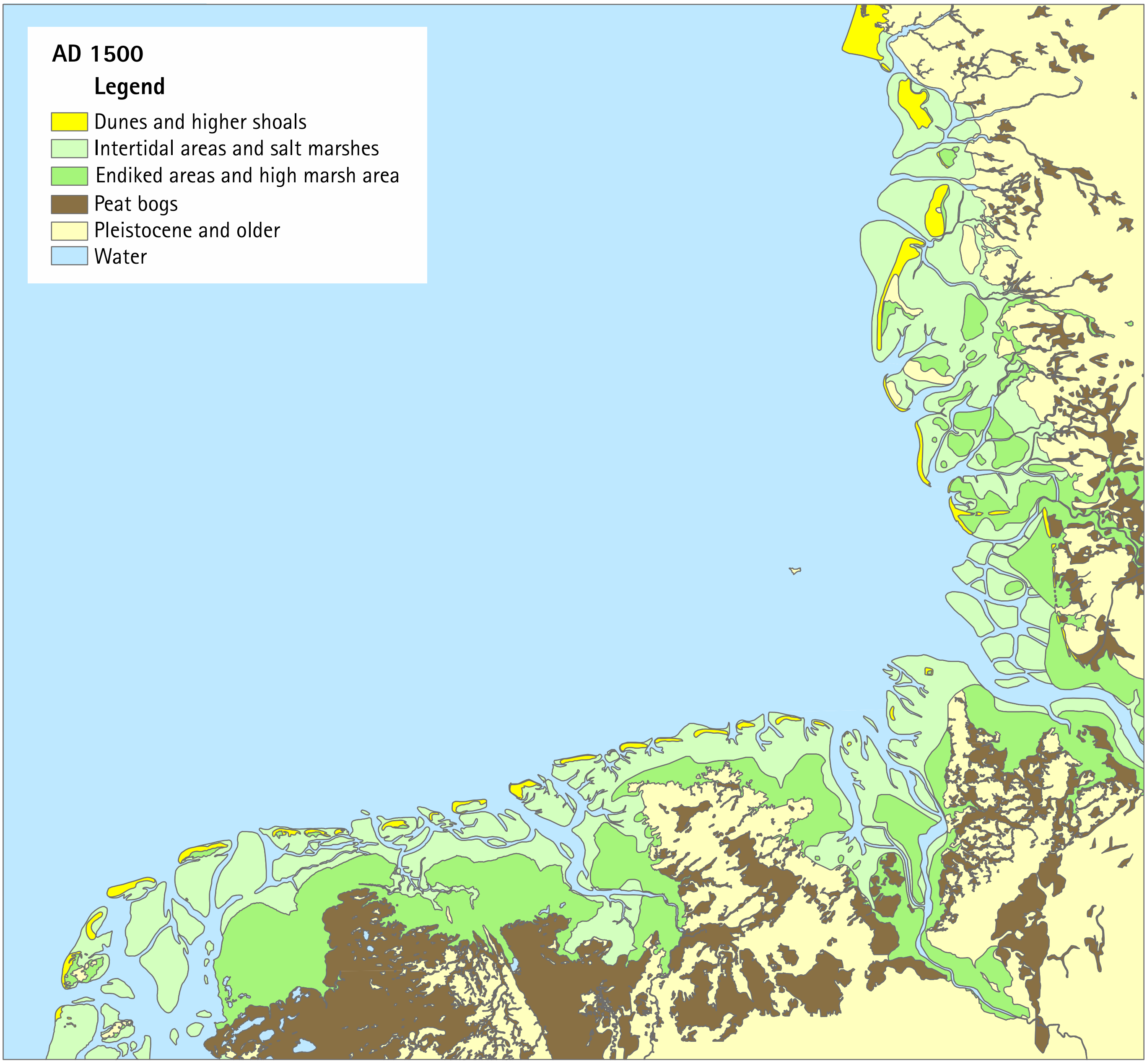
Annex 1: A.D. 800

Legend

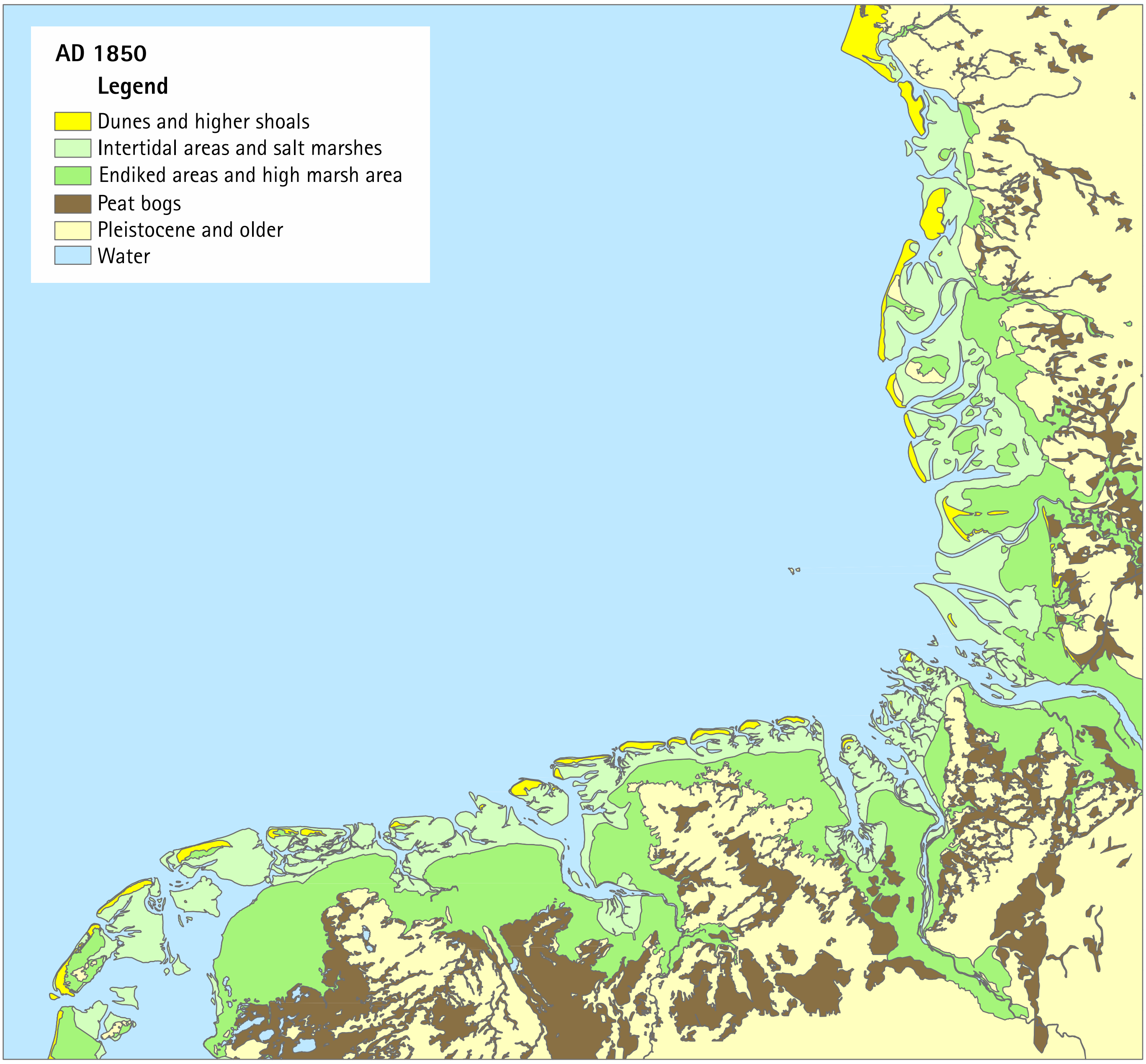
I	Dwelling mounds
	Dunes and higher shoals
	Intertidal areas and salt marshes
	Peat bogs
	Pleistocene and older
	Water
	Germany



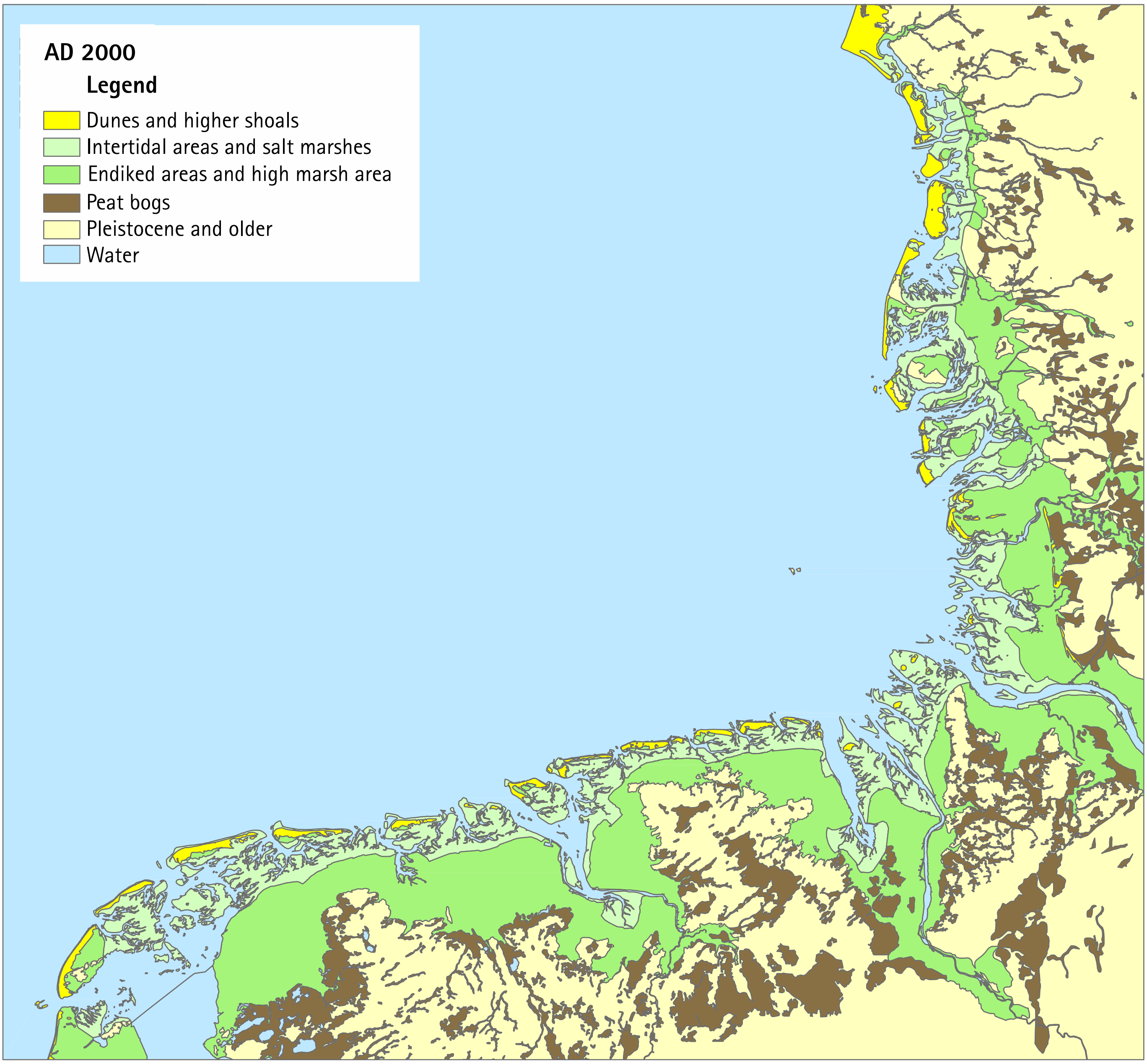
Annex 2: A.D. 1500



Annex 3: A.D. 1850



Annex 4: A.D. 2000



WADDEN SEA ECOSYSTEM No. 25

Quality Status Report 2009
Thematic Report No. 10

Macrozoobenthos

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10.1 Introduction

Macrozoobenthos is defined as invertebrate bottom fauna living on, or in the bottom, which is retained on a sieve with a mesh size of 1 mm x 1 mm. Smaller animals that pass through such a sieve are called meiozoobenthos. There are about 400 macrozoobenthic species in the Wadden Sea area, of which approximately 150 inhabit the tidal flats. Most are mollusks, mainly bivalves, polychaetes or decapod crustaceans. The macrozoobenthos plays a dominant role in the food web of the Wadden Sea ecosystem. It is the main connector between the primary producers and higher trophic levels. They are the most important consumers of both the pelagic phytoplankton and benthic microphytobenthos which are responsible for the larger part of the systems primary production. In turn the macrozoobenthos make up the rich feeding grounds for predatory fish and birds. Especially the bird community depends strongly on the macrozoobenthos.

Protection and management

Macrobenthic animals live in an environment that is influenced by eutrophication, pollution, fisheries, removal of substrate and dumping of substrate. Not any macrobenthic species in the Wadden Sea is being protected on an individual basis, for instance by a law that prohibits the removal of a single worm or shellfish. Instead, laws on fishery and on water quality should provide a more general protection against unwanted declines in the populations of susceptible species and/or target species. Special attention is paid to the protection of mussel beds including their accompanying fauna (see Thematic Report 11 on blue mussel beds).

Macrozoobenthos is part of several habitats that are protected under the EU Habitats Directive (92/43/EEC): Sandbanks (1110), Estuaries (1130), Mudflats (1140), Lagoons (1150), Shallow inlets and bays (1160), Reefs (1170).

The EU Water Framework Directive (WFD) aims at an integrated water management based on river basins on a European level. The WFD (2000/60/EC) requires an evaluation of the ecological status in terms of the individual types of waters as well as the achievement of the "good ecological status" (GES) in all European waters by 2015. Macrozoobenthos is one of the biological quality elements that has to be used to make a classification of the ecological status of the coastal waters. The generic definition of a GES for benthic invertebrate fauna is: The level of diversity and abundance of invertebrate taxa is slightly outside the range associated with the type-specific condition" and "Most of the sensitive taxa of the type-specific communities are present" (WFD Annex V).

Different Member States use different methods to classify the status of macrozoobenthos. In Germany the M-AMBI index (Muxika *et al.*, 2007) has been tested amongst others as a tool for classification. The index is based on the assessment of species numbers, diversity of the macrobenthos community and relation between species, which are sensitive or tolerant to organic enrichment (AMBI index) in comparison with undisturbed reference conditions. Denmark uses the DKI index. Like the M-AMBI the DKI index is based on species number, diversity and AMBI, since these parameters are essential for the assessment of the ecological status in line with the WFD. The

Dutch BEQI index (van Hoey *et al.*, 2007), contrary to the DKI and M-AMBI, uses additionally the macrobenthos biomass for the assessment, but it neglects the ratio of sensitive to tolerant species concerning pollution.

Target

No specific trilateral Target was developed for the macrozoobenthos of soft sediments in the Tidal Area of the Wadden Sea. However, the general Target of an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas applies. The previous QSRs (1999 and 2004) concluded that there is evidence for a loss of undisturbed tidal flat areas as a settling habitat for juvenile bivalves due to several factors.

Findings of previous QSRs

In the QSR 1999 (De Jong *et al.*, 1999), an attempt was made to clarify the possible causes of long-term variability in total biomass of the intertidal macrozoobenthic community measured at a limited number of monitoring locations within the Wadden Sea. Severity of winterers and eutrophication status were mentioned as major factors that caused short- and long-term changes in the macrozoobenthos. In addition, the possible negative effects of mechanized shellfish fisheries were briefly introduced. The QSR 2004 (Essink *et al.*, 2005) contained an update of this work based on new data and literature. In 2004 the most notable developments in macrozoobenthos were a decline in bivalve recruitment success in the last 15 years alongside a shift in spatial distribution of spat fall towards the higher tidal zone observed in the Netherlands. It was postulated that this could be the effect of climatic change. Especially milder winters would have lead to increased predation pressure by crustaceans on bivalve spat reducing bivalve recruitment success most strongly in the lower tidal areas. Additionally a change in the distribution of fine sediment towards the coast possibly due to mussel bed removal and mechanical cockle dredging may have negatively impacted bivalve recruitment. Another trend that was mentioned in the previous QSRs is the increase in the biomass of polychaetes in the Netherlands and western coast of Germany (Lower Saxony), but not in Denmark. Further research into these trends in order to find an explanation was recommended.

Sampling station Buesum, Schleswig-Holstein (Photo: J. Voss).

10.2 Methods

The present chapter will reconsider the monitoring data since 1970, and expand on those trends discussed in the previous QSRs. It will also describe possible new trends in biomass, species composition and the occurrence of new species. Data from the TMAP monitoring program, stored in the TMAP data unit, are used from the Netherlands, Germany (Lower-Saxony and Schleswig-Holstein) and Denmark (Figure 1, Table 1). The monitoring takes place on a regular basis at least once a year. More detailed site characteristics are presented in Appendix 1. Below, methodology and data handling is briefly described. For further details see the TMAP manual (http://www.waddensea-secretariat.org/TMAP/guidelines/Manual.html).

Methodology

Long term monitoring of abundance and biomass of macrozoobenthos in the Wadden Sea is done at several monitoring sites with a few differences in the sampling strategy (Table 1). In general macrozoobenthos is sampled twice annually, in late winter/early spring and in late summer/early autumn. Samples are either taken along transects or at permanent stations. The sediment is collected with a tube corer or by digging out a specific surface area to a depth of about 30 cm and washed over a sieve with 1 mm mesh size. Material retained on the sieve is preserved and is sorted in the laboratory. All animals are – if possible - indentified to species level or to the lowest possible taxa level and counted. In the Dutch samples additionally the age of the bivalves is estimated by counting the number of growth rings of the shell.

After sorting and counting, the measure for biomass, ash free dry mass (AFDM) is determined per species.

Data handling and analysis

To harmonize the nomenclature of the different data series species names were adjusted according to the online available list of macrozoobenthos at the MARBEF species identification portal (www.marinespecies.eu) and the Integrated Taxonomic Information System ITIS (www.itis.gov).

For each area, the analyses at the species level are restricted to species with a biomass that accounted for at least one percent of the total sampled biomass during the entire period that data were available. The biomass (AFDM) measured in late winter/early spring was used for this decision.

Both biomass and numerical densities are presented. Biomass values were used to calculate

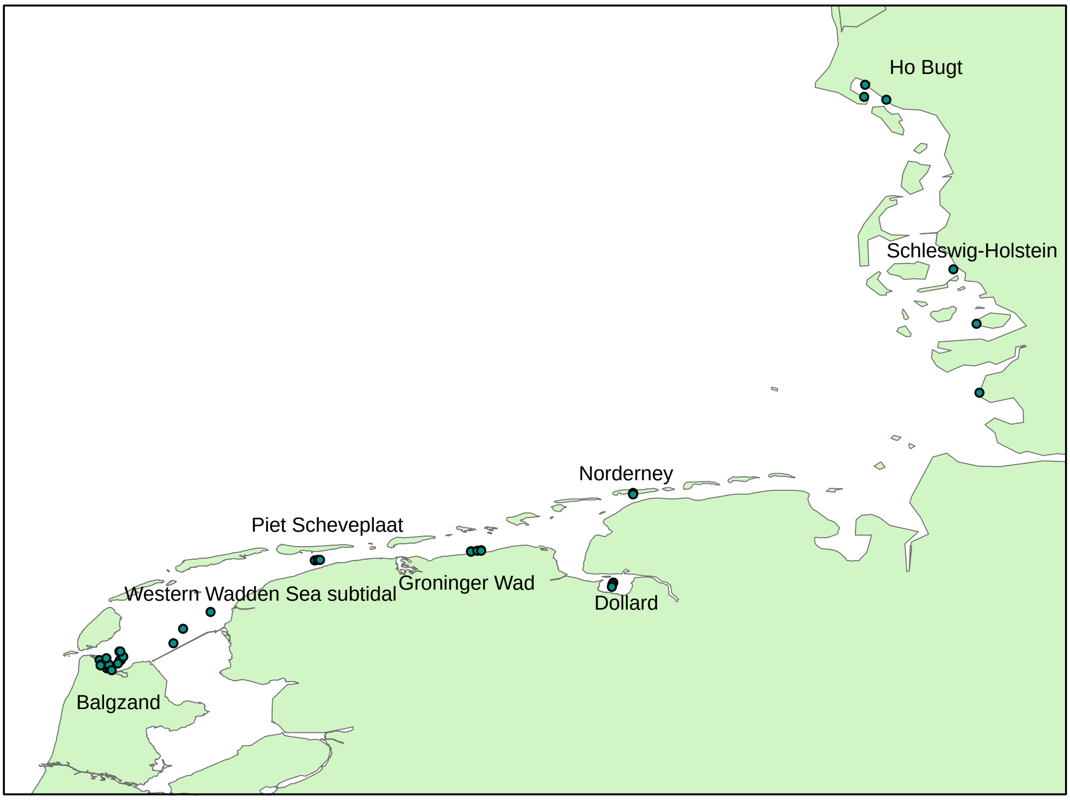


Figure 1: Map of the Wadden Sea area with the location of the monitoring sites (details see Table 1).

Table 1: Monitoring sites in the Wadden Sea. Grouping based on a similarity analyses of species biomass data (see text), futher details on sites in Appendix 1.

Monitoring site	Code	Grouping	Samples[1]	Sampled surface area (m²)	Sample depth (cm)	Data over period	References
Balgzand	BZh BZm BZl	high middle low	2 tran 9 tran/2 stat 1 tran/1 stat	1.9 /0.9[2] 10.6/6.1 1.95/1.45	35	1969/1980-2008[3]	Beukema & Cadée 1997
Western Wadden Sea Subtidal	WS	subtidal	3 tran	2.7	20-25	1990-2008	Dekker & Waasdorp 2008
Piet Scheveplaat	PS	middle	3 tran	1.6	35	1988-2008	Dekker & Waasdorp 2008
Groninger Wad	GW	middle	5 stat	0.72	30	1988-2007	Van der Graaf & Tydeman (2008)
Dollard	DD	estuarine	3 tran	0.16	35	1988-2008	Dekker & Waasdorp 2008
Norderney	NN	middle	1 tran	0.72/0.54[4]	30	1976-2007	Dörjes et al. (1986) Essink et al. (2006)
Dithmarschen	DM	middle	1 stat	0.16/0.85	20/40[5]	1987-2007	Voss (1992)
Nordfriesland	NF	middle	2 stat	0.32/1.65	20/40[5]	1987-2007	Voss (1992)
Ho Bugt	HB	NA6	3 tran	NA[6]	NA[6]	1980-2006	Miljøcenter Ribe

[1] Samples are either collected along a transect (tran) or at a permanent station (stat). [2] At the Balgzand total sampled surface in winter is larger than in summer, because of different core diameters used. [3] Winter sampling from 1969, summer from 1980 onwards. [4] At Norderney sampled area is less since 2007. 5 At Dithmarschen and Nordfriesland additional larger samples to a greater depth are collected for deep living species *A. marina* and M. arenaria. [6] NA = not available

total biomass of the macrozoobenthos community and to check the community composition. At the species level abundance data are used to show trends. Significance of trends was tested with a Pearson correlation without correcting for multiple testing. Significance was taken at alpha<0.05, it should however be mentioned that consecutive measurements of macrozoobenthos are often highly correlated and significance of trends is only an indicator for the strongest trends.

It was chosen to use biomass rather than numerical densities. In the first place biomass is a more useful metric in an ecosystem perspective linking macrozoobenthos to primary production on the one side and higher trophic levels on the other side. In the second place, very small abundant species, which would otherwise dominate the analysis, receive less weight using biomass.

In a first explorative multivariate analysis of species biomass data the similarity of stations and transects was checked. Stations tended to cluster in accordance to the environmental characteristics, sediment composition and height in the tidal zone. To improve the comparability between areas the Balgzand stations and transects were grouped in low middle and high according to the level in the tidal zone. For Schleswig-Holstein two stations were grouped as Nordfriesland and one separate station in the area influenced by the Elbe outflow as Dithmarschen. The Dollard stations which are in a brackish estuarine habitat and the subtidal stations in the Western Wadden Sea do strongly diverge from the other stations and are because of the different environment not good comparable with the other areas.

For methodological reasons the biomass values of the Danish monitoring sites are not comparable to the monitoring sites in the rest of the Wadden Sea and are not taken into account in this report.

Recruitment

Recruitment of the bivalve species *Macoma balthica*, *Cerastoderma edule*, Mya arenaria and *Ensis americanus* was estimated by subtracting spring densities (n m-2) from autumn densities. This method could be checked for the areas where counts of the bivalve spat (0 year class) were available, and proved to be reliable for differences between years.

10.3 Status of the macrozoobenthos

10.3.1 Biomass

There are large differences in the total biomass of the macrozoobenthos (summed AFDM of all species averaged per site) between the monitoring sites. Sites with more extreme abiotic conditions, Balgzand high, Balgzand low and Dollard have the lowest biomass of on average less than 20 g m^{-2}. At the other sites total biomass ranges between 20 and 200 g m^{-2}. Time series of total biomass in late winter and summer have been plotted separately per monitoring site in Figure 2. In general late winter/early spring biomass is less than late summer/early autumn biomass. This is mainly due to growth of the macrozoobenthos and settlement of new recruits (especially bivalves) between the winter and summer sampling. During the winter half year body mass loss and mortality are the dominating processes causing a decline in total biomass. There is no general Wadden Sea wide trend in total biomass, but there are several noteworthy trends within monitoring sites. A striking long term trend is the linear increase in winter biomass continuing for four decades at the Balgzand high and mid regions. During this period winter biomass doubled from 20 to 40 g m^{-2} at the mid region and got four times higher from 4 to 15 g m^{-2} in the Balgzand high region Summer biomass at Balgzand high and mid also increased but after 2000 this has reversed into a decline. At Balgzand low after thirty years of little change biomass both in summer and winter has increased dramatically since 2005, due to two very strong year classes of *Ensis americanus*. Both at Piet Scheveplaat and Groninger Wad winter biomass values have been stable in the last 20 years, while summer biomass values peaked around 1995. At Norderney winter biomass increased slightly over the past three decades, while summer biomass had large inter annual variability. Apart from a large drop in the summer biomass values in the beginning of the series there are no trends at the Schleswig-Holstein sites Dithmarschen and Nordfriesland. These high values during the beginning of the series are caused by large densities of bivalves probably originating from a large spatfall in 1987. In Dithmarshen these were *Macoma balthica*, *Cerastoderma edule* and Mya arenaria in Nordfriesland only *C. edule*. In addition *Heteromastus filiformis* and *Hydrobia ulvae* were exceptionally strongly represented in Dithmarshen and Nordfriesland respectively.

In the Dollard estuary the biomass development is characterized by relatively high biomass values at the start of the time series. This strong deviation from the other areas was caused by very high abundances of the invasive polychaete *Marenzelleria viridis* in the late eighties after it initially appeared in 1983. After the initial very strong development of *M. viridis* its share in the total biomass dropped from more than 50% to about 20% during the last ten years. Total biomass in the subtidal of the Western Wadden Sea has increased. During the last two decades winter biomass has nearly doubled, while the summer biomass trend was less pronounced.

Since the previous QSR, the strongest change in total macrozoobenthos biomass has taken place at the intertidal monitoring areas in the Dutch Wadden Sea. Here, the previous increase in summer biomass is reversed in a decline. Only at Balgzand low this pattern is disrupted by the outburst of *E. americanus*. At the German sites, there are no obvious changes of the long-term developments.

Winter biomass developments are explored in more detail looking at the underlying species composition divided into the main species and the summed biomass of the remaining species (Figure 3). Again, there are no uniform trends for the entire Wadden Sea. However, there are local trends, which are summarized below:

- At Balgzand high *M. balthica* and *N. diversicolor* are the species contributing most to the total biomass. In the last ten years however *M. balthica* decreased strongly while H. ulvea and *M. arenaria* gained in importance.
- Balgzand middle is dominated by *M. arenaria* making up on average 32% of the total biomass. The cockle *C. edule* and the lugworm *A. marina* are also important but during the last decade there contribution to the total biomass decreased. Striking is the strong decline of *M. balthica*, good for 10% of the total biomass in the first 3 decades of the series, but during the last decade on average less than 2%.
- Before recent Balgzand low was an area low in biomass with *A. marina* and *M. balthica* as main species. Since 1985 *E. americanus* is present and gained in importance since, accounting for more then 90% of the total biomass in the last three years of the series.
- At Piet Scheveplaat *A. marina* and *C. edule* contribute most to the total biomass especially gaining importance during the last ten years. During the nineties *M. arenaria* had its peak in dominance (44%) but nowadays does contribute less than 10% to the total biomass.
- Groninger Wad shows a temporal pattern similar to Piet Scheveplaat. However *A. marina* is less dominating while *H. filiformis* is relatively important.

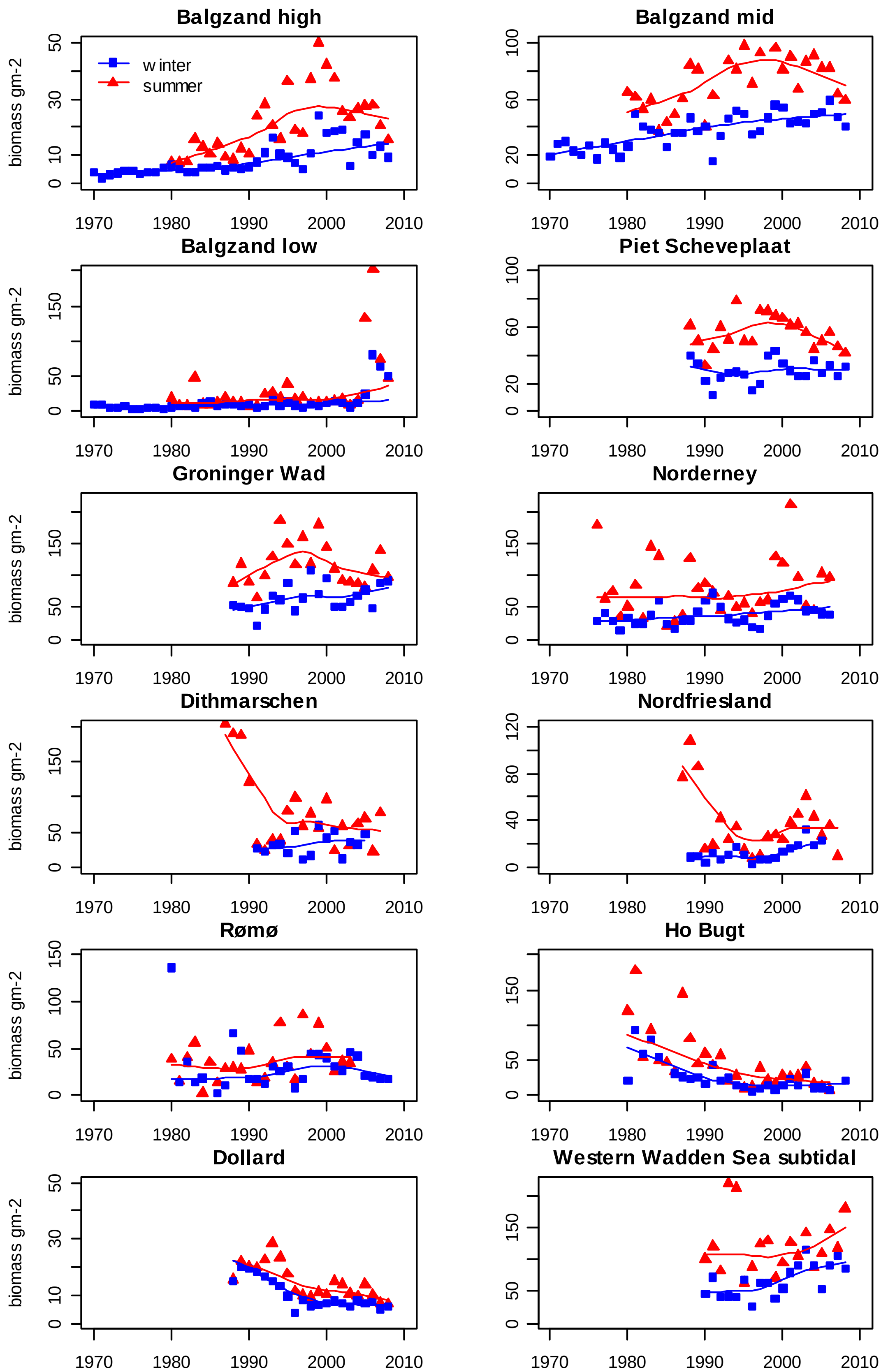


Figure 2: Biomass (ash free dry mass) time series of the total macrozoobenthos community (g m^{-2}) in winter/early spring and summer/early autumn. Different monitoring areas are show in separate panels. Means per season (symbols), and Lowess smoother (solid lines). Note differences in y scales.

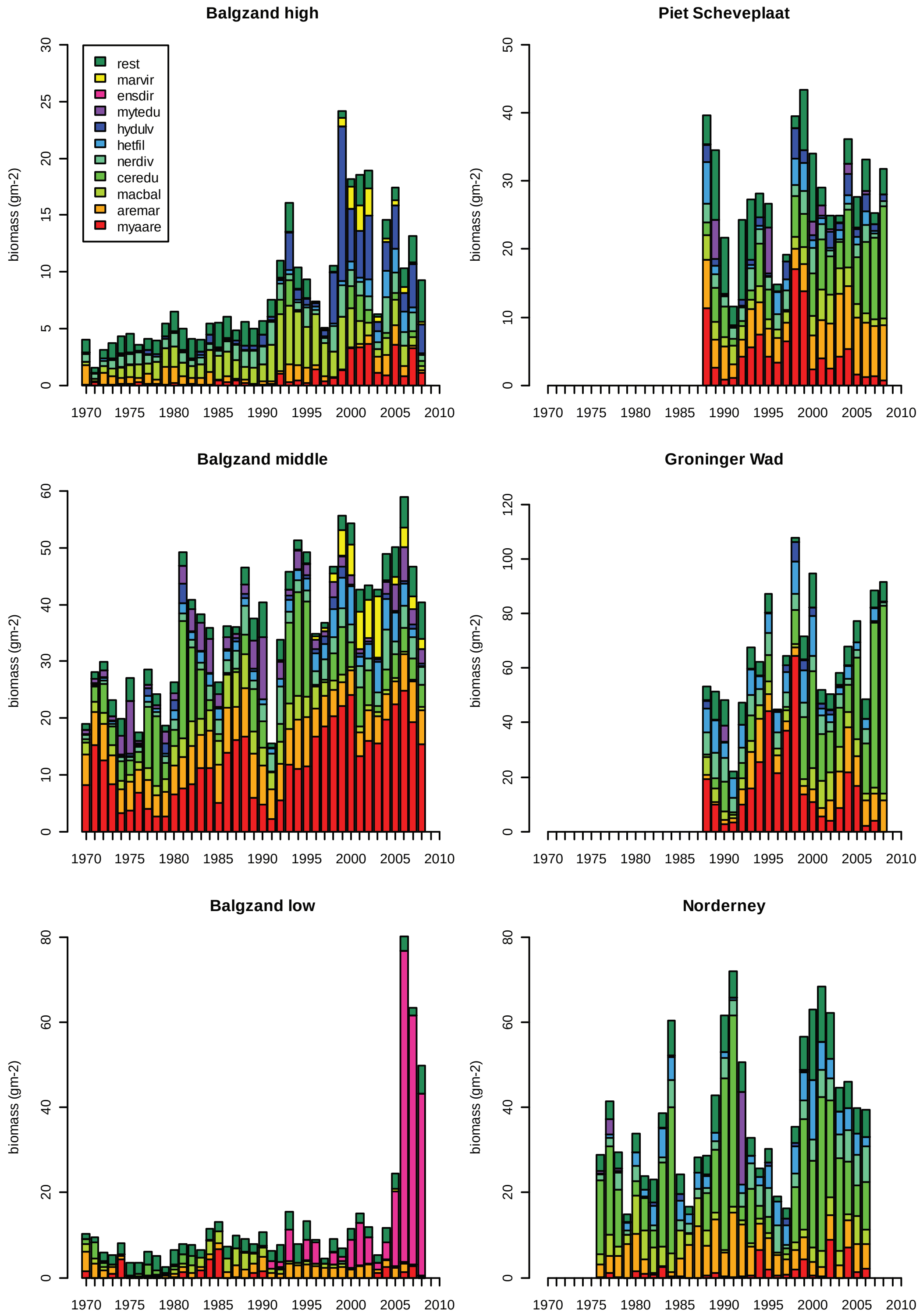
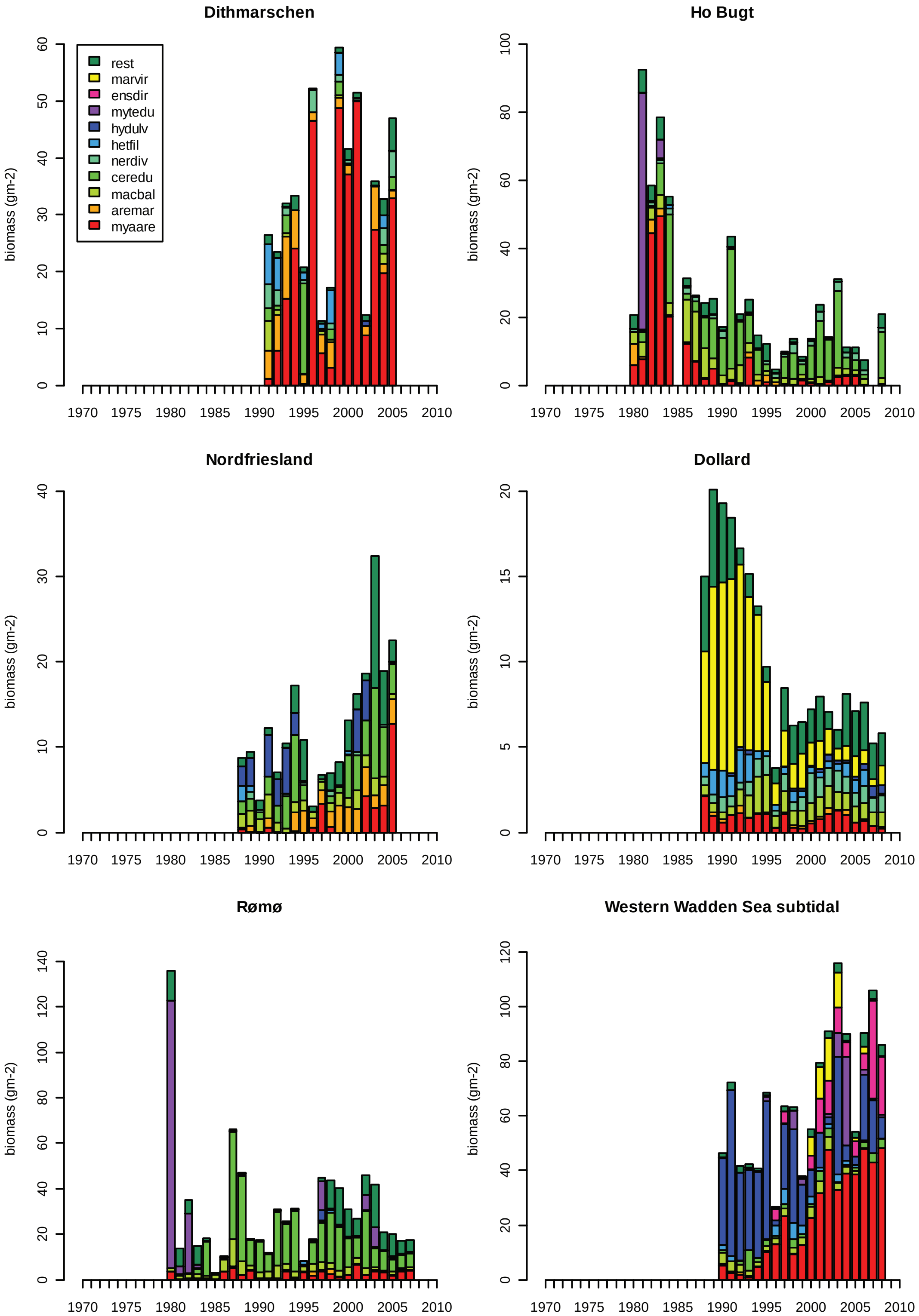


Figure 3 (a): Stacked bar graphs of late winter/early spring biomass per monitoring area. Biomass is specified for the eight most common species in terms of biomass plus rest, in addition invasive species *Ensis americanus* and *Marenzelleria viridis* are shown. Note that y scales differ.

Figure 3 (b): Stacked bar graphs of late winter/early spring biomass per monitoring area. Biomass is specified for the eight most common species in terms of biomass plus rest, in addition invasive species *Ensis americanus* and *Marenzelleria viridis* are shown. Note that y scales differ.



– The Norderney community is dominated by *C. edule*. Fluctuations in the total biomass are mainly the result of changes in the cockle stock. After the cockle, *A. marina* and *H. filiformis* are most dominating species.

– The macrozoobenthic community at Dithmarschen to the north of the Elbe estuary is largely dominated by *M. arenaria*. During the last 7 years of the time series it always has accounted for at least 60% of the summed community biomass.

– The mudsnail *H. ulvae* is the dominant species at Nordfriesland. The increase in total mass during the last decade is mainly due to an increase in *M. arenaria* and *C. edule*. During this same period the share of *M. balthica* dropped from more than 20% to less than 5%.

– In the end of the eighties and the beginning of the nineties species composition in the Dollard was heavily dominated by invasive *M. viridis*. After this strong initial development the *M. viridis* contribution declined and is now more or less stable below 20%. Besides *M. viridis*, *M. balthica* and *N. diversicolor* are relatively important species in the community both with a stable contribution of about 15% to the total community.

– In the Western Wadden Sea subtidal the community once dominated by the benthic grazer *H. ulvae* has changed into a community dominated by the bivalve filter feeders *M. arenaria* and *E. americanus*.

Species	Site and period																						Total	
	BZm		BZh		GW		BZl		DM		NN		WS		DD		HB		NF		PS			
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
nersuc		+		+		+	-									+							-1	4
uropos		+				+		+														+	0	4
marvir	+		+		+	-							+		-	-							3	-2
scrpla		+								+		+									+		1	3
ensame								+					+	+									1	2
hetfil	+		+									-		-	-							-	1	-3
myaare					+	-			+			-		+			-	+				-	1	-1
pygele													+										1	0
ceredu																	-				-	+	-2	1
cragig		+																					0	1
lancon	-				-																		-2	0
nephom	-						-	+			-		-	+					-		-		-6	2
hydulv		-				-									-	+							-1	-1
mytedu																							0	0
nerdiv			-			-		-				+											-1	-1
aremar						+		-					-	-		-						+	-1	-1
corvol																					-		-1	0
scoarm					-	-			-			-							-	-	-	-	-4	-4
macbal		-		-			-							-			-	-				-	-2	-5

aremar	*Arenicola marina*	myaare	Mya arenaria
ceredu	*Cerastoderma edule*	mytedu	Mytilus edulis
corvol	*Corophium volutator*	nephom	Nephtys hombergii
cragig	*Crassostrea gigas*	nerdiv	Nereis diversicolor
ensame	*Ensis americanus*	nersuc	Nereis succinea
hetfil	*Heteromastus filiformis*	pygele	Pygospio elegans
hydulv	*Hydrobia ulvae*	scoarm	Scoloplos armiger
lancon	*Lanice conchilega*	scrpla	Scrobicularia plana
macbal	*Macoma balthica*	uropos	Urothoe poseidonis
marvir	*Marenzelleria viridis*		

Table 2: Sign of significant temporal winter abundance (log nm^{-2}) trends of 19 main macrozoobenthos species (list of abbreviations of species names below the Table) at 11 monitoring sites in the Wadden Sea (see table 1 for abbreviations). Results are divided over two periods, period 1, 1988–1997 and period 2, 1998–2008. Totals are the number of positive minus the number of negative trends per row.

Figure 4:
Abundance (log10(n+1))of 19 dominant macrozoobenthos species in the period 1988 – 2008. Late winter/early spring averages per area (symbols), Lowess smoother (solid lines). Significant positive Pearson correlations between abundance (log10(n+1)) and year are shown in blue, significant negative in red. Species and area are ordered according to the number of significant positive minus negative relationships (positive upper left, negative lower right). Note that y scales differ. Area names are given in table 1.

10.3.2 Abundance

For an analysis of trends at the species level species were selected that accounted for at least one percent of the summed biomass at one or more of the monitoring sites taken over the entire time series. In total there were 18 species (Table 2). Because the Pacific oyster is rapidly increasing in importance this species was added to the list as well. Abundance (nm^{-2}) time series of 1988 onwards are presented in a species times site matrix ordered by the number of significant positive minus negative correlations with time (Figure 4). For 34 species site combinations there were no observations. Of the remaining 175 series most significant linear trends were positive (36, 21%) and only 18 (10%) trends were negative. In the Wadden Sea area polychaete *N. succinea* and the crustacean *U. poseidonis* are the species with the most widespread increase. However these two species only have a minor contribution to the total biomass. Other species that increased in abundance during the last two decades at two or more monitoring sites are the invasive polychaete *M. viridis*, the bivalve S. plana, the invasive bivalve *E. americanus* the polychaete *H. filiformis* and the bivalve *M. arenaria*. Most declining trends, five out of eleven, were found for the bivalve *M. balthica*. Other species declining at two or more sites were the polychaete S. armiger, the crustacean *C. volutator* and the polychaete *A. marina*.

At all sites except Piet Scheveplaat there were more species increasing in abundance than decreasing. At Balgzand middle the highest net number of increasing species was found, while Groninger Wad has most species with increasing trends.

To focus on shorter term developments the period of 1988 to present was divided in two periods, period 1, 1988-1997 and period 2, 1998-2008. Over these two periods for each species site combination biomass time correlations were calculated. Results of positive and negative correlations are given in Table 2 with the same order as Figure 4. Most positive trends took place in the second period. The three strongest negative developments during the last period where those of *M. balthica*, S. armiger and *H. filiformis*. Declines of *M. balthica* and S. armiger are most serious without any positive trend during either period. Overall negative trends in abundance of N. hombergii, *L. conchilega* and *C. edule* during the first period are reversed into positive trends during the second period. The opposite happened with the invasive *M. viridis*, increasing in the first period and decreasing in the last decade

The main factor underlying the variability in numbers and biomass of bivalve stocks is the variation in numbers of recruits (Van der Meer *et al.*, 2001). Bivalve recruitment (Figure 5a-d) is temporally variable with very large differences between years. Periods without strong year classes can span more then 10 years, with consequently very low abundance and biomass of adult stocks. At the Balgzand area recruitment of *M. balthica* and *C. edule* has been moderate to poor since the beginning of the 1990s. At the Groninger Wad and Norderney *C. edule* spat fall has been moderate for a twenty-year period between mid eighties and 2005 before an exceptional strong year class appeared again. The recruitment variability is to some degree synchronized between sites, especially in the southern Wadden Sea (Beukema *et al.*, 2001, Strasser *et al.*, 2003). This effect is stronger in *M. balthica* than in *C. edule*. The similarity between areas can be attributed to the effect of winter temperature on recruitment. With decreasing winter temperature the chance of a good bivalve spat fall in the following spring increases, mainly due to low abundance of epibenthic predators after cold winters (Beukema *et al.*, 1998, Philippart *et al.*, 2003).

10.3.3 Number of species

Since 1988 a total of 168 species/taxa have been recorded in the combined macrozoobenthos monitoring programs in the Wadden Sea area. This is a conservative count because it excludes the species that are only identified to the genus level while there are already fully indentified species in the list from the same genus. So for instance Corophium sp. is not counted because C. arenarium and *C. volutator* are already in the list and it is assumed that Corophium sp. is most likely one of the two fully identified species. Less than one third of these species are found in more than half of the eleven distinguished monitoring sites and thus can be regarded as common species. Appendix 2 gives the species lists for each monitoring site. The number of encountered species varies between monitoring sites. Least species are found high in the Balgzand tidal zone and in the Dollard. In these two sites number of species will be limited by extreme abiotic conditions, long exposure time in case of the Balgzand and low salinity in the Dollard. Dithmarschen, Nordfriesland and Balgzand also have low species counts; this is mainly attributable to the limited number of stations sampled per site, only one or two. Sites with more stations will cover a larger range of environmental heterogeneity increasing the chance to find additional species.

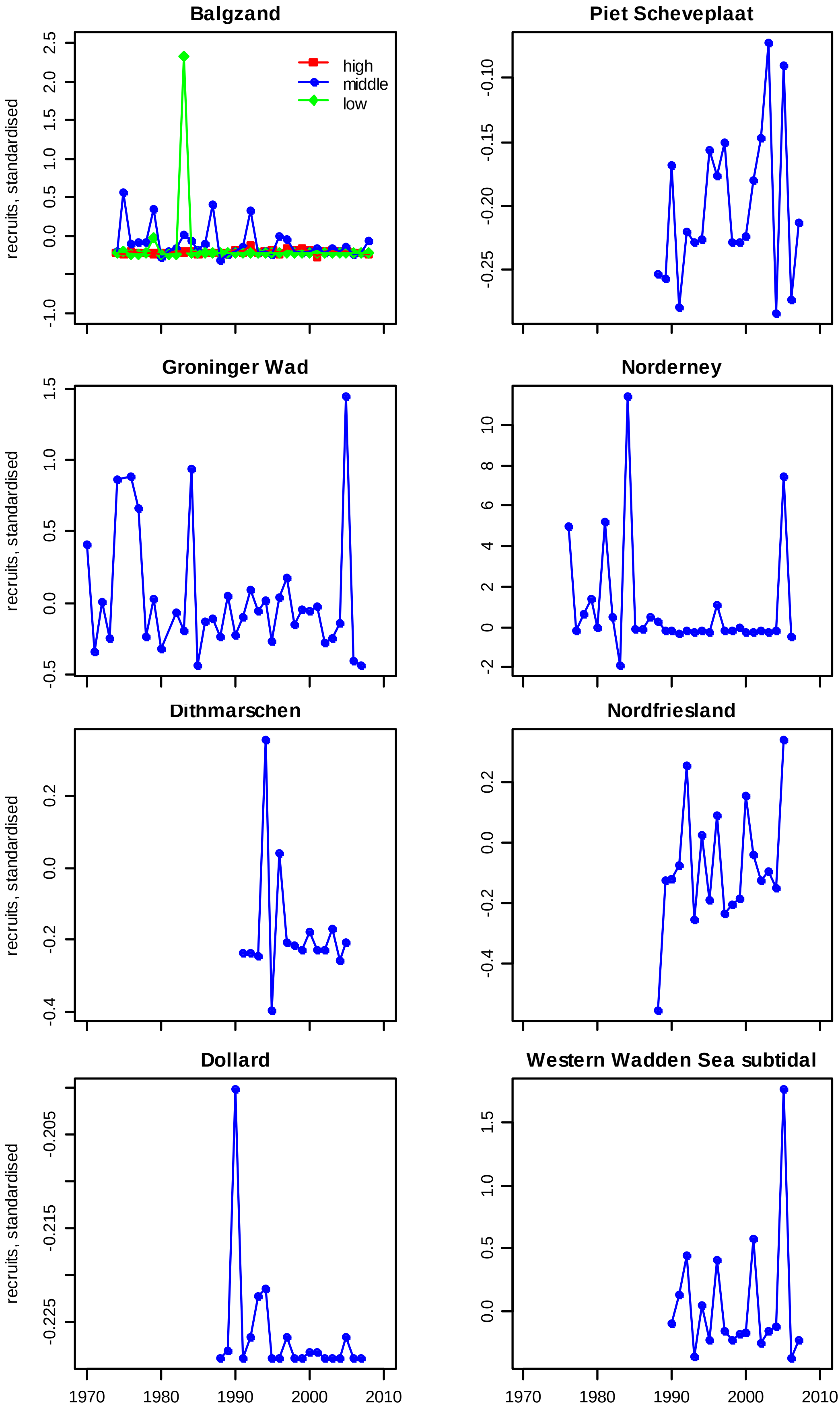
At the Balgzand, Groninger Wad and Norderney sites number of species is increasing (Figure 6). For a large part methodological reasons are the cause of these trends. The clear break in the Balgzand series is attributable to the change to a new responsible scientist in 1995 (Beukema-Dekker transfer). Since then 29 species new to the area have been recorded of which only five are unambiguously newcomers. These are the pacific oyster *Crassostrea gigas*, the brush-clawed shore crab Hemigrapsus takanoi, the slipper limpet Crepidula fornicata, the chiton Lepidochitona cinerea and the polychaete Glycera alba. The rest are mainly small crustaceans and polychaetes. The increase in species number at Groninger Wad and Norderney are also at least partly due to more careful identification of specimens. Nevertheless there are new species appearing and also the nowadays frequent mild winters have a positive effect on the number of species (Figure 7) (Beukema 1992).

10.3.4 New species

Two species from North America, the polychaete *Marenzelleria viridis* and the bivalve *Ensis americanus*, appeared in the Wadden Sea in the 1970s/80s

M. viridis was found for the first time in the Dollard in 1983 (Essink 1999) and its occurrence is associated with brackish conditions. The population of *M. viridis* had a very strong development especially in the Dollard. Overall the occurrence

Figure 5a:
Standardised recruit density of *Cerastoderma edule* in late summer/early autumn. Note different y scales.



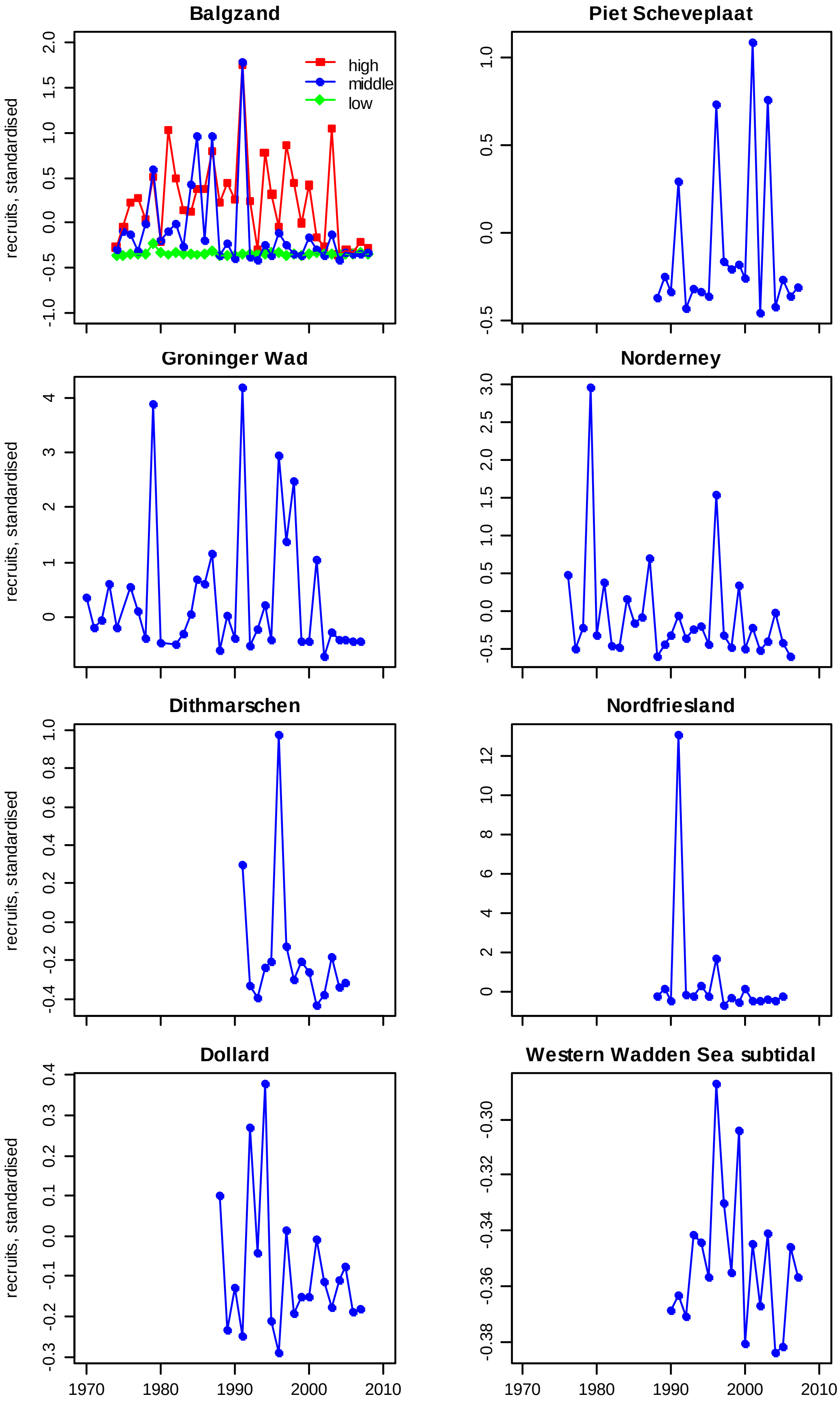
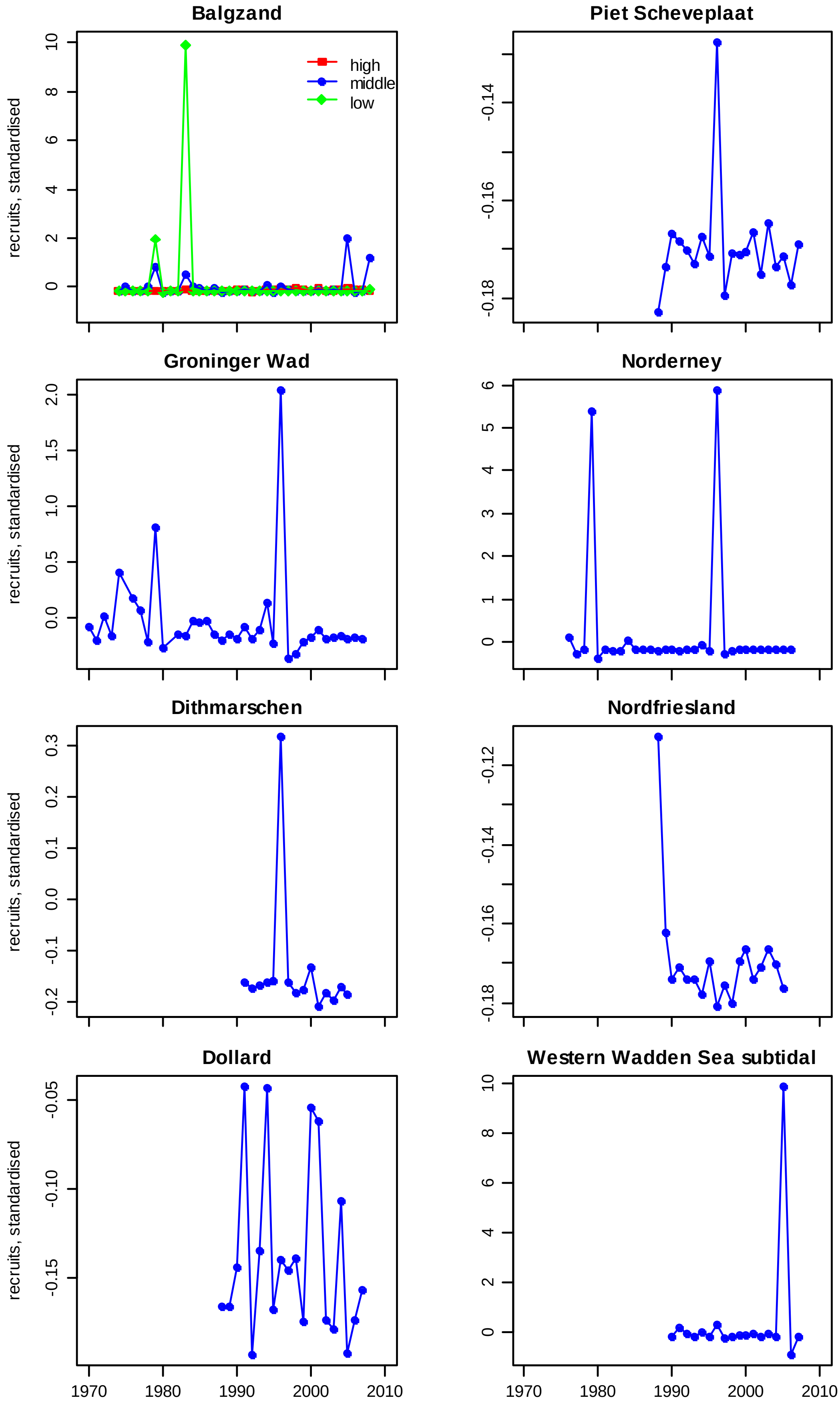


Figure 5b: Standardised recruit density of *Macoma balthica* in late summer/early autumn. Note different y scales.

Figure 5c:
Standardised recruit density of Mya arenaria in late summer/early autumn. Note different y scales.



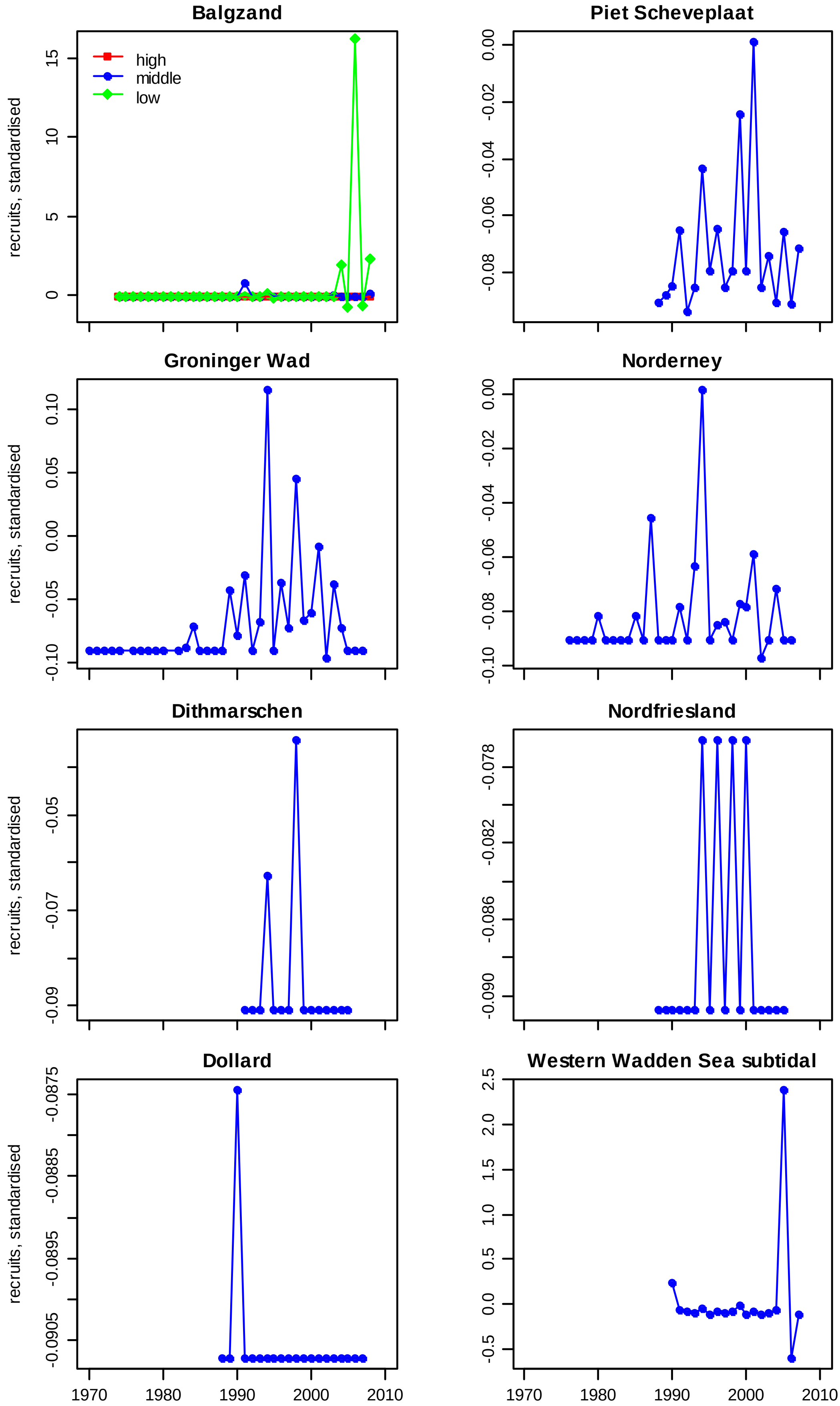
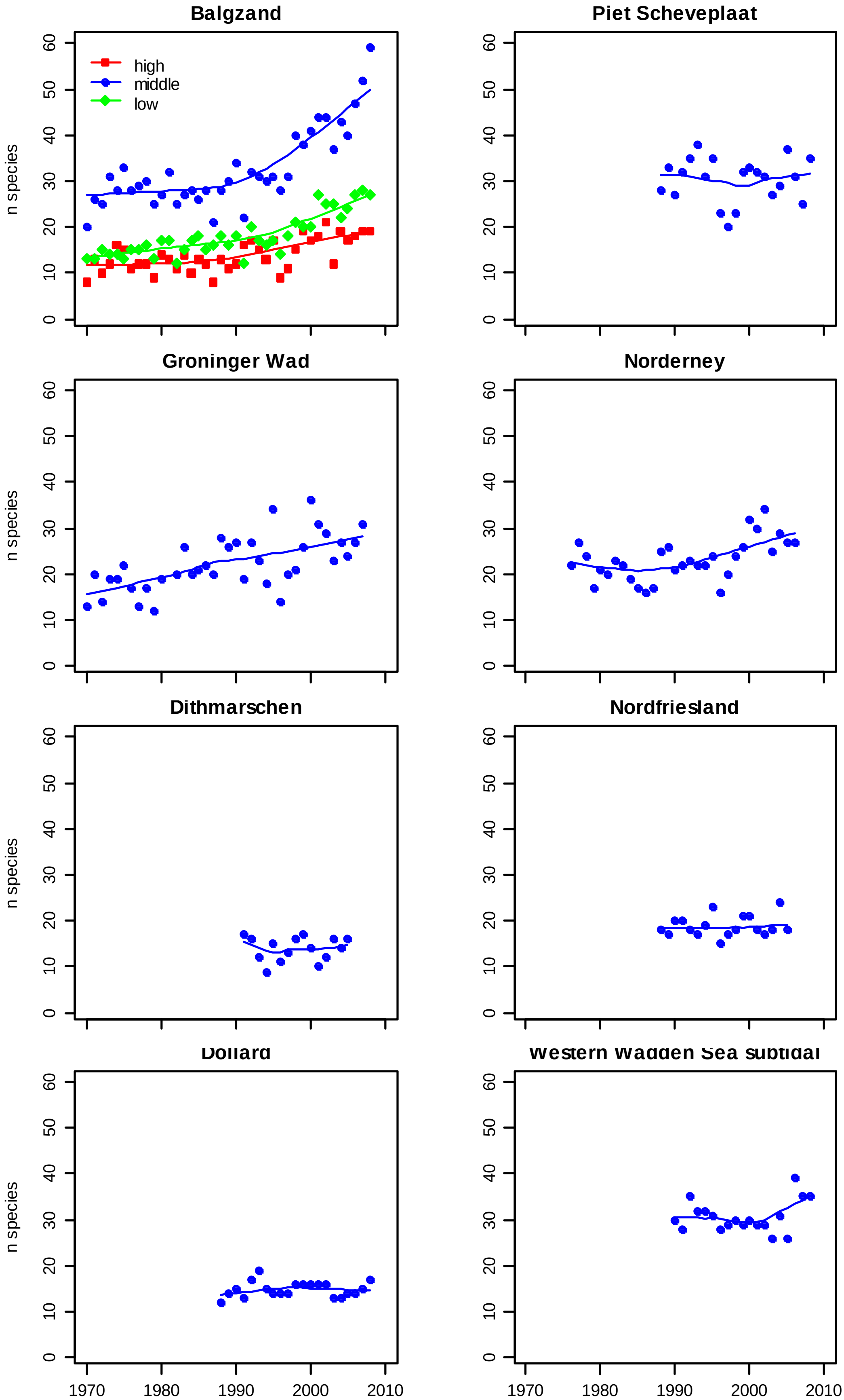


Figure 5d: Standardised recruit density of *Ensis americanus* in late summer/early autumn. Note different y scales.

Figure 6: Time series of number of macrozoobenthos species in late winter/early spring (symbols), and Lowess smoother (solid lines). Different monitoring areas are show in separate panels.



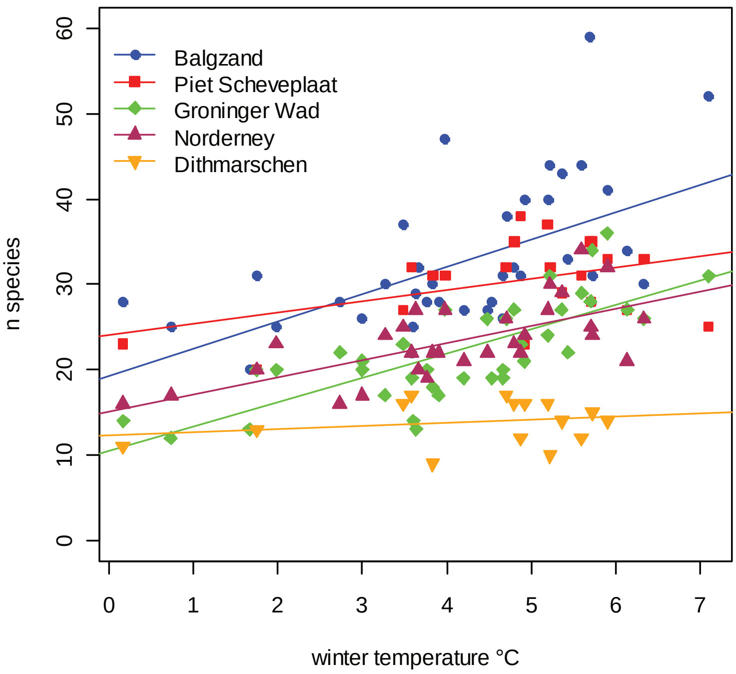


Figure 7: Number of macrozoobenthos species in late winter early spring, winter temperature relationships of five monitoring areas in the mid tidal zone with linear regression lines.

of *M. viridis* showed a peak around the year 2000 and even briefly appeared in the more eastern sites (except Schleswig-Holstein), but it has been decreasing again since 2002 in the two western areas and has completely disappeared from the other sites.

E. americanus appeared in the late 1970s (Armonies 2001). The population of *E. americanus* is still increasing in the Western sites; however, it seems like *E. americanus* is not replacing any Wadden Sea species but just adds to the total biomass (hence the increase in biomass in Balgzand low). This is also spatially the case as *E. americanus* has mainly established around the low water line, which has always been poor in species richness and biomass. At the Piet Scheveplaat *E. americanus* shows an increase in biomass the last 2 years. At the Groninger Wad, Norderney and Schleswig-Holstein, *E. americanus* was found in a few years but did not establish permanent populations.

Another new species in the Wadden Sea is the Pacific Oyster *Crassostrea gigas*. This species too has been increasing in biomass on Balgzand, but until now does not form a significant part of the total biomass in this area. However, the developments in the relatively small areas where long-term macrozoobenthos monitoring is being carried out are not appropriate for population studies of *C. gigas*. In general, it can be observed that *C. gigas* has become dominant in terms of biomass in many intertidal blue mussel beds. The recent developments and resulting impacts concerning these species are further covered in Thematic Reports 7 (Alien species) and 11 (Blue mussel / Oyster beds) of this QSR.

Sieving of macrozoobenthos **(Photo: J. Voss).**

10.4 Discussion

10.4.1 Abiotic Factors

Climate change

The most important climatic factor affecting macrozoobenthos in the Wadden Sea is winter temperature (Beukema 1990,1992 and Armonies *et al.*, 1990). There are two main effects, first the winter survival of species sensitive for low temperatures increases with winter temperature. Second the chance of successful bivalve recruitment declines with increasing winter temperatures. Indicative for the whole Wadden Sea area, winter water temperatures (mean of temperature during December, January and February) in the Marsdiep tidal inlet have increased about 1.5°C during the last two decades (Van Aken 2008, Figure 8). (Winter air temperatures are similar over the entire Wadden Sea area apart from a lower average of about 1.5°C in the northeastern compared to southwestern Wadden Sea and strongly correlated with water temperature. Winter water temperature of the Marsdiep inlet therefore is a good indicator of temporal variability in winter character over the entire Wadden Sea area.) Is there any indication that the recent warm winters are having lasting effects on the macrozoobenthos?

With the present available dataset in each site number of encountered species after the winter is positively related with winter water temperature of the Marsdiep (Figure 7). However the correlations were not significant for the Western Wadden Sea subtidal, Dollard, Dithmarschen and Nordfriesland. At several sites there is a long-term increase of number of species as would be expected when winters become milder. Although part of these increases in species numbers could be attributed to more precise identification. After accounting for this still a temporal increase in species numbers is observed at Balgzand Groninger Wad and Norderney. It is likely that these trends are caused by a warmer climate and in addition by the appearance of several invasive species.

The generality of the other important effect of winter temperature, the negative relation with bivalve recruitment, depends on the species. The effect is most pronounced for *M. balthica*. For this species the relationship was significantly negative at seven out of the eleven sites (Spearman rank correlation between Marsdiep winter water temperature (Figure 8) and the estimate of the number of recruits (Figure 5)). For *C. edule* only 3 out of 11 sites showed significant negative relationships. For *M. arenaria* a significant negative temperature effect was only found at Balgzand middle and Groninger Wad. And finally for *E. americanus* there was no site at all where winter water temperature was significantly correlated with number of recruits. Concerning recruitment success, such mechanism is also assumed for Mytilus edulis (Nehls *et al.*, 2006).

The difference in the effect of winter temperature on recruitment between bivalve species could lead to shifts in the bivalve community. *M. balthica* would be most severely affected by warmer winters, *C. edule* and *M. arenaria* to a lesser extend and *E. americanus* would not suffer at all. And indeed of all the major macrozoobenthos species *M. balthica* had the overall strongest negative development in abundance particularly during the last decade (Figure 4). It is likely that from the Wadden Sea macrozoobenthos this species is most severally impacted by warmer temperatures as not only recruitment but also growth and survival are negatively related with temperature (Beukema and Dekker 2009). At the same time *E. americanus* increased (Figure 4, Table 2) but this is limited to a subtidal and a very low intertidal site in the most westerly part of the Wadden Sea. At the higher tidal levels no negative impact of reduced *C. edule* spat fall is not visible in the biomass and abundance time series; apparently the negative impact of winters with higher temperatures on recruitment is compensated by a higher adult survival that is better during warm than cold winters. Overall *M. arenaria* is increasing (Figure 4, Table 2) not suggesting any negative impact of elevated temperatures..

An interesting point is that of the common species the ones most sensitive to cold winters, *L. conchilega*, *C. edule*, *N. succinea* and N. hombergii only *N. succinea* is showing a clear increase in abundance. Of the four least sensitive

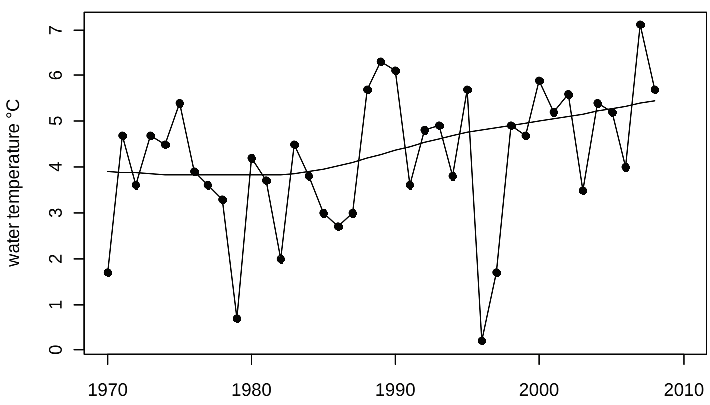


Figure 8: Winter water temperature calculated as the average over January, February and December of the previous year, of the Marsdiep inlet.

species, *A. marina*, *C. volutator M. balthica* and S. plana three are among the species with overall negative trends in abundance (Figure 4, Table 2). If a temperature increase is having an effect this is less clear for species sensitive to cold winters than for species not affected by low temperatures.

Eutrophication

Thematic Report 6 on Eutrophication concludes that riverine nutrient inputs into the Wadden Sea have been gradually decreasing since 1985; this has had a significant effect on the phytoplankton biomass (measured as chlorophyll) in summer in most of the Western Wadden Sea and some areas in the Eastern Wadden Sea (Thematic Report 6 Eutrophication).

Macrozoobenthos is primarily dependent on primary production of microphytobenthos and phytoplankton as a food source. Phytoplankton biomass is usually expressed as the chlorophyll a concentration in the water. A significant positive relation between chlorophyll concentration and density and biomass of macrozoobenthos was found in two long-term data series in the Dutch Wadden Sea (Beukema *et al.,* 2002), especially at places with already high macrozoobenthos biomass, where food, presumably, was strongly limiting. A decrease in phytoplankton which is presumably caused by decreasing nutrient input (*e.g.* primary production) would thus be predicted to lead back to lower food availability for macrozoobenthos and a decreased biomass, especially of the suspension and deposit feeders. Instead of continuing to use chlorophyll as the only measurement for primary production, research into additionally measuring primary production directly (*e.g.* by determination of phytoplankton biovolume and biomass) is needed as a combination of both measurements may give a better causative relationship to benthos biomass.

Philippart *et al.,* (2007) presented an analysis of 30-year concurrent field observations on phytoplankton, macrozoobenthos and estuarine birds in the Dutch Wadden Sea, which has been subject to decades of nutrient enrichment and subsequent nutrient reduction. They demonstrated that long-term variations in limiting nutrients (phosphate and silicon) were weakly correlated with biomass and more strongly with community structures of phytoplankton, macrozoobenthos and estuarine birds. Macrozoobenthos data were obtained from four Balgzand transects. The biomass of deposit and mixed feeding macrozoobenthos seemed to be correlated with the eutrophication status (increasing the 1980s decreasing in the 1990s), but the biomass of filter feeders did not. Hence, community structure slightly changed to include more deposit and mixed feeding species at the peak of eutrophication. Although Philippart *et al.,* (2007) could not conclusively determine if, and if so to what extent, nutrient enrichment and subsequent nutrient reduction actually contributed to the concurrent trends in these communities, they concluded that is was likely that part of the variance in the studied coastal communities is related to changes in nutrient loads.

Effects of eutrophication on the macrozoobenthos have been relatively mild in the Wadden Sea area and it is therefore not expected that the present reduction in nutrient loads and concurrent decline in Chlorophyll a levels will lead to strong and clear responses of the macrozoobenthos community. There are two trends that could be related to the decline primary production. The first is the declining trend of summer biomass during the past ten years at all monitoring sites above the lowest tidal zone in the Dutch part of the Wadden Sea while the winter biomass does not show any recent changes (Fig. 2). This means that the difference between winter and summer biomass is declining, which can be interpreted as a decline of production by the macrozoobenthos (secondary production). This decline is a likely consequence of reduced food availability for the benthic community.

A second trend that might be related with the eutrophication status is recent decline of the deposit feeder associated with high organic loads *Heteromastus filiformis*, which shows a decrease during the last 10 years at several monitoring sites (Figure 4, Table 2) This happened after an initial increase between since 1975.

It is, however, possible that the expected decrease in benthic biomass for other species is being postponed or blurred by other developments. More detailed research and analyses, including continuation of long term monitoring, is necessary to be able to analyse whether food limitation due to the decrease of eutrophication has an effect on biomass and community structure of macrozoobenthos.

Furthermore, research is needed on the release of nutrients from the sediment by the benthos itself.

Fisheries

The main macrozoobenthos species that is fished is the blue mussel (Mytilus edulis). Only in the Netherlands cockle (*Cerastoderma edule*) fisheries used to be an important economical sector and had an impact on the cockle stock and distribution. In 2005 the EVA II report was published (Ens *et al.,* 2004). This report evaluated the effects of shellfish fisheries in the Netherlands. The research showed that in areas closed for cockle-fisheries the cockle biomass was higher than in areas open to cockle-fisheries. It also showed a decrease in other macrozoobenthos in areas open to cockle-fisheries. Only one species was found to profit from the fisheries; the polychaete Nereis diversicolor. Concurrently it was shown that the numbers of worm-eating birds increased in the Wadden Sea (Ens *et al.,* 2004). As a result of the EVA II report mechanical cockle fisheries were stopped in the Dutch part of the Wadden Sea since 2005. Cockle-fisheries were stopped in Schleswig-Holstein and Lower Saxony in respectively 1989 and 1999. In Denmark, 99% of the Wadden Sea Area is closed for cockle fisheries.

Fisheries of blue mussels have been regulated in all countries with regard to the amount of permits, size of culture lots, fishing periods and other regulations. In the Netherlands and Germany, blue mussel fisheries are mainly carried out on seed mussels from natural beds. In Denmark commercially sized mussels are fished from wild natural beds. More information on blue mussel and cockle fisheries is in Thematic Report 3.5 (Fishery), see also Herlyn *et al.,* 2008.

Kraan *et al.,* 2007 Show that both cockles and other species had relatively higher abundances in areas that were soon to be dredged and that species richness was also higher in the soon-to-be-dredged areas than in untouched areas. Differences in developments between dredged and undredged areas are attributed to fishing activity. However it is problematic to do this because any difference in development of species between areas can as well just be an effect of the innate difference in areas in the first place.

Van Gils *et al.,* 2006 shows an effect of fisheries on recruitment as before by Piersma *et al.,* 2001. Specifically after cockle dredging, cockle recruits are in a poorer body condition than in areas not previously dredged. This may be caused by the disturbance of the sediment affecting benthic primary producers and sediment stability.]

10.4.2 Increase of polychaetes

Reise (1982) drew attention to an increasing trend of polychaetes abundances in the intertidal Wadden Sea. He concluded that half of the changes are due to human interferences, such as disturbed habitats from overfishing or destruction of Sabellaria reefs. Similarly Beukema *et al.,* (2002) reported that at the Balgzand intertidal flats small-sized worms became very abundant during the 1980s and 1990s. In the 1999 and 2004 QSRs an increasing trend in polychaete biomass was described for several locations: Balgzand, Groninger Wad and Norderney (Reise 1982; Beukema *et al.,* 2002). The idea of increasing polychaete abundances was further worked out in Essink *et al.,* (2006). They showed a trend of increasing biomass values of polychaetes, whereas bivalve biomass (making up 40-60% of total macrozoobenthic biomass) showed strong fluctuations mainly governed by the severity of winter conditions. Similarly, the EVA II research (Ens *et al.,* 2004) showed an increase in the biomass of the polychaete Nereis diversicolor. Cockle fisheries and eutrophication were in the 2004 QSR mentioned as possible causes. Essink *et al.,* (2006), however, indicated that at the same time as the increase in polychaete biomass, riverine nutrient discharges into the Wadden Sea have decreased, thus not supporting the hypothesis of a causal relationship between polychaete biomass and eutrophication. They did conclude, however, that polychaete biomass, is larger in the more eutrophicated southern, than in the less eutrophicated northern part of the Wadden Sea.

Figure 9 shows the bivalve/polychaete ratio (biomass) for all areas in the Wadden Sea. For some cases, where one species is very abundant this ratio may mainly indicate the variability of one species, however, the index gives an overall picture. In the 1980s/early 1990s, the bivalve/polychaete ratio in summer did indeed go down on the Balgzand, Norderney and Nordfriesland. These initial declines, however, levelled off or even changed into an increase. On other locations (Piet Scheveplaat and Dollard), initial increase levelled of towards a more stable situation in the past decade. No trend towards more polychaetes is visible for any area in the Wadden Sea in the last 10 years. Neither do we find support in the datasets for the last statement of Essink *et al.,* (2006), which was based on the same dataset up to 2004, that polychaete biomass is larger in the southern than in the northern part of the Wadden Sea. In the Dollard, the ratio used to be strongly in favour of the polychaetes (Figure 3: mainly *Marenzelleria viridis*. In the early 1990s, however, *M. viridis* strongly declined, leading to an increase in the bivalve/polychaete ratio. In the Western Wadden Sea subtidal the increase of *M. arenaria* and *E. americanus* is the cause of the increased ratio.

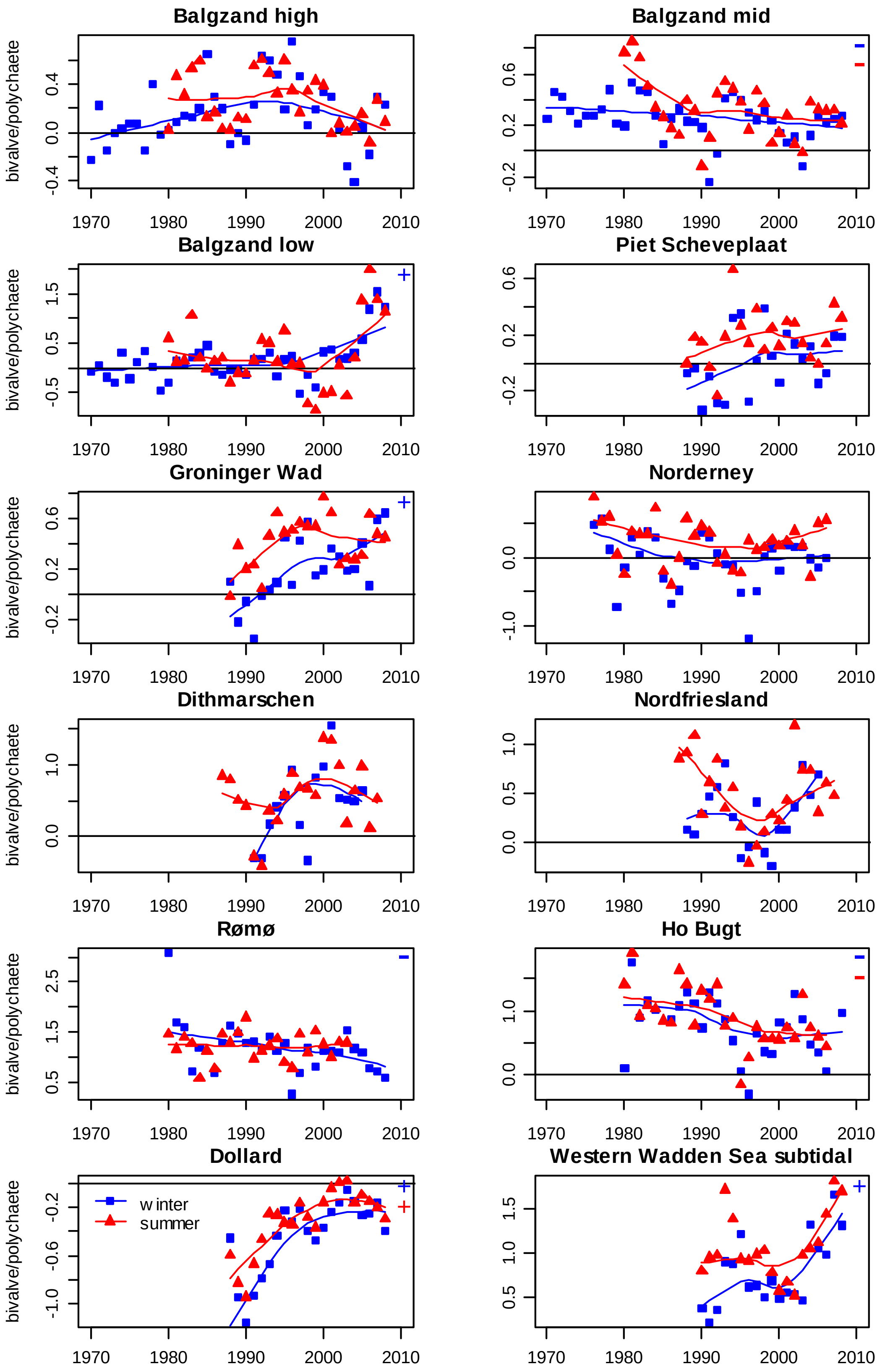


Figure 9: Bivalve-to-polychaete mass-ratio (log10 transformed) time series in winter/early spring and summer/early autumn. Different monitoring areas are show in separate panels. Means per season (symbols), and Lowess smoother (solid lines). Note differences in y scales.

10.5 Conclusions and target evaluation

10.5.1 Conclusions

Long-term monitoring, during the last 30 years, has proven to be very important in the analysis of trends in biomass and species composition. Without such a long-term data set it would be impossible to distinguish real changes from incidental highs or lows. Continuation of the monitoring on these long-term sites remains also in the future very important.

The long-time series used in this chapter show different signals in different sites. Also small scale, within-site, variations may play a role. The following conclusions can be drawn:

Biomass

- There are some regional trends
- The clear and significant increase of total biomass in Balgzand during winter/early spring can not be extrapolated to other areas
- At monitoring sites in the Netherlands total summer biomass is declining while winter biomass continuous to increase or remains stable.

Abundance

- There are few clear trends in abundance of species that are the same for all sites. M. baltica, S. armiger and recently also *H. filiformis* are declining. *N. succinea* and *U. poseidonis* are the species with strongest increase. The development of the polychaete *Heteromastus filiformis* may be reflecting the eutrophication status of the Wadden Sea.

Species number and composition

- In general, species number remain stable; some sites show an increase especially at Balgzand
- There are no indications for polychaete take over
- There are no clear trends in the species composition. There are however large differences between monitoring sites, Sites in the vicinity of fresh water outflow (Balgzand, Western Wadden Sea subtidal and Dithmarschen) are dominated by *M. arenaria*, while *C. edule* is more important at the other sites.

Neobiota

- The abundances of the newcomers *Ensis americanus*, *Crassostrea gigas* are generally increasing, except the abundance of the polychaete Marenzellaria viridis, which came up during the 90ties and has been decreasing strongly since 2000
- There is no indication that newcomers take over from the "old" species, their biomass just adds to the "old" biomass

Environmental effects and human impacts

- At present, there is no clear indication of any effects of climate change on most of the macrozoobenthos species. However, the number of species has increased with increasing winter temperature and some cold tolerant species are declining most notable *M. balthica*.
- Global warming may have negative impact on the recruitment success of the bivalves *Macoma balthica*, Cerastoderma edulis, Mya arenaria and Mytilus edulis
- There is no strong indication of effects of the reduction in eutrophication on macrozoobenthos – there may be some indications of summer biomass reduction in the Western Wadden Sea

10.5.2 Target evaluation

In the Wadden Sea Plan no specific target was developed for macrozoobenthos, therefore, no evaluation is possible. Possible targets could be developed in relation to the distribution of macrozoobenthos (for example: a natural distribution), endangered species or habitat disturbance. If a target is developed in the future this should integrate the WFD and HD assessments.

10.6 Recommendations

10.6.1 Research

1. Investigations for a better understanding of the impact of climate change on the development (*e.g.* on recruitment success) of macrozoobenthos species are necessary.
2. More research is needed on the link between macrozoobenthos and its food resources (primary production), especially more data on the primary production are needed for eutrophication assessment.

10.6.2 Monitoring and Assessment:

1. Continuation of existing long-time monitoring stations.
2. Further harmonization of monitoring programs and methods by applying the demands of the EC Directives and the Wadden Sea Plan.
3. The representativeness of existing stations (total overview MZB distribution) should be assessed. A better spatial coverage can be achieved by additional stations to enhance the comparability between different regions.
4. Integrate the parameter "Recruitment of bivalves" in all monitoring series, to calculate this parameter the size classes of bivalves need to be recorded.
5. Establishment of a subtidal monitoring program in the Wadden Sea.
6. Information and metadata of research projects should be made available for the macrozoobenthos assessment in the Wadden Sea by use of meta-data catalogues (NOKIS, WISE, INSPIRE *etc.*).
7. Experiences form the QSR assessment should be used for a standardized analysis and reporting *e.g.* in a framework of a future information system.

10.6.3 Management

1. No specific Target for macrozoobenthos has to be developed, but the integration of the overall WSP targets of natural dynamics with the demands of HD, WFD and MSD should be aimed at.
2. There is a need for a regular exchange of results from macrozoobenthos assessments within a trilateral workshop or ad-hoc working group (further harmonization of programs, methods and assessment procedures).

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Appendix 1: Site characteristics

Area	Row	Media grain µm	silt %	Method silt measurement	Average period	Emergence % of time	N_WGS84	E_WGS84	Height (m)	Height refer-ence
Balgzand	B	138,3	5,43	<16 µm laserdiffraction	2000-2007	34,8	52,93544	4,824101	-0,45	NAP
Balgzand	C	168,6	3,39	<16 µm laserdiffraction	2000-2007	34,1	52,94122	4,905574	-0,49	NAP
Balgzand	D	174,2	3,35	<16 µm laserdiffraction	2000-2007	33,8	52,9421	4,901213	-0,46	NAP
Balgzand	E	157,9	4,39	<16 µm laserdiffraction	2000-2007	37,2	52,94233	4,808935	-0,35	NAP
Balgzand	F	180,3	3,05	<16 µm laserdiffraction	2000-2007	36,5	52,95619	4,916324	-0,42	NAP
Balgzand	G	117,5	9,72	<16 µm laserdiffraction	2000-2007	57,3	52,90463	4,842371	0,2	NAP
Balgzand	H	139,9	5,68	<16 µm laserdiffraction	2000-2007	42,7	52,91114	4,849611	-0,31	NAP
Balgzand	J	249,9	1,52	<16 µm laserdiffraction	2000-2007	1,8	52,9804	4,89965	-1,02	NAP
Balgzand	K	147,6	4,35	<16 µm laserdiffraction	2000-2007	38,7	52,92177	4,850379	-0,33	NAP
Balgzand	L	153,4	3,92	<16 µm laserdiffraction	2000-2007	32	52,92621	4,89226	-0,43	NAP
Balgzand	M	180,6	3,09	<16 µm laserdiffraction	2000-2007	49,4	52,95001	4,839855	-0,42	NAP
Balgzand	N	98,6	11,61	<16 µm laserdiffraction	2000-2007	82,1	52,89635	4,862944	0,44	NAP
Balgzand	Sl	165,6	3,63	<16 µm laserdiffraction	2000-2007	61	52,92174	4,814122	0,11	NAP
Balgzand	Dk	137,2	8,49	<16 µm laserdiffraction	2000-2007	61	52,91731	4,813377	0,1	NAP
Balgzand	Mz	260,0	1,42	<16 µm laserdiffraction	2000-2007	0	52,98196	4,90318	-0,9	NAP
Western Wadden Sea	O	138,9	6,80	<16 µm laserdiffraction	2000-2007	0	53,0179	5,145097	-4,3	NAP
Western Wadden Sea	P	170,4	3,20	<16 µm laserdiffraction	2000-2007	0	53,08494	5,188295	-1,6	NAP
Western Wadden Sea	Q	138,5	6,24	<16 µm laserdiffraction	2000-2007	0	53,16217	5,313576	-2,35	NAP
Piet Scheveplaat	R	168,9	2,50	<16 µm laserdiffraction	2000-2007	51,45	53,39709	5,788211	0,2	NAP
Piet Scheveplaat	S	159,2	2,24	<16 µm laserdiffraction	2000-2007	54,15	53,39929	5,802137	0,4	NAP
Piet Scheveplaat	T	139,2	5,91	<16 µm laserdiffraction	2000-2007	40,55	53,39857	5,813556	-0,25	NAP
Dollard	U	124,4	7,26	<16 µm laserdiffraction	2000-2007	60,05	53,29445	7,147873	0,2	NAP
Dollard	V	106,1	9,78	<16 µm laserdiffraction	2000-2007	53,7	53,28601	7,144574	0,35	NAP
Dollard	W	105,4	10,07	<16 µm laserdiffraction	2000-2007	64,65	53,27634	7,141902	0,5	NAP
Groninger Wad	47-0	107,4	7,21	<16 µm laserdiffraction	2001-2006	54	53,43839	6,500374	0,13	NAP
Groninger Wad	47-1	137,8	4,32	<16 µm laserdiffraction	2001-2006	54	53,43673	6,501129	-0,43	NAP
Groninger Wad	51-2	136,0	3,06	<16 µm laserdiffraction	2001-2006	55	53,4396	6,528622	0,26	NAP
Groninger Wad	54-0	129,4	5,59	<16 µm laserdiffraction	2001-2006	52	53,44142	6,545963	0,02	NAP
Groninger Wad	54-1	142,0	1,99	<16 µm laserdiffraction	2001-2006	54	53,44065	6,545761	0,26	NAP
Norderney	T1	180	6,0	<63 µm stacked sieves	2003	71	53,70278	7,237778	0,37	NN
Norderney	T2	185	4,6	<63 µm stacked sieves	2003	66	53,70083	7,237778	0,27	NN
Norderney	T3	210	9,7	<63 µm stacked sieves	2003	50	53,69917	7,237778	0,00	NN
Norderney	T4	160	7,5	<63 µm stacked sieves	2003	58	53,69778	7,237778	0,21	NN
Dithmarschen/ Büsum	B1-8	88.0	25	<63 µm stacked sieves	1987-1988	62	54,16167	8,816167	0,97	NN
Nordfriesland / Dagebüll	D1-8	110.0	11	<63 µm stacked sieves	1987-1988	40	54,723	8,697	-0,20	NN
Nordfriesland / Nord-strand	N1-8	130.0	10	<63 µm stacked sieves	1987-1988	50	54,47417	8,801167	0,34	NN

*NN = Normalnull DHN92 (Deutsches Höhennetz 92) mit dem Höhenstatus 160, same as NAP = Normaal Amsterdams Peil

Appendix 2: List of names and class of species recorded in the macrozoobenthos monitoring programs in the Wadden Sea between 1988 and present. The list is ordered by commonness defined as the count of the number of sites where the species was encountered. The 18 species that contribute at least one percent to the total biomass at, at least one of the monitoring sites are printed in bold. Site abbreviations are explained in Table 1.

WADDEN SEA ECOSYSTEM No. 25

Quality Status Report 2009
Thematic Report No. 11

Beds of blue mussels and Pacific oysters

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1. Introduction

Intertidal blue mussel bed
(Photo: Gerald Millat)

Blue mussel beds (*Mytilus edulis*) are important biogenic structures in the Wadden Sea ecosystem, serving as diverse habitat and as important food source for a number of species, especially mussel-eating birds.

Trilateral Targets for intertidal blue mussels have been adopted in 1994 and a trilateral policy and management plan for blue mussel fishery has been laid down in the Wadden Sea Plan 1997.

Strong decreases in intertidal mussel bed area in all parts of the Wadden Sea in the 1980s and 1990s led to an intense discussion about the impact of fisheries and protection measures were established. Within the entire Wadden Sea, substantial parts of the intertidal area have been permanently closed for blue mussel fisheries in order to protect mussel beds. In The Netherlands, intertidal fishery is restricted to experimental fishery on young, unstable beds outside areas that are permanently closed. In the subtidal, unstable beds are fished in autumn, stable beds in spring. In Niedersachsen, fishery of seed mussels is allowed in the subtidal and defined parts of the intertidal, in accordance with the existing management plan, which is revised regularly. In Schleswig-Holstein, mussel fishery has not been allowed in the intertidal area nor in most subtidal parts of the national park core zone since 1997. About 50% of the Danish Wadden Sea has been closed for mussel fishery since 1992. Although mussel fishery is allowed in intertidal as well as subtidal areas, intertidal mussel beds of the Danish Wadden Sea usually remain unfished, due to a smaller tidal range.

Trilateral Targets for the Tidal Area (subtidal and intertidal).

- A natural dynamic situation in the Tidal Area.
- An increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas.
- An increased area of and a more natural distribution and development of natural mussel beds, *Sabellaria* reefs and *Zostera* fields.

Despite considerable efforts in mussel management, long-term observations of intertidal blue mussel beds revealed that the number and size of mature mussel beds continuously declined over the last decades in most parts of the Wadden Sea. Several factors relevant for survival of mussel beds have been discussed. At the beginning, mussel fishery was considered to be the main reason leading to a large decline of intertidal mussel beds, especially in periods of failing spatfall. As a consequence, it was proposed that the management of mussel fishery should be based on protection of sites where stable beds occur and of sites with a high potential for the development of stable beds. Recent studies, however, showed that the development of mussel stocks is not only influenced by fisheries but also affected by considerable natural factors and most probably by the proceeding climate change, *e.g.* the availability of seed mussels is linked to the temperature in January – March and the probability of spatfall increases with decreasing winter temperatures (Dankers and Zuidema, 1995; Strasser *et al.,* 2001a; Beukema and Dekker, 2005).

In 2007, the Interpretation Manual of European Union Habitats was updated with new definitions for the three marine habitat types listed in Annex I of the 92/43 Habitats Directive including habitat type 1170 (reefs). According to the new definition, 'bivalve mussel beds originating from dead or living animals' may be regarded as reefs, but the definition restricts this mainly to the subtidal zone as it states: 'reefs may extend from the subtidal uninterrupted into the intertidal (littoral) zone or may only occur in the subtidal zone'. Reefs have been mentioned in the standard data forms of the Wadden Sea Natura 2000 areas in Niedersachsen and Schleswig-Holstein. Although a clear definition and a protocol on how to map intertidal blue mussel beds in the Wadden Sea based on visual methods has been available for years, this is not the case for subtidal mussel beds, where visual methods are not applicable. Therefore, member states will still have to agree on criteria and a procedure to identify and map subtidal mussel beds and how to classify them as reefs. In addition, mussel beds may also occur as parts of the habitats 1140 'mudflats' and 1110 'sandbanks' and 1160 'large shallow inlets and bays'.

In preparation for the 2010 Wadden Sea Ministerial Conference, the Trilateral Wadden Sea Plan is getting revised with mussel fishery as an important element of the plan and in conjunction with the EU Habitats and Bird Directives. The next paragraphs report on the implementation of the recommendations in the 2004 QSR, the developments of intertidal as well as subtidal mussel beds and mussel stocks since 2004, the impact of mussel fishery, and the role of bio-invaders, especially the introduced Pacific oyster (*Crassostrea gigas*), in mussel beds.

2. Recommendations of the QSR 2004

In the 2004 QSR, the following recommendations were made:

1. Further research is needed to get insight into the spatfall process in general, and the cause of low recruitment of intertidal mussels and mussel beds.
2. The settlement of the introduced Pacific oysters may have a major impact on native mussel beds and their biomass in the near future. Therefore, the further spread of the Pacific oyster in and outside mussel beds as well as possible consequences to the Wadden Sea ecosystem should be subject of a detailed research and monitoring program. A common approach should be developed also aiming at development of management tools that could be used to reduce the influence of Pacific oysters on mussel beds.
3. The biotope 'intertidal blue mussel bed at stable sites' should be considered within the EU Water Framework Directive as a biological quality element for coastal waters. Additionally, because of its ecological importance, the biotope 'subtidal blue mussel bed at stable sites' should be considered as a biological quality element for water in the relevant EC Directives.
4. Substantial investigation effort is needed to document the location and extent of subtidal mussel beds in the Wadden Sea and their structure and function.
5. The management measure of protecting stable mussel beds or sites is still valid.
6. Protection of mussel beds (at stable sites) against fishery should not be restricted to the intertidal area but at least part of the subtidal beds should be protected as well.
7. To extend – if possible – the habitat model for intertidal mussel beds developed as a management tool for the Dutch Wadden Sea also to the German and Danish Wadden Sea.

Since then, progress has been made in respect of most of the recommendations, but not in all cases and not always in all regions of the Wadden Sea:

1. Mussel beds are monitored annually in The Netherlands, Niedersachsen and Schleswig-Holstein. In the Danish Wadden Sea a regular monitoring of all mussel beds in areas open for fishery is conducted every second year. The recommendations of the Trilateral Monitoring and Assessment Program (TMAP) are not always fulfilled. In The Netherlands and in Denmark, the annual stock assessment covers both intertidal and subtidal mussel beds. In Niedersachsen and Schleswig-Holstein the main effort is concentrated on intertidal beds. In Schleswig-Holstein some information on mussel stocks and newly established spatfall areas in the subtidal is available from the vessel's blackbox data as well. Research on the important questions into the spatfall process in general, and the cause of low recruitment of intertidal mussels and subsequent survival of the mussel beds is limited. Some research on spatfall dynamics is carried out by fundamental research institutes such as NIOZ (Royal Netherlands Institute for Sea Research) in The Netherlands and AWI (Alfred Wegener Institute for Polar and Marine Research) in Schleswig-Holstein but main questions on spatfall dynamics still need to be answered.

2. The spread of the Pacific oyster has received much attention in the last years and research projects have been conducted in all parts of the Wadden Sea. A common approach to monitoring of Pacific oyster has been developed by the TMAP blue mussel group. In The Netherlands no specific monitoring for oysters is carried out, but oysters are sampled and registered in blue mussel inventories (Fey *et al.*, 2009a). In Schleswig-Holstein, Pacific oysters have been monitored since 1998 within the blue mussel monitoring. In Niedersachsen, 12 intertidal mussel beds evenly distributed in the area have been under investigation since 2003. The spread of Pacific oysters as well as their impact on intertidal mussel beds in terms of ecological functioning have been documented in two reports (Wehrmann *et al.*, 2006; Wehrmann *et al.*, 2009). In Denmark, surveys on Pacific oyster development are carried out biannually (Kristensen and Pihl, 2006, 2008). Spread of the Pacific Oyster has been further documented in a report commissioned by CWSS (Nehls and Büttger, 2007) and at a trilateral workshop in 2007.

3. An approach to include mussel beds of the Wadden Sea into quality assessments according to the EU Water Framework Directive has been made in Schleswig-Holstein (Büttger and Nehls, 2009) and this subject is in discussion in other parts of the Wadden Sea as well. In The Netherlands mussel beds are considered as a quality parameter in the habitat type 1140 (intertidal sand- and mudflats), in the subtidal (1110) and in the estuary of the Ems (1160). From Danish experiences it is regarded as a problem that beds are actually not stable but varied strongly through the years. *E.g.* the intertidal beds along

the Sædding Strand in Ho Bight in the Danish Wadden Sea have never been fished through the last 20 years, but still varied considerably both in cover and biomass. On the other hand there are also examples of beds that have survived for decades, such as between Langli and Skallingen. In Niedersachsen similar observations were made, but there, "stable sites" were recognised within beds which generally occur.

4. Monitoring of subtidal mussel beds is undertaken annually in The Netherlands on a stratified grid, but little effort is made in the other parts of the Wadden Sea. Currently, in Niedersachsen, a research project (named "Kartierung subintertidaler Habitate im Niedersächsischen Wattenmeer mittels akustischer Fernerkundung") is carried out by the Research Institute Senckenberg to detect, classify and map in detail the different types of subtidal habitats in the Wadden Sea by means of acoustical remote sensing methods. In Schleswig-Holstein, a pilot project with comparable aims on behalf of the National Park authority started in 2009. Until now, due to methodological constraints and the higher effort needed, knowledge on distribution and dynamics of subtidal mussel beds is much lower as compared to intertidal mussel beds. Within the Dutch research project PRODUS, subtidal mussel beds receive much attention, but in the other parts of the Wadden Sea the efforts to study and monitor subtidal mussel beds remain at a low level (see also QSR 2009 Thematic Report 13).

5. No changes.

6. In all parts of the Wadden Sea, substantial areas in the intertidal have been closed for shellfish fisheries. It is, however, not always well documented whether these areas actually contain substantial parts of the mussel population. At the moment the fishery of mussels in the Danish Wadden Sea is closed due to lack of food for the birds depended of mussels (oystercatchers, eiders, gulls).

In The Netherlands, licenses are today only provided if the outcome of an appropriate assessment indicates no significant impacts on conservation targets within the Natura 2000 area. After 1 July 2008, any fishery taking place in a Natura 2000 area in Denmark has, according to the Fishery legislation, likewise to be evaluated and the ecological consequences have to be assessed before fishery can be permitted.

7. The habitat model developed in The Netherlands has so far not been extended to other parts of the Wadden Sea.

So far, the quality status description of mussel beds has been mainly focused on the area of present beds. However, due to lack of recruitment, existing beds grow older and although their areas may remain the same, the quality of the beds, in terms of cover and mussel density, decreases. Only in a limited number of beds detailed information on percentage cover, population and community structure and other relevant variables are monitored.

Moreover, over the past five years, Pacific oysters became increasingly abundant in both intertidal mussel beds and subtidal structures. Recently the debate started about when beds are still mussel beds or should be considered oyster beds. Altogether, the discussion on the quality and identity of mussel beds has started and needs to be resolved in the near future.

3. Development of blue mussel beds

3.1 Size and biomass of intertidal blue mussel / Pacific oyster beds

Overall development of mussel beds in the Wadden Sea is characterized by a marked decrease over the last decade in all areas except the Dutch Wadden Sea, where mussel beds recovered after a crash in the early 1990s (Figure 1). In all areas, Pacific oysters increased markedly and reached equal or even higher levels in biomass (live wet weight) as compared to mussels.

Most mussel beds decrease in size when storms remove areas along the wind-exposed side, although sometimes these mussels regain strongholds along the leeward site and causing the beds to grow there. The individual patch sizes also decrease resulting in a lower percentage cover, although when most of the bed disappears the remaining patches may lead to an increase of the percentage cover. Therefore the quantity (area) and quality (coverage) of the beds should not be examined independently of each other. The density per unit area also decreased.

The Netherlands

In their evaluation of the historical development of intertidal mussel beds, Dankers *et al.* (2003) re-estimated the area of mussel beds in the period 1960-1990. This area may have varied between 1,000 and 6,000 ha. The value of 4,120 ha for 1976 and 1978, presented in the 1999 QSR and well documented in the habitat maps for the Wadden Sea (Dijkema, 1989), lies well within this range. These mussel bed areas occurred in spite of fishery, so these estimates can be considered as minimum values of the 'natural' area. Dankers *et al.* (2003) and van Stralen (2002) described the dynamics of the Dutch intertidal mussel beds. They stated that in most years some spatfall occurs in existing beds. Losses due to storms and ice winters are often compensated by spatfall which results in the formation of new beds, but mostly in the neighborhood of or on the remainders of these.

After intensive fishery in a period with low spatfall, most intertidal mussel beds in the Dutch Wadden Sea disappeared in the period 1988-1991 (Dankers *et al.*, 1999). The oldest intertidal beds now present in The Netherlands, with a total surface of about 200 ha (Dankers *et al.*, 2003 and *unpubl. data* for recent years) are from the 1994 spatfall. The spatfalls of 1999, 2001, 2003 and 2005 are the main contributors to the present situation. Based on the ground survey and expert judgment the area of intertidal mussel beds in the spring of 2006 was estimated at about 2,600 ha (Goudswaard *et al.*, 2008; Figure 1). Since then there has been a gradual decrease (Goudswaard *et al.*, 2008; Fey *et al.*, 2008a), and the area was less than 1,500 ha in the spring of 2008 (see section 3.2).

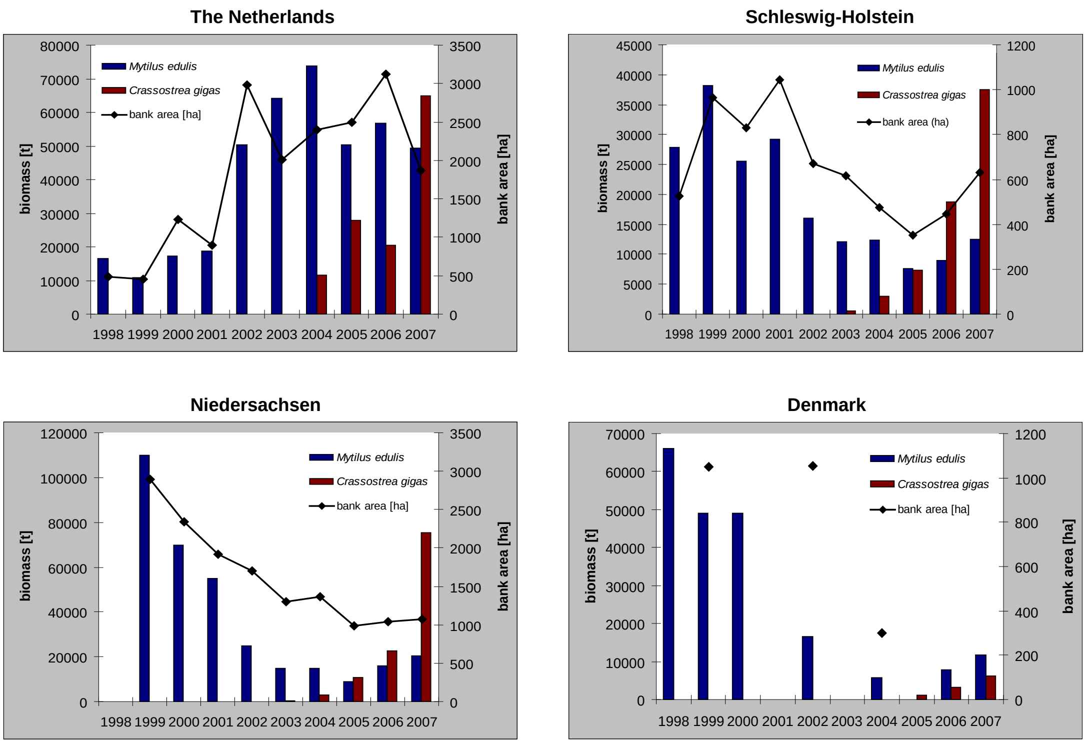


Figure 1: Development of mussel bed area and biomass of blue mussels and Pacific oysters in the Wadden Sea regions between 1998 and 2007. Biomass is given as total wet weight (Goudswaard *et al.*, 2008, Millat, Herlyn, Markert and Kristensen *pers. com.*).

Since 1991, mussel fishery has been restricted to the subtidal part of the Dutch Wadden Sea, however with two exceptions. First, fishery was allowed in the autumn of 1994 on young seed beds of the 1994 spatfall. Many of these seed beds (both fished and unfished) disappeared in early 1995 due to storms, and subsequently were heavily damaged by the severe winters of 1996 and 1997. Second, a restricted experimental fishery was carried out in 2001 on plots on beds that were considered unstable, to test the hypothesis that moderate fishery could increase the stability of young mussel beds. The experimental fishery did not show stabilization of the beds as autumn and winter storms destroyed the fished as well as unfished experimental plots (Smaal *et al.,* 2003). Therefore, it can be stated that in the Dutch Wadden Sea the mussel fishery since 1991 had no, or at the most a negligible, impact on the development of mussel beds on the intertidal flats.

Each year in spring the biomass of the mussel population in the Dutch Wadden Sea is determined by a stratified survey. The total biomass has increased from about 11,000 t fresh weight in 1999 to about 54,800 t in 2008 (Goudswaard *et al.,* 2008). In the last three years spatfall has been low, resulting in a population of older mussels (Fey *et al.,* 2008a; Goudswaard *et al.,* 2008). In this period of limited spatfall the area of mussel beds gradually decreased because natural losses are not compensated.

Niedersachsen

Between 1950 and 1987, mussel beds covered an estimated surface area of up to 5,000 ha (Dijkema, 1989; Michaelis *et al.,* 1995). Since then mussel beds have decreased continuously. In 1994, mussel beds covered an area of only 1,300 ha. After the severe winter of 1995/96, the lowest value of 170 ha has been recorded (Michaelis *et al.,* 1995; Herlyn and Michaelis, 1996; Zens *et al.,* 1997; Herlyn and Millat, 2004) (Figure 1). In the same year a strong spatfall led to an increase of the mussel beds, but three years later the area covered by blue mussel beds started to decrease again. Since 1996, some additional spatfall occurred, leading to a mixed age structure. Over the last five years mussel bed area in Niedersachsen stabilized at 1,000 to 1,300 ha. The biomass of intertidal mussel beds showed a similar trend. In spring 1996, mussel biomass was estimated at about 1,000 tons wet weight. Following a strong spatfall in the same year, biomass increased again and reached a maximum of 110,000 tons wet weight in 1999. Up to 2005, the biomass of the mussel beds showed a continuous decrease to 9,000 tons. Since 2005, there has been a slight increase in biomass to 20,000 tons in 2007, but surface area of the beds has shown no positive trend.

Schleswig-Holstein

The area of mussel beds present in 1989 was reassessed by analysis of aerial photographs and estimated at 1,500 ha. This is the highest value documented so far in this part of the Wadden Sea (Nehls, 2003; Nehls and Ruth, 2004; Stoddard, 2003). Mussel beds at that time originated mainly from the strong spatfall of 1987 which occurred after a series of three cold winters. Until today, the last good spatfall was observed after the severe winter of 1995/96 at locations that were considered to be low in hydrodynamics and mainly on the lower parts of intertidal flats and in existing mussel beds at high shore. Monitoring of blue mussel beds was resumed in 1998 (Nehls, 2003). The area covered with mussel beds in 1999 was about 1,000 ha (Figure 1). Since then, it decreased to 354 ha in 2005 which was mainly a result of storms and a lack of recruitment in this period. Percentage of cover decreased from 43% in 1998 to 26% in 2002. In the following years, the area of mussel beds increased from 445 ha in 2006 to 652 ha in 2007, which did not result from increasing blue mussel abundances but rather from successful recruitment of the Pacific oyster *Crassostrea gigas* (Nehls and Büttger, 2009).

Biomass estimates from times before the intensive fisheries of the mid 1980s are not available. After the good spatfall of 1987, 60,000 t (wet weight) were documented in 1988 and 1989. This stock decreased to 35,000 t in the early 1990s due to fisheries on 30 out of 64 beds and strong winter gales in the early 1990. Since 1992, the majority of the mussel seed fishery occurred in the subtidal and, after 1994, intertidal fishery has been abandoned. After 1996, total biomass of intertidal mussel beds increased from 32,000 t in 1998 to 40,000 t in 1999, and decreased to 8,000 t in 2005 (Figure 1). Coverage was highest in the first two years of the monitoring with 43% in 1998 and 32% in 1999. Between 2001 and 2007 coverage ranges between 19 and 27% (Nehls and Büttger, 2006, 2009).

Denmark

For the Danish Wadden Sea, Munch-Petersen and Kristensen (1987) estimated the total area covered with mussel beds, present before the overfishing in 1984-1987, at 4,000 ha, based on aerial photographs and includes scattered mussels

('Streusiedlung') in very large areas. As these areas with scattered mussels do not meet the present criteria for mussel beds, these historic estimates should be reduced to about 2,000 ha (Kristensen, personal judgment) to allow comparison with recent data. After a period of heavy fishery, Munksgaard (1989) estimated the total area of mussel beds to be only about 500 ha in 1989 (scattered mussels were not included). In 1991, 1,100 ha were present but in 1996 the area decreased again to only 600 ha (Kristensen, 1997). In 1999, the area had increased again to 1,000 ha (Kristensen and Pihl, 2003) (Figure 1). The areas with mussels varied considerably since the mid 1980s but never exceeded 2,000 ha. In the Juvre Dyb, Mandø and Knude Dyb areas, beds never returned after their removal by fisheries. In the Ho Bight area (partly closed for fishery), almost 70% of the original beds returned by an autumn settlement immediately after the breakdown in 1989. This situation remained stable in the years after 1999. Some intertidal beds disappeared and some new beds appeared. In 2002, 650-900 ha of mussel beds were present (Kristensen and Pihl, 2003). So, the area covered with mussel beds as well as the biomass has been variable over the years (Kristensen, 1997; Kristensen and Pihl, 2003).

3.2 Distribution and age composition of intertidal blue mussel beds in the Wadden Sea since 1999

Overall distribution of mussel beds in the Wadden Sea changed over the last decade. Mussel bed area in the northern half of the Wadden Sea strongly decreased whereas it was more stable in the eastern Dutch Wadden Sea and the western part of Niedersachsen (Figure 2).

The Netherlands

The age structure of the mussels on the mussel beds varied considerably (van Stralen, 2002; Steenbergen, 2003; Goudswaard *et al.*, 2008). Marked spatfall events occurred about every 2-4 years, and there are indications of large variations in sizes of the beds (Dankers *et al.*, 2004). Because of this irregular occurrence, age composition also varies substantially between years. In years after a considerable spatfall, small mussels may dominate the population, but a few years later different cohorts shape the population because, even in poor years, some spatfalls occurs in existing beds.

Survey data indicate that in the Dutch part of the Wadden Sea several major spatfall events oc-

Figure 2: Distribution of intertidal blue mussel beds in the Wadden Sea in the period 1999-2007.

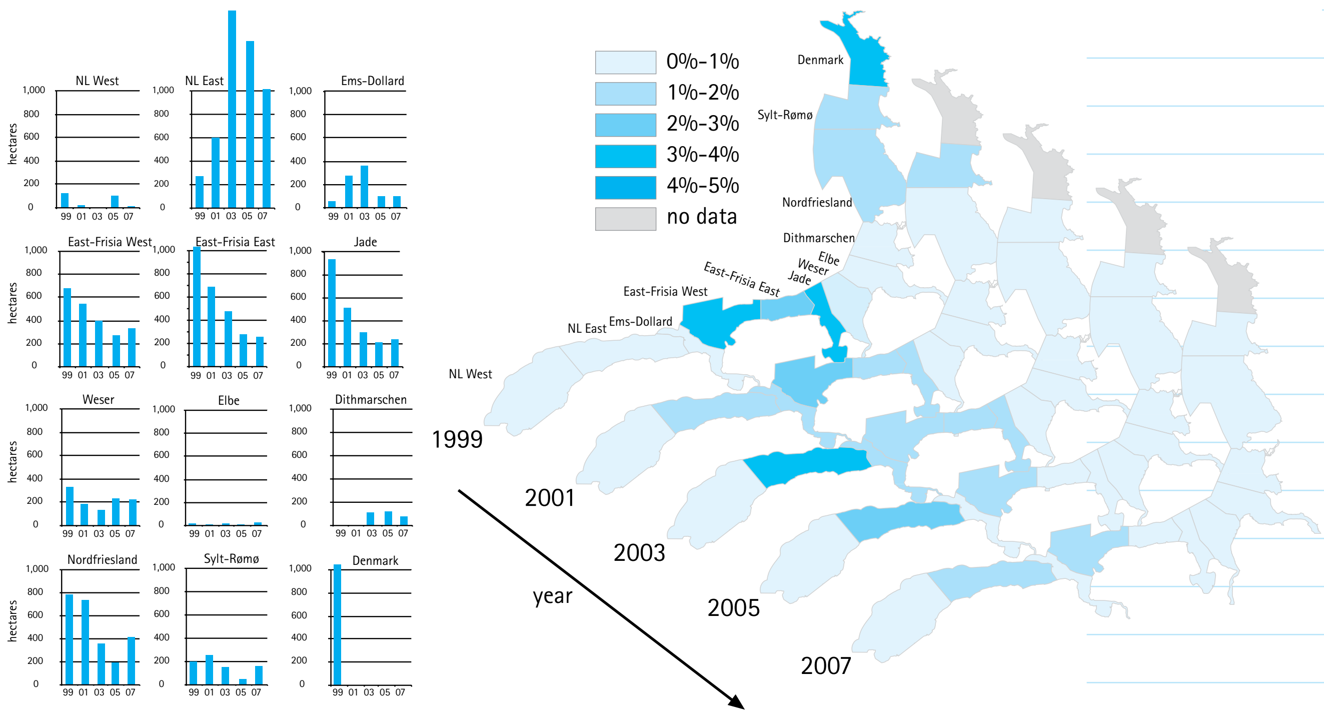
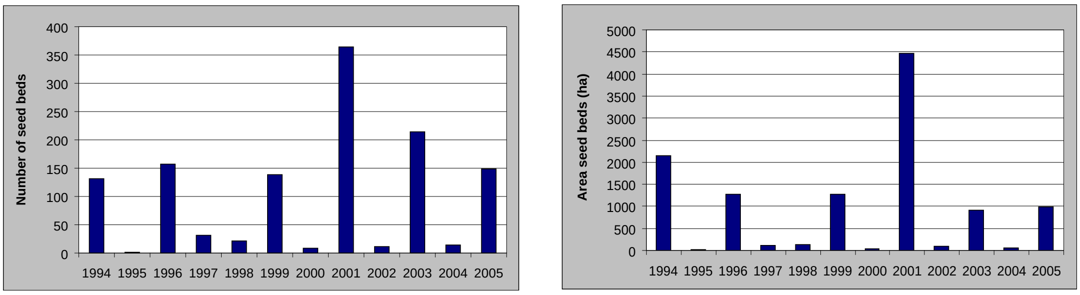


Figure 3:
Number (left) and area (right) of intertidal seed mussel beds in The Netherlands from 1994 to 2005.



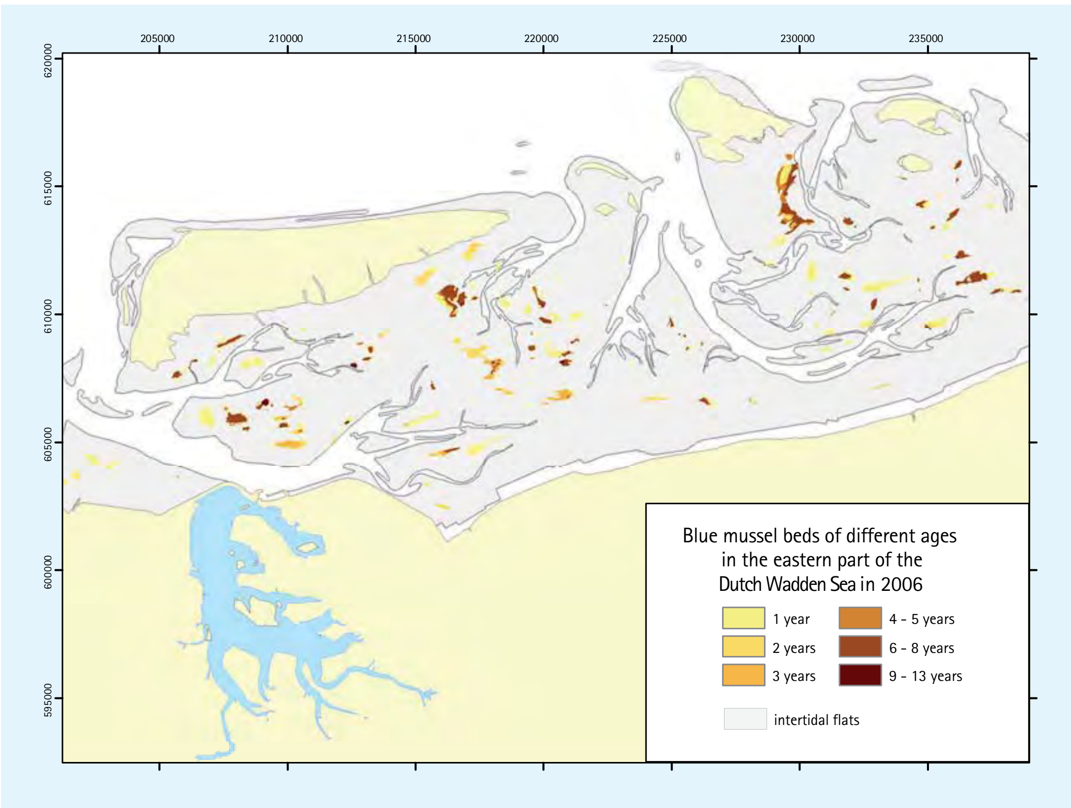
curred over the last 20 years. Good to reasonable years, with spatfall either on existing beds or resulting in new seedbeds, are 1984, 1985, 1987, 1994, 1996, 1999, 2001, 2003 and 2005. Figure 3 gives the number as well as the area of seed mussel beds in the Dutch Wadden Sea. In years of good spatfall, between 100 and 150 new beds establish and an area of 1000 ha new seed beds is quite common.

Since 1995, all beds have been mapped each spring. Several beds have reached an age of more than 10 years. Maps of beds or parts of beds of different ages are available at IMARES. An example of a small area is given in Figure 4.

Niedersachsen

Until the end of the 1990s, the age structure of the mussel beds in Niedersachsen was dominated by blue mussels from the spatfall in 1996, which reached densities above 75,000 ind./m² in the settling stage (Herlyn *et al.*, submitted). As a consequence of decreasing numbers of older mussels and local spatfalls, the population structure mixed in age over the course of the years. Especially smaller mussels settle in the manifold system of gaps within mixed blue mussel/oyster beds providing shelter *e.g.* from predation (Markert *et al.*, 2009).

Figure 4:
Mussel beds of different ages in the intertidal area south of the Dutch islands of Schiermonnikoog and Rottum.



Schleswig-Holstein

Mussel beds have been recorded in about 200 locations so far. They are not evenly distributed within the Wadden Sea of Schleswig-Holstein but are high in numbers in the Lister Deep, between the islands of Amrum and Föhr and east of the island of Pellworm. In some areas where mussel beds were abundant in former years, such as the Hörnum Deep and the area east of the island of Föhr, only a few mussel beds are currently present. Since 2000, only few newly established blue mussel beds have been recorded in the area between Eiderstedt and the Danish border because of insufficient recruitment success (Figure 5). The difference with the situation in the Dutch part (Figure 3) is striking.

The age structure of the mussels indicated in the late 1990s that mussel beds were dominated by the 1996 recruitment event that followed upon the severe winter in 1995/96. In the following years spatfall varied regionally. Mean densities of new settlers in the mussel beds in September averaged 500 ind./m^2 in the Lister Deep and 1,200 ind./m^2 in Norderhever and Rummelloch. A strong spatfall leading to the colonization of new beds reaches 10,000 to 50,000 ind./m^2. In all years some spatfall occurred in spring, but it was usually much weaker than in late summer, and reached locally up to 6,000 ind./m^2. In most years, spatfall did not result in new beds and was insufficient to compensate for losses in existing beds (Nehls and Büttger, 2006).

Denmark

After the breakdown of the mussel stock in the Danish Wadden Sea in 1988, mussel beds rapidly recovered in many areas - as soon as the following year. In 1989 densities up to 100,000 ind./m^2 (shell length < 5 mm) have been determined for intertidal mussel beds in Ho Bight (Munch-Petersen and Kristensen, 2002). In 2002, the abundance on patches still covered by mussels reached 2,000 ind./m^2 (shell length ~ 55 mm) (Munch-Petersen and Kristensen, 2002). On these patches the biomass must have increased from around 5 kg/m^2 to 30-50 kg/m^2. In recent years, mussel beds in the intertidal in Ho Bight recovered and reached a stock size comparable to 1989 (Kristensen and Phil, 2008).

3.3 Subtidal mussel beds

Ecological conditions differ greatly between subtidal and intertidal areas of the Wadden Sea, leading to different developments and structures of mussel beds and associated communities. Subtidal mussels reach larger sizes and higher meat contents as compared to intertidal mussels. Knowledge on distribution, structure and ecology of natural subtidal mussel beds is limited in most parts of the Wadden Sea and little is known about productivity per area. It is also not clear to what extent subtidal mussel stocks could be classified according to the TMAP definition for intertidal mussel beds. Comparative field investigations of intertidal and adjacent shallow subtidal mussel beds near the island of Sylt in the northern Wadden Sea revealed substantial differences in biogenic mussel bed structure, species interactions and associated organisms. In this area, total number and distribution of associated species differ between intertidal and subtidal mussel beds. Some species occur in both tidal zones, but many are restricted to either intertidal or subtidal sites and especially subtidal mussel beds harbor a distinct and more diverse community of associated organisms (Saier, 2002; Buschbaum and Saier, 2003). Subtidal mussel beds are often more overgrown by epifauna, especially barnacles and slipper limpets, but little is known about endofauna of subtidal mussel beds. Structural differences include lower densities of mussels on subtidal than on intertidal beds (Saier, 2001, 2002; Buschbaum and Saier, 2001). Additionally, mussel individuals on intertidal beds are smaller. Therefore, in the northern Wadden Sea intertidal and subtidal mussel beds are ecologically different (Saier, 2002; Buschbaum and Saier, 2003).It is not clear, whether these results can be generally applied to other areas as well. However, it is also known from other parts of the Wadden Sea that natural subtidal mussel beds may have their own characteristic and species-rich community (Buhs and Reise, 1997 and references therein; Westphalen, 2006).

In former times, blue mussels were collected and fished from wild intertidal and subtidal mussel beds. This strategy changed with increasing mussel demand in the middle of the last century to subtidal bottom cultures in the Dutch and German

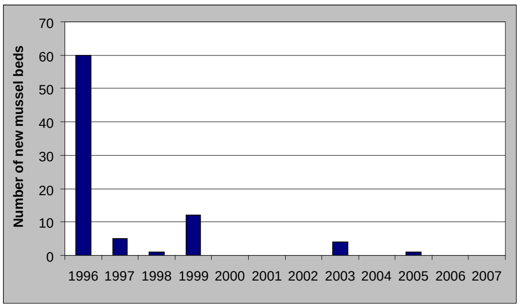


Figure 5: Number of new or re-established mussel beds in Schleswig-Holstein since 1996.

parts of the Wadden Sea (Dankers and Zuidema, 1995; Seaman and Ruth, 1997). The bottleneck for a successful mussel culture is the availability of juvenile seed mussels which are predominantly fished from the subtidal zone. The resulting high fishery pressure causes a number of possible impacts such as changes in seabed topography and disturbance of non-target organisms (Kaiser and Spencer, 1996). Additionally, fishery for seed mussels may affect the establishment of natural perennial subtidal mussel beds and at present these can be hardly found. However, the subtidal zone may become of increasing importance for mussels and may provide a refuge because intertidal beds are heavily overgrown with the Pacific oyster *Crassostrea gigas* (see section 4) and have partly shifted to oyster beds with changes in the associated species community and ecological function (Kochmann *et al.,* 2008; Markert *et al.,* 2009). Additionally, well established subtidal mussel beds may provide a nursery ground for juvenile mussels. Field experiments have shown that mussel recruitment on well established highly structured subtidal beds is about 20 times higher than on short living and less diverse culture lots (Buschbaum, unpubl. data). Thus, subtidal mussel beds are of high ecological value and more consideration should be concentrated on this comparatively less investigated but important habitat.

3.3.1 Status and exploitation of subtidal mussel beds

Annual landings of blue mussels in the Wadden Sea show a long-term decrease which is mainly attributed to the development in The Netherlands (see QSR 2009 Thematic Report 3.5 Fishery). In the other parts, landings are rather variable, but low over the last years.

The Netherlands

Status

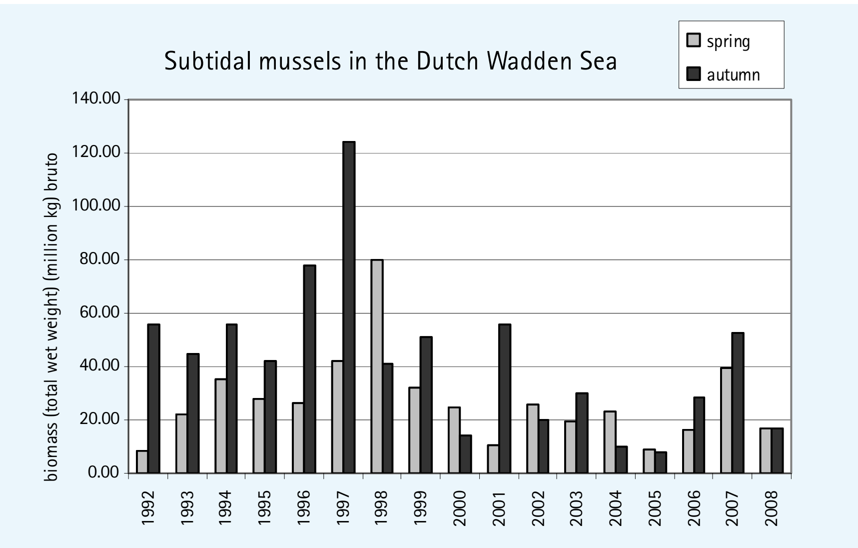
The location of subtidal mussel beds and their biomass has been monitored annually since 1992, in order to regulate fishery for seed mussels needed by mussel farmers to stock their culture lots. In The Netherlands, subtidal mussel beds mainly occur in the westernmost part of the Wadden Sea, in an area of about 500 km², in the vicinity of the 'Afsluitdijk'. The biomass is presented in Figure 6. Figure 7 shows the area where subtidal young mussel beds occurred in the period 1997-2007. This area, with large subtidal mussel beds interspaced with the channels of the Marsdiep tidal basin and some relatively low intertidal flats that hardly emerge during low tide, is influenced by release of fresh water via sluices in the 'Afsluitdijk', causing more or less brackish conditions with salinity usually between 15 and 25 PSU.

Mussel fishery

All natural subtidal mussel beds in the western Dutch Wadden Sea are heavily exploited by mussel farmers, collecting young or half-grown mussels ('seed mussels') to stock their culture lots. Due to fluctuating recruitment success the total biomass is highly variable, ranging from less than 10,000 to about 80,000 t fresh weight during the period 1992-2008 (Figure 6).

New spatfall occurs fairly often, leading to a moderate to good recruitment in some years, but there are also many years with almost failing

Figure 6: Biomass (total wet weight) of subtidal mussels in the Dutch Wadden Sea in spring and autumn from 1992-2007 (adjusted to Fey *et al.*, 2008b).



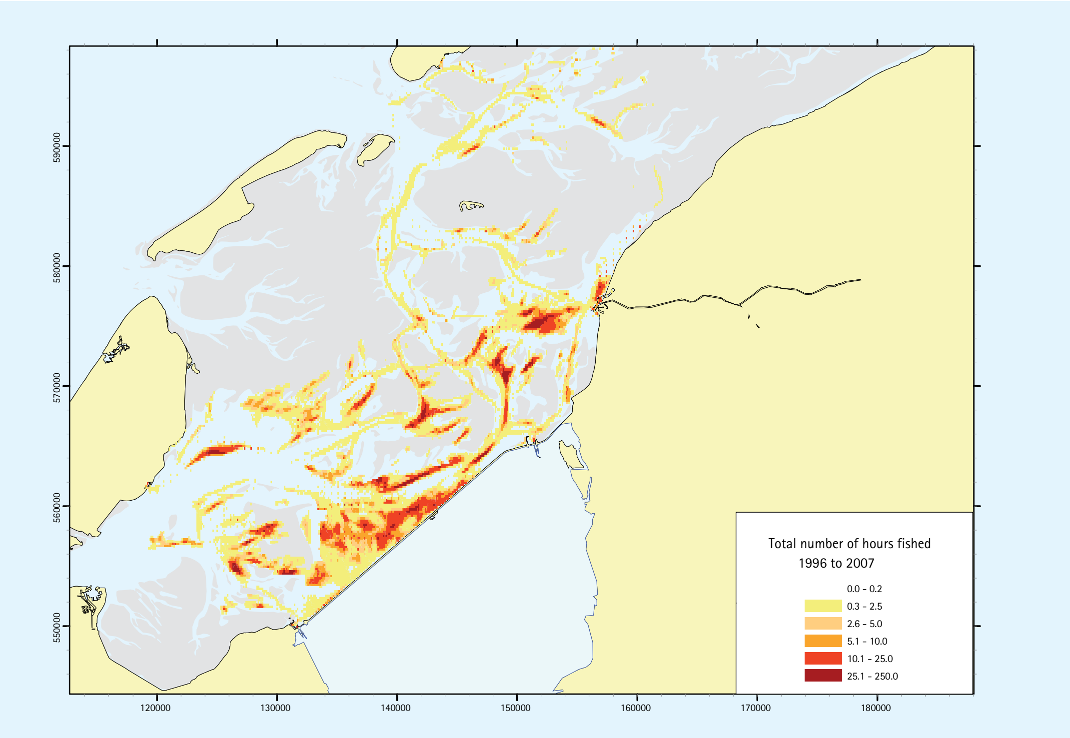


Figure 7: Subtidal seed mussel beds in the Dutch Western Wadden Sea depicted by fishing intensity.

spatfall. After 1990, however, recruitment appears to be less frequent than before, leading to lower biomass values than in the period 1970-1990 (Figure 8) (Brinkman and Smaal, 2003; Ens *et al.*, 2004).

There is no knowledge about the potential, age structure or biocoenosis of subtidal mussel beds in absence of fishery. A proposal has been made in the new Dutch fishery policy (2004) to establish some areas in which the development of undisturbed subtidal mussel beds can be studied, and the first bed of 100 ha has been protected since 2009 (see QSR Thematic Report 3.5 'Fishery').

Niedersachsen

Status

In Niedersachsen natural subtidal mussel beds have been recorded on every occasion within the last decades, but data about area and biomass are missing. In recent years, subtidal mussel beds between Borkum and Cuxhaven could not be recorded any longer, except for some young mussel aggregations.

Mussel fishery

Due to the increased occurrence of the Pacific oyster, seed mussel fishery in the intertidal be-

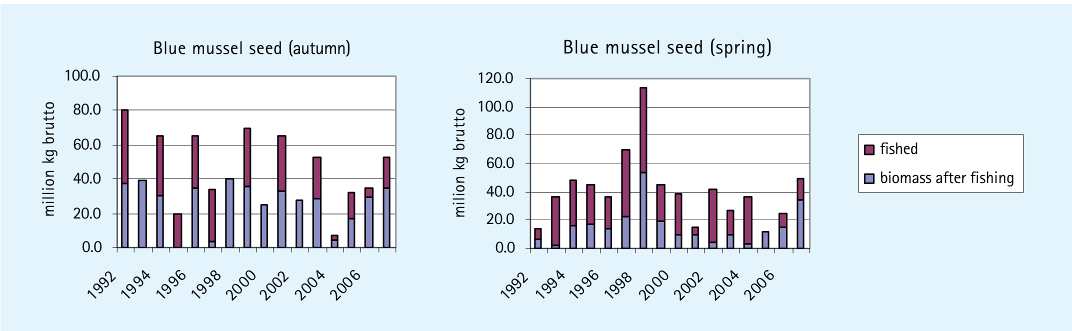


Figure 8: Biomass and fished mussels in autumn (left) and spring (right).

came less attractive in recent years, in some parts mussel fishery was even not practicable any longer. Recently, the deficiency of intertidal seed mussels is substituted mainly by seed mussel fishery of subtidal beds (Anonymus 2006, 2007). Furthermore, the enhanced use of seed collectors in the form of long-line cultures was developed in the Jade.

Schleswig-Holstein

Status

Subtidal mussel stocks were detected during partial annual surveys in 13 locations of the North Frisian Wadden Sea (Nehls and Büttger, 2006). Although no data on distribution and biomass could be gathered, the results indicate stable subtidal sites with regular recruitment in some locations. About a third of the subtidal area where spatfall can be expected has been closed for seed fishery since 1997. Actually, there is relatively little information about the subtidal stocks in the area closed for the seed fishery.

In 2003, some successful spatfall occurred in the area south of Sylt, south of the Hallig Langeness and in the area near Büsum. In 2004, spatfall has been observed only at one location near Büsum, but the mussels remained very small and died off very soon. In 2005, spatfall was again restricted to two small locations near Büsum. In 2006, 2007 and 2008, no spatfall at all has been observed in the Wadden Sea area of Schleswig-Holstein.

Mussel fishery

In Schleswig-Holstein, mussel seed fishing of new spatfall starts as early as possible, normally in July or early August at a mean mussel length of about 5 mm. Seed fishing is continued until late October/November when the mussels have reached mean length of about 35 mm. Quantities are not restricted, and the capacity of the fleet is high enough to reduce all existing stocks in the areas that are allowed to fish down to below 0.1 to 0.05 kg/m^2 until the next July. The companies start a common search for suitable mussel stocks in July, and are able to detect any reasonable stocks within the area they are allowed to fish for spat, *e.g.* the subtidal area outside the core zone of the national park. They are allowed to fish spat mussels within four small areas within the core area too, and may apply for permits for additional areas. Under this agreement they also make some effort to detect stocks in the entire core zone too. From 2004 onwards, only a few areas with reasonable stocks have been detected; since 2006 no fishable spatfall has been observed. Consequently there is pretty good evidence that no reasonable subtidal mussel stocks exist in the Schleswig-Holstein Wadden Sea at present.

Denmark

Status

Subtidal mussel beds in the Danish Wadden Sea are small compared to beds found in the intertidal. The area is estimated at about 200 ha since the survey program began in 1986 (Munch-Petersen and Kristensen, 1987, 2002). The main subtidal beds are situated in the Ho Bugt area. Some subtidal beds have disappeared and new ones have appeared. Subtidal beds are also found in Knude Deep and in Lister Deep. Those were formerly regularly exploited by fishery.

A nature conservation project started in 2002 to study whether transplantation of seed mussels to Jørgens Lo and Ribe Stream could contribute to re-establishment of mussel beds in this area. The results of the experiment were disappointing. Due to strong currents, the transplanted mussels of around 116 t were carried away from the subtidal to the intertidal area. However, they did not establish a new spawning stock as planned and expected.

Mussel fishery

There are no culture lots in Denmark and no fishing for seed mussels takes place. Export of seed mussels to The Netherlands or Schleswig-Holstein is prohibited.

The subtidal beds in Ho Bight are regularly fished, restricted by a quota set by the government. Since 1989, only limited fishing has taken place on subtidal mussel beds in the Lister Deep area.

No fishery has taken place in the last four years because the biomass of blue mussels present in the Danish Wadden Sea has been below the food level demands of the most important mussel-eating bird species (oystercatcher, eider and herring gull). A new estimation of the food demand for these species may postpone the possibilities of mussel fisheries for several more years and even endanger mussel fisheries in the Danish Wadden Sea. In 2009 it has been decided by the authorities responsible for the Danish Wadden Sea, to allocate 37,000 t (wet weight) of mussels in the future to the three bird species mentioned.

3.3.2 Culture lots

Culturing takes place in all areas of the Wadden Sea except for Denmark, which only allows quotas for direct landings from natural beds. Mussel beds on culture lots represent a man-made type of subtidal mussel bed with more disturbances (relaying, removal of seastars and algae) and therefore with a less diverse associated fauna than natural mussel beds.

The Netherlands

Currently, the total available area for culturing amounts about 7,600 ha, of which about 3,300 ha is stocked with mussels. The production at the culture lots in the Dutch Wadden Sea has tended to decrease since 1990 due to shortage of seed mussels.

Niedersachsen

Most culture lots in Niedersachsen are situated between the islands of Borkum, Juist and the mainland, and along the east side of the Jade and in the Jadebusen. Their total surface is about 1,300 ha. Fishing for seed mussels takes place in both intertidal and subtidal areas. Occasionally, seed mussels have been imported from Great Britain (Anonymus, 2005).

Schleswig-Holstein

Most of the culture lots in Schleswig-Holstein are situated in the northern part of the area, between Pellworm and the Danish border. The area of all culture lots in Schleswig-Holstein was reduced from an area of about 3,000 ha to a maximum of 2,000 ha at the end of 2006. Only two-third of the total surface can be used simultaneously. The remaining area is needed for replacing mussels from exposed to sheltered lots and vice versa. The landings of blue mussels in Schleswig-Holstein in 1985-2007 varied considerably. As the market has not been saturated since 1989, this variation is an expression of the availability of seed mussels in the preceding years.

Denmark

There are no culture lots in Denmark. All Danish blue mussels for human consumption are harvested from natural mussel beds in the subtidal area which are open for fishery.

4. Invasion of the Pacific oyster

4.1 Status of the Pacific oyster

Overfishing of the native European flat oyster beds (*Ostrea edulis*) at the end of the 19th Century resulted in a dramatic decline in the native oyster populations of the Wadden Sea. In the North Sea region, imports of *Crassostrea gigas* started in 1964 to The Netherlands, England, and France, later followed by Germany. The cultivation of the Pacific oyster *C. gigas* turned out to be successful. In most regions, the Pacific oysters did not remain restricted to their culture lots but reproduced and also dispersed in the Wadden Sea (Figure 9). The success of natural recruitment and the rate of spread are different in specific regions and seem to depend on abiotic factors. Total biomass in the Wadden Sea was calculated at 190,000 t total wet weight (TWW) in 2007. The most recent regional figures are as follows: The Netherlands: 65,000 t, Niedersachsen: 75,550 t, Schleswig-Holstein: 43,606 t, Denmark: 6,264 t. However, due to sampling difficulties the accuracy of these figures should be regarded with care.

Today, the Pacific oyster is found in all parts of the Wadden Sea, leading to the most obvious change in the habitat structure of mussel beds in the Wadden Sea. Oyster larvae settle on any kind of hard substrate (Fey *et al.*, 2009a), mainly as epibionts on intertidal mussel beds. A positive feedback in settlement (Troost *et al.*, 2004; Diederich, 2005; Wehrmann *et al.*, 2006) leads to cluster formation while areas with high densities are characterized by rigid and stable bioconstructions (Rabe, 2008; Wehrmann *et al.*, 2009).

Due to its high growth rate and recruitment success, accelerated by high summer temperatures and missing natural predators, the Pacific oyster is considered to be a potential risk to the mussel beds of the Wadden Sea. Being a suspension feeding organism, *C. gigas* competes with the native blue mussel for food as well as for space. Blue mussels have higher filtration rates than equal sized oysters (May, 2006). However, total amount of filtration capacity depends on biomass. As an ecosystem engineer, oysters are promoting complex and biodiverse communities, replacing and enhancing the ecological function of intertidal blue mussel beds in the Wadden Sea (Markert *et al.*, 2009).

Contrary to the native blue mussel, this species seems to be largely restricted to the intertidal during the first years of development (Nehls and Büttger, 2007; Kristensen and Pihl, 2008). In the Netherlands oysters occurred in large densities in the subtidal of the Eastern Scheldt, and recently also in the Wadden Sea there is a strong increase in the subtidal (Lang and Buschbaum 2009). In

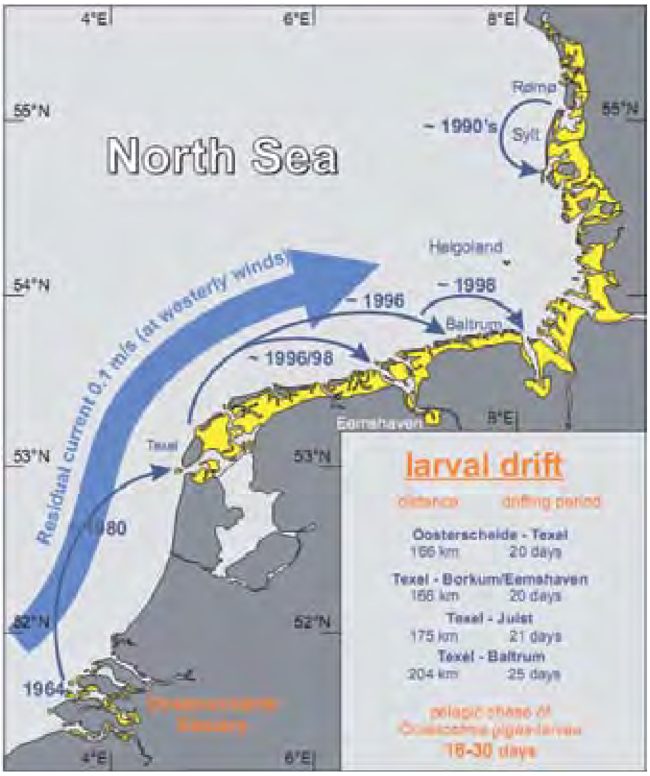


Figure 9: Pacific oysters in the Wadden Sea: Potential drift ways and year of invasion of *Crassostrea gigas* larvae from the known culture plots and wild populations of the Oosterschelde estuary and Texel into the backbarrier area of the East Frisian Islands, southern North Sea (Wehrmann *et al.*, 2000).

Niedersachsen, Pacific oysters have been reported in the subtidal at southern Randzel and in the Jade (Wehrmann, *unpubl. data*). In Schleswig-Holstein subtidal stocks are known from the Lister basin. Subtidal surveys (dredge hauls) between 2005 and 2007 in different channels outside the List basin detected only a few individuals in the subtidal, which might be transferred there by currents or storm events (Nehls and Büttger, 2007). There is evidence that in the Hörnum Deep near the island of Sylt, a strong spatfall from 2006 formed out large subtidal stocks of *C. gigas* (Ruth, *unpubl. data*). Reise (*pers. com.*) searched the subtidal parts of the Lister Deep for Pacific oysters in 2006 and reported a mean density of about two oysters per 100 m². In Denmark, subtidal Pacific oysters are reported in the Limfjorden (Kristensen unpubl. data).

The Netherlands

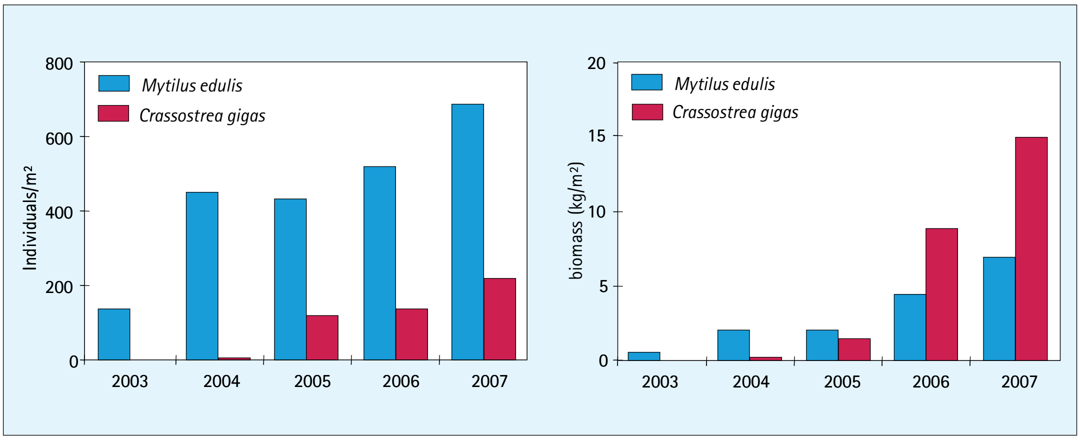
In 1983, wild grown Pacific oysters were first recorded near the island of Texel (Bruins, 1983), resulting from direct releases of oysters imported from the Oosterschelde (Tydeman, 2008). Since 2000, *C. gigas* is found in all parts of the Dutch Wadden Sea, although in most places in small numbers. After the rapid spread until 2004 the mean densities on several places (transect of Oudeschild, oyster bed Zeeburg, mussel bed near Ameland) seemed to stabilize, but densities still increased on a mussel bed near Ameland in 2006 (Fey *et al.,* 2009a). The maximum density reported by Fey *et al.* (2007) in the Dutch Wadden Sea was found on the oyster bed near Zeeburg (Texel) with more than 500 ind./m² in 2003. The area with a clear dominance of Pacific oysters in the Dutch Wadden Sea covered about 430 ha in 2005 and slightly decreased again in 2006. Areas with a mixed community of Pacific oysters and blue mussels increased since 2004, which might be a result from mussel spatfall. Scattered oysters were found in another 250 ha in 2005 and this area increased in 2006 up to nearly 400 ha indicating that Pacific oysters start to populate new areas.

Niedersachsen

First Pacific oysters in Niedersachsen were recorded in 1998 on an intertidal mussel bed near the island of Baltrum (Wehrmann *et al.,* 2000). Ten years later, Pacific oysters were found on all intertidal mussel beds in Niedersachsen. In 2003, only the western mussel beds reached marked abundances with up to 40 ind./m². In 2004 and 2005, Pacific oyster distribution and increasing abundances followed a gradient from high abundance in the west to low abundance in the east (Brandt *et al.,* 2008; Schmidt *et al.,* 2008). Especially after a strong spatfall in 2006, abundances were increasing in the eastern parts as well. Maximum abundance then reached 2,228 ind./m² in 2007. Maximum mean abundance in 2007 was 746 (± 667) ind./m² on an intertidal mussel bed in the Jade. Average abundance calculated for the tidal flats of Niedersachsen was 256 (± 210) ind./m² in 2007 which corresponds to a mean biomass of 7.1 (± 6,0) kg/m² (total wet weight). Total biomass in 2007, calculated for a total mussel bed area of 1,069 ha in Niedersachsen, is 75,500 t total wet weight (Wehrmann *et al.*, 2009). Compared to data from the Easter Scheld estuary and Schleswig-Holstein, mean values for biomass still seem to be at a lower level as invasion started much later in Niedersachsen. However, after a lack of spatfall in 2007 a strong spatfall was recorded in summer 2008.

Figure 10: Aggregation of Pacific oysters and blue mussels on an intertidal mussel bed in Niedersachsen where both ecosystem engineers, *Mytilus edulis* and *Crassostrea gigas*, are forming the shared habitat (Photo: A. Markert).

Figure 11: Development of abundance (individuals per m²) and biomass in kg total wet weight (TWW) per m² of blue mussels (*Mytilus edulis*) and Pacific Oysters (*Crassostrea gigas*) on a mussel bed in the Jade, Niedersachsen.



So far, Pacific oysters reach a maximum length of 30 cm. The presence of dead oysters is increasing as oysters stay cemented to their substrate. The ratio living/dead stayed ± constant at 1:1 but shell weight (length and/or age) of dead oysters increases and is already dominating the western mussel beds (Wehrmann *et al.*, 2009). Mussel bed areas with high oyster densities are characterized by increased habitat matrix and tend to increase in relief developing pronounced mounds (patches) and pools (open spaces).

Almost all intertidal mussel beds in Niedersachsen are mixed beds (Figure 10) with increasing densities of Pacific oysters as well as blue mussels. Blue mussels on sites densely colonized by oysters may show higher abundances than oysters, but oysters are dominant in forming the shared habitat (Figure 11).

Schleswig-Holstein

In Schleswig-Holstein, the main distribution area of the Pacific oyster is located in the intertidal of the Lister deep and on the tidal flats between the islands of Amrum and Föhr. In 1999, first surveys for oysters, conducted in the Lister Deep (first record in 1991), resulted in average densities of about 4 ind./m². Since that time, oysters have spread successfully in their new habitat. As a consequence, nearly all blue mussel beds of the Lister intertidal have been turned into Pacific oyster bedss over the years. In 2003, Pacific oysters reached densities of >100 ind./m² due to a considerable spatfall in 2002. In 2006, mean densities in the Lister Deep were 722 (± 267) ind./m² with a mean biomass of 50 kg/m² (TWW). This is similar to the highest values in the Oosterschelde. Since 2005, Pacific oysters form massive bedss in the Lister deep. Pacific oysters settle mainly on mussel beds but since 2004 some larger areas with empty shells from former mussel beds were colonized. In the area between Amrum and Föhr Pacific oysters appeared since 1998 in low densities. In 2004, higher abundances were recorded. In 2006 a strong spatfall was recorded in many areas of the Wadden Sea of Schleswig-Holstein.

Several tidal basins in Schleswig-Holstein show differences in spatial and temporal development. In the Lister Deep the spread occurred earlier and much stronger than in other places. This might be caused by the Pacific oyster cultures present in this area which potentially produces a large number of larvae. In other tidal basins oyster colonization occurred later. This is remarkable, for Pacific oysters being present in this region since 1995 and on nearly all intertidal mussel beds in 1998, although in low densities (<1 ind./m²). Recently, the change in species composition seems to be in an advanced phase between Amrum and Föhr. Going south from these two tidal basins, Pacific oysters are still found in low densities (1 ind./m²). Also, the spatfall in late 2006 appeared to be much less compared to the northern area. In 2006, about 95% of the oyster biomass in the Wadden Sea of Schleswig-Holstein was found in the Lister Deep (13,838 t), whereas oyster biomass on the tidal flats near Amrum was rather low (643 t) and negligible in the rest of the area. Due to the spatfall in 2006 the oyster biomass increased in 2007 to about 65 kg/m² in the Lister Deep and dropped again to 50 kg/m² in 2008 because of natural losses (mortality). In the Norderaue about 11 kg/m² were found in 2007 and the value reduced to 6.7 kg/m² in 2008.

Denmark

Pacific oysters have been recorded in the Danish Wadden Sea since 1996, but until 2004 oysters were found in low densities with only few individuals per km² (Kristensen unpubl. data). In 2004, a strong spatfall of Pacific oysters on former mussel beds in the Danish part of the Lister deep strongly enhanced the population growth. The biomass was estimated at 1,000 t. Kristensen and Pihl (2006) report biomass values (TWW) of Pacific oysters between 0 and 30.36 kg/m² in 2006. As a result of the growth of the Pacific oysters, biomass increased to 3,289 tons in the Danish Wadden Sea in 2006. The biomass of Pacific oysters has increased to 6,264 t in 2007 with local biomass values up to 71.5 kg/m² and about 1,500 ind./m² (Kristensen and Pihl, 2008). These biomass values are low in comparison to the other parts of the Wadden Sea.

4.2 Definition of mussel/oyster beds

Boundaries between mussel beds and the surrounding intertidal flats are not always clear-cut, which can easily lead to differences in size estimates among individual observers. Therefore, several criteria have been developed in order to make standardized decisions on the boundaries of mussel beds when carrying out field surveys (Figure 12) (TMAP Monitoring Handbook 2008). These criteria have been used since 2002 and proved to be useful.

Fields of scattered mussels, consisting of individuals and small conglomerates, are not included in the definition of mussel beds. They are generally not able to form a sizeable biogenic structure. Nevertheless, fields of scattered mussel clumps may consolidate to mussel beds after new spatfall or by more mussels being washed to these areas, but most of them disappear within one or two years.

A new method to estimate bed area has been developed (Kristensen and Borgstrøm, 2006), where digitized aerial pictures are applied and only the areas with mussels within the "old" bed structure are measured. All "sand"-parts are omitted in the calculation (Figure 13).

Aerial photographs and ground-surveys are used to determine the location and size and shape of mussel beds. For good recognition of intertidal mussel beds on aerial photographs, a stereoscope should be used. On average more than 75% of the beds can be recognized when information is available on preceding years (Fey-Hofstede *et al.*, 2009b). For monitoring purposes, it is important to carry out photographic surveys in a well-defined

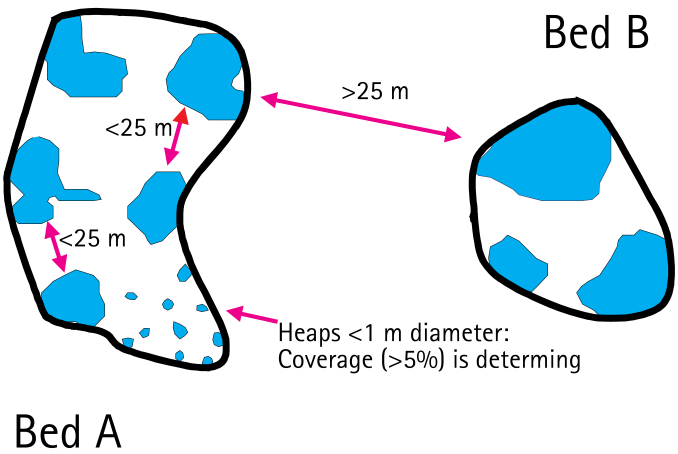


Figure 12: Blue mussel bed measuring protocol, with mussel patches (blue) and envelope (green).

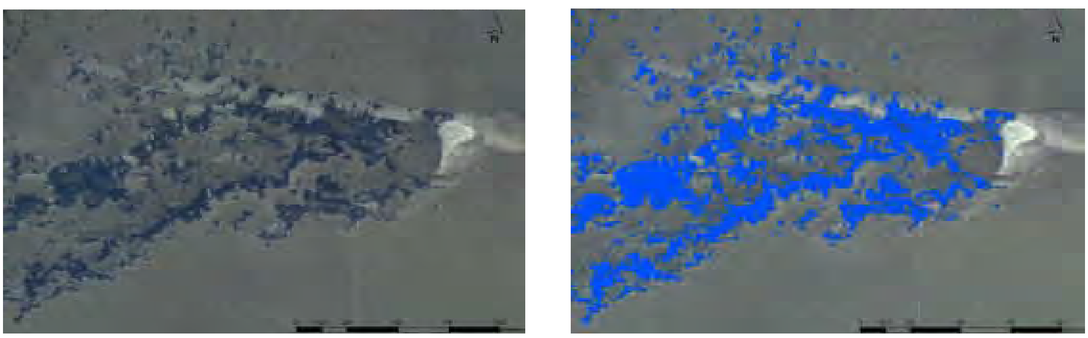


Figure 13: Scanned orthophoto of a smaller mussel bed in the Danish Wadden Sea (aerial photos from 2002, note: each pixel in blue is 0.16 m²). (From Kristensen and Borgstrøm, 2006).

time of the year because the surface covered by mussel beds can increase by spatfall during the summer months and will often decrease during autumn and winter due to storms and/or ice-scour. A relatively stable period is between March and July, after the winter and before new recruits can be detected on aerial photographs. Most of the maps of Dijkema (1989) were drawn from aerial photographs from this period. In The Netherlands (Ens *et al.*, 2004) and Niedersachsen (Herlyn and Millat, 2004), this period is recommended for aerial surveys of the surface covered with mussel beds. In Schleswig-Holstein, aerial photographs are intentionally made in autumn and therefore potentially include new spatfall.

Definition oyster beds/mixed beds

Pacific oysters and blue mussels often occur together, shaping the tidal flat as habitat builder in varying proportions. As they are different species and as the Pacific oyster is an introduced species, oyster beds should clearly be distinguished from blue mussel beds.

The question is when a wild bed is classified as an oyster bed or a mussel bed. Therefore a general definition is needed. A first approach is to use the live wet weight as parameter. The species which dominates the biomass (live wet weight) of a bed should define the classification.

If no samples are taken for measuring the flesh weight, the dominance of either mussels or oysters on these beds should be classified from its visual appearance. To this end, the following scale of oyster density is proposed:

1: <30% (pure mussel bed with scattered oysters)

2: >30% - 60% (balance between mussel and oyster patches)

3: >60% (oyster bed with mussel patches)

4.3 Consequences for monitoring and assessment

Due to its rapid spread and current stock development during the last years, it is strongly recommended that the development of the Pacific oyster becomes subject of a detailed monitoring program, considering the monitoring requirements from the EU Habitat Directives and the EU Water Framework Directive.

Definitions

Mussel bed

A mussel bed is a benthic community structured by blue mussels. Similarly, an oyster bed is a benthic community structured by oysters. Both communities mix. Mussel and oyster beds may consist of a spatially well defined irregular collection of more or less protruding smaller beds, which may be called patches, separated by open spaces. This description also includes young beds with a high abundance of small mussels. The described structure may not be so distinct in young beds or newly-settled beds (spatfall) (Blue mussel workshop, 2002).

Stable bed

Bed where the structure (patches, formed relief) is clearly recognizable over many years (Blue mussel workshop, 2003; QSR 1999).

Stable site

Location where mature mussel beds (one or more) occur regularly over several years (Blue mussel workshop, 2002).

Assessment criteria for persistence of a mussel bed

Age of bed, type of location, sediment structure of mussel bed basis (Blue mussel workshop, 2002).

Larvae settlement

The first benthic migrating stage of blue mussel larvae smaller than 1 mm is defined as primary settlement. The larvae can settle several times on various substrates until they get larger and settle more permanently on structures such as existing mussel beds or stones (secondary settlement) (Blue mussel workshop, 2000).

Spatfall

Settlement of young mussels or oysters on a tidal flat or in existing beds. These small bivalves are called 'spat' during the year of settlement only.

Recruitment

The addition of young mussels to the reproducing population. For blue mussels, the concept of recruitment is used for young mussels which survived the winter (age = 1 year).

The following aspects are recommended for an annual monitoring program:

- total area covered by Pacific oysters,
- biomass (stocks' development),
- in selected areas: density, size structure and biomass of both, blue mussels and Pacific oysters,
- annual recruitment of blue mussels and Pacific oysters.

The resulting data will allow the most important aspects of stocks' development to be monitored. However, more detailed investigations on filtration rate, production and energy flow as well as studies of the associated benthic and bird community are highly recommended.

The monitoring of Pacific oyster beds can in many aspects follow the standards defined for blue mussel monitoring implemented in the Wadden Sea (TMAP Monitoring Handbook 2008). Like the blue mussel beds, oyster beds can be identified from aerial photos. However, they cannot be distinguished from each other, thus additional ground-based investigations are necessary. Aerial pictures can be either made in spring or autumn. Different methods are used to determine the coverage (patches per bed). Similarly to blue mussel beds, oyster beds can be mapped at the tidal flats with the so-called 'Stiefelmethode' which means walking along transects over the mussel bed and counting the steps on mussels and bare sediment. Length and position of the transects may be tracked using a GPS. Sampling of oyster beds might need slightly larger frames than those used for blue mussels. In the monitoring program in the Wadden Sea National Park of Schleswig-Holstein a 25 cm x 25 cm frame is now used to sample both species and it is recommended to use it as a standard for further monitoring (TMAP blue mussel expert meeting, Wilhelmshaven September 2007). In Niedersachsen, the 'Stiefelmethode' is applied using a 25 cm x 25 cm frame for both species since 2008. In The Netherlands some specific beds are monitored with a 15.5 cm x 32 cm frame, and the majority of beds with sampling devices covering 0.4 or 16 m^2.

Samples may be taken randomly over the entire bed or in the covered heaps only if coverage of the bed is assessed in the same time. Sampling can best be carried out in the period between summer and autumn to monitor the oyster spatfall that has survived the winter.

Biomass of Pacific oysters could be measured as cooked flesh weight (g/m^2). Total wet weight, which is often used in the monitoring of blue mussel is useful, however, data from both species cannot be compared directly as the flesh content of oysters is lower than that of blue mussels, and a reef can consist of many dead shells which are inseparable cemented together with live specimens.

Currently, the monitoring of Pacific oysters in the Wadden Sea is not done in a harmonized way, *e.g.* no specific monitoring was conducted in the Dutch Wadden Sea in 2007 and 2008, whereas further assessments in Niedersachsen and Schleswig-Holstein are continuing. Such gaps should be filled as soon as possible by establishing a regular monitoring within the framework of the TMAP. Additionally, an extension of the surveys to the subtidal is essential, because the Pacific oyster spreads rapidly into this area as well.

5. Change in mussel bed community

Mussel beds provide a habitat for a diverse community of both endo- and epi-fauna, with higher densities and biomass as compared to surrounding tidal flats (Asmus 1987). Community structure has been changing with decreasing mussel densities and the transition of mussel beds to oyster beds, however, oyster offer a similar habitat for associated fauna (Büttger *et al.*, 2008, Markert *et al.*, 2009).

Oysters are not the only invasive species settling on mussel beds. The rate of species introductions is continuously increasing worldwide. Especially, the Wadden Sea area is very receptive to introductions of non-indigenuous species. There is a high number of alien species in the Wadden Sea that have established successfully on mussel beds, some of which have significant effects on the populations of native species (see also QSR 2009 Thematic Report 7 "Alien Species").

Figure 14 gives an example of the proportion of non-indigenous and native species of two mussel bed areas in the Wadden Sea of Schleswig-Holstein.

On the tidal flats of the Wadden Sea, mussel beds naturally provide the only suitable biogenic hard substrate for the attachment of sessile epibenthic species (natives as well as alien species). The most important non-indigenous species which established successfully in the Wadden Sea and occur especially in high densities on mussel beds are the Pacific oyster *Crassostrea gigas*, the American slipper limpet *Crepidula fornicata* and the Australian barnacle *Elminius modestus*. Over the last decades, two algae species have also invaded the Wadden Sea: the Japanese seaweed *Sargassum muticum* and the red macro-alga *Gracilaria vermiculophylla*. Most recently, the non-native Asian crab of the genus *Hemigrapsus* which invaded the Easter Scheld estuary in 2000 has been recorded in the Dutch and German Wadden Sea.

Crepidula used to be rare in the Dutch Wadden Sea and more common in Germany. It has spread out in the entire Wadden Sea area. In the last decade, *Crepidula* has locally established dense layers on mussel beds in the low intertidal and the shallow subtidal, but the development seems to have little effect on mussel beds (Thieltges *et al.*, 2003; Nehls *et al.*, 2006; Wehrmann and Schmidt, unpubl.).

In the years following its introduction into the Wadden Sea, *Elminius modestus* has extended its range slowly. In the intertidal area of the northern Wadden Sea, population density grew significantly within the last two years, but has presumably not reached its maximum yet (Witte *et al.*, submitted).

Sargassum muticum has presumably been introduced with oysters and spread rapidly along the European coasts. In the Wadden Sea, *Sargassum* occurs mainly epizootically attached to mussels and especially oysters in the shallow subtidal zone. Tolerating a wide range of abiotic conditions, it is considered to be highly invasive (Nyberg and Wallentinus, 2005). However, in the Wadden Sea it provides an additional highly structured habitat with facilitating effects for native algal, invertebrate and fish species (Buschbaum *et al.*, 2006; Polte and Buschbaum 2008).

Algae of the genus *Gracilaria* were first noticed in the Dutch Wadden Sea around 1990, but species information are not available. It was fairly common but not considered a problem nor covering vast areas. Less than 5 years following its first observation in the German Wadden Sea, the invasive species *Gracilaria vermiculophylla* is common in many regions. In Schleswig-Holstein, the algae has strongly spread after 2003 and covered many mussel beds with dense layers, but since 2007, development has been stable or even decreasing. The algae occurs in all intertidal habitats of the Wadden Sea but reaches highest densities on mussel beds (Buschbaum *et al.*, 2008) and cockle beds (Dankers, unpubl. data).

In 2006, first specimens of the Asian crab *Hemigrapsus* were found on a mussel bed in the Dutch Wadden Sea and on a westernmost oyster bed in the Wadden Sea of Niedersachsen (Markert, unpubl. data). In 2007, grapsid crabs were reported from several locations in the whole German Wadden Sea. The spread of *Hemigrapsus* will be tracked in Niedersachsen.

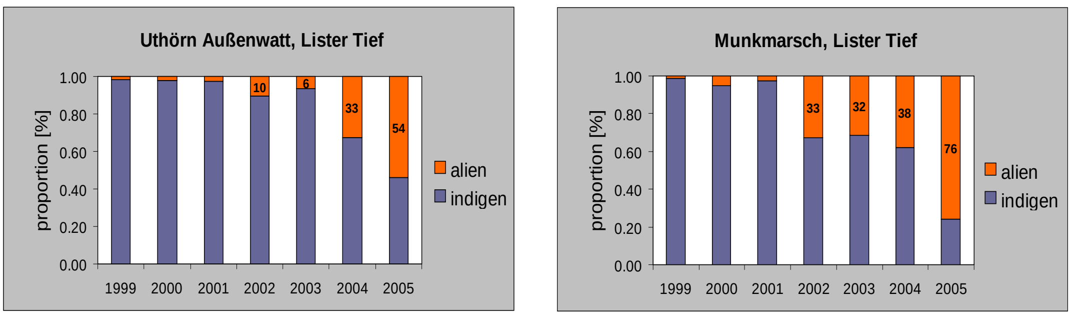


Figure 14: Proportion (individuals) between introduced and native species on two mussel beds near the island of Sylt, Schleswig-Holstein.

6. Factors influencing mussel bed development

6.1 Recruitment success

The establishment of new blue mussel beds has been a rare event for almost a decade in most parts of the Wadden Sea, except for the Netherlands. After the cold winter 1995/96 many blue mussel beds were replenished by a strong spatfall in summer 1996 and again in 1997. In the following years, very limited spatfall occurred and only a few blue mussel beds were recovered or had increased in size (Strasser *et al.,* 2001b). Spatfall into existing beds was noticed but it was too insufficient to allow a stable population. Only in the Dutch part of the Wadden Sea there was an appreciable spatfall into existing beds and establishment of new beds. However, blue mussel beds are decreasing in most parts of the Wadden Sea; even small losses in mussel bed area are apparently not compensated by spatfall. As a result, annual losses accumulate and lead to a permanent decrease. The mechanism behind the influence of winter severity on recruitment success is poorly understood. The failure of recruitment may be initiated by mild winters, resulting in a synchronized settling of mussels and the occurrence of their main predators in the Wadden Sea. Variability in predation on postlarvae is presumably contributing to the annual variability in recruitment. On tidal flats, epibenthic predation pressure in spring and early summer is related to preceding winter's temperatures: after cold winters, both seasonal arrival on tidal flats of epibenthic predators such as shrimps and shore crabs takes place later in the year as well as in lower numbers, minimizing predation pressure. Additionally, a succession of warm summers is expected to lead to an overgrowth of mussel beds by the Pacific oyster which is expanding its range rapidly facilitated by high summer temperatures (Nehls *et al.*, 2006). Observations in all Wadden Sea areas show that in the long run existing mussel beds would disappear when recruitment is low (Fey *et al.,* 2008a, 2009c). Besides, the total surface of beds will diminish due to storms and ice cover as long as these losses are not compensated by new settlement.

The proceeding global climate change is leading to an increase in surface water temperatures which again facilitates specifically warm-water species such as the Pacific oyster, allowing these species to successfully reproduce in the presence of potential predators. In a warming Wadden Sea, cold winters occur less frequent and so does good recruitment of blue mussels.

6.2 Impact of fisheries/ mussel farming on intertidal mussel beds

In The Netherlands, mussel stocks and natural beds crashed in the early 1990s due to overfishing. Since 1995, there was almost no impact of mussel fishery on the intertidal area. Seed mussels which are used to stock the culture lots have been obtained from subtidal areas. Following the prohibition of mussel fishery, mussel stocks of the intertidal have recovered slowly. The landings increased slightly for some years, but have not reached former levels yet (Ens *et al.,* 2004). In all other parts of the Wadden Sea, natural beds of the intertidal have decreased for a decade now and so have mussel landings. It is not clear, to what extent the harvesting of seed mussels has contributed to the decline of the natural stock. Intertidal mussel beds in Schleswig-Holstein are declining although there has been no impact of mussel fishery in the intertidal since 1995. Hence, the loss of mussel stocks here must have other causes. In Niedersachsen, the management plan for mussel fishery is being renewed with the intention to protect mature beds in balance with economic fishery interests (Herlyn *et al.,* 2008). However, the fishing of seed mussels in intertidal areas will still be allowed, although investigations of stable sites of blue mussel beds in the Niedersachsen Wadden Sea showed that in most cases mussel fishery led to heavy or even complete losses which have been larger than the amounts of mussels actually removed by fishery (Herlyn and Millat, 2000). In Denmark, mussel fishery is allowed only in about 50% of the Danish Wadden Sea since 1992. These areas contain intertidal as well as subtidal beds, the latter being preferred by the fishermen. As a consequence, the intertidal beds in the Danish Wadden Sea have not been fished since 1992.

In conclusion, it can be stated that in The Netherlands, in Schleswig-Holstein and in Denmark the direct impact of mussel fishery on the natural development of intertidal mussel beds has been limited or absent in recent years. Only in Niedersachsen does mussel fishery in the intertidal area continue.

6.3 Detrophication

Considerable effort has been made over the last decades to reduce nutrient inputs to rivers and North Sea. There have been discussions whether an impact of reduced nutrient loads already affect primary production of the Wadden Sea and consequently biomass of filterfeeders as mussels. At present, there is no evidence that mussel growth and population dynamics are affected by detrophication. However, this aspect should be watched closely in the future as impacts are likely to occur.

6.4 Pacific oyster invasion

Beds of blue mussels provide a suitable hard substrate for settling oyster larvae and are considered to be the main reason for the rapid expansion and successful establishment of *C. gigas* in the Wadden Sea. Several studies showed that the abundance of blue mussels apparently remains on a stable level even in dense Pacific oyster beds. However, densities have decreased and the biomass of blue mussels in these beds is now much lower than it was before Pacific oysters were present. According to that, decline of the blue mussel populations may particularly be ascribed to the wide spread of *C. gigas*, but in fact, mussel stocks have decreased already before the Pacific oyster started to spread out. In addition, loss of blue mussel populations did not vary between areas where oysters occurred and areas where they have been absent. Thus, the spread of *C. gigas* cannot be related to the reason for the decline of the mussel stocks in the Wadden Sea so far (Nehls and Büttger, 2007). The Pacific oyster obviously has established a stable population in the Wadden Sea. Further spread of the oyster population is expected and might lead to a functional change in the Wadden Sea and in the whole associated community. A complete displacement of blue mussels by oysters is not expected. There are several examples of co-existence of blue mussels and oysters on mixed beds. In some regions with good blue mussel spatfall, the occurrence of oyster beds is relatively small. A spreading of the Pacific oyster into the subtidal area cannot be excluded. This is an ongoing process and further development cannot be predicted (Nehls and Büttger, 2007). In that case, mussel recruitment may be reduced, because of predation by oysters that filter mussel larvae from the water column (Troost, 2004).

7. Conclusions

To protect intertidal blue mussel beds, considerable parts of the intertidal area of the Wadden Sea have been permanently closed for mussel fisheries. Differences between the three countries in measures to increase the area of naturally developing mussel beds as well as in the results are substantial. In The Netherlands arrangements have been successful: intertidal mussel beds have recovered in a few places, but have not reached former levels. Contrary to the Dutch Wadden Sea, mussel beds in Niedersachsen, Schleswig-Holstein and Denmark decreased in the last decade. In these countries the last considerable spatfalls occurred in 1996 and 1997, leading to establishment of beds at a large scale, whereas the establishment of new beds occurred only locally after this.

The contrasting developments of natural mussel beds lead to uncertainties regarding the causes of recruitment failure in most areas of the Wadden Sea. Predation on the spatfall seems to be the most important, which again is facilitated by climate change. It is assumed that annual variation in predation rate and recruitment success relates to winter temperatures: cold winters result in low predation rates because the main predators of bivalve spat (*e.g.* shrimp and shore crab) return later in spring to the tidal flats. As a consequence, the bivalve larvae can establish successfully. By contrast, warm winters lead to high predation rates and low recruitment success.

In the same time, Pacific oysters spread out very strongly, facilitated by climate change which in turn is leading to more favourable conditions for this species. By now, oysters have densely colonized many former mussel beds in the Wadden Sea, but there is no indication that their spreading has caused the recent decline of the blue mussels in the Wadden Sea. Several studies showed that coexistence might be possible, but the questions whether or not native blue mussel beds will disappear over time due to the rapid spread of the Pacific oyster cannot be answered so far (Diederich, 2005; Betz, 2007). There are several examples of co-existence of blue mussels and oysters in mixed beds. In the Dutch Wadden Sea, blue mussels have successfully re-established a strong population in the last years. If sufficient blue mussel recruits manage to settle, new beds may develop and blue mussels may co-exist with oyster beds.

Knowledge on the ecology of natural subtidal mussel beds of the Wadden Sea is scarce. However, intertidal and subtidal mussel beds seem to differ in (1) biogenic bed structure, (2) species interactions and (3) associated organisms. The ecosystem of subtidal beds is potentially more diverse than on intertidal beds, but further investigations are needed. The main known subtidal mussel beds are in the western Dutch Wadden Sea, in the Schleswig-Holstein area and Ho Bugt in Denmark.

8. Target evaluation and recommendations

8.1 Target evaluation

After a period of intensive fishing of many intertidal mussel beds and relatively low mussel stocks, a specific trilateral target was formulated, aiming for (1) an increase of the area and (2) a more natural distribution and development of natural mussel beds. Since then, strict regulations have been applied in most of the areas.

Referring to several long-term investigations, it can be concluded that despite considerable efforts in mussel management, the target of increasing mussel bed areas in the intertidal has not been achieved in three out of four subregions in the Wadden Sea. Only in the middle and the eastern part of the Dutch Wadden Sea an increased area was reached, whereas in all other parts of the Wadden Sea total area of mussel beds is still below former levels. This does not lead to the conclusion that management has failed over the last decade, as the development of mussel stocks is not only influenced by fisheries but subject of considerable natural variation and most probably effected by long-term changes of the climatic conditions.

With regard to the subtidal mussel beds, an evaluation of the target is still not possible.

The target of a more natural distribution and development of intertidal mussel beds has been achieved in all areas which have been closed for mussel fishery, however, increasing proportions of alien species indicate that a natural development today is influenced by factors acting on larger scales and cannot be achieved only by regulations within the Wadden Sea.

8.2 Recommendations

More research needs to be done both in relation to natural dynamics and long-term changes of intertidal and subtidal mussel beds in the Wadden Sea as well as on the impacts of fisheries. Impact studies on mussel fisheries are still rare and not yet sufficient to draw general conclusions.

The further development of the Pacific oyster and its possible effects on the Wadden Sea ecosystem should be subject of an annual research and monitoring program. Monitoring standards should be harmonized within the entire Wadden Sea and comply with the objectives of the EU Habitats Directive as well as of the EU Water Framework Directive. Pacific oyster monitoring should be included in the existing monitoring of blue mussel beds, which requires extra funding.

Nature conservation targets and habitat definitions have to be clarified and a procedure to classify mussel beds as habitats according to the new definitions has to be developed.

Conservation targets have to be evaluated against the background of a changing Wadden Sea where increasing temperatures are in favour of a marked change from mussels to Pacific oysters and detrophication may induce a decreasing trend in productivity.

The management measure of protecting stable mussel beds or sites is still valid.

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Seagrass

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1. Introduction

Narrow-leaved *Zostera noltii* and broader-leaved *Z. marina* on a tidal flat near Sylt (Photo: K. Reise).

Seagrasses occur worldwide in shallow coastal waters. In the Wadden Sea these periodically submersed flowering plants are represented by two species of the genus *Zostera*. The small and very narrow-leaved *Z. noltii* is the most common. It grows in the intertidal zone and is usually perennial. It is often accompanied by a mostly annual, narrow-leaved, small morph of the large *Z. marina*, growing particularly in puddles which remain filled with water at low tide. Around the low-water line and deeper, beds of a large and perennial *Z. marina*, with rigid bases and broad leaves, once occurred in the western and northern Wadden Sea. In the course of a wasting phenomenon in the early 1930s these beds vanished and never came back. The primary cause of the decline of the perennial *Z. marina* beds might have been anomalously cloudy and/or warm years in the 1930s, and the conspicuous infestation with the pathogenic protist *Labyrinthula zosterae* – which may have come up as a response to the already weakened seagrasses (den Hartog and Phillips, 2001).

In spite of this historic decline, a high allelic diversity was observed in the Wadden Sea, indicating a confluence of populations in this region (Olsen *et al.*, 2004). *Z. noltii* also shows a high genetic diversity (Coyer *et al.*, 2004).

Zostera beds, when growing in dense stands, protect the sediment against erosion and facilitate deposition during summer. They provide a substrate for fouling algae, which in turn are grazed by snails and other invertebrates. The canopy offers protection for small animals. The now vanished subtidal beds of *Zostera marina* offered shelter for small fishes that utilized the beds as a nursery. *Zostera* beds constitute a food resource for brent geese and wigeon. In the Wadden Sea at present, most beds are to be found in the mid to upper tidal zone along the leeside of islands and high sand bars as well as along sheltered parts of the mainland coast. A conspicuous decline of the intertidal beds of *Z. noltii* and *Z. marina* has occurred since the 1950s or 1960s, suspected to have been caused by human impacts, as outlined in the QSR 1999. This situation led to the target of 'an increased area and a more natural distribution and development of *Zostera* fields' agreed upon in the Trilateral Wadden Sea Plan (1997) (http://www.waddensea-secretariat.org/management/Plan.html).

1.1 Findings of the QSR 2004

In 2004, this target was evaluated for the first time. It was concluded that the target of an increased area of *Zostera* beds had not yet been met in all sub-regions of the Wadden Sea. However, it was noted that the decline of intertidal seagrass in the southern and central Wadden Sea had come to an end and that some recovery was evident. In 2004, more than 80% of the seagrass area in the Wadden Sea occurred in the Northern Wadden Sea. At all locations both species showed considerable fluctuations between years in the size and shape of local beds.

Eutrophication and hydrodynamics were defined as the overall variables determining seagrass distribution in the Wadden Sea, while positive effects of low salinity and negative effects of shellfish fishery and land reclamation works were seen as more locally relevant.

Recommendations were made for a complete and concerted survey of seagrass in the Wadden Sea, avoidance of disturbance of seagrass by shellfish fishery and land reclamation works, further reductions in nutrient loads, restoring of ebb-sluices with continuous freshwater runoffs and reintroduction of seagrass.

1.2 Method and data sources

A revised TMAP guideline with common definitions and a classification of seagrass beds was developed in 2006 to enable a common interpretation of monitoring results of the entire Wadden Sea (http://www.waddensea-secretariat.org/TMAP/Handbook/guideline9.html). Because of the extremely uneven distribution of intertidal seagrass, different monitoring methods are in use.

For all regions, seagrass areas are divided into three categories: (1) areas with scarce seagrass, less than 5% coverage, (2) areas with scattered seagrass, 5-20% coverage, (3) seagrass beds with more than 20% coverage. Furthermore the type of seagrass bed is noted (only *Z. noltii*, only *Z. marina*, mixed *Zostera* or *Ruppia*)

1.2.1 The Netherlands

In The Netherlands, monitoring has been focusing on areas where seagrass beds have already occurred in the past. Additionally a map with potential occurrence of seagrass from model calculations has been used. Monitoring is carried out annually or bi-annually by aerial photographs in combination with field surveys. There was a good consistency when comparing results from aerial photographs and field surveys. In addition to this mapping program, a system is set up in which people in the field are asked to pass on observations on presence of seagrass in other parts of the Wadden Sea. In areas with low density of seagrass (e.g. Groningen coast), groups of plants are mapped individually. Seagrass fields with a density of less than 5% are not included in the overall calculations. In addition to seagrass, *Ruppia maritima* is also monitored in the site where it is present (on Balgzand).

Reports of the mapping exercises as well as maps of the seagrass distribution are published on a website http://www.zeegras.nl.

1.2.2 Germany

In 2000-2002, the entire Lower Saxonian Wadden Sea was mapped using field surveys, supported by aerial surveys. The border of seagrass beds as well as areas with small seagrass stocks were mapped. In summer 2008, a new survey of the total intertidal *Zostera* stock was conducted. It was the first almost synchronous survey of the total Lower Saxonian stock since the beginning of the regular monitoring in the 1990s. Again, the seagrass beds were mapped by field surveys. In addition, aerial photographs (colour photographs; scale: 1:20,000) were analyzed with the aim to gain additional information about locations of seagrass beds. Beside the completion of the monitoring program and therewith, the gaining of necessary data about the stock development, these investigations aim at the further development of remote sensing techniques for the mapping of seagrass beds. The following parameters were determined:

- position and spatial extent of seagrass beds (GPS-measurement of 5%- and 20%-border);
- cover (area of seagrass-covered patches in relation to the total seagrass bed area [%]) and proportion (area covered by seagrass within the patches in relation to the total area of seagrass patches [%]) according to the definitions of cover and proportion for mussel beds (Herlyn, 2005). On the basis of these variables, the total coverage can be calculated, which is equivalent to the coverage of NL and SH. Cover and proportion were divided into five %-classes: <1; 1-5; 5-20; 20-60; 60-100;
- additionally, the biomass of seven beds was measured as ash-free dry weight (10 random samples each of 181.46 cm² area and approx. 30 cm depth per bed).

With as much as 100 km², the largest extent of seagrass beds abounds in the Schleswig-Holstein Wadden Sea. Because of this large areal size, aerial mapping has been the main method of assessment, and has been carried out three times annually (June, July and August) since 1994. This rapid assessment method provides a good overview on the spatial pattern, seasonal development and interannual variation of seagrass beds with a coverage of 20% or more. A rough distinction is made between coverage < and ≥ 60%. However, ground-truthing is essential to (a) include beds with a coverage between 5 and 20%, (b) distinguish between seagrass species, and (c) estimate density of macroalgal cover within seagrass beds.

Particularly, green algal mats may give rise to confusion. These are therefore mapped from the air concurrently, and in some cases it is necessary to verify on the ground whether it is a seagrass bed, a field of macroalgae or both mixed together. Ground surveys in the Schleswig-Holstein Wadden Sea are carried out from mid July until mid September. In addition to visiting beds of uncertain composition, the survey consists of 12 permanent sites spread evenly along the coast. Included are areas where seagrass actually occurs, used to occur or where it could potentially thrive.

Furthermore, 1/6th of the Schleswig-Holstein Wadden Sea area is completely mapped for seagrass beds by field surveys each year since 2007. The aim is to map the entire area once until 2012. Thus, all seagrass beds in the Schleswig-Holstein Wadden Sea area will be surveyed gradually within 6 years to obtain a comprehensive ecological inventory. In the first year of this six-year interval (2007), the area around the island of Sylt was mapped while all seagrass beds between the cities Husum and Büsum were recorded in 2008. The tidal flat areas in the Meldorfer Bucht and south of the Hindenburgdamm down to and including the islands Amrum and Föhr were surveyed in 2009. While monitoring the spatial extent and position, the inner core of a seagrass bed (≥ 20% coverage) and the outer fringe (≥ 5% coverage) are recorded. Furthermore, seagrass cover (5 classes), seagrass species composition, epiphyte cover (4 classes), macroalgal cover (6 classes) and the two most dominant macroalgal taxa and the substrate are noted.

1.2.3 Denmark

In the Danish Wadden Sea, seagrass is monitored on a regular basis. Simple aerial mapping is carried out in the entire area every year. Additionally field survey is carried out in large seagrass beds near the islands of Fanø and Rømø and near Jordsand and Ballum about every second year. In these areas percentage cover of *Z. marina, Z. noltii*, *Chaetomorpha* sp., *Ulva* sp., blue mussels and Pacific oysters is registered on several transects of 4 m width.

1.3 Relation to the EU Water Framework and Habitats Directives

With respect to the EU Water Framework Directive (WFD), the status of seagrass is regarded as an important indicator for the effects of eutrophication in coastal waters and transitional water bodies and is requested to be monitored at least every six years. In general, for a good ecological quality within the Wadden Sea, the presence of both species, *Z. marina* and *Z. noltii*, is required while the areal share of seagrass beds in the intertidal zone is considered to be specific for the sub-regions of the Wadden Sea.

In the Habitats Directive's goals for the Wadden Sea, seagrass is mentioned in the description of the habitat type 1140. It calls for an expansion of seagrass beds in the Wadden Sea.

Low intertidal bed of *Zostera marina* in the northern Wadden Sea (Tonnenlegerbucht at the island of Sylt, August 2007) (Photo: T. Dolch).

2. Status

2.1 Distribution of seagrass beds in the Wadden Sea

The occurrence of seagrass beds on intertidal flats in the Wadden Sea is rather uneven. From a rough aerial survey in 1998 with a total of 5,100 ha of seagrass beds recognizable from a plane, it is estimated that more than 90% of the beds occur in the northern Wadden Sea between the Eiderstedt and Skallingen peninsula (Reise, 2001).

In 2002/03 the total area of seagrass beds (all types of bed densities for all sub-regions) was about 7,300 ha with 82% in the northern part (combination of aerial and ground surveys). In 2007/2008, the total area of seagrass beds increased to about 13,000 ha with 77% in the northern part (Table 1). The real figure may be even higher, with an even higher percentage in the northern part because beds with densities lower than 20% are not recorded in Schleswig-Holstein.

In 2008, seagrass beds with coverage of more than 20% spanned an area of about 10,000 ha, with about 95% occurrence in the northern part (Table 1; Figure 1). In the southern part, coverage is generally much lower: in Niedersachsen, half of the seagrass beds have a coverage of 5-20%, in The Netherlands, 95% of the seagrass beds have a coverage lower than 5%.

It has to be recognized, however, that differences in methodology can render different results. In particular, data from air and ground surveys tend to differ in the lower limit for the density that is included. As a rule of thumb, aerial surveys with a lower limit of 20% cover are lower by one third compared to ground surveys with 5% as lower limit.

No new knowledge has become evident on seagrass occurrence in the shallow subtidal region of the Wadden Sea in recent years. There may still be no subtidal occurrence, but a systematic survey has not been attempted so far. However, prior to their collapse in the 1930s, the subtidal beds were found at and just below spring low tide level. If present, encounter by chance of such subtidal stands, or even detection from the air, would have been rather likely. For example, near the island of Sylt, subtidal kelp forests composed of the invasive *Sargassum muticum* were readily seen from 500 m above (Reise and Buschbaum, personal observation). The following description of seagrass status is confined to the intertidal zone of the Wadden Sea.

In The Netherlands, seagrass beds occur mainly along the Groningen coast and in the outer part of the Ems estuary. Some smaller beds are found on the leeside of the island of Terschelling and along the southwesterly border of Balgzand. In Niedersachsen, the largest seagrass beds occur within the sheltered Jade bay. Smaller beds can be found in other sheltered regions along the mainland coast. They are the remains of a former coherent belt. The most dominant species is *Z. noltii*; beds with dominance of *Z. marina* are rare (*e.g.* on Eversand and Knechtsand in 2008). In the North Frisian region, seagrass beds predominantly occur at sites sheltered against the prevailing surf from the southwestern direction. The largest seagrass beds in this region are found east and north of Pellworm, at Südfall, Gröde, Hooge, Langeness, Oland and Sylt (Figure 2). Both species of *Zostera* are present. *Z. noltii* dominates but mixed beds with *Z. marina* are also common. Beds dominated by *Z. marina,* however, are small and rare. Similarly, in Denmark, large beds occur at the leeside of Rømø and Fanø as well as between Jordsands Flak and Koldby. Both *Zostera* species are present.

Figure 2 also nicely illustrates that seagrass fields are less constant than we usually assume. There is a core where seagrass is always present and around that a zone where it occurs regularly.

Table 1: Seagrass coverage in 2007/2008, as recorded in the TMAP database
* Area with coverage 5-20% has been calculated by total area minus area with coverage < 5% minus area with coverage >20%
** In Schleswig-Holstein only areas above 20% coverage are monitored.

Region	Total Area (ha)	Area (ha) with coverage < 5%	Area (ha) with coverage 5-20%	Area (ha) with coverage >20%
The Netherlands (2007)	303	285	14	4
Germany / Niedersachsen* (2008)	2928	1051	1452	425
Germany / Schleswig-Holstein** (2008)	9621	not detected	not detected	9621
Denmark (2008)	932	no data available	no data available	no data available

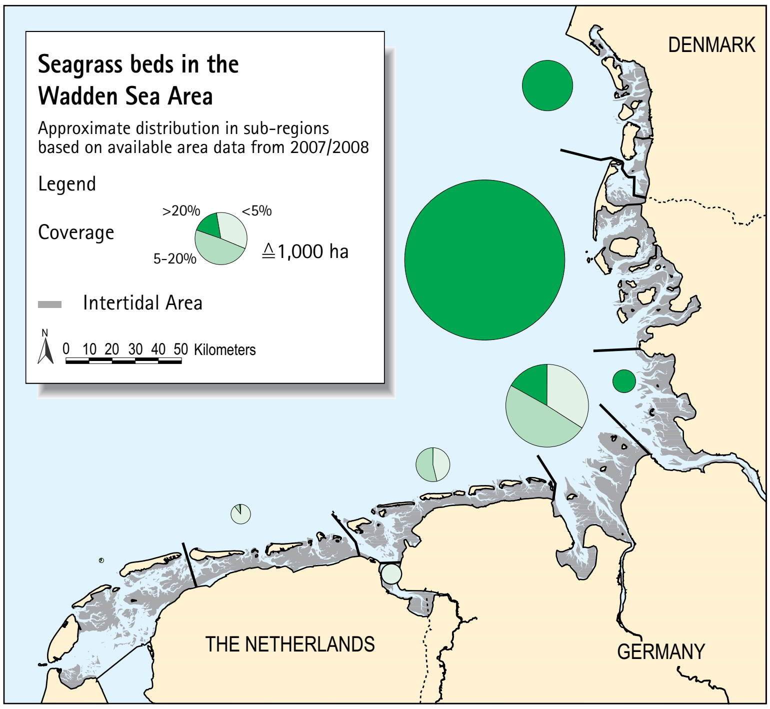

Figure 1: Distribution of intertidal seagrass beds (with various densities) in the Wadden Sea (in ha) in different sub-regions in 2007/2008.

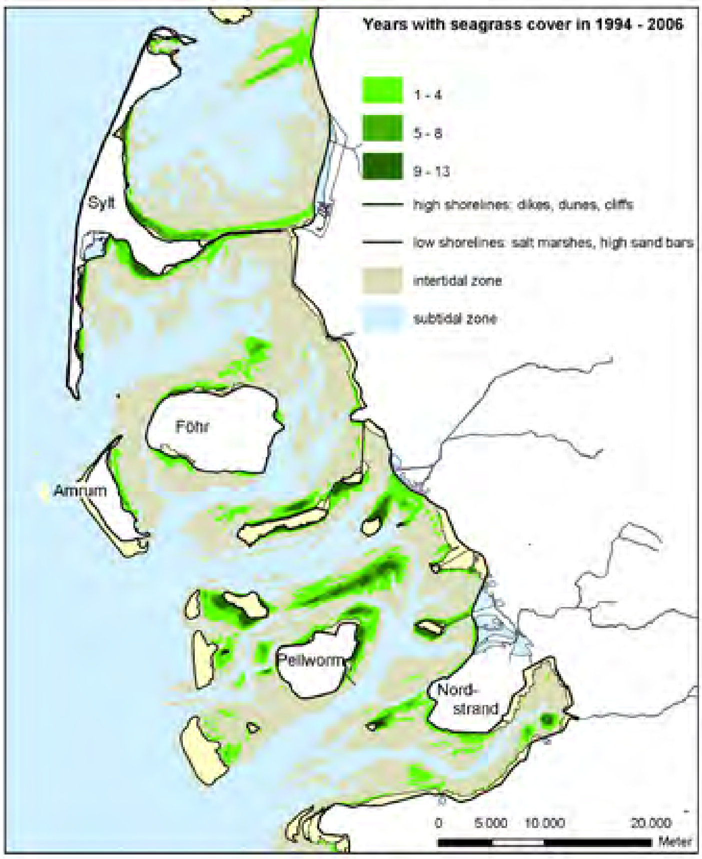

Figure 2: Occurrence of seagrass (*Zostera noltii* and *Z. marina*) in the intertidal zone of the North Frisian Wadden Sea in August/September 1994–2006. Intensity of shading refers to the number of years seagrass has been observed by aerial survey. Beds with <20% coverage are not included (from Reise and Kohlus, 2008).

2.2 Long term trends

2.2.1 Southern and central Wadden Sea

The region from Den Helder to the Elbe estuary has been subject to a continuous decline in number and size of seagrass beds in the tidal zone since about the 1960s (Den Hartog and Polderman, 1975; de Jonge *et al.*, 1993; Michaelis *et al.*, 1971; Kastler and Michaelis, 1999).

In the Dutch part of the Wadden Sea, *Z. marina* was in 2004-2007 confined to a few small patches along the Terschelling coast, the Groningen coast and the Ems estuary. On the tidal flat Hond-Paap in the Ems estuary, the bed of *Z. marina* remained. However, both the total area as well as the cover has been decreasing continuously since 2004. In 2007 cover was nowhere higher than 5%. Since 2003, a low-density seagrass location was found at the adjacent Groningen coast, probably colonised by seeds originating from the Hond-Paap. This location has remained more or less stable. The decrease of the seagrass bed at Hond-Paap might be caused by an increased turbidity of the Ems through continuous deepening and dredging techniques.

Elsewhere, *Z. noltii* is more common than *Z. marina* and was observed in 2000-2007 at Terschelling and along the Groningen coast with a total area of about 30 ha (cover >5%), with a maximum of 100 ha in 2006. Along the Groninger coast, the area of *Z. noltii* increased since the year 2000, whereas the beds at Terschelling decreased in size. This increase is particular notable along the Groningen coast since the year 2000 (Figure 3). In a 2007 study (van der Graaf and Wanink, 2007), the information on the location of seagrass beds in the Dutch Wadden Sea was reviewed using a GIS model. It compared wave intensity, turbidity and sedimentation rates with location and growth of seagrass. Along the Groninger coast *Z. noltii* only occurs in places where sedimentation was low. This might also be the reason for the absence of *Z. noltii* along the Frisian coast, where sedimentation is generally much higher.

In the Niedersachsen part of the Wadden Sea, more seagrass is present than in the Dutch part. It was estimated that seagrass beds (5%-border) occurred on 1,880 ha in 2008 (Adolph, 2009). For the period 2000-2003 the estimate was 960 ha. With a total bed area of about 1,450 ha, *Z. noltii* is the dominant species, whereas beds of *Z. marina* covered 420 ha. Regarding the 20%-border, the total seagrass bed area reached 710 ha, whereof *Z. marina* dominated beds occurred on 80 ha. *Z. marina* is generally sparse, not forming dense beds with the exception of the two beds along the Wurster Küste (on Eversand and Knechtsand) which have increased considerably since the last survey in 2000-2003. Increases of beds of *Z. noltii* were noted on the Randzel (south of Borkum) and along the mainland shore between Norddeich and Hooksiel, particularly as well in the Jadebusen. In this embayment the largest beds, in total roughly 60% (respectively 1,090 ha) of the total seagrass bed area, was recorded. Although seagrass has been continuously present with both species in Jadebusen since at least the 1930s, conspicuous changes in sizes and positions of beds and species dominance occurred in the long term. An almost coherent belt of *Z. noltii* along large parts of the shore in the 1930s was converted to singular large

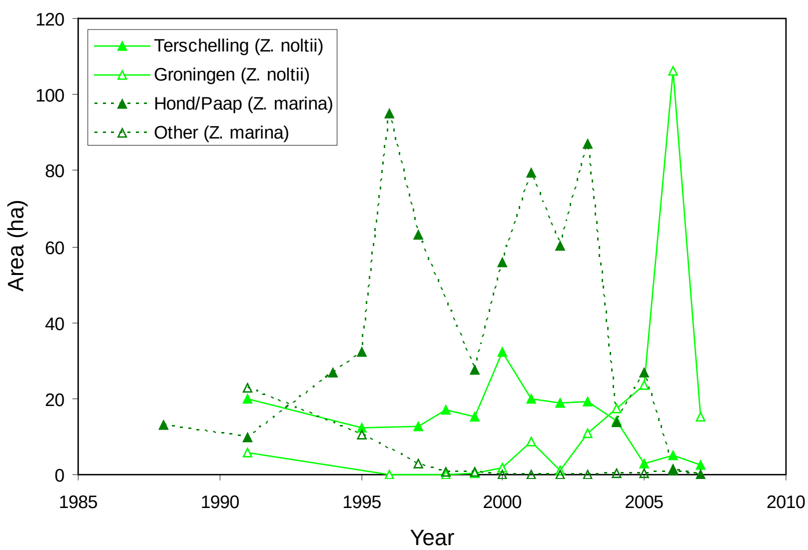

Figure 3: Total area of seagrass (cover >5%) in The Netherlands in ha.

beds. Also, the *Z. noltii* beds in the Weser estuary showed an increasing trend compared with the situation in 2000-2003. As already mentioned, two *Z. marina* beds have developed along the coast between the Weser and Elbe (Wurster Küste) covering a combined total of 420 ha.

In the tidal area between the Elbe and Eider estuary, only *Z. noltii* is present. A recurrent bed is found on the leeside of a high sand bar (Blauort), along a tidal divide in the Wesselburener Watt and a few small beds occur inside brushwood groins along the southern shore of Eiderstedt peninsula. This Dithmarschen area was visited for ground verification in 2008, and 165 ha of seagrass beds with >20% cover and 250 ha when including beds of 5-20% cover were recorded, respectively (Dolch *et al.,* 2009).

2.2.2 Northern Wadden Sea

In contrast to the southern and central Wadden Sea, no general decline in seagrass beds has been observed in the region between the Eiderstedt and Skallingen peninsulas over the last decades. Aerial surveys on seagrass between Eiderstedt and the Danish/German border indicate a three to fourfold increase in bed area from 31.7 km^2 in 1994 to up to 100.2 km^2 (or 11% of the total intertidal flat area with seagrass beds of >20% cover) in 2006, observed by aerial surveys at the seasonal maximum in August 2006 (Reise and Kohlus, 2008). A notable increase took place since 2001 (Figure 4). The trend in seagrass area development in this region may well be explained by a decrease in strength of storm surges since the 1990s (Weisse and Plüß, 2006). Considering winter periods (November-March) in the German Bight; an increase in storm activity since the 1960s with highest levels around 1990-1995, was followed by a decrease in storm activity. Storm surge water levels in summer (April to October) showed a slight decrease over the entire period. A small decrease in seagrass area after an anomalous storm frequency observed in November-December 2006 seems to support this explanation.

The spatial distribution of these large seagrass areas in the North Frisian Wadden Sea shows extensive beds at the leeside of the islands and high sand bars as well as along tidal divides on the elevated flats between adjacent tidal basins. However, there is a conspicuous scarcity of seagrass along the mainland shore. This is assumed to be the result of diking tidal flats in the course of the 20th Century and of ongoing land claim works with brushwood groins and ditches (Reise and Kohlus, 2008). These have probably eliminated or perpetually disturbed seagrass beds. At some sites where land claim works have been phased out (*i.e.* Dagebüll), recovery seems to be on its way (see Figure 2).

The development of seagrass in the Danish Wadden Sea seems to be similar to the adjacent North Frisian tidal area. Aerial surveys in the northern Lister Dyb and in the Juvre Dyb tidal area revealed 527 ha of seagrass beds in 2002 and approx. 750 ha in both 2005 and 2006, which in 2008 had increased to 836 ha. The increase in seagrass area in Lister and Juvre Dyb was mainly seen along the west coast of Jutland and the northern part of Rømø. However, the increase in seagrass area since 2002 should be considered with caution as the mapping method was changed in 2004. In 2008 the seagrass area was also mapped in Grådyb and Knude Dyb, where the total area was 85 ha.

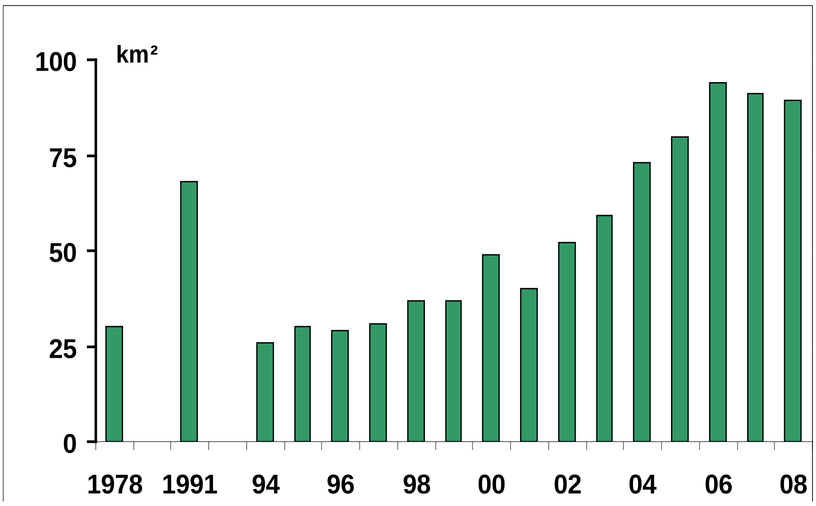

Figure 4: Seagrass bed (>20% coverage) area (km²) in the North Frisian Wadden Sea in August/ September from aerial surveys in 1978, 1991 and 1994–2008 (from Reise *et al., unpubl.*).

3. Discussion

3.1 Threats to seagrass

In the QSR 2004, eutrophication and hydrodynamics were regarded as the overall variables determining seagrass status, while salinity, shellfish fishery and land claim works were seen as of more local relevance. As nothing can be done on hydrodynamics, recommendations were made to further decrease direct and indirect nutrient discharge into the Wadden Sea, to restore natural freshwater inflows, refrain from shellfish fishery and land claim at sites with actual and potential seagrass beds, and to explore further the feasibility of intertidal and subtidal seagrass reintroductions.

3.1.1 Eutrophication

The observed signs for a gradual recovery of seagrass in the Wadden Sea are in line with declining loads in phosphorus and nitrogen over the last two decades and concomitant declines in phytoplankton in the Wadden Sea (Philippart *et al.,* 2007; van Beusekom *et al.,* 2009). However, the present state of eutrophication is still assumed to be well above pre-industrial loads of phosphorus and nitrogen (van Beusekom, 2005). Seagrass is well known to be adapted to low nutrient conditions, and one may expect the status of seagrass beds to improve further if nutrient discharges into the Wadden Sea continue to decline. However, other changes in environmental conditions and their interactions need to be considered as well when attempting to project seagrass development into the future (see below).

3.1.2 Sediment stability

Considering the spatial pattern of intertidal seagrass in the North Frisian Wadden Sea (Figure 2) it is apparent that seagrass predominantly occurs at sites sheltered against prevailing storms. In this region, where more seagrass grows than in all the other regions of the Wadden Sea, the largest seagrass beds are found where surface sediments are underlain by solid peat and clay in which seagrass rhizomes and roots get a fair hold (Reise and Kohlus, 2008). From field experiments it is known that seagrass is highly susceptible to sediment turnover, as may happen during storm surges (Cabaço and Santos, 2007).

Elevated sand accretions with a generally oblong structure are called sand waves or megaripples and are widely observed on the tidal flats of the Wadden Sea. These large sandy bedforms may be formed by strong currents during storm surges and occur in extensive fields. These may be regarded as indicators of increased sediment mobility. Long-term studies near the island of Sylt have shown that fields with sand waves have expanded and replaced seagrass beds (Dolch and Reise, 2009).

Also, land claim works or maintenance works at the outer salt marshes that increase sedimentation rates may have a negative effect on the occurrence and the establishment of seagrass. A conflict with coastal protection measures arises when this is done by setting up brushwood groins in an existing seagrass bed (as is done in the North Frisian region). However, the effects of brushwood groins seem to vary with the hydrodynamic regime. They either stabilize the nearshore zone to the benefit of seagrass (Figure 5, Photo A) or enhance sedimentation to such an extent that seagrass is displaced. Fields with brushwood groins often trap green macroalgae which then smother the seagrass underneath (see below). When fields of brushwood groins are drained by ditches, the maintenance of these land claim works exterminates the seagrass from such sites (Figure 5, Photo B).

Figure 5: Depending on the hydrodynamic regime, seagrass can benefit from brushwood groins when they cause stable sediment conditions (A; south of Eiderstedt peninsula). However, severe damage can be done to a seagrass bed when drainage ditches are dug as happened at Hamburger Hallig (B) (Photos: T. Dolch, August 2008).

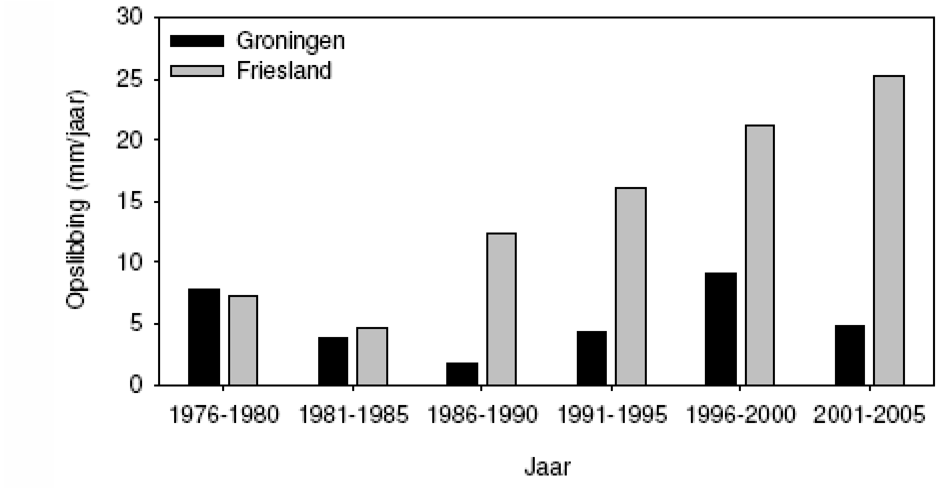

Figure 6: Sedimentation rates along the Groninger coast (where seagrass has been increasing) and the Frisian coast (where no seagrass beds have established) from 1975-2005 (van der Graaf and Wanink, 2007).

For the Western Wadden Sea it was suggested (van der Graaf and Wanink, 2007) that seagrass predominantly occurs on places with a low sedimentation rate and therefore does not occur at the Frisian coast where sedimentation rates are very high (Figure 6).

3.1.3 Turbidity

An increasing concern is the state of the former expanded seagrass bed at the Hond-Paap in the Ems-estuary. This bed has been decreasing in size and cover since 2004. In summer 2007 and 2008, this *Z. marina* stock was near to extinction. A possible cause for this is the increased turbidity of the Ems, caused by repeated deepening of the riverbed and continuous dredging in the river and especially in harbors. Dredging is carried out by means of re-suspending the mud by air injection, in this way bringing the sedimentated mud into the water column where it can reach high concentrations. The turbidity in the sea grass area in the Ems estuary has increased by about 20% from 1990-2000 (Merkelbach and Eijsink, 2001). However, although turbidity was increased in the 1990s, nevertheless the seagrass field at Hond-Paap increased in size in this period. Turbidity may, therefore, not be the (only) reason for the recent decline. More research into the effect of these dredging techniques on turbidity and on the growth of seagrass is necessary. Turbidity in the Dutch part of the Wadden Sea may also be influenced by sediment input from Rotterdam Harbour and the location of dredge disposal sites (de Jonge and de Jong, 2002).

3.1.4 Macroalgae smothering seagrass

High nutrient supply may either facilitate epiphyte growth on seagrass leaves or weedy green algae ('green tides'). The latter often accumulate in sheltered bays or between brushwood groins and other coastal defenses. At such localities green algal cover may replace seagrass beds. For a bay near Sylt this has been documented by historic comparison of benthic assemblages in 1932 and 2002 (Figure 7; Reise *et al.*, 2008). As green tides are assumed to be triggered by an excess of nutrient supply, this threat may also be seen as an effect of eutrophication. Another important factor for the growth of macroalgae are light conditions (Colijn and Cadee, 2003). Improved light conditions may have contributed to the increased growth of macroalgae. At least for the Dutch part of the Wadden Sea there are signs that light conditions have improved (D. de Jong, *pers comm.*, see also de Jonge and de Jong, 2002). Similarly, in the Dutch Oosterschelde estuary it was concluded that the growth of macroalgae increased strongly through improved light conditions, while the nutrient status of this estuary is meso/oligotrophic (Stapel and de Jong, 1998).

3.1.5 Global warming

Global warming may have direct effects on *Zostera marina* and *Z. noltii* in the Wadden Sea in the future. However, so far no mortality caused by heat stress has been described from this region. The extremely warm summer 2003 did affect *Z. marina* in the more stagnant waters of a lagoon in the Baltic Sea (Reusch *et al.*, 2005). *Z. noltii* in Portugal may have responded to that same extremely warm summer, but probably more to the associated drought event (Cardoso *et al.*, 2008). Both species of *Zostera* occur along the entire length of the European Atlantic coast but fall into genetically distinct groups (Olsen *et al.*, 2004; Coyer *et al.*, 2004). Thus, rapid warming or extreme heat events may worsen the conditions for *Zostera* in the Wadden Sea in spite of heat

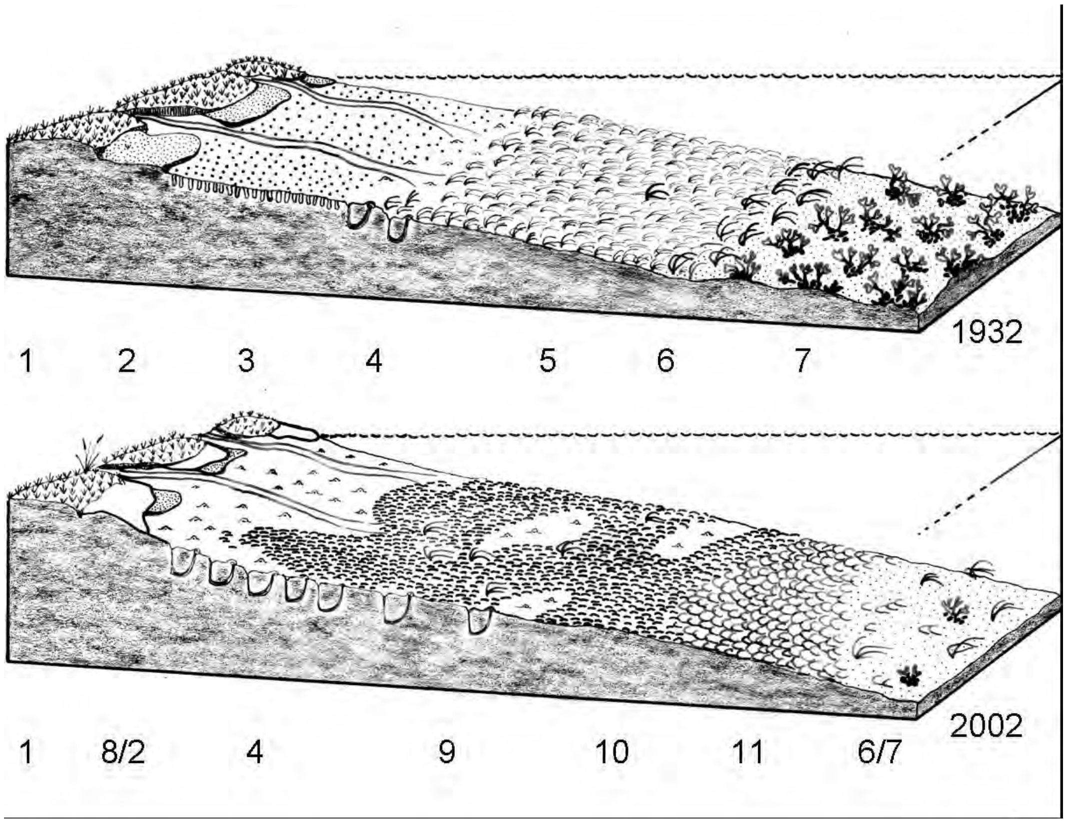

Figure 7: Macrobenthic zonation in Gröning-Watt (Königshafen Sylt) from a salt marsh down to low tide level in 1932 and seven decades later following a rise in high tide level of 25 cm and a period of elevated nitrate concentration in the tidal water. 1 salt marsh, 2 Cynaobacteria-mats, 3 *Corophium volutator* – belt, 4 *Arenicola marina*, 5 *Zostera noltii*, 6 *Zostera marina*, 7 *Fucus vesiculosus* anchored by mussels, 8 sandy beach, 9 filiform green algal mats of *Enteromorpha* spp., 10 *Chaetomorpha sutoria* – mats, 11 lettuce-like green algal mats of *Ulva* spp. (from Reise *et al.*, 2008).

adapted genotypes which may be present in the southern ranges of these species. Massa *et al.* (2009) determined experimentally the sub-lethal temperature limit at 38°C for *Z. noltii* in Portugal. This is beyond what is likely to occur in the Wadden Sea, but genotypes north of Portugal may have lower limits of tolerance.

3.1.6 Sea level rise and storm surges

The sea level is expected to rise by 0.5 to 1.4 m until the end of this century in response to global warming (Rahmstorf, 2007). It is not clear to what extent natural sediment accretion could compensate for such an increase in water levels especially in the face of the fixed coastline, but it is assumed that at least in the larger tidal basins the sediment supply may lag behind and consequently the duration of tidal submergence will increase (CPSL, 2005). With higher water levels above seagrass beds, storm surges will have stronger effects on sediment stability. This could affect the seagrass directly (see above). Extrapolating winter storm surge levels observed at tide gauges over the last four decades (Weisse and Plüß, 2006) into the next 40 years, water levels would rise by about half a meter, irrespective of any acceleration in global sea level rise.

3.1.7 Interactive effects

Attempts to understand observed changes in seagrass performance and to project its prospects in a future Wadden Sea should combine the various relevant factors rather than treating them separately. This is a highly complex endeavor and opens a new field of research in seagrass ecology. It is necessary to undertake this challenge because we find within the Wadden Sea the largest intertidal seagrass beds in Europe. At first sight it seems simple: nutrient loads have declined and seagrass area has increased over the last decade. If this would be the sole causal relation relevant to long-term seagrass development in the Wadden Sea, one would expect seagrass bed area to follow inversely the nutrient loads of the main rivers discharging into the southern North Sea. However, caution is advised. As pointed out by Reise and Kohlus (2008), the conspicuous increase of seagrass area in the North Frisian Wadden Sea (Figure 4) may also correlate with a relaxation in storm frequency since the second half of the 1990s. At least the spatial pattern of seagrass beds suggests in part the importance of shelter against storm surges from the south-westerly direction. Field experiments combining transplantations and fertilizer additions into locations of low and high exposure to hydrodynamics could help to partition effects of eutrophication, hydrodynamics and their interaction terms.

Particularly at sheltered locations, smothering by green algal mats could harm the seagrasses while, at more exposed locations, epiphytes may become problematic because there grazing on fouling microalgae by snails is depressed (Schanz *et al.,* 2002). Both factors, cover by opportunistic macroalgae and fouling by microalgae, are part of the eutrophication process but have reverse relations to hydrodynamics. A decline in phytoplankton due to a combination of decreased nutrient availability and increasing temperature during summer months (Philippart *et al.,* 2005; van Beusekom *et al.,* 2009) could improve transparency during tidal submergence of seagrass beds. For a more detailed discussion see Reise and van Beusekom (2008).

In considering the prospects of seagrass in the Wadden Sea, we also need to take into account the influx of alien species (see QSR 2009, Thematic Report 7). Beds and reefs of Pacific oysters have been proliferating in recent years. These spread mainly along the low tide line and may eventually provide more shelter to seagrass beds than blue mussel beds ever did. Transplantation experiments with seagrass indicated that such a shelter could be essential (Bos and van Katwijk, 2005 and 2007). In addition to Pacific oysters, the invasions of Pacific macroalgae like *Sargassum muticum* and *Gracilaria vermiculophylla* could also be relevant to seagrass performance in subtidal and intertidal areas, respectively.

In conclusion, it is rather unlikely that seagrass long-term development will be a straightforward function of nutrient supply in the Wadden Sea. Interactions with a wide spectrum of other factors may mask such a relationship and they also require the attention of environmental management.

3.2 Reintroduction of *Zostera marina*

The project "Reintroduction of eelgrass (*Zostera marina*) in the western Wadden Sea" was carried out from 2002 to 2005 (Bos and van Katwijk, 2005). During this 4-year period, approximately 5,900 *Zostera marina* seedlings were transplanted from the donor population in the Ems estuary (eastern Dutch Wadden Sea) to several carefully selected locations at the tidal flats of Balgzand (mainland of North-Holland Province) and Mokbaai (Texel Island). The transplantation locations varied in height, hydrodynamic conditions and presence of mussel beds. Furthermore, *Z. marina* seedlings were planted in different densities and numbers per transplantation unit. By doing so, the transplantation techniques were optimized and the risk of losing plants by local disturbances was reduced. Transplantations were carried out in June and plant survival and plant development were monitored during the growing seasons. Each year in August, plant cover, leaf development and seed production were monitored. Moreover, biotic and abiotic parameters, such as epiphyte cover, macro-algal abundance, invertebrate densities, pore water quality and sediment quality were intensively studied.

Only two transplantation locations were successful. At one location *Z. marina* has asserted itself since 1998, but does not flourish due to regularly being covered by dense mats of macroalgae. The other location shows high survival of transplanted *Z. marina* seedlings, but poor seed survival and germination due to intermediate hydrodynamic conditions and slightly lower salinity. This contradiction describes the situation of *Z. marina* populations in the entire Dutch Wadden Sea. *Z. marina* prefers locations with little hydrodynamic disturbances, but such locations also tend to accumulate macroalgae that smother the *Zostera* plants (Bos and van Katwijk, 2007; van Katwijk *et al.*, 2009). Nevertheless, in the northern Wadden Sea, local sub-populations of *Z. marina* manage to thrive under such conditions (Reise *et al.,* 2008)

In 2005, a small population of *Z. marina* was present at the tidal flats of the Balgzand area, as a result of the aforementioned transplantation activities. Next to it, a number of *Z. noltii* plots were present, the result of an earlier small-scale transplantation experiment. The *Z. noltii* plots gradually increased in size and cover. The *Z. marina* transplants gradually disappeared. Larger scale transplantations could increase the chances of *Z. marina* survival, but their outcome is generally unknown (van Katwijk *et al.,* 2009). Therefore it is recommended not to continue with expensive large-scale transplantations of seedlings. The cheaper alternative of deposition of seed bearing reproductive shoots is suggested instead. This method has been tested on a small scale in The Netherlands (Bos and van Katwijk, 2005).

3.3 Possibilities for re-establishment of seagrass in the Wadden Sea

In The Netherlands, the large area of submerged seagrass beds that was present in the south-western part in the past was formed by Z. marina growing around and below the low water mark. Due to the construction of the 'Afsluitdijk' this submerged Z. marina could not recover from its collapse in the 1930s. Van der Heide et al. (2007) investigated the possibilities for this submerged Z. marina re-establishing itself in this area. In this study, the current conditions in the Dutch Wadden Sea regarding tidal exposure, turbidity, salinity and nutrient availability, were compared with the conditions at the time that Z. marina was still abundant in the Dutch Wadden Sea or with conditions in neighbouring areas where Z. marina still occurs. It was concluded that especially light availability and the large fluctuations in salinity limit the possibilities for re-establishment of submerged Z. marina in the south western Wadden Sea.

Ever since the start of the mapping (from 1950 onwards) the distribution and area of intertidal seagrass beds in the western Wadden Sea has shown little change. However, in the 1950s the distribution between the two species was somewhat more even. This limited distribution of intertidal seagrasses can be ascribed to the exposed situation for prevailing storms.

For the Netherlands, the current surface area of intertidal seagrass beds is regarded as more or less the maximum that can be expected in the intertidal area. Only by intensive effort might an increase in area be possible. The seagrass opportunities map (de Jong *et al.*, 2005) estimates that there is potentially 180 ha very suitable for *Z. noltii* or *Z marina* and 1,750 ha suitable. Even though this is more than the current seagrass area, it is far below the 30,000 ha from before the 1930s.

In a report by Wanink and van der Graaf (2008), research on the subject of seagrass in the Dutch Wadden Sea was summarised with the following conclusions:

1. There are no chances in the Dutch Wadden Sea for natural restoration of *Z. marina*, due to salinity fluctuations, nutrient-supply and turbidity (see also Van der Heide *et al.*, 2007). It would be better to focus the attention on re-introduction towards other Dutch locations, such as brackish lakes in the southwest part of the country.
2. The chances for expansion of intertidal *Z. noltii* are very restricted. The best results are probably to be obtained within and in front of the artificial saltmarshes.
3. The seagrass beds on "De Paap" are possibly somehow connected to the old artificial gas-island on the northern part of this natural island. This might reduce the wave energy. The present reduction in seagrass area might be due to the increased turbidity in the location.

One of the reasons for the postulated low chance of re-establishment may be that the Dutch part of the Wadden Sea is very exposed to wave energy; along the coast of Friesland and Groningen to winds from the N-NW-W-directions, and near the island to winds from SW-W-directions. These are the main storm directions. Only in very sheltered areas like in the reclamation works or in the shelter of (artificial) islands are there some chances. Probably, further expansion of seagrass can only be achieved by creating more of these sheltered areas, but this is against the general policy against human interference with natural proceses.

In 2008, the total area of Lower Saxonian intertidal seagrass beds reaches approx. 50% of the bed area in the 1950s/70s and can be regarded as clearly below the potential area which may be estimated to at least 35 km^2. In Schleswig-Holstein, the maximum surface area of seagrass beds which seems possible (no more land claim and other mechanical disturbances, continued decrease of nutrient input) would be about 5-10% areal share in the Dithmarschen intertidal area (today 0.3%) and about 15-30% in the North Frisian Wadden Sea (today 10% of the intertidal zone) assuming a more or less continuous belt of seagrass along the mainland coast where it is scarce today. In the North Frisian Wadden Sea seagrass beds with >20% coverage were at least once recorded in the interval from 1994 to 2006 on an area of 187 km^2 or about 20% of the entire tidal area (Figure 2), adding to this a continuous belt with seagrass of about 2 km in width fringing the mainland shore, brings the areal share to 30%. The only reliable map of seagrass area from the time prior to significant eutrophication is available for 1924 from Königshafen on the island of Sylt, indicating an areal share of about 60% (see Nienburg 1927). In conclusion, the potential area for seagrass beds amounting to an areal share of 15-30% in the North Frisian Wadden Sea constitutes a conservative assumption.

The considerations above on the potential seagrass area can be regionally summarized as follows:

- The Netherlands: the current seagrass area is below the potential area; potentially the area could increase up to about 180 ha.
- Niedersachsen: current areal share of seagrass beds is approx. 50% below the potential area.
- In Schleswig Holstein: seagrass is far below the potential area in the Dithmarschen intertidal area, and at about half to one third of the potential area in the North Frisian Wadden Sea.
- Denmark: there is not sufficient information about the areal share of intertidal seagrass beds in the past, therefore it can not be estimated to which extent the current share meets the potential area.

4. Conclusions

- Most of the seagrass in the Wadden Sea occurs in the northern part. Beds are mainly positioned on the leeside of islands or in the shelter of high sand bars. Few, and generally smaller, beds are found in the Central and Southern Wadden Sea. A larger stock is present in the Jadebusen, mainly consisting of *Z. noltii*. The large *Z. marina* bed in the Ems estuary had almost vanished in 2008, whereas large *Z. marina* beds had developed on the coast between Weser and Elbe (Wurster Küste). Furthermore, some remaining *Z. noltii* beds of a former more or less closed belt of beds occur along the mainland shore. Almost no seagrass is found in the westerly part of the Dutch Wadden Sea.
- In the Southern and Central Wadden Sea, the cover of seagrass has been declining since the 1960s. However, in 2008 a considerable recovery (mainly of *Z. noltii*, only locally of *Z. marina*) is notable. In the Northern Wadden Sea no decline could be ascertained. Here seagrass bed area has doubled since 2001 (mainly *Z. noltii*).
- The reason for the recent increase in seagrass bed area in many parts of the Wadden Sea could be a relaxation from eutrophication stress, improved light conditions or from intermittent decrease in storminess. More research is needed into these and possible other conditions and the interaction between them to determine conditions factors are most important for the establishment of seagrass.
- Sediment stability is an important condition for the growth of seagrass. It does not grow in areas with high sediment turnover, erosion or deposition. High sediment turnover can be caused by strong currents, storm surges, dredging and dumping of sediments, deepening of gullies and rivers as shipping lanes and by land claim operations in the nearshore zone.
- In addition to an excess of nutrients (including smothering by macroalgae), high sediment turnover and turbidity are considered as the main threats to seagrass in the Wadden Sea.
- In the wake of global warming, sea level rise with an associated increase in hydrodynamics would diminish seagrass beds in the long term.
- In The Netherlands, reintroduction experiments with intertidal *Zostera marina* have been carried out with limited success. It is concluded that there are no chances for re-establishment of subtidal *Z. marina* in the Dutch Wadden Sea. *Z. noltii* was successfully reintroduced in the western Wadden Sea (Balgzand), but has disappeared again recently (since 2008).
- Seagrass bed area in the Wadden Sea is assumed to be below the potential seagrass area but estimates differ substantially between sub-regions, indicating a need for research and better definition on this subject. In all areas the coverage of *Zostera* beds is below the estimated potential area. In The Netherlands coverage was much higher in the past. Under the current conditions, however, there seem to be few chances of development of new or larger subridal seagrass beds in the Dutch part of the Wadden Sea.

5. Target evaluation and recommnedations

5.1 Target evaluation

The target of an increased area of *Zostera* fields has not been met in all sub-regions of the Wadden Sea.

5.2. Recommendations

Research

- Studies on interactive effects of eutrophication, climate change, storm surges and land claim activities on seagrass performance;
- Measurements on the strength of hydrodynamics at sites where seagrass is well established, sites where seagrass is colonizing and sites where seagrass has disappeared, throughout the entire Wadden Sea;
- Studies on the effects of salinity fluctuations and changes in salinity on seagrass performance (van der Heide *et al.* 2007), in relation to changes in freshwater inlets all over the Wadden Sea area;
- Studies on the general effects of dredging and especially dumping of sediments on turbidity and subsequent growth of seagrass;

Monitoring and assessment

- Joint efforts to further harmonize assessment methods in the trilateral Wadden Sea.

Management

- Continue to reduce nutrient loads to improve seagrass performance; further reductions of nutrient loads may lead to reduction of epiphyte growth and of green macroalgae on beds of *Zostera* spp.
- If dredging and dumping of sediments proves to have an effect on the growth of seagrass (see the recommendation for research), there is a need to change dredging techniques in the estuaries to lower turbidity during the growth season of seagrass.

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1. Introduction

The Wadden Sea, as a tidal area, can be divided in intertidal and subtidal zones. The intertidal area is alternately flooded and drained during the tidal cycle while the subtidal area is influenced by the tidal currents but stays submerged during low tide. About 27% of the Wadden sea is subtidal. The benthic species diversity and density in the Wadden Sea is generally higher in the subtidal area compared to the intertidal (Johnson, 1970; Saier, 2002). However, information on habitats in the subtidal of the Wadden Sea is very limited, its enhancement is urgently needed for both scientific demands and ecosystem-based Wadden Sea management.

1.1 Developments in the subtidal area

Changes in the faunal composition of the subtidal were recorded for certain areas in the Wadden Sea (Riesen and Reise, 1982). In the past ages human influences on the existing habitats, organisms and ecosystem processes have increased enormously. Intensive exploitation has resulted in the disappearance of habitat forming species (Wolff, 2000). Since the 20th Century, pollution, eutrophication, invasive species and climate change have also induced changes in the Wadden Sea ecosystem. The relatively high biodiversity in the subtidal, the noted changes and the lack of knowledge in respect to distribution and occurrence of many benthic species and habitats, all contribute to the urgency of research on the subtidal habitats of the Wadden Sea.

1.2 European Directives and trilateral agreements

Knowledge of subtidal habitats is not only required for scientific demands, but also to facilitate the protection of threatened and rare habitats and to improve spatial and strategic planning of human activities, in particular where there are competing demands like fishing, mariculture, sand extraction, wind energy generation and nature conservation. Marine habitats are one of the key items addressed in European directives. In the European Habitats Directive, three subtidal habitat types are pointed out in the Wadden Sea. As stated in Annex I, sandbanks (habitat 1110), large shallow inlets and bays (habitat 1160) and reefs (habitat 1170) which combines biogenic as well as geogenic structures, belong to marine habitats of community interest and should therefore remain in a favourable status. In accordance with the Marine Strategy Directive (Annex II) evaluation of the status of habitat types, the identification and mapping of habitats of special scientific or biodiversity interest is required, including the occurrence and population dynamics of 'habitat specific' species.

The subtidal area is also one of the items the Wadden Sea Plan aims at where namely Sabellaria reefs and blue mussel beds are important topics with specific targets.

Keywords in the assessment of the status of habitat types stated in the Habitats Directive are the surface and natural distribution of the habitat and 'habitat specific species' and the structure and function of the habitat. Besides knowledge on the distribution and covered area of different habitat types (habitat mapping), it is also important to know the ecological processes that are key to certain habitats and influence population dynamics and distribution of habitat specific species, *e.g. Sabellaria spinulosa, Mytilus edulis or Crassostrea gigas*.

2. Findings from the QSR 2004

In the past, reflections on subtidal habitats were restricted to Sabellaria reefs (QSR 1999, 2004) and blue mussel beds (QSR 2004).

2.1 Sabellaria spinulosa

Since the reefs of *Sabellaria spinulosa* are of great importance to biodiversity (Gruet 1971, Gore *et al*. 1978, Mettam, 1992), but show a dramatic decline over the last decades, the intention for their protection as an ecological target exists at different levels in the EU Habitats Directive (Annex I). Although a routine monitoring program on the occurrence and development of Sabellaria reefs has been strongly recommended for many years, it has not been adopted so far.

Subtidal blue mussel beds

Subtidal mussel beds differ significantly from intertidal beds in structure, species interactions and associated organisms (Buschbaum and Saier, 2003). Besides their importance as habitat structure, subtidal mussel beds are important feeding grounds for eider ducks (Ens and Kats, 2003), and presumably also for other diving ducks as the greater scaup and the common scoter, all protected in the European Birds Directive. Protection of mussel beds against anthropogenic bottom-disturbance is, however, still predominantly restricted to the intertidal. Although location and biomass is monitored in The Netherlands and Denmark, so far almost no substantial investigation effort is invested in their structure and function.

3. Inventory of habitat mapping activities

Marine habitat mapping combines biological data from discrete observations (direct sampling) with remotely sensed images (remote sensing) to create a visual product, the habitat map (Mapping European Submarine Habitats, www.searchmesh.net). A habitat map makes it possible to visualize the occurrence and distribution of different habitat types on the seabed. The term habitat is used generically in scientific, management, policy and legal circles, resulting in many different definitions and meanings. A specific definition with respect to Wadden Sea conditions is still missing and should be one of the first tasks of a future TMAP working group (see section recommendations). In this chapter we will follow the definition of ICES: '*A particular environment which can be distinguished by its (a)biotic characteristics and associated biological assemblage, operating at particular but dynamic spatial and temporal scales in a recognizable geographic area*' (ICES working group on marine habitat mapping).

In the natural world, sharp boundaries between different habitat types are rarely encountered and therefore clear divisions of the main parameters of a habitat type need to be designed. Habitat classification schemes help to define habitats in a consistent way. Within Europe there is a single pan-European habitat classification scheme, developed by the European Topic Centre on Biological Diversity (see http:// eunis.eea.europa.eu/habitats.jsp).

Although terrestrial habitat mapping has a long history, seabed mapping is a relatively new procedure. The main reason why information on subtidal habitats was limited so far is the lack of appropriate methods to investigate the seafloor in the deeper parts of the Wadden Sea. The improvement of remote sensing techniques such as multibeam echo sounding and side scan sonar mapping of the subtidal mean that the determination of habitats and biologically relevant structures is now in reach. For a comprehensive overview of available methods, see the website and reports of the MESH project. In this chapter information will be presented on methods, existing activities and first results on habitat mapping in the Wadden Sea which is an obligation under the Habitats Directive.

3.1 Habitat mapping in the Wadden Sea

In preparation for the first trilateral workshop on subtidal habitat mapping in December 2008 a compilation was made, giving an overview of the institutions engaged, methods and sampling gear used (Table 1) and the sites surveyed so far (Figure 1). Several working groups in The Netherlands, Germany and Denmark are investigating the subtidal zone of the Wadden Sea area, but mainly on a small spatial and temporal scale. The methods used range from classic benthos sampling with dredges and corers to remote sensing techniques with echo sounding.

Figure 1: Survey sites in the Wadden Sea area where subtidal habitat mapping has taken place.

Table 1: Sampling gear/methods used in the Wadden Sea area for subtidal habitat mapping.

Sampling gear/method	NL	D	DK
Dredge	x	x	x
Grab/box corer	x	x	x
Underwater photography		x	
Underwater video	x	x	
Single beam echo sounding	x	x	
Multi beam echo sounding	x	x	
Sidescan sonar	x	x	

A variety of biological and geological datasets from the deeper parts of the Wadden Sea is available, mainly achieved from small-scale and short-term research projects. Long-term routine monitoring programs on habitat structures only exist in Denmark (since 1986) and The Netherlands (since 1992), where dredge sampling of subtidal blue mussel beds take place. In Schleswig-Holstein, regular seafloor mapping by means of single beam echo sounding (Roxanne) and underwater videoing are carried out by the State Agency for Agriculture, Environment and Rural Areas (LLUR). Since 2006 the Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN, Germany) is carrying out subtidal dredge and grab sampling in and between the estuaries of the Ems and Weser to assess the ecological status of benthic communities due to the Water Framework Directive (WFD). Additionally, several projects have taken place with full-coverage mapping of extended seabed areas and habitat characterization has been deduced by the Research Centre GKSS and the Senckenberg Institute, using multibeam sonar/underwater video and sidescan sonar/dredge sampling, respectively.

3.2 Methods used for subtidal habitat mapping

3.2.1 Direct sampling

In the Danish Wadden Sea, bivalve stocks have been monitored since 1986 by the Danish Institute of Fisheries Research (Kristensen and Borgstrøm, 2006). Monitoring has been carried out using traditional biological methods. Different sampling techniques have been applied during these years of monitoring (Kristensen *et al.*, 2007). Sampling of blue mussels on subtidal beds in the Wadden Sea was carried out with help from local fishermen applying their traditional mussel dredge. For sampling of Pacific oysters, an old type oyster dredge was used. All samples have been used to estimate the mussel biomass in the subtidal beds. An example of dredge tracks in the Ho Bight in 2004 is shown in Figure 2. Similar dredging has been performed south of Esbjerg in Grey Deep and Knude Deep. In Figure 3, blue mussel biomass and distribution pattern in the Danish Wadden Sea is given for the years 2000, 2002 and 2004.

In the subtidal of the Lower Saxon Wadden Sea, benthic communities have been monitored since 2006 by the NLWKN by dredging and grab sampling (Van-Veen-grab). Once or twice a year, ten grab- and two dredge-samples were taken at several transects of about one km length in order to get information on sediment and benthic communities as required by the WFD.

In the Dutch Wadden Sea, grab or dredge sampling are used for monitoring programs on distribution and biomass estimates of shellfish.

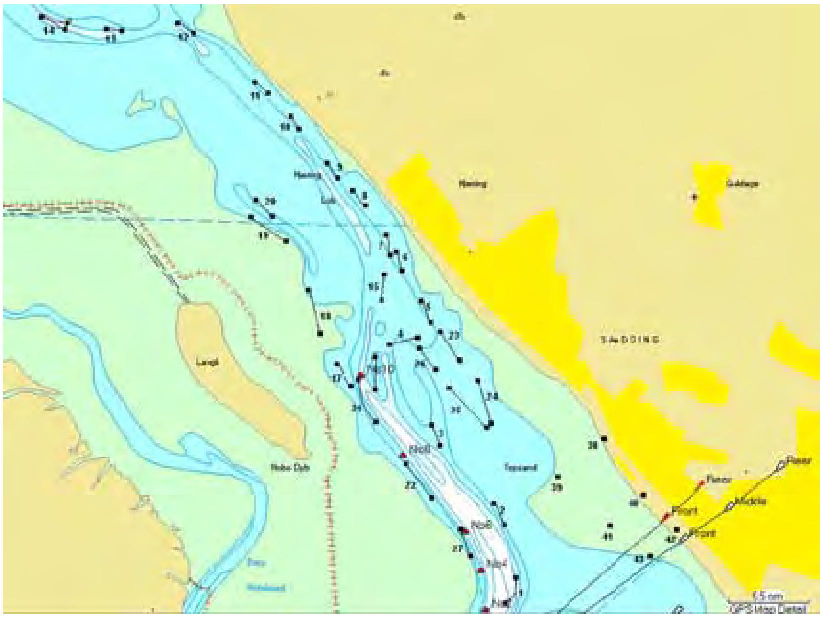

Figure 2: Dredging transects (No. 1-27) for sampling blue mussel in the survey from September 2004 in Ho Bight

The biomass of the subtidal shellfish populations is monitored every year in spring/summer by a stratified dredge sampling survey. Additionally the entire subtidal area is investigated, taking 30 m² with a hydraulic dredge on a stratified grid. This survey is carried out in September/October. Since 2008 the focus is not only on mussels (*Mytilus edulis*) and cockles (*Cerastoderma edule*), but also on Pacific oysters (*Crassostrea gigas*), razorshell clams (*Ensis directus*) and soft-shelled clams (*Mya arenaria*). In addition several small scale but long term studies on subtidal benthic biodiversity take place in the Dutch Wadden sea, using grab sampling or box-corer (Fey *et al.*, 2008). From 1989-1997 a survey on sediment classification took place in the Dutch Wadden Sea by grab sampling. This survey resulted in a sediment atlas produced by the water management directorate (mentioned by Zwarts, 2004, but published separately by the RIKZ). More recent data on sediment classification consists of local data collected for scientific studies or habitat studies, for example in a reference area near Rottum using the Medusa method (see 3.2.4).

3.2.2 Acoustic remote sensing

For decades, acoustic systems have been successful instruments for marine research (Newton and Stefanon, 1975; Flemming, 1976), because they can 'see' the sea bottom without needing underwater optical visibility. Nowadays sidescan sonar, single beam and multibeam sonar are commonly used for the identification of the seafloor environment. Seabed structures and sediment types are determined by the acoustic response of the bottom, which is a function of the physical properties of the sea bottom (grain size, texture, roughness, slope).

Multibeam Sonar

The multibeam sonar system sends out multiple beams of sound energy and records the time elapsed between the emission of each acoustic pulse from the transducer to the seafloor and back again to the receiver of the system. Transducer and receiver are mounted on the hull of a research vessel, so the ship's positioning can be integrated into the data collection. By means of a differential global positioning (D-GPS) or even real time kinematic (RTK) system and an intertidal motion unit (IMU), the ship's position can be recorded at the time of each pulse and a highly accurate bathymetric record can be produced. Modern shallow-water systems can describe the seabed at spatial resolutions of as little as a few centimetres (Hughes, Clarke *et al.*, 1996). Simultaneously the

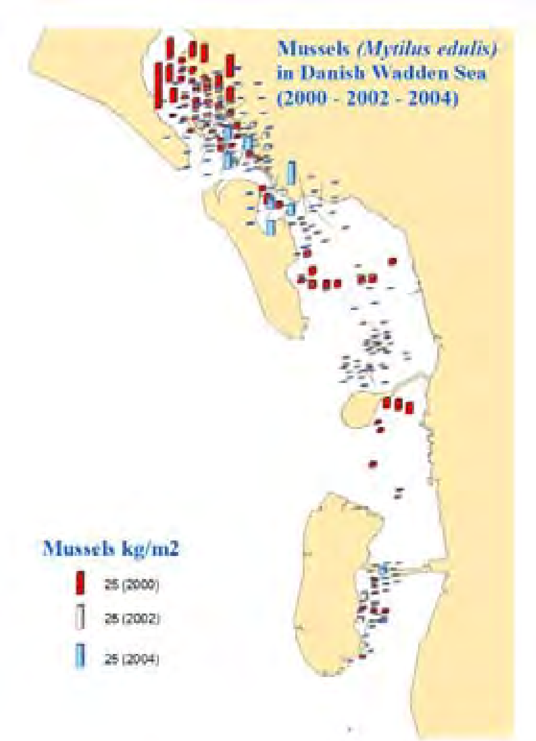

Figure 3: Blue mussel biomass and distribution pattern in the Danish Wadden Sea in 2000, 2002 and 2004 (Kristensen *et al.*, 2007).

'sidescan mode' of the multibeam sonar system records the backscatter intensity of the acoustic return in order to derive seabed characteristics for habitat mapping. By running parallel survey lines, large areas of the seabed can be mapped. Thus, the bathymetric data deliver a precise full-coverage digital elevation model of the studied area and the backscattering data can be used for sediment classification.

In the German Wadden Sea, multibeam sonar was used for a number of research projects conducted by the Research Centre GKSS. The system (here: Simrad EM 3000/3002) is especially adapted for shallow water with a range for application between one and 100 meters water depth. In the Dutch Wadden Sea, single beam echo sounding is used to produce a new bathymetric map for the entire Wadden Sea area every six years. Multibeam sonar is used in individual construction or dredging projects in the Wadden Sea, but not in monitoring programs.

Sidescan Sonar

Sidescan Sonar produces images of the seabed based on sound transmitted and received from a sonar tow fish trailed behind a ship. In contrast to the multibeam system, sidescan sonar measures not the time but the strength of the returning acoustic beam. The signal sent out is a single beam with a wide opening, one on the right and one on the left side of the tow fish. The positioning of the sonar fields creates a blind spot perpendicular under the sonar fish, visible as a black line in the middle of sidescan sonar images. The scan range achieves nearly 180° and the system is independent of water depth. Thus, the productivity of survey work is especially good in shallow areas. Based on textural patterns and the intensity of the reflected sound, the image can be used to identify discrete seabed structures and to characterize sediment types. Sidescan sonar does not provide data on depth and an exact geographical reference of the tow fish position behind the ship is not available.

This acoustic technique is used in the Dutch Wadden Sea to map the contours and patterns of shellfish beds (mainly blue mussel and Pacific oyster). In a study on the effects of mussel seed fisheries (PRODUS) sidescan sonar gave an impression of the distribution and development of mussel patterns on the research plots (Fey *et al.*, 2008). Sidescan sonar was also used in a study on the development of individual subtidal mussel beds, describing the contours and patterns (Figure 4). Sidescan sonar images are sometimes used to identify the location of oyster or mussel structures which thereafter are sampled by grab sampling for quantitative data on biomass (Kater *et al.*, 2002). As the sidescan sonar images are not yet resulting directly in quantified data, they are used in a descriptive way and are always combined with dredge or grab sampling for ground truthing.

Underwater Video

Underwater videoing is a well established method for investigating the marine environment from the intertidal up to the deep sea (Holme, 1984). Frequently, underwater video is used as ground-truth procedure in combination with acoustic seabed mapping (Vorberg, 1998; Rooper and Zimmermann, 2007). The camera can be mounted on a towed sledge or remotely operated vehicle (ROV). In both cases the camera is connected to the vessel by a bidirectional umbilical for data transfer. An underwater light is attached to the video system to illuminate the seabed in case of insufficient light conditions. The underwater video is viewed in real time on board and recorded for further analysis. The time stamp of the video is linked to the temporal information of the global positioning system.

Strong tidal currents and high turbidity in the Wadden Sea often yield unfavourable conditions for visual surveys and applicability was therefore limited in this area. Best results for underwater videoing in the Wadden Sea were obtained one hour before and after high water when current speed is low and the clear water from the open North Sea has entered the system. Under good conditions the video recordings enable a detailed analysis of the sediment type and biotic and abiotic

Figure 4: Sidescan sonar image of a subtidal mussel bed in the Dutch Wadden Sea. The red line indicates the contours of the mussel structure. On the image the parallel survey lines are clearly identifiable as separate horizontal bars on the picture. Within the red contour lines the structures or "patches" of the mussel bed are visualised by dark spots, which are not present on the bare sand outside the mussel bed.

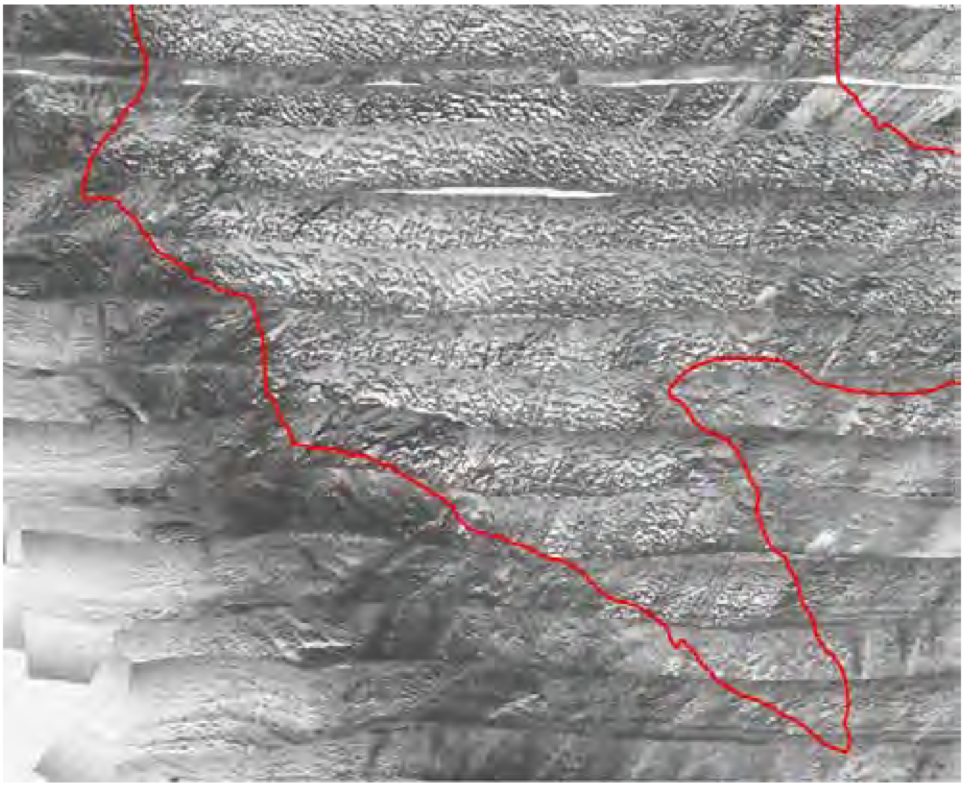

Figure 5: Screenshots from underwater video recordings of different sediment types (A: pure sand with ripples; B: sand covered by mussel shells; C: *Cancer pagurus* and *Pholis gunnellus*)

structures on the sea bottom can be determined, as well as macrobenthic species (Figure 5).

In the Dutch Wadden Sea, the technique is used on specific research plots, mainly for measurements on blue mussel densities, but also on other macrobenthos like crab and starfish. The camera is combined with a water-filled, pyramid-shaped lens and the system is lowered from a boat.

Thus, underwater videoing is on one hand a suitable method for seabed mapping and can on the other hand as ground truth procedure to verify the findings of acoustic surveys.

3.2.4 Other methods

The multi-element detector for underwater sediment activity (MEDUSA) uses a combination of a detector for natural gamma radiation and a detector for friction sounds when the instrument is dragged over the sea floor. The method measures the coarseness and composition of the top layer of the sediment. In The Netherlands this method is used in individual small research or construction projects (e.g. Dankers *et al*, 2006).

4. Subtidal Wadden Sea habitats

Habitat types in the subtidal of the Wadden Sea can be based on specific abiotic characteristics, resulting from relief, sediment type or seabed structures like gravel, shells, stones or peat. These physical characteristics can, however, also result from habitat-forming species or biogenic structures, which influence physical conditions in such a way that they form a habitat.

4.1 Seabed or sediment classes

In the subtidal Wadden Sea region, sandy sediments prevail. Natural rock formations do not occur, although pebbles and boulders are scattered locally. In some locations, patches of peat occur on the seabed surface, with a thin cover of tidal sediments. The Wadden Sea sand is of fluvial and glacial origin, the fine clay fraction in the sediments is thought to be primarily derived from recent riverine sources. Most subtidal sediment consists of fine sand. The coarsest sediment can be found near the coastal zones and the sea entries. From the Wadden islands towards the east the sand particles become smaller. The fine clay fraction increases towards the mainland. Each seabed or sediment type accommodates specific biological assemblages, which is of course also influenced by other environmental factors such as salinity and water movement. Only little information exists on seabed type or sediment distribution in the Wadden Sea. In the Dutch Wadden Sea the most recent survey on sediment classification took place in 1989-1997. Some recent data on sediment classification consists of local data collected for scientific studies, but no information exists on changes of sediment composition in recent decades.

4.2 Biogenic structures

4.2.1 Sabellaria reefs

Polychaetes of the species *Sabellaria spinulosa* produce reef like structures in the subtidal of the Wadden Sea. It is a common and widespread polychaete species in the North Sea. Although single individuals of this species can be found throughout the entire Wadden Sea, reef-like structures occur only in a few locations. It is believed that only under certain conditions reefs are built but there is a serious lack of knowledge of the primary conditions for the genesis and further development of those reefs. In the Jade River near Hooksiel, harbour reef structures were known for many decades. Investigations in the 1990s confirmed the existence of extended reefs (Vorberg, 1997; Grotjahn, 2000). At this site an acoustic survey by means of multibeam echosounding was conducted in 2005. By using this acoustic method only little reef fragments could be found. The digital elevation model of the studied area shows a uniformly shaped sandy sea bottom with no noticeable structures occurring and only the analysis of the backscatter data gave hints of the existence of bottom structures with hard texture (Figure 6). Underwater video records could confirm little

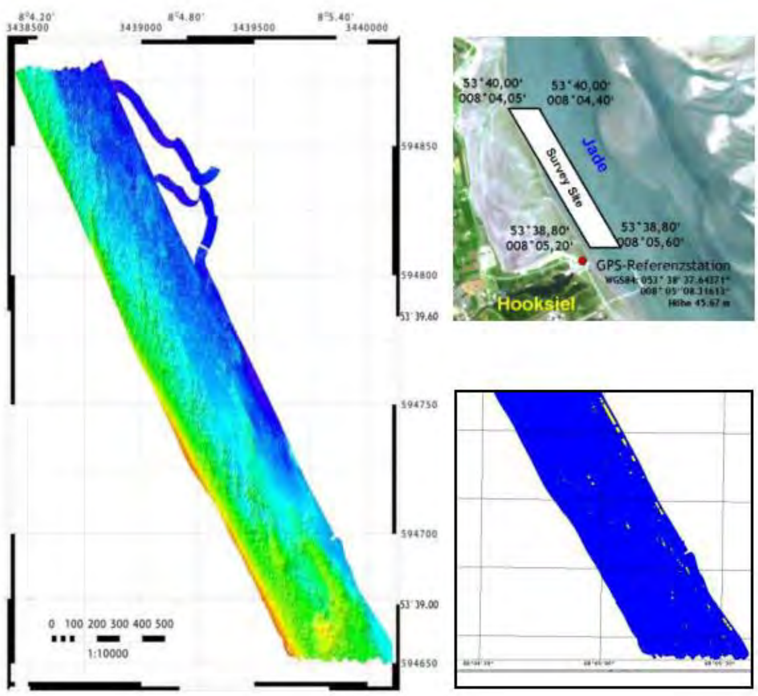

Figure 6: Mapping of Sabellaria reef structures in the Jade river near Hooksiel: location of the survey site (right above), digital elevation model (left) and sediment composition analysed by backscatter data (right down).

Sabellaria reef-clumps mainly along the slope in 9-12 meter water depths. Reef structures as known from the past were no more present in this area. Sabellaria reefs are not known in the Dutch or Danish Wadden Sea, although, at least in the Dutch Wadden Sea, individuals of these species are sporadically found (Dekker, *pers. comm.*).

4.2.2 Lanice fields

The polychaete *Lanice conchilega* constructs small tubes of fine sand particles or shell fragments. Lanice can occur in dense fields of a few hundred to several thousands of indivduals per square meter. Extended beds were found in the course of a seabed mapping survey in the Osterems area between the East Frisian islands of Borkum and Memmert (Figure 7). Some small stretches of subtidal *Lanice* fields were found the Dutch Wadden Sea near Texel in a study on acoustic (sidescan sonar) type signatures of different macrobenthic species (Overmeeren, 2009). They were visible on sidescan sonar images and found in grab samples taken on the spot. No monitoring programs exist which can give insight into the development and distribution of this habitat forming species.

4.2.3 Subtidal blue mussel beds

Blue mussel beds come into existence after annual spatfall events and can survive at a specific location for many years. The current status of subtidal mussel beds is broadly discussed in the QSR 2009 (Nehls *et al.*, 2009). Although the importance of blue mussel beds for associated species is broadly recognised, there is limited information on the fauna associated with subtidal mussel beds in the Wadden Sea area. Some work has been done on associated fauna and species interactions differed between intertidal and subtidal mussel beds and between wild subtidal beds and culture plots (Buschbaum and Saier, 2001; Saier, 2003). Besides their importance as habitat structures, subtidal mussel beds, including associated species, form important feeding grounds for diving ducks. In the Dutch Wadden Sea, a research program named PRODUS studies the effects of seed fisheries on the biodiversity of subtidal mussel beds. In this research project a comparison between natural beds and culture lots is included. The project will be finalized in 2012.

Occurrences and distribution of intertidal mussel beds is monitored regularly throughout the entire Wadden Sea. Monitoring programs on subtidal blue mussel beds do not exist, except in the Dutch Wadden Sea, where subtidal beds are roughly mapped in spring and autumn for fishing purposes.

4.2.4 Subtidal Pacific oyster beds

The current status of Pacific oyster development is discussed in detail in the QSR 2009 (Nehls *et al.*, 2009). Although the Pacific oyster (*Crassostrea gigas)* population in the subtidal has remained small compared to the intertidal, recent expo-

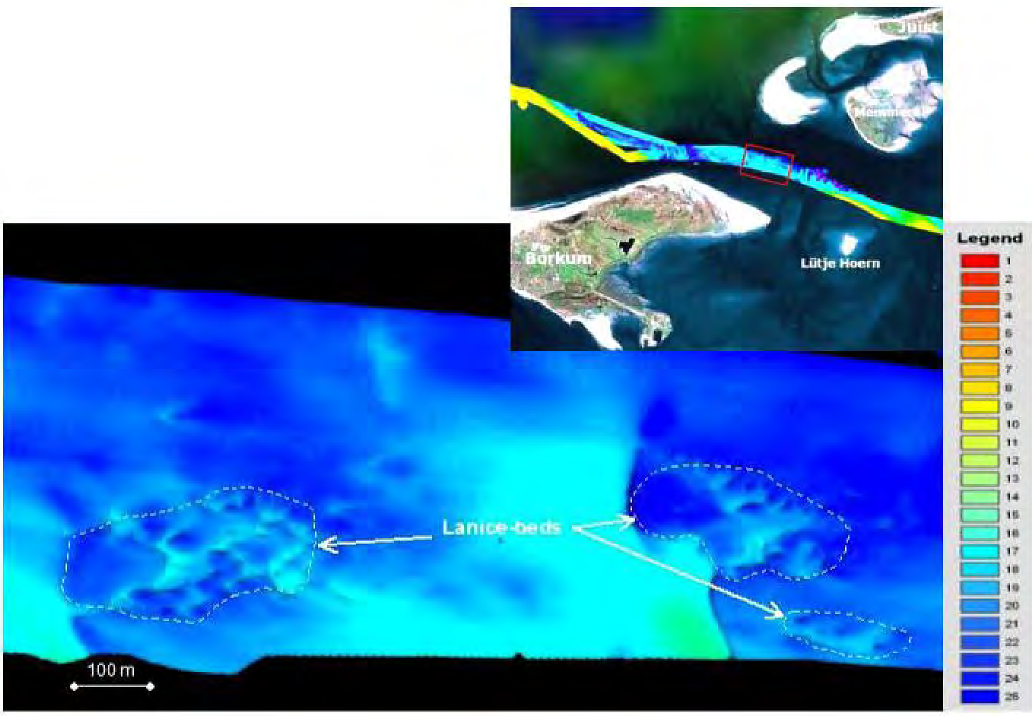

Figure 7: Extended Lanice fields in the Osterems could be detected by the digital elevation model obtained from the mulitbeam sonar data (Legend: water depth [m]).

nential growth of the subtidal population was observed in Dutch waters. While subtidal oysters mainly occur scattered, associated with blue mussels, reefs are formed at some localities, with multiple oyster generations accumulating. It is not known if and to what extent subtidal oyster reefs differ in biodiversity from intertidal oyster reefs or subtidal mussel beds. In a study on differences between intertidal blue mussel beds and oyster reefs in the German Wadden Sea (Markert, 2006), it was found that oyster reefs are characterized by a higher availability of hard substrate, a more complex habitat matrix and an increased biodeposition. These habitat features affected the living community and the composition of the associated macrofauna. Pacific oyster reefs showed a higher biodiversity than sites predominantly occupied by blue mussels.

Occurrence and distribution of subtidal Pacific oyster beds has been monitored in The Netherlands since 2008. Regular investigations in Germany and Denmark are restricted to the intertidal, but pilot and research projects in Germany are carried out to enlighten the situation in the subtidal.

4.2.5 Subtidal seagrass and macroalgae

The surface of subtidal *Zostera marina* in the Dutch western Wadden Sea was estimated to occupy a total area of 6,500-15,000 ha (Wolff, 1983). Since the extermination of this form by the wasting disease in 1932, only individual intertidal stands occur. The development of seagrass and macroalgae in the intertidal is further discussed in the QSR 2009 (van der Graaf *et al.*, 2009). There is no monitoring program on subtidal seagrass and macroalgae in the Wadden Sea.

5. Discussion and conclusion

5.1 Target evaluation

The following ecological targets for tidal areas (Trilateral Waden Sea Plan) are valid for the subtidal:

- a natural dynamic situation in the tidal area;
- an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas;
- an increased area of, and a more natural distribution and development of, natural mussel beds and *Sabellaria* reefs and *Zostera fields*,

In addition, targets for marine mammals and birds have been formulated.

Three habitats types are relevant in the Wadden Sea concerning Annex I of the EU Habitats Directive. In The Netherlands, the subtidal habitat is classified as habitat 1110 (sandbanks which are slightly covered by sea water all the time). In Germany and Denmark an additional habitat type (1170, reefs) is recognized. The Dutch government does not consider subtidal reefs as a separate habitat type and includes reefs in the habitat 1110 description. Habitat 1110 extends over about 120,000 ha in the Dutch Wadden Sea, of which 0.1% is closed for all commercial activities and thereby about 120 ha are valid as undisturbed subtidal area. In total, the status of conservation of the Dutch habitat type 1110 is evaluated in 2007 as moderately unfavourable. In Germany, the entire Wadden Sea national parks of both Schleswig-Hostein (452,000 ha) and Lower Saxony (278,000 ha) were reported as habitats to the European Commission. Due to the limited knowledge of the subtidal, the conservation status of habitat types 1110 (submerged sandbanks) and 1160 (large shallow inlets and bays) is unknown and despite an unknown situation, reefs (habitat type 1170) were evaluated as moderately unfavourable.

5.1.1 Mussel beds and Sabellaria reefs

Mussel beds fulfil an important role in the subtidal ecosystem. They form, together with Pacific oyster reefs, the only remaining biogenic structures forming hard substrate in the Wadden Sea, but little is known about the occurrence and distribution of subtidal mussel beds

All subtidal blue mussel beds are exploited by mussel (seed) fisheries, except for a part of the Hörnum Deep (Schleswig-Holstein), which is a zero use area since 1997. Recent agreements between mussel growers and nature conservation organisations in The Netherlands have resulted in plans to close parts of the subtidal mussel beds for fisheries. A growing surface area of older mussel beds in this part of the Wadden Sea should be promoted.

Information concerning Sabellaria reefs is unsatisfactory and based on surveys several years ago. Latest results indicate a further decrease of one of the last existing reefs in the Jade near Hooksiel and the occurrence of other reef sites is unknown. Suitable methods for searching and monitoring are available, but due to lacking monitoring work a target evaluation for Sabellaria reefs is not possible.

5.2 Appropriate methods for habitat mapping

For a complete detection and assessment of all Wadden Sea habitats, a variety of different methods is required. Assessment of habitat types is based on the occurrence and distribution of habitat types, reflected in the morphology of the seabed, the sediment type and biogenic structures, and the function and structure of the habitat in combination with the occurrence and development of habitat specific species.

Acoustic remote sensing methods allow large-scale registration of the seabed, resulting in detailed three-dimensional pictures of the morphology, information of the sediment types and occurrence and distribution of biogenic structures. Direct sampling generates validation of remote sensing techniques and information on structure and function and the status of specific species. Full-coverage mapping of the entire Wadden Sea by means of remote acoustic methods is the first step towards an ecosystem-based management and should be supported by traditional sampling techniques (dredging, grab sampling) in order to get information on biodiversity, species variation and abundance on different habitat types.

5.2..1 Remote sensing

Pictures derived from multibeam echosounding or sidescan sonar give information of the seafloor comparable to aerial photos from ashore. In contrast to that, dredge and grab sampling and close-up photography yield very detailed but very small-scale information. The large-scale approach of acoustic methods in combination with direct measurement validation fits the trilateral policy and management demands as well as the requirements of the EU Habitats Directive. Full-coverage mapping of the subtidal of the Wadden Sea enables the detection of Sabellaria reefs, blue mussel and oyster beds as well as the habitat types sandbanks (habitat type 1110), large shallow inlets and bays (habitat type 1160) and reefs (habitat type 1170), which are relevant in the sense of the EU Habitats Directive. In addition to the detection of subtidal habitats, long-term investigations of the extent, distribution, structure and development of habitats yield valuable information concerning the assessment and evaluation of management measures.

Which sonar system to use for a specific task depends on a number of factors, including the seabed properties to be measured (*e.g.* bathymetry, surface texture, sediment type), the area of seabed to be surveyed, and whether complete coverage of the seabed is required. The special challenge surveyors are faced with in the subtidal of the Wadden Sea is the water depth, which is in wide parts very low and permanently changing due to the tidal regime. Because sidescan sonar works independent of water depth, the system is suitable for the Wadden Sea. The attractiveness of multibeam echo sounding lies in the exact three-dimensional positioning of the backscattered data. Moreover, the high reproducibility of multibeam sonar surveys is advantageous for monitoring purposes.

A promising way in hydro-acoustic surveys of shallow tidal areas can be the integration of both, multibeam and sidescan sonar. Shono *et al.* (2004) suggest a combination of the techniques and could demonstrate an economic and effective way for mapping seagrass beds.

5.2.2 Direct sampling

Besides as validation of remote sensing techniques, direct sampling is essential to evaluate the occurrence and natural distribution of 'habitat specific or typical species' and the structure and function of the habitat. Remote sensing techniques are very strong in delivering full coverage information on structural characteristics, but do not provide information on population dynamics or occurrences of infauna species, missing out the majority of the biological/ecological information. While a stratified sampling survey by means of dredging may assess a mussel or oyster stock with an accuracy (95%) of approximately ±25% (Jansen *et al.* 2008), translation of sonar images via ground-truth analysis will add a considerable error to such a biomass estimate.

5.3 Future perspectives

To be able to give a valid and complete assessment of subtidal habitats, there is an urgent need for information on the surface and natural distribution as well as on the structure and function of these habitats.

5.3.1 Practical work

Full-coverage mapping of the subtidal of the Wadden Sea can be achieved if a trilaterally integrated survey work program can be installed. Closest attention should be paid to remote acoustic methods since sidescan and multibeam sonar are the most effective techniques to map the seabed, sediment and surface of biogenic structures of the entire subtidal of about 5,000 km² in an appropriate period of time, although direct sampling on regular intervals will remain necessary. Given that multibeam sonar maps about 3 km² per day and sidescan sonar reaches twice as much, we can assume, that a fleet of 5 research vessels can carry out the survey work for the entire Wadden Sea area within 1 – 2 years. This calculation ignores already existing results, as well as methodological difficulties and the time needed for ground truthing work. The availability of research vessels, appropriate equipment and manpower is a matter of organisational work, which could be done in the framework of a coming trilateral working group on habitat mapping. Main tasks of this working group must be the integration and harmonization of existing activities just like the equilibration and further development of the methods.

5.3.2 Theoretical work

An important task for the working group is to elaborate the theoretical basis for habitat mapping in the subtidal of the Wadden Sea. A special working group should come up with proposals of which habitats should be mapped. Wadden Sea specific habitats have to be worked out on the basis of classification schemes set up by the EU Habitats Directive or by ICES and EUNIS. The theoretical background about the framework and how to use the classification for habitat mapping purposes is given by Connor *et al.* (2004).

6. Recommendations

The following recommendations for subtidal habitat monitoring and assessment can be given:

- Installation of a trilateral working group on subtidal habitat mapping.
- Full-coverage approach should be the main objective for subtidal habitat mapping.
- Development of an integrated hydro-acoustic survey combining multibeam and sidescan sonar technology for full-coverage mapping and underwater video for ground truthing.
- Harmonization of the trilateral survey work.
- Equilibration of methods applied for habitat mapping.
- Regular workshops for joint analyses of the data and trilaterally tuned results.

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Fish

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1. Introduction

Twaite shad
(Photo: Z. Jager)

The shallow coastal waters of the Wadden Sea and its tributary estuaries provide indispensable ecological functions for a whole range of species in the course of their respective lifecycles. For fish, they support functions such as reproduction, maturing and feeding and they serve as an acclimatization area and transit route for long-distance migrants from sea to their spawning grounds located in fresh water (*e.g.* Haedrich 1982, Kerstan 1991, Elliott and Hemingway 2002, Elliott *et al.*, 2007). The estuaries are even more than the Wadden Sea itself characterized by a pronounced salinity gradient and a dynamic mixture of limnetic and marine elements which is also reflected by a special fish fauna composition. Thus, they constitute a habitat of a very particular nature within the Wadden Sea. At the same time there is a close relationship between estuaries and the Wadden Sea due to the intensive exchange of substances and organisms, which is reflected in the fish fauna as well. The Wadden Sea ecosystem is also connected with and influenced by the North Sea: marine juvenile and marine seasonal species form an important constituent of the Wadden Sea fish fauna.

The Wadden Sea and estuaries, especially the upstream sections, were and are subject to substantial anthropogenic pressures (Lozán *et al.*, 1994, Schuchardt *et al.*, 1999, 2007; Essink *et al.*, 2005). These pressures are reflected in the aquatic biotic communities and in the fish fauna in particular. Among the most relevant anthropogenic factors influencing the estuaries are dredging and the disposal of dredged material, coastal protection and flood defence and the direct or diffuse input of substances from industry and agriculture. In the Wadden Sea the dominance and relative importance of the anthropogenic pressures are slightly different compared to the estuaries. Recreation plays a more pronounced role here, as well as shrimp fishery and mussel culture. The North Sea in its turn is subject to increasing human demands for shipping, exploitation of resources (gas and oil, sand and gravel), fishery and wind energy.

Intermingled with the anthropogenic pressures that are exerted, natural variability plays a very important role influencing fish fauna abundance and distribution. Recently, an increasing number of publications point to the relations between the North Atlantic Oscillation (NAO) and fish populations (Attrill and Power, 2002; Henderson and Seaby, 2005) or the effects of increasing water temperatures on fish (Henderson and Seaby, 1994; Genner *et al.*, 2003; Pörtner and Knust, 2007; Van Keeken *et al.*, 2007). New species are reported in the Wadden Sea, such as the black goby *Gobius niger* (H. Asmus, pers. comm.) and the exotic Atlantic croaker *Micropogonias undulatus* which turned up in the Weser estuary in 2004 (Bioconsult, *unpubl.*).

1.1 Findings and recommendation of the QSR 2004

The previous Quality Status Report (QSR 2004; Vorberg *et al.,* 2005) described and assessed the temporal trends and spatial distribution of 20 fish species and the brown shrimp (*Crangon crangon*). It underlined the need for a regular assessment of the fish fauna and formulated recommendations on management, monitoring and research. These were adopted in the recommendations of the 11th International Scientific Wadden Sea Symposium in Esbjerg (April 2005), and it was advised to include fish monitoring in the ongoing Trilateral Monitoring and Assessment Program (further indicated as TMAP) revision process. The establishment of a trilateral expert group on fish, functioning under the Trilateral Monitoring and Assessment Group (TMAG), was recommended to support TMAP and the implementation of EU Directives.

At the time of the QSR 2004, pelagic fish monitoring was restricted to the Meldorf Bight and Hörnum Deep (Schleswig Holstein). Vorberg *et al.* (2005) judged the status of herring (*Clupea harengus*) in Meldorf Bight stable; sprat (*Sprattus sprattus*) showed a decreasing trend and anchovy (*Engraulis encrasicolus*) an increasing trend in that area, possibly related to increased temperatures. Twaite shad (*Alosa fallax*) seemed to do well in the Meldorf Bight, but in contrast, the population in the Ems seemed unstable. High densities of smelt (*Osmerus eperlanus*) occurred in the lower reaches of the Elbe, but no reliable information was available for the other estuaries. River lamprey (*Lampetra fluviatilis*) showed an increasing trend in abundance. Results from the demersal fish surveys showed that numbers of juvenile flatfish using the Wadden Sea as a nursery were declining, partly as a consequence of a distribution shift towards offshore areas. The causal factors underlying this shift in distribution are as yet not fully understood.

The trends in resident species were fluctuating up and down on a decadal scale. The brown shrimp (*Crangon crangon*) stock seemed in no way endangered and possibly benefited from low predation rates by the low population levels of cod (*Gadus morhua*) and whiting (*Merlangius merlangus*).

1.2 Trilateral policy and management

Despite the recognised importance of fish as an element of the Wadden Sea ecosystem (Vorberg *et al.,* 2005), fish was not considered in the Trilateral Wadden Sea Plan (1997). Neither did it appear in the Common Package of the Trilateral Monitoring and Assessment Program (TMAG, 1997) to a sufficient extent, nor had trilateral targets referring explicitly to fish been formulated.

In the mean time, the need to include fish in the Wadden Sea Plan and the TMAP has grown because the Water Framework Directive (WFD, 2000/60/EC) recognizes fish as a biological quality element for transitional waters (estuaries) and selected fish species are listed in the Habitats Directive (HD, 92/43/EEC); among those are the twaite shad, river lamprey and sea lamprey (*Petromyzon marinus*). In addition, characteristic fish species should be used to assess the status of the relevant habitat types described in the HD (*e.g.* H1110 submerged sandbanks, H1130 estuaries, H1140 intertidal sand- and mudflats). Furthermore, some fish species serve as main food item for birds or seals, which are listed under the Bird and Habitats Directive for the Wadden Sea. Recently, the Marine Strategy Framework Directive (2008/56/EC) has been adopted and is now being implemented. In this Directive, fish again are one of the qualitative descriptors of the good environmental status.

Because the TMAP common package does not include fish monitoring, one is dependent on information that is provided by fish monitoring for other purposes (fish stock assessment for ICES) or (European) obligations. Following the requirements of the EU Water Framework Directive, new fish monitoring was initiated in 2006 in all Wadden Sea estuaries (the 'transitional waters' of the Ems, Weser, Elbe and Eider), to collect data on particularly pelagic (herring, smelt) and diadromous (twaite shad, smelt) fish species in these water bodies.

In contrast to transitional waters, fish is not considered as a WFD biological quality element for coastal waters such as the Wadden Sea - even though fish are an important group within these ecosystems. For this reason, there still is no specific (pelagic) fish monitoring in the Wadden Sea (which should also meet the demands of the Habitats Directive) and considerable gaps remain, especially in the western Wadden Sea. From a trilateral fish monitoring perspective, another regretted gap is the missing fish monitoring in the Danish Wadden Sea.

Expansion of the ongoing monitoring to other locations, or times of the year - to cover fish species with a very strong seasonal pattern of abundance - is not feasible given the current funding available for these monitoring programs. On the functional relationship between fish species and habitats, some new data have been collected demonstrating the role of intertidal seagrass as a habitat and spawning area for fish (Polte and Asmus 2006a, 2006b).

As a result of the QSR 2004 and the recommendations following from the Trilateral Ministers Conference, a TMAP ad hoc expert group on fish monitoring was established in March 2006. This group has been given the task support the TMAP Revision process (monitoring for the Wadden Sea Plan and the EU Directives) and enhance the trilateral coordination of Wadden Sea fish monitoring, based on the QSR 2004 experiences.

1.3 Proposed Fish targets for the Wadden Sea

As one of its tasks, the TMAP ad hoc fish expert group formulated a proposal of trilateral targets for fish which should be including in the further development of the Wadden Sea Plan. Targets for Wadden Sea fish have to take into account the natural fluctuations and the fact that many fish populations in the Wadden Sea depend on the North Sea. Therefore, assessment should be based on long-term monitoring including information about development and distribution of fish stocks in the North Sea. At the other end, estuaries are part of the Wadden Sea and have their influence on the fish fauna. The proposed <u>Fish Targets</u> are:

- Presence of a typical Wadden Sea fish fauna;
- Occurrence and abundance of fish species according to the natural dynamics in (a)biotic conditions.

In addition to these general targets of a typical Wadden Sea fish fauna, conditional sub-targets can be formulated for the different ecological guilds:

- Unhindered migration between the sea and upstream and/or inland waters [for diadromous fish];
- Viable stocks [populations] and a natural reproduction of typical fish species;
- Diversity of habitats (subtidal areas and tidal flats, including areas with seagrass and mussel beds), to provide shelter and food for juvenile fish [nursery function] and substratum for spawning [for estuarine resident species and marine seasonal species];
- Suitable physical, chemical and morphological conditions with the underlying dynamic processes typical for tidal areas [for resident species and marine seasonal species].

In addition, existing Targets on Tidal Area (subtidal and intertidal) are regarded as beneficial:

- Natural dynamic situation in the tidal area;
- Increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas.

Furthermore, a general Target on Estuaries is proposed because estuaries provide important habitats for various fish species:

- Maintaining the tidal influences with their characteristic salt, brackish and fresh water zones.

Beside the fish targets and sub-targets, the topic of trophic integrity should be addressed in the Wadden Sea Plan targets. Fish is an important food resource for birds and marine mammals. To sustain populations of the latter the following target is proposed:

- A natural fish fauna, providing food for sustainable populations of fish-eating birds and marine mammals.

To Denmark, the houting (*Coregonus oxyrinchus*) is a very important target species.

1.4 Relation to EU Water Framework Directive (WFD) and Habitats Directive (HD)

The European Water Framework Directive (WFD) creates a regulatory framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. According to internationally standardized WFD criteria, the following water types occur in the Wadden Sea area: 'euhaline and polyhaline open coastal waters', 'euhaline and polyhaline Wadden Sea' and 'transitional waters'; the latter are found in the estuaries of the Ems, Weser, Elbe and Eider. For all surface waters the WFD aims at achieving a good ecological and a good chemical state by 2015, or (in case of heavily modified or artificial water bodies) the implementation of a good ecological potential and a good chemical state by 2015, and a ban on any deterioration of the status of the water body.

As a consequence of anthropogenic use, which led to morphological changes, all Wadden Sea estuaries have been classified as 'heavily modified'. In heavily modified or artificial water bodies a good ecological state can often not be restored, or at least not by reasonable means. In such case it is allowed to aim at a good ecological potential, which represents a lower environmental goal and which allows for continued anthropogenic uses, such as flood protection and shipping.

The directive defines the 'good ecological state/ potential' as a target that should be achieved by 2015 (or in exceptional cases by 2027). In view of

Table 1:
List of fish species relevant for the Wadden Sea area according to the Habitats Directive, *) only for freshwater (TMAP, 2006).

HD No.	Fish species	Scientific name	Functional guild	Vertical distribution	Habitats Directive	Red List Status
1102	Allis shad	*Alosa alosa*	diadromous	pelagic	Annex II	nearly extinct
1103	Twaite shad	*Alosa fallax*	diadromous	pelagic	Annex II, V	endangered
1106	Salmon	*Salmo salar*	diadromous	pelagic	Annex II, V, *)	nearly extinct
1113	Houting	*Coregonus oxyrinchus*	diadromous	pelagic	Annex II, IV	nearly extinct
1095	Sea Lamprey	*Petromyzon marinus*	diadromous	demersal	Annex II	endangered
1099	River Lamprey	*Lampetra fluviatilis*	diadromous	demersal	Annex II, V	endangered

this, the current state of the water bodies must be evaluated to point out the need for action with respect to the objectives of the WFD. To be able to take this first step, it was necessary to develop suitable assessment methods for the quality components specified by the WFD. One of the biological quality elements in transitional waters (but not in coastal waters) is fish.

The Habitats Directive (HD) was installed in 1992. Up until now, most of the attention regarding the implementation of the HD has focused on the establishment of the Natura 2000 network. This "1st pillar" of the directive refers to the conservation of natural habitats and of the habitats of species. The Wadden Sea is part of this Natura 2000 network. The HD, however, comprises a "2nd pillar" which is related to the protection of species. In particular, Articles 12 and 16 are aimed at the establishment and implementation of a strict protection regime for animal species listed in Annex IV(a) of the HD within the whole territory of Member States. Species of Community Interest include all flora and fauna referred to in Annexes II, IV and V (Articles 1c and 2 of the Habitats Directive).

Good knowledge of a species (range/distribution, occurrence, biology, ecology, threats and sensitivity, conservation needs, *etc.*) and regular surveillance of its conservation status over time (as required in Article 11 Habitats Directive) are essential preconditions for any meaningful conservation strategy.

Some Wadden Sea fish species are listed in the Annexes of the Habitats Directive (Table 1).

The relations between the different EU Directives and the TMAP are summarized in Table 2. Fish species that are part of the WFD and the HD have been included in the selection of priority species that was made by the TMAP ad hoc fish expert group (see 2.4).

1.5. Guidance

This thematic report on fish presents the results and conclusions of the work that was carried out by the TMAP ad hoc fish expert group since 2006, and will give an update on the status of fish in the Wadden Sea. The contents of the report reflect the working process that was followed.

To assess the status of fish in the Wadden Sea a joint data analysis was carried out, based on the WFD approach. For a better understanding, the WFD assessment procedure is presented first. The available surveys for QSR 2009 are described and the metrics needed to describe the fish fauna are selected from the available monitoring data. The priority species and the method of selecting those are described. The joint data analysis that has been carried out on these species is described and the results are presented. Results from the preliminary WFD assessment of fish in transitional waters and the status of shrimp are also included in this report. The suitability of the WFD approach for Wadden Sea fish is discussed. The long-term trends in priority fish species are interpreted and discussed. Conclusions on the status of Wadden Sea fish and recommendations for future monitoring, research, management and policy are formulated.

Table 2:
Connections between the TMAP and the WFD and HD focused on fish.

	TMAP	WFD	HD
Where	Entire Wadden Sea area (Trilateral Cooperation Area)	Transitional waters	Natura 2000 sites
What	All relevant species (see TMAP priority species)	Selected Fish species (section 2.1)	Annex II, IV, V species (Table 1), habitat types (section 1.4)
Assessment	WSP targets (proposed)	Fish index, assessment tool	Under development

2. Methods

2.1 Towards a Fish assessment tool

The approach chosen by the TMAP ad hoc fish expert group was inspired by the work carried out in the estuaries to implement the WFD requirements for transitional waters. A WFD estuarine fish index was developed, which combines a number of fish metrics. These fish metrics are selected variables of the fish community which together are considered to give a good reflection of the status of the fish in the specific water body. In the case of the WFD, the fish metrics for transitional water bodies (estuaries) consist of species composition indices, based on the number of species in certain ecological guilds, and abundance indices of key species. These are compared with a reference situation. The underlying assumption is that the metrics are in some way related to anthropogenic pressures acting on the water system. Considerable effort and progress have been made in developing fish indices and assessment tools for transitional waters with the WFD (Jager and Kranenbarg, 2004; Bioconsult, 2006a, 2007a; Scholle *et al., in prep.*; Scholle and Schuchardt, *in prep.*; Kranenbarg and Jager, 2008). On a European level the fish indices developed in the different countries are compared and calibrated in the North East Atlantic Geographical Intercalibration Group (NEA-GIG).

Reference conditions

The reference fish community (species composition and abundance) for transitional waters was derived from historical descriptions that predominantly date from the period 1870-1920, *i.e.* a period before or at the beginning of the first large-scale river engineering measures. Since the estuaries were subject to anthropogenic use already at that time (Gaumert, 2002), the reference does not represent a pristine state, but nevertheless it does constitute a (very) good ecological state in terms of fish fauna because the species diversity was high and the principal characteristic species of the estuaries, such as sturgeon (*Acipenser sturio*), houting (*Coregonus oxyrinchus*), shad (*Alosa alosa* and *A. fallax*) and salmon (*Salmo salar*) were still caught in large quantities. A reference species list was constructed. Reference abundances were reconstructed based on existing recent and historical, methodologically comparable data (Bioconsult, 2006a).

Species composition

The species composition was differentiated according to the ecological guilds (diadromous, estuarine resident, marine juvenile, marine seasonal species) as defined by Elliott and Dewailly (1995) and Elliott *et al. (*2007). Species of these guilds have more or less specific demands on their habitat and indicate specific impairments to a certain extent. The number of species per ecological guild, in relation to the reference situation, is a variable which is relevant for the assessment.

Abundance and age structure

It was not possible to derive reference abundances for all historically documented species. For this reason the quantitative analysis was limited to selected 'indicator species', representing the most relevant ecological guilds (diadromous, estuarine resident and marine juvenile species): *Alosa fallax, Gymnocephalus cernuus, Clupea harengus, Osmerus eperlanus, Liparis liparis, Plathichtys flesus, Pleuronectes platessa, Zoarces viviparus.* These indicators are characteristic for the estuarine fish community and, with the exception of ruffe (*G. cernuus*) and sea snail (*L. liparis*), are also included in the priority species for the trilateral Wadden Sea region (see 2.4). Although age composition is not obligatory for fish in transitional waters, this parameter was included for two species representing the diadromous guild (smelt and twaite shad) to indicate the presence of a self-sustained population of those species in the estuary.

Requirements regarding data collection for WFD fish monitoring

The use of a fish-based assessment tool for transitional waters requires specific data collection. The assessment procedure is calibrated to catches obtained with the stow net (also called anchor net) and therefore requires this method for its application. The large spatial and temporal variability of estuarine fish communities played an important role in the development of the monitoring concept. Particularly the parameter of abundance is influenced by interannual, seasonal and diurnal as well as spatial variability. The aspects of salinity zone, seasonality and tidal phase were taken into account by careful selection of the sampling locations (one per salinity zone), sampling time (twice a year) and sampling duration (flood and ebb period) to generate reliable data for a confident assessment of the ecological state or ecological potential of the estuary. Fish monitoring conform the method stipulated by the WFD took place in all Wadden Sea estuaries in coordination with The Netherlands and Lower Saxony (Ems estuary), Schleswig-Holstein and the Elbe River Water Quality Board (Wassergütestelle Elbe, WGE), starting in 2006. These data form the basis for the WFD fish-based assessment of transitional water bodies. Nevertheless, the amount of data differs between the estuaries: in the tidal Elbe, comparable data are available for every year since 2000 (Wassergütestelle Elbe, 2000-2007), whereas bi-annual fish monitoring in the Ems started in 2006 within the scope of Dutch-German cooperation. Data for the Weser and Eider are available from one single monitoring campaign (3 sites, sampled in spring and autumn) in each estuary (Weser: 2007, Eider: 2006). In addition, comparable data of 2003 (Voigt, 2003; Schubert, 2003) can be used. The frequency at which WFD fish monitoring will take place from 2010 on will be evaluated in the near future, and will be decided based on the monitoring results.

2.2 Overview of fish monitoring data available to TMAP

An overview of ongoing long-term fish monitoring programs of the different countries in the trilateral Wadden Sea area was prepared by R. Vorberg and was reported in Annex 4 of the Report of the TMAP ad hoc WG Fish (TMAP 2006). The sampling locations are indicated in Figure 1. The most extensive and long-running surveys are the Demersal Fish Survey (DFS) and the Demersal Young Fish and Brown Shrimp Survey (DYFS) (see further description in section 2.5). Pelagic monitoring with a stow net has been carried out in the Schelswig-Holstein Wadden Sea area (this survey is further indicated with SHS) since 1991 (Meldorf Bight) and since 2001 (Hörnum Deep). The Seabird-Fish interaction survey is not a regular monitoring program but was undertaken for specific research goals. Results of this study are presented in **Box 1**. The results of the NIOZ fyke net monitoring (since 1960 in the western Wadden Sea) were not available for analysis; results have been previously published in Van der Meer *et al.* (1995) and Philippart *et al.* (1996). WFD monitoring data were not suitable for trend analyses, because this monitoring was installed as from 2006 and does not yet cover long time series. However, the WFD approach is described in section 2.1 and a preliminary assessment of the transitional waters based on the WFD fish monitoring data is presented in 3.5.

2.3 Reference list of Wadden Sea fish species

As a starting point for the development and evaluation of trilateral targets for Wadden Sea fish, a basic reference list was compiled describing the fish species that (can) occur in the Wadden Sea (Annex I). Information was derived from the running monitoring programs, such as the >35-year

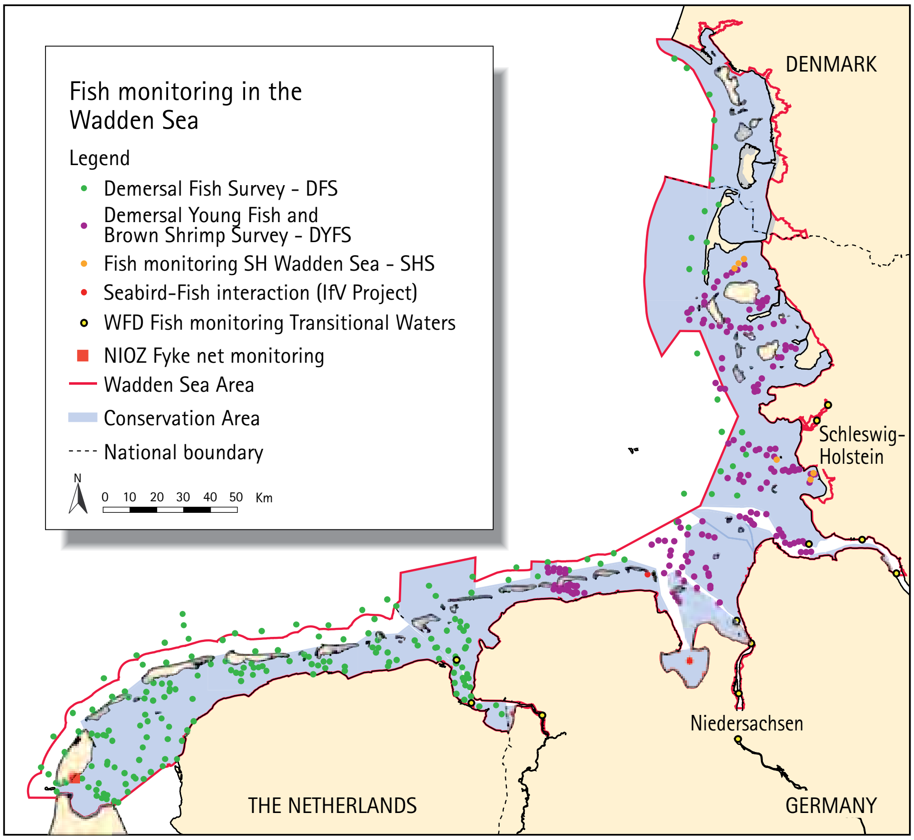


Figure 1: Trilateral Wadden Sea Area and Conservation Area including the locations where different fish monitoring programs are carried out: Demersal Fish Survey - DFS, Demersal Young Fish and Brown Shrimp Survey - DYFS, Fish monitoring Schleswig-Holstein Wadden Sea - SHS, Seabird-Fish interaction (IfV Project), WFD Fish monitoring Transitional Waters, NIOZ Fyke net monitoring.

data sets of the demersal (young) fish survey in The Netherlands and Germany and of the stow net surveys in Schleswig-Holstein, Lower Saxony and from the River Elbe. In addition species lists from the literature were used (Witte and Zijlstra, 1979; Fricke *et al.,* 1994; Vorberg and Breckling, 1999). Altogether the list covers a time period of several decades.

2.4 Selection of Priority Species

The objectives of (TMAP) fish monitoring are to assess the status and the development of relevant or characteristic fish species in the Wadden Sea. In practice it is impossible to do this for all the fish species potentially occurring in this area. To help select the priority fish species, different selection criteria were applied (TMAP, 2006). They were grouped into criteria on ecology (ecological guild, habitat preference), relevance for management (HD species or species belonging to the characteristic fish fauna of HD habitat types[1], WFD species, endangered or vulnerable species, food for birds or marine mammals) and sensitivity to driving forces (climate change, nutrient enrichment, habitat degradation, fishing mortality and local pressures). In addition, monitoring criteria were considered (abundance, occurrence and catchability in the ongoing monitoring programs). Applying these criteria resulted in an exhaustive table, indicating the scores of different fish species according to the criteria mentioned above. A selection of some 14 species, defined as 'priority species' because they were scoring high on these selection criteria (Table 3), was further considered in a joint data analysis (Bolle *et al.,* 2007, 2009).

[1] For H1110A in the Netherlands, recently the following fish species have been listed as qualitative indicators (LNV Profieldocument H1110, vs. September 2008): *Clupea harengus, Liparis liparis, Myoxocephalus scorpius, Pholis gunnellus, Platichthys flesus, Pleuronectes platessa, Pomatoschistus minutus, Syngnathus acus, Zoarces viviparus.*

The allis shad (*Alosa alosa*), sea lamprey (*Petromyzon marinus*), houting (*Coregonus oxyrinchus*) and ruffe (*Gymnocephalus cernuus*) scored high on ecological and management relevance but are not covered by the current monitoring methods and programs. Despite their relevance, they could not be taken further into the analyses.

2.5 Joint analysis of survey data

Considerable effort was put into a joint analysis of the German Demersal Young Fish Survey (DYFS, von Thünen Institut) and the Dutch Demersal Fish Survey (DFS, Wageningen IMARES), and substantial progress in tuning different monitoring data was achieved compared to the previous QSR. A joint analysis was enabled because the methods had already been harmonized in the ICES working group on beam trawl surveys (see for example ICES, 2006a). The demersal survey data have been analysed to a finer spatial resolution than in the previous QSR, namely by QSR sub-area, which allows comparison of trends in abundance of species between different parts of the trilateral Wadden Sea. In addition, the Schleswig-Holstein stow net survey (SHS; National Park Agency and Marine Science Service, Germany) was involved in the joint analysis as far as the data allowed it.

These three surveys together have a good spatial and temporal coverage (see Figure 1). The methods of these three surveys have been described elsewhere (Boddeke *et al.,* 1970; Boddeke *et al.,* 1972; Neudecker, 2001; Vorberg, 2001; ICES 2006a; Bolle *et al.,* 2009). Full descriptions of the methodology and the outcome of the joint analysis are presented in Bolle *et al.* (2009), whereas selected results are presented here for the Wadden Sea Quality Status Report 2009.

Species	Name	Ecological guild	Stratification	Caught in beam trawl	Caught in stow net
Alosa fallax	Twaite shad	CA	Pelagic	(x)	x
Osmerus eperlanus	Smelt	CA	Pelagic	(x)	x
Lampetra fluviatilis	River lamprey	CA	Pelagic	-	x
Platichthys flesus	Flounder	ER	Demersal	x	(x)
Zoarces viviparus	Eelpout	ER	Demersal	x	-
Ammodytes sp.	Sand eel	ER	Pelagic and Buried	x	-
Pleuronectes platessa	Plaice	MJ	Demersal	x	-
Solea solea	Sole	MJ	Demersal	x	-
Limanda limanda	Dab	MJ	Demersal	x	-
Gadus morhua	Cod	MJ	Demersal	x	-
Merlangius merlangus	Whiting	MJ	Demersal	x	-
Clupea harengus	Herring	MJ	Pelagic	(x)	x
Sprattus sprattus	Sprat	MS	Pelagic	(x)	x
Engraulis encrasicolus	Anchovy	MS	Pelagic	-	x

Table 3: Priority species to be included in the spatial and temporal trend analyses (CA=diadromous, ER=estuarine resident, MJ=marine juvenile, MS=marine seasonal), x = yes, (x) = partly, - = inadequate, From: Bolle *et al.,* 2007.

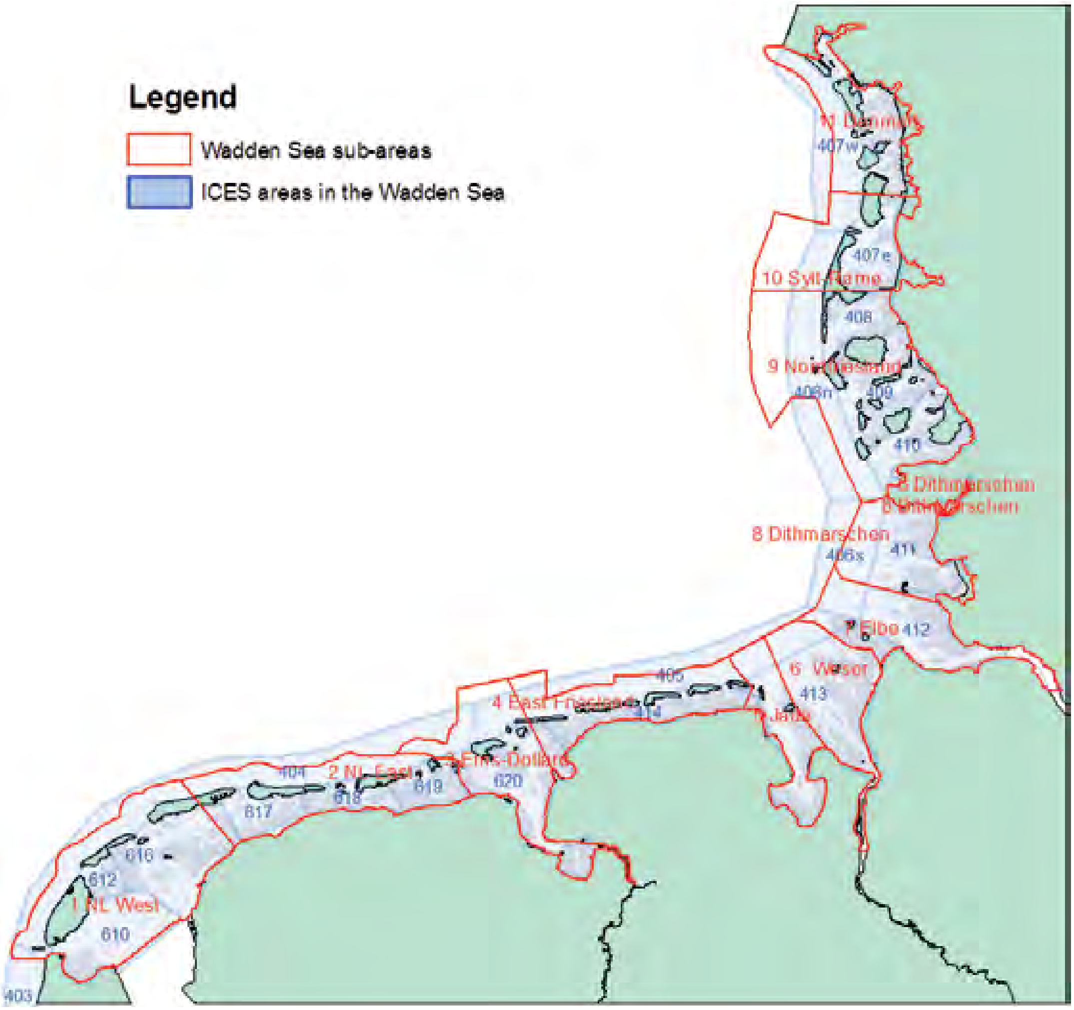


Figure 2: Map of the Wadden Sea sub-areas or QSR areas (as defined within the context of Quality Status Report), and the ICES areas or D(Y)FS areas (as defined in the original DFS/DYFS survey design). 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 5. Jade, 6. Weser, 7. Elbe, 8. Dithmarschen, 9. North Frisia, 10. Sylt-Rømø, 11. Denmark. Areas 5, 6, 10 and 11 were excluded from (part of) the joint analyses due to insufficient data.

2.6 Selection of fish metrics in the joint analysis

Within the TMAP ad hoc fish expert group, the experiences from the WFD approach were discussed. It was evaluated whether the WFD fish index could also be implemented for the entire Wadden Sea, taking into account differences in fish populations and environmental pressures, as well as the difficulty in defining reference conditions for the entire Wadden Sea area. A WFD-similar approach with respect to selecting fish metrics was chosen for the Wadden Sea fish fauna.

The following fish metrics were included in the analyses:

- Species richness and composition (by ecological guilds) by year and region;
- Mean abundance of priority species by year and region;
- Mean length of priority species by year and region.

Species richness

Species richness is defined here as the total number of species observed in a region in a year. In principle all fish were scored at the species level, but due to identification problems a higher taxonomic level was chosen for some groups of species. These were: *Pomatoschistus sp.* for *Pomatoschistus microps* and *P. minutus* (and *P. lozanoi*); *Liparis sp.* for *Liparis liparis* and *Liparis montagui; Ammodytes sp.* for *Ammodytes tobianus* and *Ammodytes marinus* and *Hyperoplus lanceolatus; Syngnathus sp.* for *Syngnathus acus* and *S. rostellatus* (but most of them are *S. rostellatus*); Triglidae for *Eutrigla gurnardus*, *Trigla lucerna*, *Trigla sp.*

Species composition

Species composition was defined as the total number of species per ecological guild (calculated for each year and region). The ecological guilds considered most relevant for the Wadden Sea are CA (diadromous), MJ (marine juvenile) and ER (estuarine resident). The other categories (excluding freshwater species) were combined in one group. The name estuarine resident (ER) may be confusing in relation to the Wadden Sea, because some scientists do not consider the Wadden Sea to be a true estuary. In this study we define ER as species that are resident in the Wadden Sea, *i.e.* they spend the majority of their life span in the Wadden Sea. Whether or not the species also occurs (abundantly) outside the Wadden Sea is irrelevant for the status of ER. The aggregation of species due to identification problems sometimes caused problems for the calculation of the number of species per ecological guild. Greater sandeel (*Hyperoplus lanceolatus*) is considered to be a MA, but the sandeel group (Ammodytes *sp.*), to which the greater sandeel has been added because of identification problems, is classified as ER.

Mean abundance

The catch rates per haul were standardized. In the case of the beam trawl catches they were converted to numbers per 1000 m^2, in the case of the SHS stow net catches to numbers per 1,000,000 m^3. These abundance estimates were then averaged by year and region. For the beam trawl surveys, a weighted mean was calculated in which the abundance estimates were weighed by the surface area of the depth strata (for further details see Bolle *et al.,* 2009).

Mean length

A shift in mean length indicates a change in the (sub-)population structure. This can be expected for species such as plaice, in which trends in abundance in the Wadden Sea are more apparent for one age group than the other. Length (mean, median, maximum) is commonly used as an indicator in marine ecosystems (see literature review in Appendix 4 of Bolle *et al.,* 2007). The mean length was calculated as the $\Sigma(N^*\text{length})/\Sigma N$, in which N is number of fish; for further details see Bolle *et al. (*2009).

Trends in abundance

For the DFS and DYFS, trends in mean abundance were analysed using TrendSpotter, which is an analytical method based on structural time-series models in combination with a Kalman filter (Visser, 2004). Full details of this analysis are described in Bolle *et al. (*2009). TrendSpotter was used to model the trend between 1970/1974 and 2006 and to assess the significance of a positive or negative trend.

3. Results

3.1 Fish species in the Wadden Sea

The compilation of Wadden Sea fish species yielded a total of 150 records, of which 13 are freshwater species (Annex 1). The total number of North Sea fish species recorded in FishBase is 190 (Fröse and Pauly, 2007), which means that about 72% of all North Sea fish species potentially occur in the Wadden Sea. (However, 13 of the Wadden Sea species listed in Annex I are not listed for the North Sea in FishBase.) With regard to a trilateral monitoring and assessment program only half of all species is of practical importance: 50 species (33,6%) are common, 25 species (16,8%) are fairly common, whereas 74 species (49,7%) have to be considered as rare or even extremely rare in the Wadden Sea (Table 4). The reference species list presented in Annex I has been used as input for the World Heritage nomination of the Wadden Sea (Common Wadden Sea Secretariat, World Heritage Nomination Project Group, 2008).

Table 4:
Occurrence of fish species in the Wadden Sea, as derived from the species list in Annex I (version December 2008).

Occurrence	Counts	Species	%
(Extremely) rare	1-3	74	49,3
Fairly common	4-6	26	17,3
Common	7-9	50	33,3
Total		150	100

Of the 76 (fairly) common species, 9 were diadromous, 15 estuarine resident, 12 marine juvenile, 9 marine seasonal and 28 marine adventitious, plus 3 fresh water species (*cf.* Elliott and Hemingway, 2002).

3.2 Species richness and species composition

The species richness as determined by the analysis of the DFS and DYFS ranged between 11 and 33 species per year over the period (October) 1970-2007 (Figure 3). The low number of species observed in 1995 in the North Frisian area is suspect and may have to do with the fact that the German DYFS data prior to 1996 have not been (sufficiently) quality controlled yet (Bolle *et al.*, 2009). Overall there appears to be no clear temporal trend, neither in species richness, nor in species composition in terms of ecological guilds (Figure 3). The number of estuarine resident species is remarkably stable, especially in the western and eastern Dutch Wadden Sea. Not much variation is observed in the number of marine juvenile species either. Most of the variation in species richness is caused by the number of diadromous species or other (marine seasonal and marine adventitious) species.

The number of species in the SHS survey (August) ranged from 18 to 29 for the period 1991-2008 (Meldorf Bight, sub-area 8 Dithmarschen) or 22 to 27 (Hörnum Deep, sub-area 9 North Frisia) over the period 2001-2008 (Figure 4).

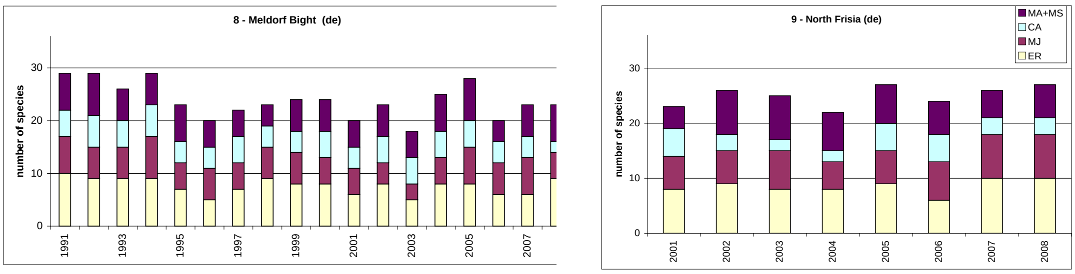


Figure 4:
Number of fish species in all catches in August per year and ecological guild, derived from the Schleswig-Holstein stow net monitoring in the Meldorf Bight (left panel) and Hörnum Deep (right panel). Source: SHS.

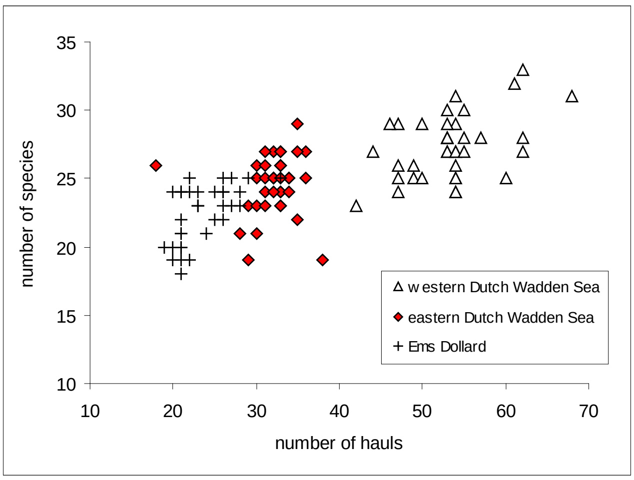


Figure 5:
Number of species per year and region in relation to the number of hauls per year and region (Bolle *et al.*, 2009).

A major drawback of the parameter 'species richness' is its dependence on the number of hauls in an asymptotic fashion. In principle, the number of species will increase asymptotically with the number of samples. Figure 5 clearly illustrates that the number of species encountered in the Dutch DFS increases with the number of hauls (per year and region). This relationship, at least partly,

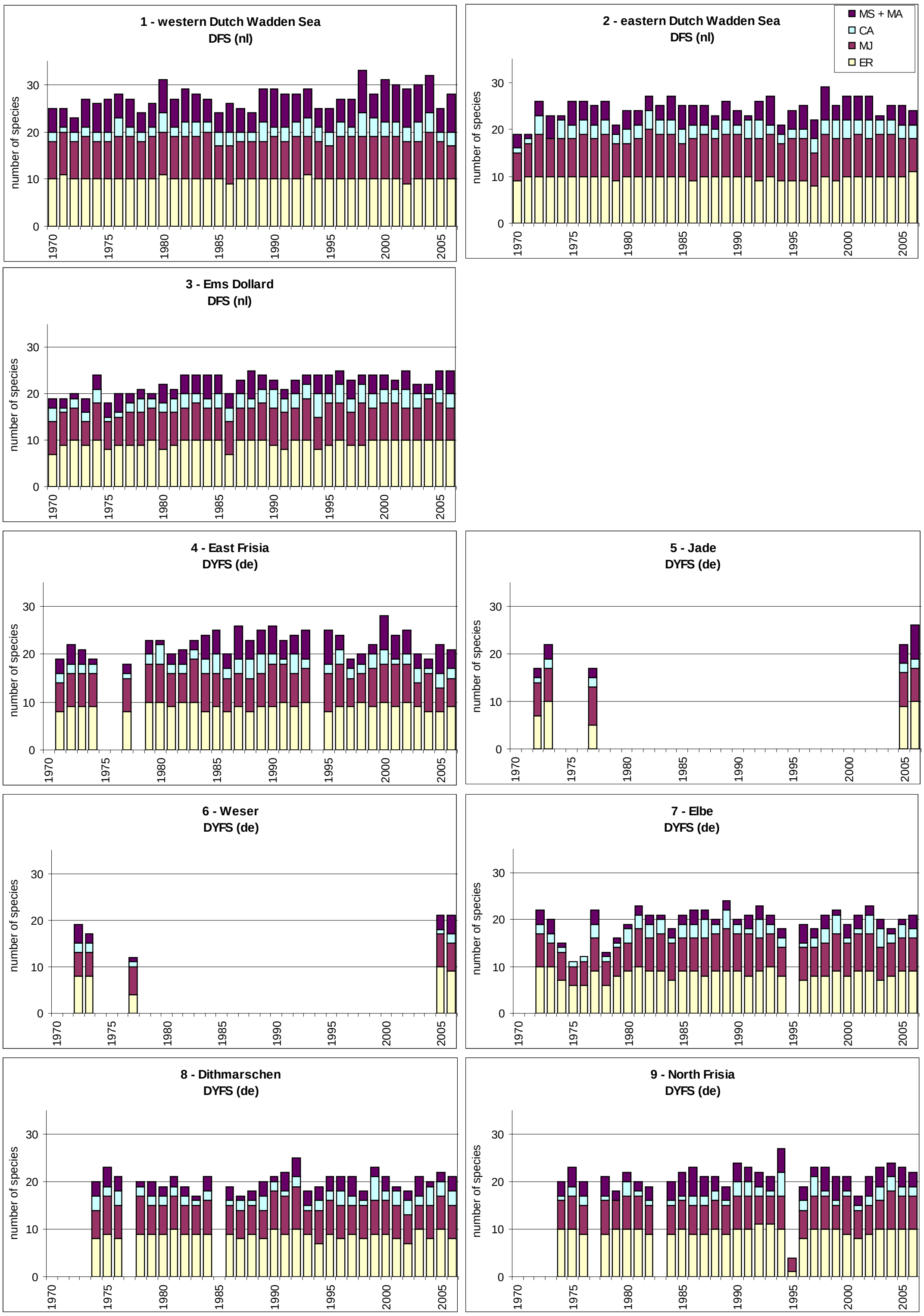


Figure 3: Number of species per year and ecological guild for each region and survey (based on DFS and DYFS; Bolle *et al.*, 2009). DYFS data prior to 1996 are still subject to (ongoing) quality control. ER=estuarine resident, MJ=marine juvenile, CA=catadromous / anadromous, MS/MA=marine seasonal and marine adventitious guild.

explains the differences in species richness between the Dutch QSR-areas (western and eastern Wadden Sea, Ems-Dollard). Species richness thus seems a less suitable metric because it cannot be compared between regions if the number of hauls differs. Furthermore, one should be careful when examining trends in species richness if the number of hauls varies seasonally and between years.

3.3 Trends in abundance of selected Wadden Sea fish species ("priority species")

The selected results of the beam trawl surveys (DFS, DYFS), presented here, are based on the joint analysis which is described and reported in full detail in Bolle *et al.* (2009).

The trends in abundance of 'priority species' are summarized in Table 5 (as in Table 3, ordered by ecological guild). The observed trends differ between species and regions. Overall, more downward than upward trends are observed. A pattern that emerges in several species and regions is an increase in abundance in the 1970s, followed by a decrease during the 1980s or 1990s. During the period covered, an overall increase was shown in the smelt, flounder, herring and sprat. An overall decrease was found in eelpout, plaice, sole, dab, cod and whiting. No significant trends were ob-

Table 5: Summary of trends in abundance of priority fish species by Wadden Sea sub-area, determined by TrendSpotter analysis of the DFS and DYFS (Bolle *et al.*, 2009). The period in which the trend was significant is indicated. Grey color means that there was no sampling. Green indicates a significant increasing trend, red a significant decreasing trend in fish abundance of a species. Explanation of the area codes: 1. Western Dutch Wadden Sea, 2. Eastern Dutch Wadden Sea, 3. Ems-Dollard, 4. East Frisia, 7. Elbe, 8. Dithmarschen, 9. North Frisia. * potential data errors, see text.

Twaite shad	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

Smelt	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase>decrease *
area 2									no significant trend
area 3									increase>decrease *
area 4									no significant trend
area 7									increase>decrease
area 8									increase
area 9									increase

Flounder	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									increase
area 4									no significant trend
area 7									increase
area 8									increase
area 9									no significant trend

Eelpout	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									increase<decrease
area 3									increase<decrease
area 4									increase<decrease
area 7									no significant trend
area 8									increase<decrease
area 9									decrease

Sandeel	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no trend
area 2									no trend
area 3									no trend
area 4									no significant trend
area 7									increase>decrease *
area 8									no trend
area 9									no trend

Plaice	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase=decrease
area 2									increase<decrease
area 3									increase=decrease
area 4									increase=decrease
area 7									no significant trend
area 8									no significant trend
area 9									no significant trend

served in twaite shad and sandeel. Sometimes the trends were only significant during a few years, or more pronounced in one sub-area or period than in another (Table 5).

Some examples are highlighted below by a selection out of the large amount of figures reported in Bolle *et al.*, 2009 from the DFS and DYFS and the SHS (pelagic species). Note that the Y-axes (abundance) of the scatter plots (DFS and DYFS) are on a log-scale.

Twaite shad (*Alosa fallax*)

The catch densities of twaite shad in the demersal surveys are variable and at a low level (Bolle *et al.*, 2009). Significant trends could be detected in none of the Wadden Sea sub-areas (Table 5). The abundances in the sub-areas Ems Dollard (3) and Elbe (7) are shown (Figure 7).

In summer the twaite shad catches in Meldorf Bight/Hörnum Deep mainly consisted of juveniles

Table 5 (continued)

Sole	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									decrease
area 3									no significant trend
area 4									increase<decrease
area 7									increase<decrease
area 8									increase<decrease
area 9									decrease

Dab	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									decrease
area 2									decrease
area 3									decrease
area 4									increase<decrease
area 7									decrease
area 8									decrease
area 9									decrease

Cod	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									increase<decrease
area 3									increase<decrease
area 4									increase=decrease
area 7									increase=decrease
area 8									decrease
area 9									decrease

Whiting	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase<decrease
area 2									increase<decrease
area 3									increase<decrease
area 4									increase=decrease
area 7									no significant trend
area 8									no significant trend
area 9									no trend

Herring	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									increase>decrease
area 2									increase>decrease
area 3									increase>decrease
area 4									increase=decrease
area 7									increase>decrease
area 8									no significant trend
area 9									no significant trend

Sprat	1970	1975	1980	1985	1990	1995	2000	2005	overall description
area 1									no significant trend
area 2									increase=decrease
area 3									no significant trend
area 4									increase=decrease
area 7									increase=decrease
area 8									no significant trend
area 9									no significant trend

* potential data errors, see text

Figure 6:
Catch density (N/1000 m²) of twaite shad in the Ems-Dollard (left panel) and the Elbe (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

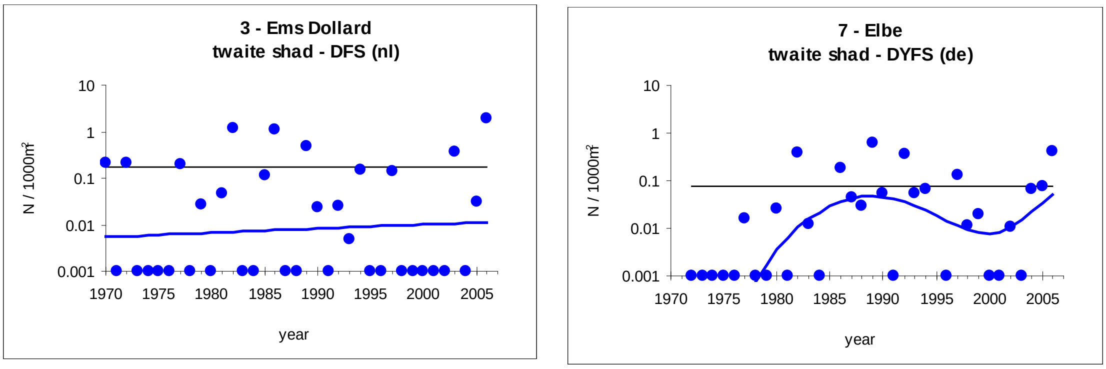
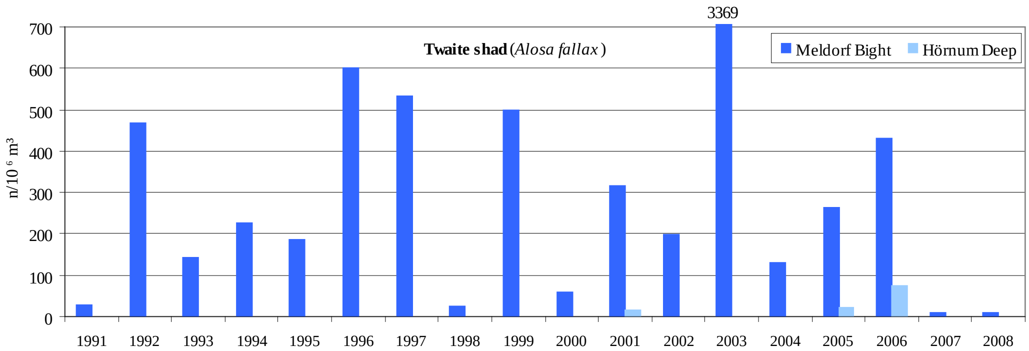


Figure 7:
Abundance of twaite shad in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.



of 6-9 cm length, while adults occurred only occasionally in the SHS. Despite its status as a vulnerable Red List species (Berg *et al.*, 1996), twaite shad was regularly caught in the Meldorf Bight showing ups and downs in abundance, whereas catches in the Hörnum Deep were generally low due to the distantly situated estuaries which this species needs for spawning. After extremely high abundances in 2003, in 2007 a remarkable decline became evident in the Schleswig-Holstein area (Figure 7).

Smelt (*Osmerus eperlanus*)

The abundance of smelt in the demersal surveys showed a significant increase between 1970 and the early 1980s in most of the Wadden Sea subareas. In the areas of Dithmarschen and North Frisia, smelt shows a significant increasing trend up to 2007 although catches remain at a low level. The abundance of smelt in Ems-Dollard tends to be declining in recent years, but the trend is not significant. A somewhat similar pattern was observed in the Elbe area (Figure 8).

Smelt abundance showed a decreasing trend between 2001 and 2006 in the Meldorf Bight, but recovered in the last two years (SHS survey). In 2008, the smelt catches in Meldorf Bight were the highest on record (Figure 9). In comparison the catch numbers of the Hörnum Deep are generally on a low but constant level.

Flounder (*Platichthys flesus*)

Flounder showed significant (increasing) trends in abundance only in the Ems-Dollard, Elbe and Dithmarschen areas. The increasing trend in the Ems-Dollard occurred between 1995 and 2005, in the Elbe between 1974 and 1985, whereas the increase in Dithmarschen continues up to date (Table 5). North Frisia showed no significant trend in flounder abundance (Figure 10).

Eelpout (*Zoarces viviparus*)

The abundance of eelpout significantly declined in the Dutch Wadden Sea and part of the German Wadden Sea (Table 5). In the Ems-Dollard and Dithmarschen, among other areas, the numbers of eelpout fluctuated up and down (Figure 11), but the abundance is presently lower than at the beginning of the demersal surveys (1970).

Plaice (*Pleuronectes platessa*)

The abundance of plaice in most of the Wadden Sea sub-areas increased until the mid-1980s and declined thereafter (Table 5). Except for the

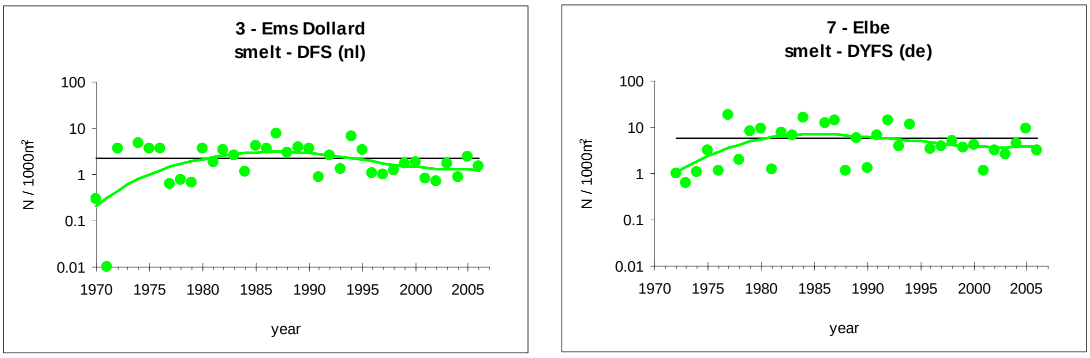


Figure 8: Catch density (N/1000 m^2) of smelt in the Ems-Dollard (left panel) and Elbe (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

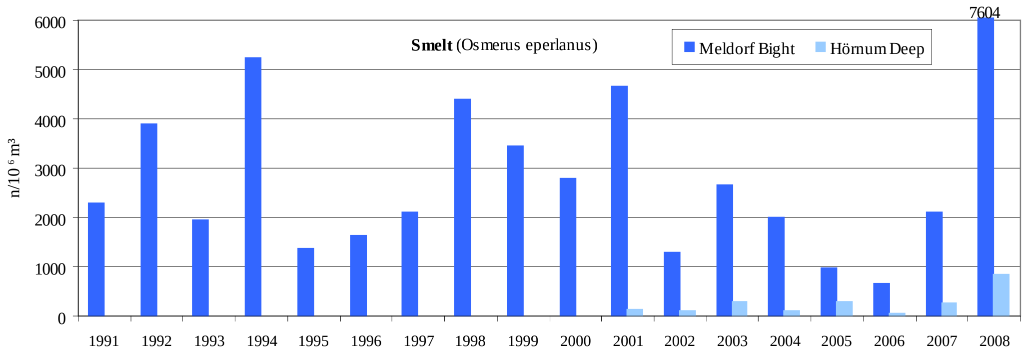


Figure 9: Abundance of smelt in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

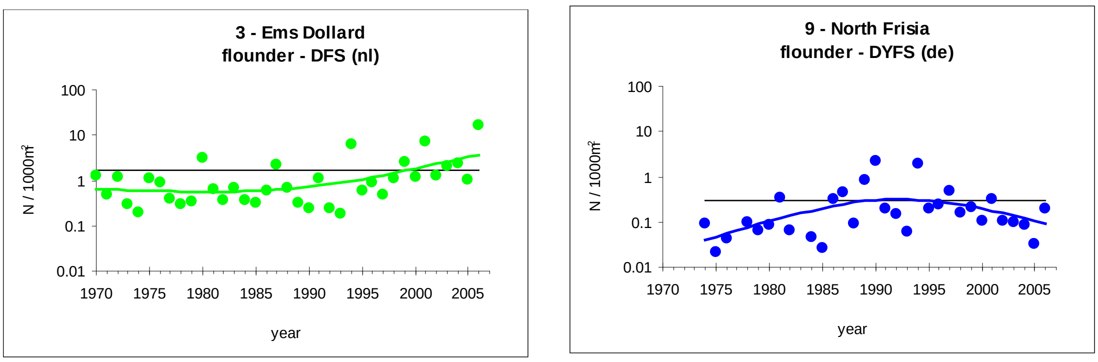


Figure 10: Catch density (N/1000 m^2) of flounder in the Ems-Dollard (left panel) and North Frisia (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

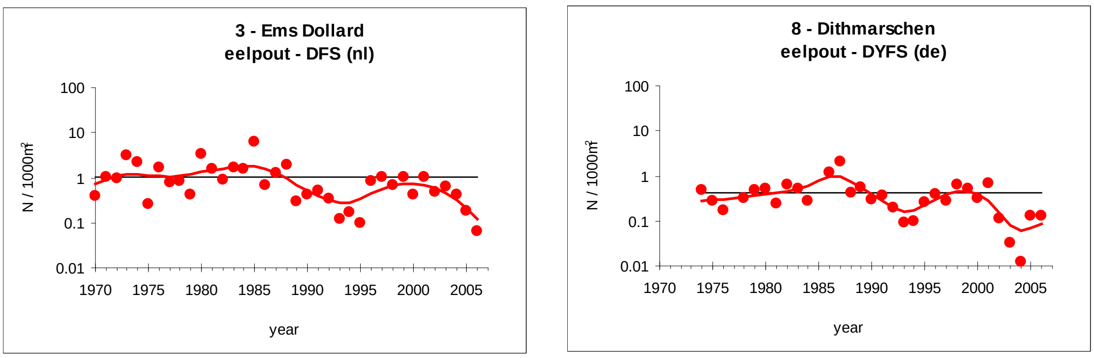


Figure 11: Catch density (N/1000 m^2) of eelpout in the Ems-Dollard (left panel) and Dithmarschen (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

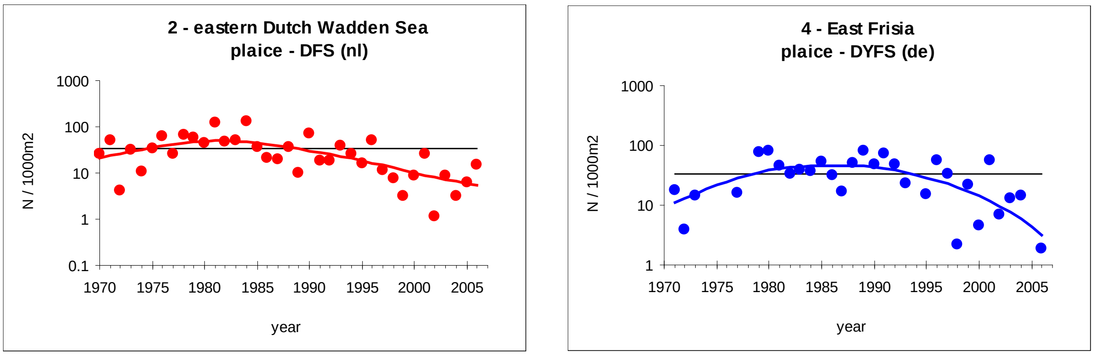


Figure 12: Catch density (N/1000 m²) of plaice in the eastern Dutch Wadden Sea (left panel) and East Frisia (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

eastern Dutch Wadden Sea (Figure 12, left panel), over the whole time series the increase often more or less equalled the decrease (Figure 12, right panel).

Sole (*Solea solea*) and dab (*Limanda limanda*)

Significant negative trends in sole and dab abundance are found in nearly all sub-areas of the Wadden Sea (Table 5). Although the abundance of sole shows considerable variations (Figure 13, left panel), the decrease is dramatic in dab, for example in the area of Dithmarschen (Figure 13, right panel).

Cod (*Gadus morhua*) and whiting (*Merlangius merlangus*)

The abundance of cod increased up to the early 1980s and steadily decreased thereafter (Table 5). In East Frisia, the decrease more or less equalled the previous increase (Figure 14, left panel). In the Dutch Wadden Sea, the whiting abundance significantly decreased (Figure 14, right panel) whereas in other Wadden Sea areas similar trends were not significant (Table 5).

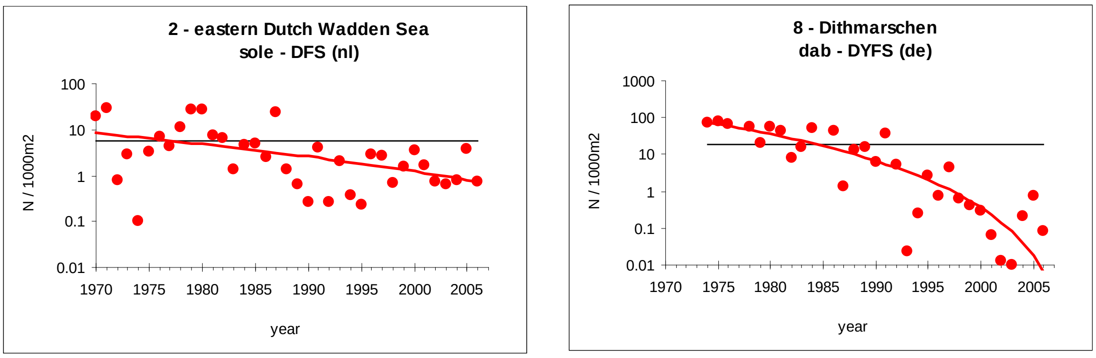


Figure 13: Catch density (N/1000 m²) of sole in the eastern Dutch Wadden Sea (left panel) and dab in Dithmarschen (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

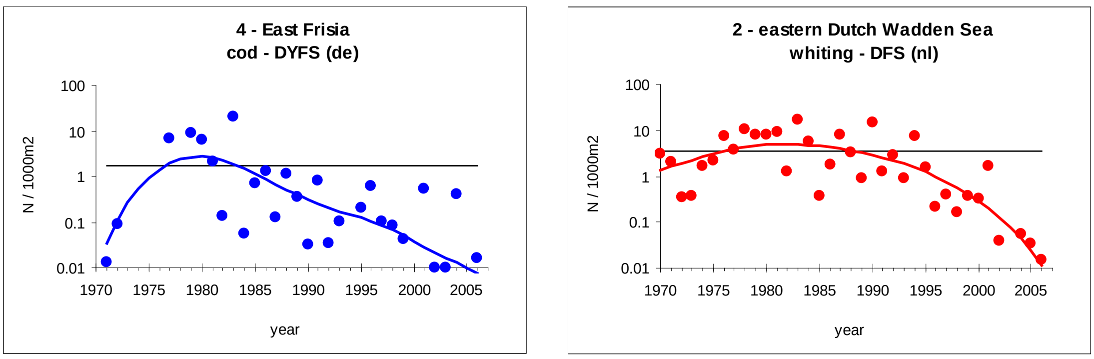
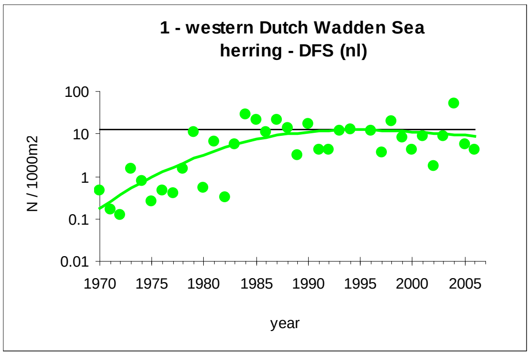


Figure 14: Catch density (N/1000 m²) of cod in East Frisia (left panel) and whiting in the eastern Dutch Wadden Sea (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).



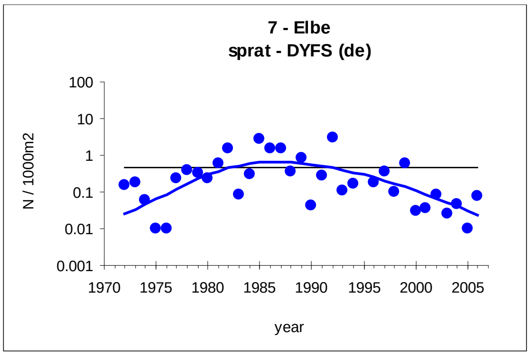


Figure 15: Catch density (N/1000 m^2) of herring in the western Dutch Wadden Sea (left panel) and sprat in the Elbe sub-area (right panel). The trend is indicated by a drawn line (green=positive, red=negative, blue=neutral trend), whereas the thin grey line indicates the long-term average abundance. Source: DFS and DYFS (Bolle *et al.*, 2009).

Herring (*Clupea harengus*) and sprat (*Sprattus sprattus*)

In the demersal surveys, herring showed significantly increasing trends in the 1970 and 1980s. The abundance in the western Wadden Sea recently seems to decrease, but the trend is not significant (Figure 15, left panel). The abundance of sprat showed an increase which was equalled by a decrease (Figure 15, right panel).

Both pelagic species regularly occur in both the Meldorf Bight and the Hörnum Deep and can become extremely abundant in the SHS fish monitoring. Catches are dominated by juveniles of maximum 10 cm length which are known to use the Wadden Sea area as a nursery. While there is no clear trend in abundance for herring (Figure 16), sprat showed a decreasing trend since 2000 in the Meldorf Bight and only occurred in low abundance in the Hörnum Deep since 2003 (Figure 17).

Anchovy (*Engraulis encrasicolus*)

The QSR 2004 reported increasing catches of adult anchovies (*Engraulis encrasicolus*), caught for the first time in the Meldorf Bight during the sampling period of June (1997-2002). Juveniles were found in August in the Hörnum Deep in 2004 and 2005. Since then juveniles seem to have disappeared from this area and anchovy is only sparsely distributed in the Schleswig-Holstein Wadden Sea. No anchovies were caught in 2008 (Figure 18).

River lamprey (*Lampetra fluviatilis*)

During the first monitoring period from 1991-2000, river lampreys in the Meldorf Bight showed strong annual fluctuations in abundance, followed by drastically declining catch rates which have remained low since 2001. Catches in the Hörnum Deep demonstrate the occurrence of this species in the entire Schleswig-Holstein Wadden Sea area (Figure 19).

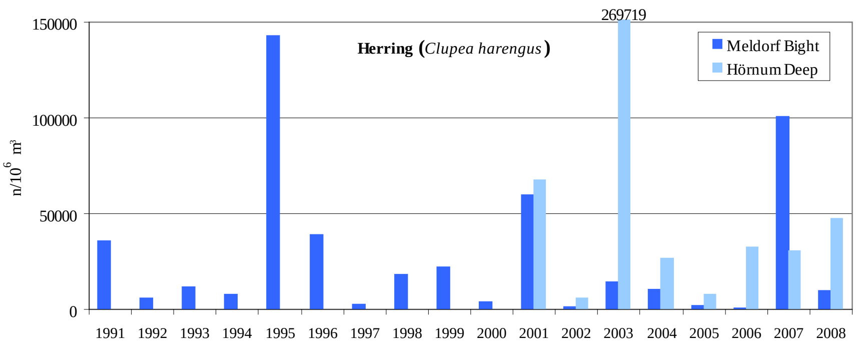


Figure 16: Abundance of herring in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

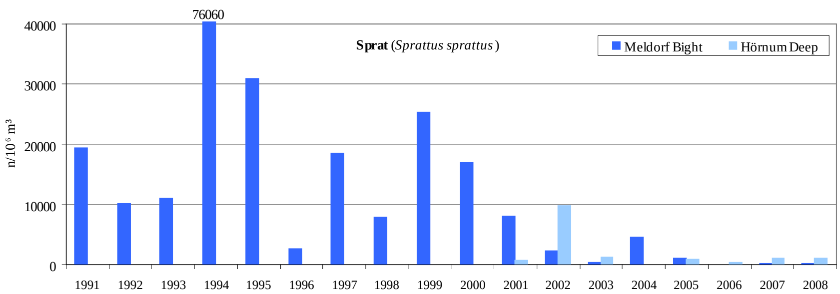


Figure 17: Abundance of sprat (*Sprattus sprattus*) derived from the fish monitoring program in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

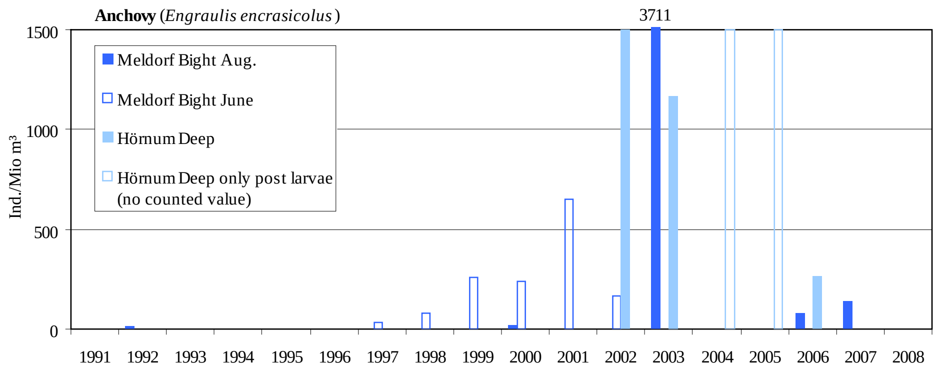


Figure 18: Abundance of anchovy (*Engraulis encrasicolus*) derived from the fish monitoring program in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of the catches in June and August in the Meldorf Bight and in August in the Hörnum Deep. The bars for 2004 and 2005 indicate only the occurrence of post larvae not a calculated value. Source: SHS.

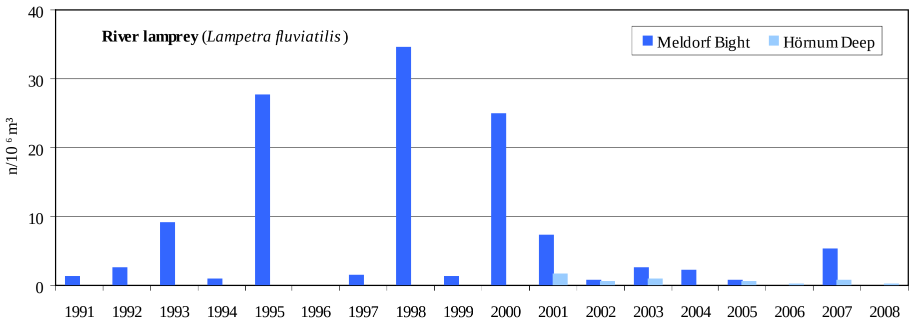


Figure 19: Abundance of river lamprey (*Lampetra fluviatilis*) in the Meldorf Bight and Hörnum Deep (Schleswig-Holstein Wadden Sea). The bars show the mean of all catches in August per year. Source: SHS.

3.4 Mean length of fish in the Wadden Sea

The mean length of the plaice population in the western Wadden Sea decreased from approximately 13 cm during the 1970s to about 9 cm in the last decade. The mean length of sole, in contrast, did not show a significant trend but fluctuates around a long-term average of 10 cm (Figure 20; Bolle *et al.*, 2009). Nevertheless, the abundance of sole in the Wadden Sea decreased significantly (see *e.g.* Figure 13) but this apparently involves all length-classes.

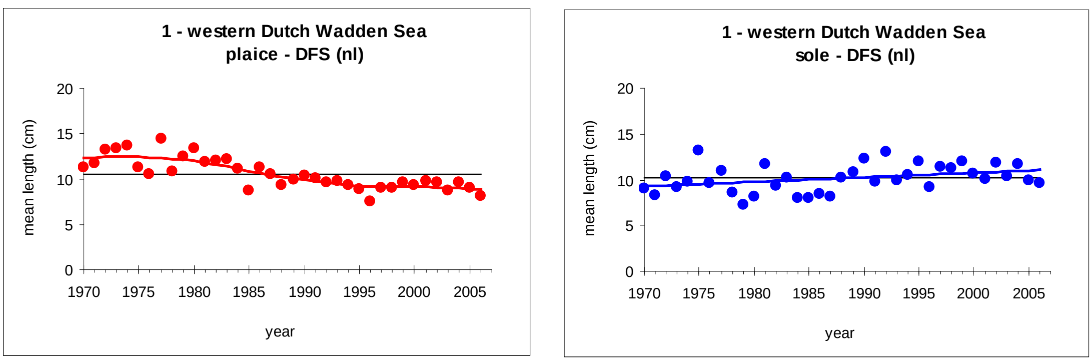


Figure 20: Mean length of plaice (left panel) and sole (right panel) in the western Dutch Wadden Sea. Source: DFS (Bolle *et al.*, 2009).

3.5 Status of estuarine fish, biological quality element in WFD transitional waters

Over 121 species (excluding present-day neozoans) were documented for the estuaries of the Wadden Sea, based on historical and recent data (in Bioconsult, 2006a), of which 52 represent typical functional guilds such as diadromous species, estuarine resident species, marine juvenile and marine seasonal migrants. About one third belong to the marine adventitious guild (marine stragglers) and are found in estuaries only occasionally. There is also a number of fresh water species that wander into the transitional waters or that are restricted to the tidally influenced freshwater section of the estuary. Neozoans probably do not play a major role in the Wadden Sea estuaries at the moment; the neozoan Atlantic croaker (*Micropogonias undulatus*) was encountered in the Weser estuary only once in 2004 (Bioconsult, *unpubl.*). Recent studies show that species diversity is still relatively high and shows pronounced spatial and temporal variability. In the stow net monitoring, between 37 (Elbe) and 46 species (Ems) were recorded in 2007, while 40 species were documented for the Weser (Wassergütestelle Elbe, 2007; Bioconsult, 2007; 2008a,b) and 31 species were detected in the Eider in 2006 (Scholle *et al.*, 2007a).

In the period 2000-2007, altogether 68 species were recorded in the Elbe (Wassergütestelle Elbe, 2000-2007).

In 2008 an initial WFD fish-based assessment was conducted on the basis of the defined type-specific reference conditions (species composition, abundance, age structure) and the available, sometimes scanty, database. At the metric level all estuaries show considerable deviations, in some cases of >80%, from the reference situation. For this reason the indexed ecological state is 'poor' for the Ems, Weser and Eider and 'moderate' for the Elbe (Table 7).

In nearly all estuaries considered, the species composition does not differ substantially from the reference. More significant deviations can be noted in the quantitative metrics of abundance and age structure. In the Ems, pronounced deficits are observed for the diadromous species (smelt, twaite shad) that reproduce within the estuary. A more detailed analysis reveals that fewer deficits are indicated for the outer Ems (mesohaline and polyhaline zone) for the twaite shad, which is illustrated by the comparatively high abundance of sub-adult shad in that area. The situation is different in the inner estuary. Successful reproduction evidently does not take place here; this is shown by the very low numbers of adult twaite shad as well as the lack of twaite shad larvae (Bioconsult, 2006b). Substantial deficits are also indicated for smelt; the abundances of all differentiated age groups are very low in comparison to the reference values. Similar to twaite shad, the reasons for the deficits in smelt are found primarily in the upper/middle section of the estuary. Very high concentrations of suspended matter and oxygen

Estuary	Ems	Weser	Elbe	Elbe	Eider
Year of sampling	2007	2007	2007	2000-2007	2006
Estuarine section	ol,me, po	fw, ol, me, po	fw, ol, me, po	fw, ol, me, po	fw/ol, me/po
No. sampling sites	3	4	14	7-14	2
Freshwater sp.	10	7	17	26	10
Diadromous sp.	7	9	8	9	7
Estuarine sp.	11	9	5	11	4
Marine juvenile sp.	11	9	3	9	6
Marine seasonal sp.	5	4	3	7	2
Marine stragglers	2	2	1	6	2

Table 6: Number of fish species in the Wadden Sea estuaries differentiated by ecological guilds on the basis of current catches with stow nets (Source: Wassergütestelle Elbe 2000-2007; Bioconsult 2007; Scholle *et al.*, 2007a). Fw = freshwater section, ol = olighaline section, me = mesohaline section, po = polyhaline section.

Estuary	Data	Species composition	Abundance	Ecological State
Ems*	2007	Moderate-Good	Bad-Poor	Poor
Weser	2007	Moderate	Poor	Poor
Elbe	2005-2007	Moderate-Good	Poor-Moderate	Moderate
Eider	2003/2006	Poor	Poor	Poor

Table 7: Tentative WFD assessment of the Wadden Sea estuaries (transitional water bodies) based on the biological quality element Fish. * = sample assessment by unmodified assessment tool (Bioconsult, 2006a), modifications have taken place for these estuaries (Ems) or are still subject of discussion (Eider).

deficits occurring from early to late summer are in all likelihood major factors here (see Box 2: description and results of concomitant research on the recruitment of smelt in the Ems).

The assessment results presented must still be regarded 'preliminary' for the following reasons:

- The present assessment criteria apply to natural waters, whereas all Wadden Sea estuaries have been classified as 'heavily modified'. This implies that the 'ecological potential' should be assessed, which represents a lower environmental goal than the 'ecological state'. However, it has not been decided yet how to assess the ecological potential.
- The database is not yet fully adequate for the WFD assessment (Ems, Weser, Eider).
- The assessment procedure, based on Weser and Elbe, should be adjusted to Ems and Eider.
- A critical review of the reference conditions and the currently defined class boundaries (especially the boundary between the 'moderate' and 'good' status or potential) is required; it should be based on all WFD monitoring results available up to and including 2009. Depending on the outcome of this analysis, further adjustments will be implemented.

Despite not being a fish, the status of brown shrimp (*Crangon crangon*) in the Wadden Sea is described in Box 3 because shrimps are very important food for fish species, and also a predator on some stages of (juvenile) fish.

4. Discussion

4.1 Assessing the status of Wadden Sea fish

The aim of the joint data analysis was to establish fish metrics that are suitable to describe trends in a comparable way for different sub-areas of the Wadden Sea. A choice for scientifically sound metrics has been made, and the long-term average in these metrics has now been calculated over a time period of >35 years from the demersal fish surveys that are available for the Dutch and German Wadden Sea. The metrics that were analyzed are the species richness and composition by ecological guild, (trends in) species abundance and mean length of selected fish species. These metrics could serve as input to a tool (to be developed) that can be used to describe and/or evaluate the status of the Wadden Sea by its fish fauna.

The joint analysis resulted in a more detailed and robust description of long-term trends in fish species. By applying the TrendSpotter methodology, a more objective way of determining the trends in abundance became available. The spatial resolution is now to the level of QSR sub-areas, giving much more detail than the previous QSR which considered only the Dutch or German Wadden Sea, but this also raises new questions. A next step might be to correlate the relevant parameters (as formulated in hypotheses, based on expert knowledge of the ecology of the species concerned) to fish metrics. For this purpose, an overview of available abiotic data has already been made on a meta-data level (Bolle *et al.,* 2007).

The status of fish in nearly all WFD transitional waters shows moderate to large deviations from the 'undisturbed' situation for natural estuaries. Although species composition is still considered to resemble reference conditions, with the exception of the number of diadromous species, the abundance of typical indicator species is currently at a very low level compared to the situation of the early 20th century.

Focusing on priority species brings the risk of overlooking developments in other fish species. However, it is inevitable to accept that the existing Wadden Sea fish monitoring has its limitations for analyzing trends in the fish fauna. Fortunately, the newly installed WFD monitoring provides additional information for the status of fish in the estuaries, where anthropogenous influence seems to be relatively more determining than natural variations compared to the Wadden Sea.

The selected metrics (species richness, species composition by ecological guild, [trends in] abundance and mean length) are a first step to develop an assessment tool. It was shown that species richness can only be compared between years and areas if monitoring effort is at the same level and constant between years. The species composition (number of species by ecological guild) is not so much dependent on individual species but focuses on the functional aspects of the fish fauna. On the other hand, this metric appears not to be very sensitive to changes that occur in the Wadden Sea. By looking at the parameter of mean length, the distribution shift occurring in some species or specific age-groups may remain concealed. Abundance by age group/length class may be more revealing in this respect.

Although we might like to draw conclusions on the status of the Wadden Sea fish in terms of 'good', 'moderate' or 'poor', from a scientific point of view it is not possible to give such qualifications to the outcome of the analyses due to the present lack of knowledge on the causal factors underlying the changes observed in the Wadden Sea. Many of the selected fish species are influenced to a large extent by natural variations, the causes of the variations are hardly understood, and the level of knowledge is not advanced enough to allow this kind of judgement. Furthermore, (historic) reference conditions are not known; but even if they were, one might ask why it would be desirable to go back to the status of hundred (or even thousand) years before.

These difficulties to define scientifically sound assessment criteria are fuelled by the topicality, because at present we are experiencing a period of rapid climatic changes (which reflect in the fish fauna) and the presence of 'regime shifts' is increasingly substantiated (*e.g.* Weijerman *et al.,* 2005). It will be interesting to monitor how these changes affect the Wadden Sea fish fauna.

4.2 Presence of a typical Wadden Sea fish fauna

To decide if a typical Wadden Sea fish fauna is present (the first target, mentioned in the introduction), the species caught in the fish surveys are compared with the reference species list (Annex 1). In the demersal surveys, 11-33 species were observed, which number could be increased with max. 6 to account for the taxonomic grouping. This is at least 14-43% of the amount of (fairly) common species on the reference species list (Annex 1) within one year and sub-area. The number of species in the SHS (18-29 in the Meldorf Bight, 22-27 in Hörnum Deep) was max. 38% of the (fairly) common species. As stated before, these numbers should not be taken too literally since an increased monitoring intensity would result in higher species numbers, because of the positive correlation between the number of hauls and the number of species. Likewise, the aggregation of regions and years would result in higher species numbers. Species richness and composition (number of species by ecological guilds) stayed more or less the same over the observed time-span, at a more or less constant monitoring effort.

"Typical" of course also refers to specific characteristics that fish species developed to adapt to the highly dynamic Wadden Sea environment. This is expressed in a variety of reproduction strategies (viviparous blenny, pipefish with brood pouch, nest-protection by gobies and bullrout), adaptations to resist strong currents (sucking disk of sea snail and lumpsucker, hooks of hooknose), fish behavior (tidal migration to tidal flats by flatfish and mullets), or by the only seasonal occurrence in the area at the time when conditions are favorable.

4.3 Abundance of fish in the Wadden Sea according to natural dynamics

Priority species

Twaite shad showed a remarkable decline in the Schleswig-Holstein area since 2007, after previous years of higher abundance. Although the Weser and Elbe still sustain twaite shad populations (Bioconsult, 2005; Gerkens and Thiel, 2001), it is questionable whether twaite shad can reproduce successfully in the Ems estuary: the numbers of adults are low, and twaite shad recruitment is very variable (Bioconsult. 2006b). Bottlenecks are found in the upstream parts of the Ems estuary, where unfavourable conditions during summer (oxygen deficits and fluid mud) hamper successful reproduction. This situation also affects the smelt, as was illustrated in Box 2 (Scholle *et al.*, 2007b).

Sandeel is not adequately covered in the D(Y)FS, SHS surveys or the WFD monitoring because it lives buried in the bottom during night. Despite its importance as a food item for sea mammals and birds, which are protected under the Bird and Habitats Directive, no reliable information on the abundance of sandeel in the Wadden Sea area is available. Due to its combined benthic (buried) and pelagic lifestyle, this species requires very specific monitoring which cannot be provided by the current programs.

Herring and sprat are pelagic species, and just like the species mentioned above, they are not sampled well by the demersal surveys. Juvenile herring are found in the Wadden Sea in considerable numbers and their abundance to a large extent reflects the processes that act during the larval phase on the North Sea. Since 2001, poor herring recruitment has been observed for 6 years in a row. Among probable causes are the changes in the hydrography, and a shift in the dominant food items (from *Calanus finmarchicus* to *C. helgolandicus*) (ICES, 2007).

The initial increase in herring abundance during the 1970s and 1980 reflects a period of recovery of the collapsed North Sea herring populations after the closure of the fishery between 1977 and 1983. To understand the trends in juvenile Wadden Sea herring, a good knowledge of the North Sea trends in recruitment and development of the populations is required.

The eelpout showed up and down trends, with a significant net decline over the last 35 years. A recent study on eelpout in the German Wadden Sea showed that thermally limited oxygen delivery in the fish tissues closely matches environmental temperatures beyond which growth performance and abundance decrease (Pörtner and Knust, 2006). The estimated putative upper critical temperature for eelpout is 22.5 °C, a level which was repeatedly exceeded during the summer periods of the 1990s and early 2000s. In the Ems estuary, high exposure to mercury (until 1976) affected the reproduction of eelpout by reduced survival of the fry (Essink, 1989).

For another estuarine resident species, the hooknose *Agonus cataphractus* (not analysed in this report), fluctuations in the abundance were linked to changes in estuarine environmental conditions, particularly temperature, freshwater flow, salinity and the abundance of suitable prey organisms which themselves depend on the maintenance of appropriate estuarine conditions. Patterns of seasonal migration also play an important role in determining fluctuations in estuarine *Agonus* abundance (Power and Attrill, 2002).

Dab and sole showed very pronounced decreases in abundance in most of the sub-areas in the Wadden Sea and a similar trend occurred in I-group plaice (Vorberg *et al.,* 2005), although this was masked in the current analysis by the still abundant presence of 0-group individuals that dominate the catches. The declining trend in I-group plaice abundance is reflected in the decrease in mean length of plaice in the western Wadden Sea (Figure 20).

An offshore shift in the spatial distribution of young plaice appeared to occur in the 1990s, which is attributed primarily to a response to increased summer temperatures. At the same time, a decrease in predation risk and competition in the offshore areas allowed the juvenile plaice to distribute more widely (Van Keeken *et al.,* 2007). The shift in distribution of juvenile plaice was also manifest in the German Wadden Sea. By comparing 1987 to 1991 and 2002 to 2006 abundance data, it could be demonstrated that the distribution of young plaice shifted within the 5 m depth strata towards the deeper as well as from inshore areas towards the further off-shore areas (Schmidt, 2008). This is an indication that throughout the Wadden Sea young plaice have either changed their preference towards deeper and more off-shore areas or that an earlier exodus occurs in that species. Whether it is caused by faster growth and/or differences in environmental conditions needs still to be proven.

Juvenile dab are, unlike plaice, sole or flounder, not confined to coastal nurseries, but can occur over a wide depth-range (Bolle *et al.,* 1994). In autumn, the 0-group migrates inshore and enters the Wadden Sea and estuaries. The catchability of dab fluctuates due to wind stress, temperature and turbidity, although these factors only explain a small proportion of variability in catch numbers (Bolle *et al.,* 2001). Dab catches in the DFS showed an inverse relation with temperature and were also inversely related to secchi-depth (>1 m), although dab density seemed to decrease again at secchi-depths of <1 m (Bolle *et al.,* 2001). Increasing catches in the BTS (beam trawl survey, North Sea) indicate that the decrease in juvenile dab abundance in the Wadden Sea must be the consequence of a distribution shift toward the offshore waters (Bolle *et al.,* 2001). The decrease in abundance of sole concerned all age groups, since the mean length in the demersal surveys remained more or less constant (Figure 20). A dynamic factor analysis (DFA) indicated for the Wadden Sea a best-fit-model with the number of seals and beam trawl intensity as the two dominant environmental variables. In this model, sole showed a significant negative relation with beam trawl effort (Tulp *et al.,* 2008).

The period of increasing trend in cod abundance in the Wadden Sea until the early 1980s reflects the 'gadoid outburst' of the 1960s and 1970s that occurred in the North Sea (Hislop, 1996; Beaugrand *et al.,* 2003). Cod recruitment is affected by overfishing and fluctuations in plankton; the survival of larval cod depends on mean size of its prey, seasonal timing and prey abundance. Beaugrand *et al.* (2003) conclude that rising temperature since the mid-1980s has modified the plankton ecosystem in a way that reduces survival of young cod. It seems therefore likely that the present low abundance of cod in the Wadden Sea is mainly connected with processes acting in the North Sea. Whiting recruitment since 2002 has been below the long-term average probably due to low stock size and environmental factors (ICES, 2008). The abundance of whiting in the Wadden Sea reflects the North Sea recruitment pattern.

Shrimp

Similar to the observed phenomenon in juvenile flatfish, shrimp also seem to have undergone a distribution shift to more offshore, and also to northerly waters. Trends in abundance from the D(Y)FS have not been part of the present analyses; accordingly an important explanatory factor for understanding trends in fish abundance is missing.

Food availability for fish-eating birds

Herring, sprat, sand eel, smelt, as well as whiting (when abundant) and brown shrimp are the preferred food items for common tern (*Sterna hirundo*) and other piscivorous birds, as follows from the research project on fish-eating birds breeding in colonies near Wilhelmshaven and on Minsener Oog (Lower Saxony) (Dänhardt and Becker, 2008; see **Box 1**). In some years food can be limiting, but other factors (predation, summer storms and/or high tides causing drowning of nests and chicks) also determine breeding success. The recruitment index of North Sea herring is not always a good predictor of food availability, because the abundance of herring in the Wadden Sea may deviate due to local conditions (Dänhardt and Becker, 2008). For birds, the availability of fish at a very local scale is relevant. Therefore, specific monitoring is required to determine if food is a limiting factor for fish-eating birds (and marine mammals).

4.4 The status of Wadden Sea fish

The broad decrease in fish abundance and biomass in the Wadden Sea since the 1980s, as evident from the present results and also described by Tulp *et al.* (2008), seems to be confirmed by data from the western Wadden Sea long-term fyke monitoring by the NIOZ (Figure 21, van der Veer, unpublished data).

The diadromous fish currently seem to suffer most from bottlenecks in the upstream parts of (some) estuaries, where water quality and essential habitats are failing, resulting in some species missing and low abundance of the remaining.

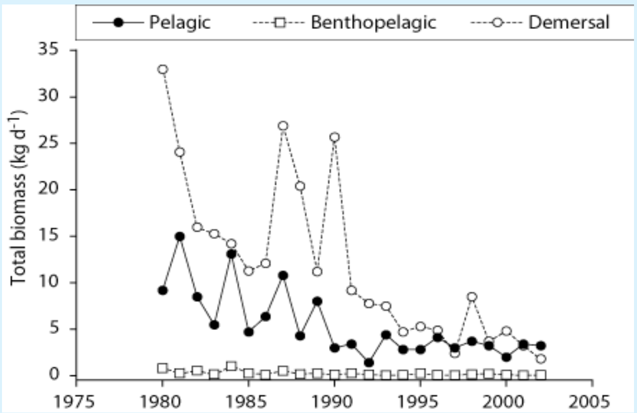


Figure 21: Trends in fish biomass (kg d^{-1}) caught in the NIOZ fyke net monitoring in the western Wadden Sea. Source: H.W. van der Veer (unpublished data).

Not only unhindered migration (as formulated in one of the sub-targets for fish) but in addition the availability of suitable spawning habitats and favorable conditions for larval recruitment are essential to maintain vital populations of diadromous fish in the estuaries and in the Wadden Sea. It illustrates that Wadden Sea fish should be evaluated in connection with the estuarine water systems.

Distribution shifts of juvenile flatfish indicate changed conditions in the Wadden Sea nursery, which may have become less favorable due to higher water temperatures during summer. At the same time, the North Sea coastal and offshore area may now offer increased chances of survival due to decreased predation risk and competition since commercial fish stocks are at low levels. Here, a combination of high fishing pressure on the North Sea and regime-shifts in the North Sea and Wadden Sea ecosystems plays a role. The low abundance of cod, whiting, herring and sprat reflect trends in North Sea recruitment to a large extent. Here again, predominant influence of fishery and climatic factors may be responsible for declining abundances. The Wadden Sea fish fauna and, more specific, the abundance of marine juvenile species cannot be seen detached from what is going on in the North Sea. Nevertheless, local conditions in the Wadden Sea may cause abundance patterns that deviate from those in the North Sea.

The estuarine resident species are as usual the least known and understood group, although, of all fish species, they may reflect the status and quality of the Wadden Sea ecosystem to the largest extent.

5. Conclusions and recommendations

5.1 Conclusions

Assessment method

The assessment of fish in estuaries has advanced by the requirements of the WFD, which urged the development of an assessment tool and according (fish) monitoring. For Wadden Sea fish, a first step toward a common assessment and the selection of suitable underlying metrics has been made. However, further effort is needed to end up with an applicable tool. The chosen metrics each have their limitations and need to be further evaluated and adapted if necessary.

Target: Presence of a typical Wadden Sea fish fauna

Concluding, a typical Wadden Sea fish fauna is defined as those species regularly found over the last century. As a reference, the table with (fairly) common species in Annex I is adopted. The term "typical" thus refers to a species composition which has been manifest over a long period (*e.g.* over the last 40 years as documented by the demersal fish surveys, and over the last 18 years as documented by the Schleswig-Holstein pelagic fish monitoring). Monitoring results of only one year can never demonstrate the presence of all species on the reference list.

Nevertheless, it is concluded that nearly all of the typical Wadden Sea species are still present.

Target: Occurrence and abundance of fish species according to the natural dynamics in (a)biotic conditions

The occurrence of fish species seems to be according to the natural dynamics. The recently experienced climatic changes, however, have led to according changes in fish abundance that are sometimes outranging the long-term average and can lead to a regime shift in the ecosystem. The marine juvenile fish species in the Wadden Sea seem to reflect the heavy fishing pressure in the North Sea in combination with the climatic and hydrographic changes. The abundance of several other fish species have decreased to levels below the long-term average, but factors (natural or anthropogenic) causing these changes are still largely unknown.

Sub-target: Unhindered migration between the sea and fresh waters

The present analyses do not allow an assessment of this sub-target. The abundance of smelt in the demersal fish surveys do not (yet) indicate declining trends although the study on smelt (Scholle *et al.*, 2007b) indicates that problems occur in some estuaries. Unhindered migration as such cannot guarantee self-sustained populations of diadromous species; in addition good water quality and availability of spawning habitats are required. There should be no bottlenecks of any kind preventing the completion of the species' life cycle in the different water systems.

Sub-target: Viable stocks and a natural reproduction of typical fish species

This sub-target cannot be assessed by the current analyses; assessment requires concomitant research.

Sub-target: Diversity of habitats and substratum for spawning

Basically, this is not a fish target and it cannot be assessed by the current analyses.

Sub-target: Suitable physical, chemical and morphological conditions with dynamic processes typical for tidal areas

This sub-target, too, has no relation with the metrics that were analysed in the current report.

Sub-target: Suitable feeding ground for all relevant ecological guilds of Wadden Sea fish

This sub-target cannot be assessed by the current analyses; assessment requires concomitant research.

Target on trophic integrity: a natural fish fauna, providing food for sustainable populations of fish-eating birds and mammals

This complex item cannot be assessed from the current analysed metrics or monitoring. Specific research is needed to further improve on our understanding of food availability and other factors determining population levels of birds and marine mammals.

In order to advance our understanding of the Wadden Sea fish fauna we should continue monitoring the occurring changes in the (Wadden Sea) fish fauna in an effective way by making the best use of available surveys and to develop a system by which we can adequately describe trends in a consistent way for future quality status reports.

Concomitant research should provide additional information to increase our fundamental knowledge of the ecology of Wadden Sea fish – a topic which deserves attention and is in need of progress.

5.2 Recommendations

Monitoring

- Comprehensive trilateral monitoring of the Wadden Sea requires expansion of the spatial coverage of the demersal fish surveys to the Danish Wadden Sea.
- The present sampling sites for pelagic fish monitoring should be extended to get reliable information on these species, which are considered as indicators of trophic integrity (food for fish-eating birds and mammals).
- For species showing strong seasonal patterns in abundance, the present monitoring periods must be extended to at least two times a year (with the appropriate seasonal timing).
- The value of new national monitoring programs can be increased by trilateral 'tuning' and harmonization of methods, gear, sampling sites and sampling times.
- Further elaboration of the TMAP Handbook and technical adaptation to integrate the results of the QSR fish report is recommended.

Research

For a better understanding of the observed changes in the fish community,

- More fundamental research on processes (ecosystem level, species level), anthropogenic impacts and climate change is required.
- More knowledge on the dynamics of Wadden Sea fish populations in relation to North Sea and estuarine populations is required.
- The functional relationship (*e.g.* food, shelter) between fish species and habitats (*e.g.* tidal flats, mussel beds, reed beds, salt marshes) should be investigated.
- The international accessibility of data and results from applied research projects (such as EIA studies on fish) should be enhanced.
- Funding for concomitant research on the ecology and changes in abundance of fish remains indispensable to understand trends observed in TMAP fish monitoring.

Management

- For now, include the metrics selected as TMAP parameters in the revised TMAP fish monitoring which should consist of a combination of (multi-method) fish surveys (Table 8).
- The further development and implementation of trilateral targets concerning fish is necessary to structure and focus the TMAP fish monitoring.
- Continue with the initiated development of a suitable and acceptable assessment tool, taking into account the lack of knowledge on reference conditions and cause-effects-relationships.
- Effective management of Wadden Sea fish cannot be achieved without tuning with North Sea and estuarine management.

Trilateral policy

- Involve Denmark in the trilateral (in practice bilateral) work of the TMAP fish expert group.
- Consider the most appropriate way and enable the continuation of the fruitful and stimulating cooperation on the joint analyses of fish monitoring data.

Table 8: Parameters of the revised TMAP for monitoring and assessment of targets on fish (TMAP Handbook 2008)

TMAP parameters	Monitoring	Remarks	Legal obligations
• species richness, • representation of ecological guilds, • distribution and abundance of species in the Wadden Sea; • length distribution of selected species	Existing beam trawl surveys for demersal fish (IMARES, vTI), stow net surveys for pelagic fish (SHS survey) and the NIOZ fyke monitoring in the western Wadden Sea.	Wadden Sea fish index under discussion (*cf* WFD fish index transitional waters).	None at present, but potential contribution to HD assessment
• species composition • abundance of type-specific fish species in transitional waters; • length distribution of twaite shad and smelt	WFD stow net monitoring on 3-4 stations in Ems, Weser, Elbe, Eider	Guidelines developed for WFD monitoring and integration of monitoring results; Assessment tool to judge the status of the water body based on the fish fauna	Obligatory under WFD

Box 1: Seabird - fish interaction

Seabird-Fish interactions in the Lower Saxon Wadden Sea

(Dänhardt and Becker, 2008)

Common tern (*Sterna hirundo*) in the Wadden Sea have synchronized their breeding phenology with the seasonal occurrence of their prey fish. Herring (*Clupea harengus*), sprat (*Sprattus sprattus*), sandeel (*Ammodytes spec.*) and smelt (*Osmerus eperlanus*) are the preferred food items, while whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) are also utilised extensively in years of mass occurrence (Becker *et al.*, 2001; Fresemann, 2008). Since 2002, the tern's breeding success was below average, possibly caused by poor food supply. Despite the key role fish play in the Wadden Sea food web, distribution patterns and abundance dynamics, especially of pelagic species, are only fragmentarily documented, presumably because fish is only recently considered in species and habitat protection concepts.

Between 2005 and 2007 fish was sampled from the cooling water system of a power plant in Wilhelmshaven and with a vertically resolving stow net near two of the most important German tern breeding colony sites at Banter See (BS) in Wilhelmshaven and on Minsener Oog (MO) in the National Park Lower Saxon Wadden Sea, where courtship and chick feedings were observed in synchrony with the fish sampling. Data on the breeding biology of the tern were collected using standard techniques (Wagener, 1998).

Among the 59 fish and 14 invertebrate species found, only a few were utilised as prey by the tern. Within the three years of investigation, the main prey species, herring, was most abundant in 2007 (Table 9).

Fish abundance peaked in early summer, corresponding well with the greatest food demand within the terns' breeding season. The composition of courtship (co) and chick (ch) prey as well as the fish samples differed between BS and MO: Clupeids were the most important tern prey on MO (co: 36-58%, ch: 72%). Other prey items were sandeel (co: 11-19%), brown shrimp (*Crangon crangon*, co: 7%) and in 2007 gadoids (presumably whiting, as inferred from the stow net catches, co: 12-37%, ch: 15%). Pipefish (*Syngnathus spec.*) were fed neither to partners nor to chicks by the common terns on MO, while at BS, together with brown shrimp, it made up 5-12% of courtship and chick prey. In 2007, 12% of the chicks' diet at BS consisted of gadoids. In addition to clupeids (co: 6-26%, ch: 26-33%), smelt was extensively fed (co: 24-63%, ch: 16-18%). This anadromous fish is hardly available more offshore (*e.g.* MO), but seems to considerably improve the food supply for avian piscivores breeding further inshore (*e.g.* BS, Neufelderkoog, Eidersperrwerk, Dänhardt and Markones, *unpubl.*).

In 2006, herring abundance in the Jade bay and the daily mean water temperature were positively correlated up to the beginning of June (Spearman rank correlation, $r_s = 0.63$, $p<0.003$), thereafter the correlation was negative ($r_s = -0.52$, $p<0.006$), culminating in the sudden disappearance of this main prey species in the 3rd quarter of July, possibly due to water temperatures exceeding 23°C. The common terns at BS replaced herring with 0-group twaite shad (*Alosa fallax*) that immigrated into the study area around the same time, as revealed by length comparisons between stow net catches and feeding observations. Despite this switch to a presumably equivalent prey alternative, chick growth rates were temporarily reduced.

Year	2005	2006	2007
Fish abundance per 10 000 m³			
mean ± SD (number of hauls)			
Herring catches stow net Jade bay	-	18 ± 19 (31)^{7}	73 ± 108 (38)^{6}
Herring catches stow net Minsener Oog	-	299 ± 712 (30)^{7}	1570 ± 3518 (24)^{6}
Herring catches cooling water intake	13 ± 26 (84)	6 ± 16 (101)	4 ± 9 (33)
Common tern breeding parameters			
(main breeding period May 1st – June 9th)			
Mean egg laying date (pentad)	29.3 ± 1.4 (455)^{7}	29.1 ± 1.9 (442)^{7}	28.2 ± 1.7 (411)^{5,6}
Clutch size (no. of eggs per clutch)	2.5 ± 0.7 (455)^{6,7}	2.3 ± 0.7 (442)^{5,7}	2.6 ± 0.6 (411)^{5,6}
Fledglings per breeding pair	0.16 ± 0.41 (455)^{6,7}	0.57 ± 0.61 (442)^{6,7}	0.45 ± 0.60 (411)^{5,6}
Weight gain (g per day, age 3–13 days)	6.8 ± 1.6 (31)^{6}	5.3 ± 2.2 (76)^{5,7}	7.2 ± 1.6 (93)^{6}
Maximum chick weight (g)	121 ± 8 (72)^{7}	121 ± 10 (272)^{7}	128 ± 10 (222)^{5,6}
Weight at fledging (g)	112 ± 9 (72)^{7}	113 ± 11 (272)^{7}	117 ± 11 (222)^{5,6}

Table 9: Fish abundance and breeding parameters obtained from the common tern colony at Banter See, Wilhelmshaven. In 2005, owl predation and in 2007 a storm flood reduced breeding success. Except for the herring catches in the cooling water intake, all differences between years were highly significant (ANOVA, GLM, χ^2-, K-W-Tests, $p < 0{,}001$). Differences are marked by the respective year: ^{5}, ^{6}, ^{7} = 2005, 2006, 2007.

In 2007, gadoids comprised up to 15% of prey fed to chicks, being attributed to a mass invasion of whiting. Together with the high abundance of herring, whiting was part of an excess food supply for the tern chicks that were observed to reject high quality prey items at the Banter See colony (Braasch, A., *pers. comm.*). Exceptional events such as the disappearance of a main prey species or the mass occurrence of another can prove either catastrophic or beneficial for the terns' reproductive performance, depending on available prey alternatives and baseline food supply, respectively.

Fish were usually located in midwater and were consequently out of reach of the terns, which are confined to prey near the surface by their plunge-diving foraging mode. Within a tidal cycle, pelagic prey was fed in highest proportions around high water, while benthic prey became more abundant during receding tide and low water. Prey diversity increased towards sub-maximal water coverage, presumably due to a greater diversity of foraging habitats. Factors determining the accessibility of prey include hydrographic phenomena (*e.g.* turbulence, upwelling, fronts), bottom topography (*e.g.* submerged sand banks, tidal pools, shorelines) or subsurface foragers chasing fish to the surface (Camphuysen and Webb, 1999). The terns' ability to use these diverse foraging conditions and thus exploit a wide variety of prey sources may explain the rather poor accordance of species proportions between the feeding observations and the stow net catches. Furthermore, direct observations of foraging terns showed that profitable prey was brought to chicks more often (clupeids: 14-28%, smelt: 50%, gadoids: 37%, gobies: 17-50%) than less favourable items (brown shrimp and pipefish 0%, respectively). These individual decisions about which prey type would be consumed directly by the forager or brought to the colony (where prey items would eventually be recorded by the human observer) may have been another source of mismatch of species percentages, yet indicate that the more unprofitable the prey that arrives at the nest, the worse is the food situation.

A storm flood in 2007 and predation in 2005 (BS) and 2006 (MO) reduced the number of fledged chicks per breeding pair, resulting in below average breeding success (Frick and Becker, 1995; Becker, 1998). According to other reproduction parameters (Table 9), feeding conditions in 2007 were superior to those of the previous two years: egg laying, hatching and fledging occurred earliest, average clutch size, weight gain, maximum and fledging weight of chicks was highest in 2007. Additionally, body mass values of chicks in 2005 and 2006 were among the lowest within 25 years, whereas 2007 was well above the long-term average. Only the storm flood at the end of June prevented an above average breeding success in 2007 (Table 9).

Together with the food supply, meteorological extremes and predation are the main determinants of breeding success, which integrates all environmental variables affecting adults, eggs and chicks over the whole breeding season, and may thus be only of limited use to draw inferences about the food availability, compared to a combination of more specific reproduction parameters (Table 9).

Box 2: Smelt recruitment in the Ems

Smelt recruitment in the Ems in relation to water quality

(Scholle *et al.*, 2007b)

The smelt (*Osmerus eperlanus*) is a diadromous species. Spawning grounds are situated upstream in the rivers (upstream of the tidal limit) whereas the estuary is used as a nursery and the adults overwinter in open sea. Smelt is sensitive to water quality (mainly dissolved oxygen, high concentrations of suspended matter). In the Water Framework Directive (WFD), smelt was chosen as one of the indicator species of transitional waters. The presence of the species contributes to the index on species composition, whereas the abundance of smelt (0-group, sub-adult and adult) is considered relevant for the index on abundance (Kranenbarg and Jager, 2008). There were indications that the abundance of smelt may have declined in the Ems since the 1990s (Jager and Kranenbarg, 2004), for which the following hypotheses were formulated:

- the reproduction of the smelt is hampered by changes in hydromorphology which caused a decrease in natural spawning habitats and a decline of the spawning conditions;
- low oxygen concentrations and high turbidity enhance larval mortality. Under these conditions, lower abundances of smelt larvae and juveniles can be expected.

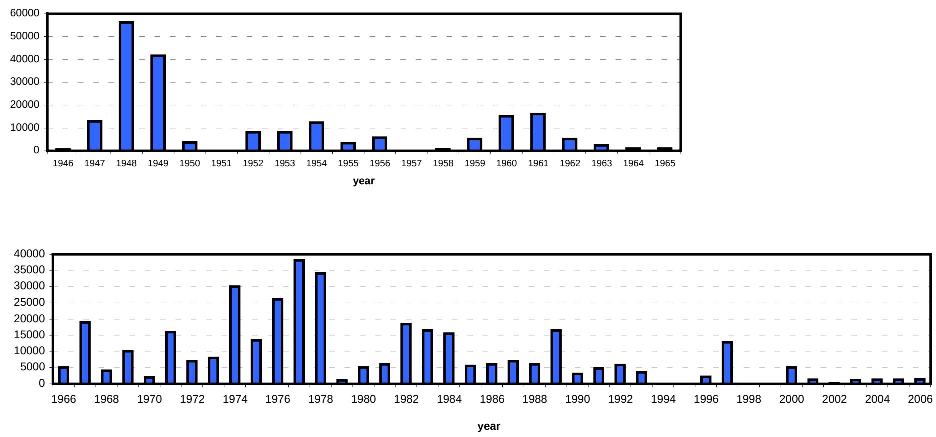
The hypotheses were tested by carrying out a pilot study during 2007 in the Ems estuary.

To identify the spatial and temporal distribution of smelt larvae in the Lower Ems, samples were taken along a longitudinal transect in the Lower Ems (Emden-Weener) and also in the tributary Leda using a Bongo net on seven different dates from the end of April to mid June 2007. In addition, samples were taken at a station 7 km downstream of Herbrum and a station 2 km upstream of the Herbrum weir. Details on the methods and nets used are given in Scholle *et al.* (2007b). Abiotic parameters were obtained from NLWKN (data of 6 locations in the Unterems, 2000-2007) or measurements taken during the survey (Scholle *et al.*, 2007b). Additional information on the smelt population was obtained from sampling with stow net (also called anchor net) in the Ems estuary at different locations between 3 May and 22 June 2007. Data on smelt landings were obtained from the State Fisheries office of Lower Saxony (Germany) and from Jaarboeken Visserij (1947-1965, Dutch fisheries data). Anecdotal information from fishermen was collected to find out where spawning locations of smelt were and are situated in the Ems.

The river discharge in 2007 followed the regular seasonal pattern of high discharges of up to 300 m^3 s^{-1} in winter/early spring and significantly lower values (<100 m^3 s^{-1}) starting in May. Winter discharges were relatively high in 2007, compared to 2006, whereas from mid April to mid June 2007, river discharges corresponded to those of an average year. Water temperatures were relatively high, especially in the winter months when water temperature was mostly above 5 °C, except for two short periods at the end of January and beginning of February 2007. Average January temperature was 2.6 °C above the average of the last 8 years. From April onwards, temperatures were comparable to the long-term average (15-20 °C). At the tidal freshwater location (Weener) daily and seasonal fluctuation ranges of <0.3 and 0.9 psu were measured, and average salinity varied between 0.3 and 1 psu. At Terborg (oligohaline zone) much higher variation in salinity occurred, both on a daily and seasonal scale. Salinity varied between <0.5 and 11 psu. Data of suspended matter were available for the tidal freshwater location of Leer. As early as January extremely high concentrations of suspended matter (10 g l^{-1}) were recorded, followed by a significant decline until mid March (values ranging between <0,3-1,5 g l^{-1}). Thereafter, suspended matter concentrations increased again, reaching maximum values up to 25 g l^{-1}. Suspended matter concentrations were highest during phases of low river discharge and were related to the tidal phase. Oxygen concentrations dropped lower at Weener, the more upstream of the two, than at Terborg. From April on they dropped below 5 mg l^{-1}. After a brief 'recovery' at the beginning of May, a phase of extreme oxygen depletion (around 1 mg l^{-1}) occurred between mid May and mid June both at Terborg and Weener, although again more pronounced at Weener. A tidal influence was apparent in the oxygen fluctuations, with lowest values during low tides.

Between the end of April and the beginning of June no smelt larvae were detected in the Bongo net catches between Herbrum and Emden. The stow net catches demonstrated the absence of 0-group smelt between May and the end of June in the Ems estuary. The majority of the smelt catches consisted of subadult individuals (7-10 cm length). However, the more downstream the catch was made, the more adult smelt were observed in the catches. The highest numbers of smelt were caught in the meso-polyhaline section of the estuary.

Figure 22: Landings of smelt from commercial fishery in the Ems estuary (kg yr^{-1}). Top panel: Dutch landings (Jaarboeken Visserij); bottom panel: German landings (Staatliches Fischereiamt Bremerhaven).



The historical Dutch landings of smelt in the Ems Dollard comprise the period 1946-1965 (Figure 22). Low landings around 1945 are assumed to result from low fishing effort due to World War II. During the following years, landings increased strongly and decreased again in the 1950s. Since then, no Dutch landings have been recorded from the Dollard, probably because the (smelt) fishery was no longer profitable in this area. The German catch statistics commence in 1966 and indicate substantial annual fluctuations as well as an overall decline in the catches, which commenced already in 1979. Landings dropped to about 1,000 kg yr^{-1} since the year 2000.

According to the five fishermen who were interviewed, the spawning locations of smelt are located between Oldersum (between Petkum and Terborg) and Papenburg, and maybe also in the tributary Leda. However, the location of the spawning grounds of smelt in the Ems could not be identified in this study. Based on comparisons with the Elbe and Weser, the spawning locations could be situated across the entire tide-influenced freshwater section or even upstream of the Herbrum weir. This includes the tributary Leda as a spawning site. Therefore, the statements of the local fishermen seem plausible.

Wherever the exact spawning locations in the Ems may be, they coincide with the zone that is presently suffering poor water quality. There also seems to be a lack of suitable spawning habitat in this stretch of the Ems, since the fairway has been canalised and the riverbed is covered with silt and fluid mud (Haberman, 2006). Successive deepenings of the upper Ems caused hydromorphological changes which led to this drastic increase in the concentrations of suspended matter in the water column and the occurrence of 'fluid mud' on the channel bottom. These changes are most pronounced in the tide-influenced freshwater section between Herbrum and Leer. The concentrations of suspended matter may reach levels above 5 g l^{-1} near the surface, which is two orders of magnitude above those in the Elbe/Weser (Bioconsult, 2007). The suspended matter is imported from the sea, due to so-called 'tidal pumping'. In the zone where freshwater and seawater mix, the sediments settle on the bottom during slack tides and move back and forth on the tidal currents because they are not consolidated.

Thiel et al. (1994) showed for the Elbe that low smelt biomasses and low oxygen concentrations were correlated to each other. Möller and Scholz (1991) pointed out that pronounced oxygen deficits may lead to a complete absence of smelt recruitment. While adult fish are able to avoid these unfavourable situations, this is not possible for eggs and early larvae. The significance of oxygen as a factor for anadromous migratory species was recently underlined by various authors (e.g. Turnpenny et al., 2004, 2005, 2006; Maes et al., 2007). Whereas Maes et al., 2007 regard an O_2 concentration of 5 mg l^{-1} as a minimum for anadromous migratory species, lower limit values are proposed by Turnpenny et al. (2006) below which substantial impairment of the estuarine fish fauna can be expected. At the same time the authors differentiate according to different standards. The 'one-week standard', for example, was defined as 4 mg l^{-1} (1-year return period, >29 tides) and was selected to ensure protection against chronic effects; these would include depression of growth and avoidance of hypoxic areas. The lowest standard (1.5 mg l^{-1}) was included to ensure protection from mass mortalities. The very pronounced summer oxygen deficits in the Ems since 2000 are clearly outside the fish tolerance ranges specified for estuaries (e.g. Turnpenny et al., 2006) (Figure 23).

No smelt larvae were detected between Emden and Herbrum in the period 23 April-11 June. Although reproduction may have occurred early, due to the high winter water temperatures, smelt larvae were present at the same time in the neighbouring lower Weser where numerous smelt larvae were verified in May 2007 (Bioconsult, unpublished data). It is thus likely that reproduction in the Ems was not successful or took place only to a small extent, if at all. The absence of 0-group smelt in the stow net/anchor net catches in May-June 2007 may partly have been caused by gear selectivity. In this type of net, 0-group smelt can be caught effectively from the beginning of August, depending on the mesh size (Kleef and Jager, 2002).

Catches of the commercial fishery should always be interpreted with caution, because fishing effort and market prices may influence the landings. However, the 'Jaarboeken Visserij' describe that the decrease in the Dutch landings during the 1950s were the consequence of deteriorating water quality, caused by the discharge of organically polluted waste water from the potato industry in autumn in those years. Fishery was no longer profitable and finally ceased in the 1960s. In the 1990s, the waste water sanitation has been completed for this industrial activity and its discharges no longer cause oxygen deficits in the Dollard. Nowadays, there is practically no commercial fishery left in the Dutch part of the Ems-Dollard and the origin of the landings is no longer documented. In contrast to the low numbers of smelt in the Ems, recent smelt population data from the other North Sea estuaries do not indicate an extensive decline in smelt stocks in the coastal area of the Wadden Sea or in the other estuaries, that could account for the low numbers of smelt in the Ems. Substantial differences between the Ems and the Weser, Elbe and Eider estuaries, rather indicate the involvement of Ems-related problems. The initial hypotheses were thus supported by the present findings.

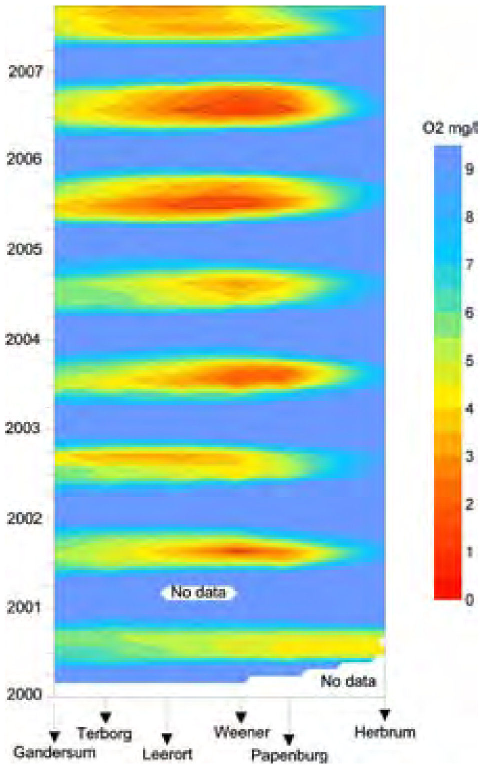


Figure 23: Spatio-temporal plot of the Ems estuary (between Herbrum Km -12.7, and Gandersum Km 35. Papenburg is situated at Km 0). Avoidance levels (<4 mg l^{-1}) are indicated in orange grades with a grey contour line, mortality levels for fish (<2 mg.l^{-1}) are indicated in red with a black contour line (source: data NLWKN).

Box 3: Status of shrimps

Status of shrimp (*Crangon crangon*) in the Wadden Sea

The stocks of brown shrimp have been monitored by the Demersal Young Fish and Brown Shrimp Surveys (DYFS) in the Wadden Sea and coastal waters since 1970. Though these surveys - being confined to a fixed survey area - show a declining trend in shrimp abundance, the yield of the fisheries on the species remained high. Increasing landings peaked in 2005, exceeding 38,000 tonnes of marketable shrimp from the North Sea. There was obviously no danger of over-fishing in the recent years.

The observed decline in shrimp abundance in the Wadden Sea may be caused by a distributional shift towards deeper and more offshore waters, as well as towards a more northern distribution outside the survey areas. This can also be concluded from fishery patterns. The shrimp fleets have shifted their fishing areas towards deeper and more northerly, even northern Danish waters, according to log-book data (Figure 24). They followed the changed shrimp distribution which might be an effect of climate change, a hypothesis which still needs to be investigated, as the opposite geographical shift has been reported in earlier decades.

The increase in landings could also be an effect of increased effort, as especially Dutch and Danish vessels increased their shrimp fishing capacity due to reduced fishing possibilities in other fishery sections. Nevertheless, landings per unit of effort (LPUE) in shrimping showed an increasing trend as well until 2006, indicating high and viable shrimp stocks, which probably benefited from reduced predation by cod. Even the high whiting presence in some years and areas led only to some smaller drawbacks of landings, instead of a collapse of the fishery which occurred in former decades.

A study on the effect of environmental factors on shrimp landings showed clear correlations (ICES 2006b). The decision to rely on landings without standardizing by effort was dictated by the absence of a consistent effort series. The study identified, as climatic factors, the North Altantic Oscillation (NAO) winter index plus the sea surface temperature (SST) in winter as significantly influencing the level of shrimp landings in the subsequent autumn and spring fishing seasons. Most likely this works through enhanced recruitment of larvae into the tidal nursery area. Predation has a significant influence in years with extreme gadoid (recently particularly whiting) invasions into the shrimp distribution area and feeding on pre-recruits, but there is no signal from about-average levels of predator abundance.

The statistical model built on these relationships performs best for the years 1980–1997. Extending the year range to 1950–2002 weakens the significance, but does not destroy the relationship (Neudecker, unpublished data). The earlier years were the phase of technical development, where most of the stock distribution area became accessible to the fishery, as opposed to the predominantly inshore fishing in the early years after World War II. Also, Dutch and Danish fleets were developing during that time. This went along with rising landings of consumption shrimp. With the year 1998, a regime of voluntary catch restrictions came into force which affected the assumed relationship between stock abundance and landings. This regime was lifted in 2003, but model-based predictions of landings for the years thereafter were only of varying quality probably due to the variations in effort and predation. It seems wise to incorporate data, since recent years available from the EU logbook system, for these parameters into the model algorithm to improve future stock assessment and catch predictions.

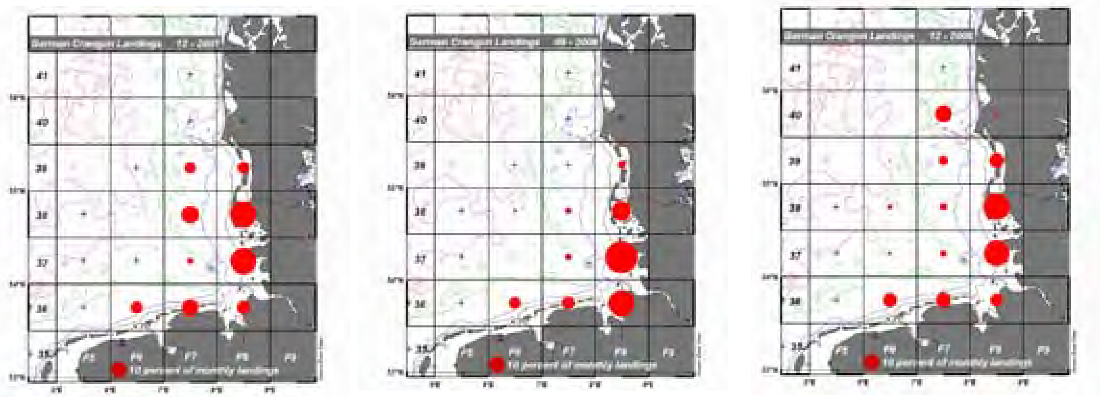


Figure 24: Comparison of log book data of fishing areas of the German fleet by ICES rectangle: Winter situation 2001 and 2006 showing the northern directed shift of fishing activity (A and C) and the seasonal shift from summer to winter activity in 2006 (B and C).

A: Landings (%) in December 2001 B: Landings (%) in September 2006 C: Landings (%) in December 2006

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Annex 1: Reference species list of fish

Fish species found in the Wadden Sea since 1960 (* Fresh water species). Table 1: Common and fairly common species; Table 2: (Extremely) rare species.
Surveys in which the species were encountered: a. DYFS, b. DFS, c. Stow net Schleswig-Holstein, d. Stow net Lower-Saxony, e. Stow net Elbe, f. Witte & Zijlstra (1978), g. Atlas Schleswig-Holstein, h. Red List Germany (Fricke et al., 1994). N= number of counts in a-h as an indication of occurrence: N≥3 (fairly) common; N<3 (extremely) rare.

Table 1: Common and fairly common fish species in the Wadden Sea (for explanation see text).

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Abramis brama *	Carp Bream	Brasse	Brasem	Brasen	x				x	x			3
Agonus cataphractus	Hooknose	Steinpicker	Harnasmannetje	Almindelig panserulk	x	x	x	x	x	x	x	x	8
Alosa alosa	Allis Shad	Maifisch	Elft	Majsild		x	x	x		x		x	5
Alosa fallax	Twaite Shad	Finte	Fint	Stavsild	x		x	x	x	x	x	x	7
Ammodytes marinus	Lesser Sandeel	Kleiner Sandaal	Noorse Zandspiering	Havtobis	x	x	x	x		x	x	x	7
Anguilla anguilla	Eel	Aal	Aal	Europæisk ål	x	x	x	x	x	x	x	x	8
Aphia minuta	Transparent Goby	Glasgrundel	Glasgrondel	Glaskutling		x	x	x		x	x	x	6
Arnoglossus laterna	Scaldfish	Lammzunge	Schurftvis	Almindelig tungehvarre	x	x		x	x	x		x	6
Atherina presbyter	Sand-smelt	Ährenfisch	Koornaarvis	Almindelig stribefisk	x	x	x	x		x	x	x	7
Belone belone	Garfish	Hornhecht	Geep	Almindelig hornfisk	x	x	x	x		x	x	x	7
Buglossidium luteum	Solenette	Zwergzunge	Dwergtong	Glastunge	x	x		x		x	x	x	6
Callionymus lyra	Dragonet	gestreifter Leierfisch	Pitvis	Stribet Fløjfisk	x	x	x		x	x	x	x	7
Chelon labrosus	Thick-lipped Mullet	Dicklippige Meeräsche	Diklipharder	Tyklæbet multe	x	x	x		x	x	x	x	7
Ciliata mustela	Five-bearded Rockling	Fünfbärtelige Seequappe	Vijfdradige Meun	Femtrådet havkvabbe	x	x	x	x	x	x	x	x	8
Clupea harengus	Herring	Hering	Haring	Atlantisk sild	x	x	x	x	x	x	x	x	8
Coregonus oxyrinchus	Houting	Nordseeschnäpel	Houting	Snæbel					x	x	x	x	4
Cyclopterus lumpus	Lumpsucker	Seehase	Snotolf	Almindelig stenbider	x	x	x	x		x	x	x	7
Dasyatis pastinaca	Common Stingray	Stechrochen	Pijlstaartrog	Europæisk pigrokke		x				x		x	3
Dicentrarchus labrax	Sea Bass	Wolfsbarsch	Zeebaars	Havbars	x	x		x	x	x		x	6
Echiichthys vipera	Lesser Weever	Vipernqueise	Kleine Pieterman	Lille Fjæsing	x	x		x		x		x	5
Enchelyopus cimbrius	Four-bearded Rockling	Vierbärtelige Seequappe	Vierdradige Meun	Firtrådet havkvabbe		x				x	x	x	4
Engraulis encrasicolus	Anchovy	Sardelle	Ansjovis	Europæisk ansjos	x	x	x	x	x	x	x	x	8
Entelurus aequoreus	Snake Pipefish	Große Schlangennadel	Adderzeenaald	Snippe	x	x	x	x	x	x	x	x	8
Eutrigla gurnadus	Grey Gurnard	Grauer Knurrhahn	Grauwe Poon	Grå knurhane	x	x	x	x	x	x	x	x	8
Gadus morhua	Cod	Kabeljau	Kabeljauw	Almindelig torsk	x	x	x	x	x	x	x	x	8
Gaidropsarus vulgaris	Three-bearded Rockling	Dreibärtelige Seequappe	Driedradige Meun	Tretrådet havkvabbe	x	x	x			x		x	5
Galeorhinus galeus	Tope Shark	Hundshai	Ruwe Haai	Almindelig gråhaj			x			x	x	x	4
Gasterosteus aculeatus	Stickleback	Dreistacheliger Stichling	Driedoornige Stekelbaars	Trepigget hundestejle	x	x	x	x	x	x	x	x	8
Glyptocephalus cynoglossus	Witch	Hundszunge	Witje	Skærising	x						x	x	3
Gymnocephalus cernuus *	Ruffe	Kaulbarsch	Pos	Nøgentobis	x	x			x				3
Hippoglossoides platessoides	American Plaice	Doggerscharbe	Lange Schar	Håising	x			x				x	3
Hyperoplus lanceolatus	Great Sandeel	Gefleckter Großer Sandaal	Smelt	Plettet tobiskonge	x	x	x	x	x	x	x	x	8
Lampetra fluviatilis	River Lamprey	Flußneunauge	Rivierprik	Almindelig flodlampret	x	x	x	x	x	x	x	x	8
Limanda limanda	Dab	Kliesche	Schar	Ising	x	x	x	x		x	x	x	7
Liparis liparis	Sea Snail	Großer Scheibenbauch	Slakdolf	Finnebræmmet Ringbug	x	x	x	x	x	x	x	x	8
Liparis montagui	Montagu's Sea Snail	Kleiner Scheibenbauch	Montagu's Slakdolf	Særfinnet Ringbug	x		x	x	x		x	x	6
Maurolicus muelleri	Pearlsides	Lachshering	Lichtend Sprotje	Laksesild					x	x	x	x	4
Merlangius merlangus	Whiting	Wittling	Wijting	Hvilling	x	x	x	x	x	x	x	x	8

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Merluccius merluccius	European Hake	Seehecht	Heek	Europæisk kulmule	x					x		x	3
Micromesistius poutassou	Blue Whiting	Blauer Wittling	Blauwe Wijting	Blåhvilling			x			x		x	3
Microstomus kitt	Lemon Sole	Limande, Rotzunge	Tongschar	Rødtunge	x	x	x	x		x	x	x	7
Mullus surmelutus	Surmullet	Streifenbarbe	Mul	Stribet mulle	x	x	x	x		x	x	x	7
Myoxocephalus scorpius	Bull Rout	Seeskorpion	Zeedonderpad	Almindelig ulk	x	x	x	x	x	x	x	x	8
Osmerus eperlanus	Smelt	Stint	Spiering	Europæisk smelt	x	x	x	x	x	x	x	x	8
Petromyzon marinus	Sea Lamprey	Meerneunauge	Zeeprik	Havlampret		x		x	x	x	x	x	6
Pholis gunellus	Butterfish	Butterfisch	Botervis	Tangspræl	x	x	x	x		x	x	x	7
Platichthys flesus	Flounder	Flunder	Bot	Skrubbe	x	x	x	x	x	x	x	x	8
Pleuronectes platessa	Plaice	Scholle	Schol	Rødspætte	x	x	x	x	x	x	x	x	8
Pollachius pollachius	Pollack	Pollack	Pollak	Lubbe		x				x		x	3
Pollachius virens	Saithe	Seelachs	Koolvis	Gråsej	x	x				x	x	x	5
Pomatoschistus lozanoi	Lozano's Goby	Lozanos Grundel	Lozano's Grondel	Lozanos kutling		x				x		x	3
Pomatoschistus microps	Common Goby	Strandgrundel	Brakwatergrondel	Lerkutling	x		x	x	x	x	x	x	7
Pomatoschistus minutus	Sand Goby	Sandgrundel	Dikkopje	Sandkutling	x		x		x	x	x	x	6
Pomatoschistus pictus	Painted Goby	Fleckengrundel	Kleurige Grondel	Spættet kutling					x	x	x		3
Psetta maxima	Turbot	Steinbutt	Tarbot	Pighvarre	x	x	x	x	x	x	x	x	8
Pungitius pungitius *	Ninespine Stickleback	Zwergstichling	Tiendoornige stekelbaars	Nipigget hundestejle	x			x			x	x	4
Salmo salar	Salmon	Lachs	Zalm	Atlanterhavslaks	x		x		x	x	x	x	6
Salmo trutta	Sea Trout	Meerforelle	Zeeforel	Almindelig ørred	x		x		x	x	x	x	6
Sardina pilchardus	Sardine	Sardine	Sardien	Almindelig sardin	x	x		x	x	x	x	x	7
Scomber scombrus	Mackerel	Atlantische Makrele	Makreel	Makrel	x	x	x	x		x	x	x	7
Scophthalmus rhombus	Brill	Glattbutt	Griet	Europæisk slethvarre	x	x	x	x	x	x	x	x	8
Solea solea	Sole	Seezunge	Tong	Almindelig tunge	x	x	x	x	x	x	x	x	8
Spinachia spinachia	Sea Stickleback	Seestichling	Zeestekelbaars	Tangsnarre	x					x	x	x	4
Sprattus sprattus	Sprat	Sprotte	Sprot	Europæisk brisling	x	x	x	x	x	x	x	x	8
Stizostedion lucioperca	Pike Perch	Zander	Snoekbaars	Sandart	x	x			x			x	4
Syngnathus acus	Great Pipefish	Große Seenadel	Grote Zeenaald	Stor Tangnål		x	x	x	x	x	x	x	7
Syngnathus rostellatus	Nilsson's Pipefish	Kleine Seenadel	Kleine Zeenaald	Lille Tangnål	x	x	x	x	x	x	x	x	8
Syngnathus typhle	Deep-snouted Pipefish	Grasnadel	Trompetterzeenaald	Almindelig tangnål				x		x		x	3
Taurulus bubalis	Long-spined Sea Scorpion	Seebull	Groene Zeedonderpad	Langtornet Ulk				x		x	x	x	4
Trachinus draco	Greater Weaver	Petermännchen	Grote Pieterman	Almindelig fjæsing	x					x		x	3
Trachurus trachurus	Horse Mackerel	Stöcker	Horsmakreel	Almindelig hestemakrel	x	x	x	x	x	x	x	x	8
Trigla lucerna	Tub Gurnard	Roter Knurrhahn	Rode Poon	Rød knurhane	x	x	x	x	x	x	x	x	8
Trisopterus esmarki	Norway Pout	Stintdorsch	Kever	Calypso	x						x	x	3
Trisopterus luscus	Bib	Franzosendorsch	Steenbolk	Skægtorsk	x	x	x			x	x	x	6
Trisopterus minutus	Poor Cod	Zwergdorsch	Dwergbolk	Glyse	x	x				x	x	x	5
Zoarces viviparus	Eelpout	Aalmutter	Puitaal	Almindelig ålekvabbe	x	x	x	x	x	x	x	x	8

Table 1:
(Extremely) rare fish species in the Wadden Sea (for explanation see text).

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Acipenser sturio	Sturgeon	Stör	Steur	Almindelig stør						x		x	2
Alburnus alburnus *	Bleak	Ukelei	Alver	Almindelig løje					x				1
Alopias vulpinus	Thresher	Fuchshai	Voshaai	Almindelig rævehaj						x			1
Ammodytes tobianus	Small Sandeel	Tobiasfisch	Zandspiering	Kysttobis						x		x	2
Anarhichas denticulatus	Northern Wolffish	Blauer Seewolf	Blauwe Zeewolf	Blå havkat								x	1
Anarhichas lupus	Wolf-fish	(Gestreifter) Seewolf	Gewone Zeewolf	Almindelig havkat						x			1
Argyrosomus regius	Meagre	Umberfisch	Ombervis	Almindelig ørnefisk								x	1
Aspitrigla cuculus	Red Gurnard	Seekuckuck	Engelse Poon	Tværstribet knurhane						x		x	2
Aspius aspius *	Asp	Rapfen	Roofblei	Asp					x				1
Atherina boyeri	Big-scale Sand Smelt	Kleiner Ährenfisch	Kleine Koornaarvis	Lille Stribefisk						x		x	2
Balistes carolinensis	Trigger-Fish	Grauer Drückerfisch	Trekkervis	Almindelig aftrækkerfisk						x			1
Barbus barbus *	Barbel	Barbe	Barbeel	Barbe					x				1
Blicca bjoerkna *	White Bream	Güster	Kolblei	Flire	x				x				2
Boops boops	Bogue	Gelbstrieme	Bokvis	Okseøjefisk						x		x	2
Brama brama	Ray's Bream	Brachsenmakrele	Braam	Almindelig havbrasen						x		x	2
Callionymus maculatus	Spotted Dragonet	gefleckter Leierfisch	Rasterpitvis	Plettet Fløjfisk	x						x		2
Callionymus reticulatus	Reticulated Dragonet	Ornament-Leierfisch	Gevlektepitvis	Kortfinnet fløjfisk	x					x			2
Carassius carassius *	Crucian Carp	Karausche	Kroeskarper	Karusse				x					1
Cetorhinus maximus	Basking Shark	Riesenhai	Reuzenhaai	Brugde						x			1
Cheilopogon heterurus	Atlantic Flying-Fish	Fliegender Fisch	Noordse Vliegende Vis	Almindelig flyvefisk								x	1
Conger conger	Conger Eel	Meeraal	Congeraal	Almindelig havål						x		x	2
Crystallogobius linearis	Crystal Goby	Kristallgrundel	Kristalgrondel	Krystalkutling								x	1
Ctenolabrus rupestris	Goldsinny	Klippenbarsch	Kliplipvis	Havkarusse					x	x			2
Cynoglossus browni	Nigerian tonguesole	Hundszunge	Nigeriaanse Hondstong	Nigeriansk hundetunge								x	1
*Cyprinus carpio**	Carp	Karpfen	Karper	Karpe					x				1
Dentex maroccanus	Morocco Dentex	Marokkanische Zahnbrasse	Rode Tandbrasem	Marokkansk havrude								x	1
Gaidropsarus mediterranaeus	Shore Rockling	Mittelmeer-Seequappe	Zuidelijke Meun	Middelhavshavkvabbe					x		x		2
Galeus melastomus	Blackmouth Catshark	Fleckhai	Spaanse Hondshaai	Ringhaj								x	1
Gobiusculus flavescens	Two-spotted Goby	Schnappgrundel	Blonde Grondel	Toplettet kutling								x	1
Hexanchus griseus	Bluntnose Sixgill Shark	Grauhai	Grauwe Haai	Almindelig seksgællet haj								x	1
Hippocampus hippocampus	Sea-Horse	Seepferdchen	Zeepaardje	Søhest						x			1
Hyperoplus immaculatus	Greater Sand-Eel	Ungefleckter Großer Sandaal	Effen Smelt	Uplettet tobiskonge								x	1
Labrus bergylta	Balan Wrasse	Gefleckter Lippfisch	Gevlekte Lipvis	Berggylte						x			1
Lamna nasus	Porbeagle	Heringshai	Neushaai	Almindelig sildehaj						x			1
Leucaspius delineatus *	Sunbleak	Moderlieschen	Vetje	Regnløje					x				1
Leuciscus idus *	Ide	Orfe	Winde	Almindelig Rimte					x				1
Lipophrys pholis	Shanny	Schan	Slijmvis	Tangkvabbe						x		x	2

Scientific name	English name	German name	Dutch name	Danish name	a	b	c	d	e	f	g	h	N
Liza aurata	Golden Grey Mullet	Goldmeeräsche	Goudharder	Guldmulte						x		x	2
Liza ramada	Thin-lipped Grey Mullet	Dünnlippige Meeräsche	Dunlipharder	Multe						x		x	2
Lophius piscatorius	Angler	Seeteufel	Zeeduivel	Europæisk havtaske						x			1
Melanogrammus aeglefinus	Haddock	Schellfisch	Schelvis	Kuller						x		x	2
Mola mola	Sunfish	Mondfisch	Maanvis	Almindelig klumpfisk						x		x	2
Molva molva	Ling	Leng	Leng	Almindelig lange							x		1
Mullus barbatus	Red Mullet	Rote Meerbarbe	Gewone Zeebarbeel	Rød mulle								x	1
Mustelus mustelus	Smooth Hound	Glatthai	Gladde Haai	Almindelig glathaj						x			1
Nerophis lumbriciformis	Worm Pipefish	Krummschnauzige Schlangennadel	Kleine Wormzeenaald	Stor næbsnog								x	1
Onchorhynchus mykiss	Rainbow Trout	Regenbogenforelle	Regenboogforel	Kamchatka-ørred					x				1
Pagellus acarne	Axillary Seabream	Achselfleckbrasse	Spaanse Zeebrasem	Akarnaisk blankesten								x	1
Pagellus bogaraveo	Blackspotted Seabream	Graubarsch	Rode Zeebrasem	Almindelig blankesten								x	1
Pagellus erythrinus	Common Pandora	Rotbrasse	Gewone Zeebrasem	Rød blankesten								x	1
Parablennius gattorugine	Tompot Blenny	Gestreifter Schleimfisch	Gehoornde Slijmvis	Stribet slimfisk						x		x	2
Perca fluviatilis *	European Perch	Flussbarsch	Baars	Europæisk aborre		x				x			2
Phrynorhombus norvegicus	Norwegian topknot	Norwegischer Zwergbutt	Dwergbot	Småhvarre								x	1
Pterycombus brama	Atlantic Fanfish	Silberbrassen	Zilverbraam	Sølvbrasen								x	1
Raja clavata	Thornback	Nagelrochen	Stekelrog	Sømrokke						x		x	2
Raniceps raninus	Tadpole-Fish	Froschdorsch	Vorskwab	Sortvels				x		x			2
Remora remora	Common Remora	Ansauger	Remora	Almindelig sugefisk								x	1
Rutilus rutilus *	Roach	Rotauge	Blankvoorn	Almindelig Skalle		x			x				2
Scomber japonicus	Chub Mackerel	Mittelmeermakrele	Spaanse Makreel	Spansk makrel								x	1
Scomberesox saurus	Skipper	Makrelenhecht	Makreelgeep	Almindelig makrelgedde					x				1
Scyliorhinus caniculus	Lesser spotted Dogfish	Kleingefleckter Katzenhai	Hondshaai	Småplettet rødhaj						x		x	2
Scyliorhinus stellaris	Greater spotted Dogfish	Großgefleckter Katzenhai	Kathaai	Storplettet rødhaj								x	1
Sebastes marinus	Redfish	Rotbarsch	Roodbaars	Stor rødfisk						x			1
Serranus cabrilla	Comber	Sägebarsch	Zaagbaars	Lille Rødfisk								x	1
Spondyliosoma cantharus	Black Sea Bream	Streifenbrasse	Zeekarper	Almindelig havrude						x			1
Squalus acanthias	Spur-Dog	Dornhai	Doornhaai	Almindelig pighaj						x			1
Squatina squatina	Monkfish	Meerengel	Zeeengel	Europæisk havengel						x		x	2
Symphodus melops	Corkwing	Goldmaid	Zwartooglipvis	Almindelig savgylte						x			1
Taractes asper	Rough pomfret	Kleine Brachsenmakrele	Hoogvinbraam	Højfinnet havbrasen								x	1
Taractichthys longipinnis	Bigscale Pomfret	Langflossen-Brachsenmakrele	(Langvinbraam)	Langfinnet havbrasen								x	1
Trachinotus ovatus	Derbio	Gabelmakrele	Gaffelmakreel	Almindelig gaffelmakrel								x	1
Xiphias gladius	Sword-Fish	Schwertfisch	Zwaardvis	Sværdfisk						x			1
Zeugopterus punctatus	Topknot	Haarbutt	Gevlekte Griet	Hårhvarre						x		x	2
Zeus faber	Dory	Heringskönig	Zonnevis	Sanktpetersfisk						x			1

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Beaches and Dunes

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1. Introduction

Dunes on Norderney
(Photo: Norbert Hecker)

Nowadays more and more attention is paid to the actual state of large nature areas along the Northwest European coastlines. In recent publications on expected sea level rise, beach plains, dunes and salt marshes are considered as elementary constituents of the coastal defense structures. The corresponding ecosystems are also subject to the implementation of Natura 2000 in compliance with European nature policy. They are considered to be of major importance because they hold such a large proportion of the total diversity of habitats and species that must be protected on the European level.

1.1 Protection and Management

Beaches and dunes in the Wadden Sea area are almost exclusively situated on the North Sea side of the barrier islands. Generally speaking, the adjacent landforms of Wadden dunes have a more or less natural character. This applies not only to the bordering beach plains and foreshores but also to the areas adjacent to the inner dune fringes on the islands. These often consist of brackish grassland or high salt marshes transcending to lower salt marshes and (sub)littoral mud flats. However, small island villages are mostly located in the inner dune fringe as well. These are protected against flooding by the dunes on the North Sea side and by artificial dikes on the Wadden Sea side. On the Dutch islands, sometimes complete former salt marshes are included within these dikes. Water management in these "polders" may even be regulated by pumping stations and the salt marshes are transformed into productive grasslands. On the German and Danish islands, only relatively small parts of these salt marshes are diked and reclaimed and they are used in a more extensive way.

On the North Sea side, there are some dune areas which are heavily protected by all kinds of hard core structures, *e.g.* bordering the largest villages on Borkum and Norderney. On the other hand there are dune areas which are not "protected" at all. Blowing sand and overwash under stormy conditions are the primary forming, *i.e.* building and demolishing, factors on those sites. Additionally, there are large stretches of the coastline, especially along the Dutch islands where 'soft' protection by sand dikes dominates the transition zone between dunes and North Sea beaches. The effects of these structures are comparable to those of harder structures in the sense that they completely restrict dynamic processes on a landscape level. On the habitat level, the recent abandonment of regular maintenance of the sand dikes affects local dynamics by sand blowing directly in or from those dikes. This abandonment, at least where no buildings or crucial human interests are present immediately behind the dikes, is part of the change of sea defense management policy. At the same time, a systematic management system of sand nourishment on beaches or foreshores was introduced, where a retreat of the coastline occurs or is expected. The consequence of this is that the coastal erosion that characterizes the natural dynamics of the Wadden Sea islands is reduced or eliminated.

Despite the presence of all kind of restrictions, it may be concluded that the adjacent landforms of Wadden dunes have a far more natural character than those of the mainland dunes along the Northwest European coast. In The Netherlands and Belgium for example, the mainland dunes are strongly squeezed between towns, buildings and infrastructure at the inland side and the very severe coastal defense requirements at the seaside. The Wadden dunes, by contrast, are to a large extent embedded in very dominant natural landscapes of the North Sea as well as of the Wadden Sea. This characteristic position gives many more opportunities to counteract the negative effects of sea level rise by adapting management to complement the natural processes which are involved. Also, the protection and restoration of priority habitats and species in Natura 2000 may be very well served by placing more emphasis on the role of natural processes on different spatial and temporal scales. Especially the complex and often fragmented transition zones between dunes and salt marshes, and also those between beaches and dunes, could be restored and flourish again. All this asks for new policy and management strategies specifically for the Wadden Sea islands, not only to adapt to climate change and to fulfil the assignments from Natura 2000, but also to develop new ways of fitting in the characteristic human activities on the islands in a sound, safe and long-lasting way.

1.2 Trilateral Policy from the 2004 QSR up till now

On the trilateral level the Trilateral Wadden Sea Plan (1997) can still be seen as the most important document where specific targets regarding beaches and dunes have been formulated.

The Quality Status Reports of 1999 and 2004 have specified recommendations for the near future based on monitoring results from the previous period. The Quality Status Report 2004 (QSR 2004), Chapters 9.1 (Mulder *et al.*, 2005) and 9.2 (Petersen and Lammerts, 2005), gave an extensive description of the state of the beach and dune ecosystems in the Wadden Sea area. Much attention was paid to the presentation of the then newly developed TMAP typology of dune vegetation which was proposed to be included in the Trilateral Monitoring and Assessment Program. An overview was given of the distribution of TMAP types which had been extracted and translated from the vegetation maps then available. Also the increasing dominance of highly competitive grass species and some neophytes were treated. Additionally, some trends and developments in faunal communities were addressed briefly. This inventory was followed by a thorough analysis of the most important threats and perspectives for the Wadden Sea dunes. According to the QSR 2004 the main ecological problems were:

A. The development of a disturbed balance between natural successional stages, culminating in an under-representation of young (pioneer) and old (natural forest) stages and an over-representation of eutrophic mid-successional stages (especially those dominated by one or two very productive grass species).

B. The lack of natural sedimentation and erosion processes along large stretches of the coastline as well as within the older dune complexes by the anthropogenic suppression of sand blowing and periodical local overflow with seawater.

C. The atmospheric deposition of nitrogen compounds which during the last century increased to a peak of about 40 kg/ha/yr in the 1980s, decreased again to 27 kg/ha/yr in 2002 but still is above the critical loads of ca. 10-15 kg/ha/yr for nutrient poor, dry and wet pioneer vegetation types.

D. The quantitative and qualitative impact of active water management and drinking water extractions on the natural fresh-groundwater systems on the islands, especially on the dune slack ecosystems.

For beaches, it was concluded in the QSR 2004, that there was insufficient knowledge about the actual status of beaches in the Wadden Sea and, therefore, an evaluation of the targets was not possible. It was also underlined that growing human impacts due to increasing activities concerning coastal defence, as a consequence of climate change, as well as increasing recreational activities, imply an urgent need for information and reconsideration of the targets for beaches.

Targets

- Increased natural dynamics of beaches, primary dunes, beach plains and primary dune valleys in connection with the offshore zone.
- An increased presence of a complete natural vegetation succession.
- Favorable conditions for migrating and breeding birds.

Based on the inventory and the analysis, some recommendations were formulated (see text box below). On these matters there has been a fruitful exchange of ideas and knowledge in a trilateral dune conference in Wilhelmshaven on 28 August 2008, which was jointly organized by the National Park Administration Lower Saxon Wadden Sea and the CWSS. However, an effective cooperation leading to an intensive interchange of ideas or to common initiatives has not yet been achieved. Hereto a more powerful structure certainly is needed. Probably, execution of a common trilateral project involving dune research, exchange of experience and information, communication and practical experiments in dune management could be the basis for structural cooperation.

1.3 The actual state of the art

Many of the conclusions and recommendations of the QSR 2004 still apply nowadays. On the role of neophytes, the influence of atmospheric deposition and the role of active management there are no significant new developments to be reported upon. On four items, new data and/or new views will be presented in this report:

Recommendations on beaches and dunes in the QSR 2004

Recommendations for beaches:

- to reconsider the targets that are defined for beaches in the Trilateral Wadden Sea Plan;
- to add parameters to the TMAP that give information about the status of beaches in the Wadden Sea in relation to the targets;
- to use the information from research programs on the ecology of sandy beaches for the formulation of new targets and an appropriate monitoring program;
- to form an 'Expert Group Beaches' under the TMAG to carry out these recommendations.

The recommendations for dunes focus on different perspectives: management (coastal protection, water management, nature management), monitoring and research.

- Information on how dry and wet pioneer stages respond to different approaches of coastal defense should be communicated more effectively, and experiments should be carried out on the stimulation of natural dynamics. Special attention should be given to different ways of handling existing hard structures or substantial sand dikes, with the purpose of eliminating their restrictive influence on dynamic processes.
- An inventory should be made of the differences between the Wadden Sea islands in water management and of the ecological consequences. Where severe effects on dune slack vegetation can be demonstrated, measures should be taken to improve the situation.
- A discussion should be held among nature managers and policy makers on views of nature management, especially on differences in strategies aimed at reaching common goals, such as increasing natural dynamics and natural succession and maintaining biodiversity (at least at the level of the Habitats Directive requirements).
- The use of a harmonized monitoring program in the Wadden Sea dunes, recognizing the developed TMAP classification for dunes, species lists, cover, *etc.*, is a prerequisite for trilateral assessment of dune development and for the detection of trends. Such a program cannot operate without concurrent data collecting on atmospheric deposition, coastal protection measures and water management.
- Research should be stimulated into the possibilities of re-establishing very early pioneer stages in the outer dune area by stimulating dynamics in huge stabilized sand dikes ('constructed' by frequently repeated artificial sand trapping) or even by removing them locally. An integrated geomorphological and ecological approach must result in practical advice for coastal managers. In addition, more fundamental studies are necessary of the speed and direction of natural succession under different conditions. Such studies should include the lifespan of successional stages, dynamic equilibrium between such stages as influenced by human activities, as well as by large scale processes such as sea level rise and bottom subsidence. The outcome of these studies will contribute to the future policy and management questions concerning the Wadden Sea dunes.

1 Thanks to a more intensive vegetation mapping, the distribution of TMAP vegetation types can be updated. For the Lower Saxon islands, new mappings have been made of much higher quality and detail than the former ones. For some of the Dutch islands, reliable comparisons can be made between two high quality chronosequential mappings.

2 New concepts on island dynamics based on geo-ecological analyses on the Dutch and East Frisian Wadden Sea islands have been developed. Some examples of the applicability for nature management will be presented.

3 No progress has been made in forcing back the influence of groundwater extraction for drinking water production on the Wadden Sea islands, nor has any exchange of experiences and knowledge taken place since the QSR 2004. An update of the development of groundwater extractions during the last few years has been included in this report to stimulate activities on this subject in the years to come.

4 In general, it is more difficult for fauna- than for flora-elements to assess suitable management strategies to protect them. One of the reasons is the overwhelming number of species, at least when arthropods are included, and the small amount of information we have on their distribution. Additionally this complexity makes it very difficult to select species which generate information on the actual state of ecosystem components. The reason is that yet very little is known about the role of fauna groups within dune ecosystems. As a consequence, it is very difficult to define functional fauna groups, let alone to select the indicative species for such groups. However a more adequate nature management on the ecosystem level as well as the preservation of fauna biodiversity itself requires a filling up of these knowledge gaps. Adequate monitoring programs paralleled by scientific research on the role of functional animal groups or their indicators in ecosystem development are needed to meet these demands. Some possible approaches will be discussed.

The report will close with a short evaluation of trilateral targets and the formulation of some new recommendations.

2. Updating vegetation distribution maps

In the QSR 2004, a trilateral vegetation typology for Wadden Sea dune areas was presented. This new so-called TMAP typology (product of the Trilateral Monitoring and Assessment Program) was developed as a classification wherein all typologies of available local mappings of dune areas can be translated. A description of this typology is published in Petersen and Lammerts (2005). On the basis of this instrument, for the first time an overview could be given of the vegetation of dune areas in the whole trilateral Wadden Sea area. Some of the main conclusions were:

- Grey dunes cover larger areas in the Dutch and Lower Saxony dunes than in the North German and Danish dunes, while it is the other way round for dune heathland.
- Embryonic dunes are only sparsely present on the Dutch islands in comparison with the other islands.
- Only in very few dune slacks species rich pioneer communities occur; in particular, lime-rich vegetation is scarcely present.

Since 2004, several new vegetation mappings have been performed on some of the Dutch and all German Wadden Sea islands. On Texel (Everts and Pranger, 2006) and Vlieland (Bakker, 2005) completely new maps were made of nearly the same areas and on the same level of detail as the maps used for the QSR 2004. Only for these islands, vegetation *changes* over the last decade can be analyzed in considerable detail. In 2004, the complete terrestrial part of the National Park in Lower Saxony was mapped in TMAP units (Nature-consult, 2006). This mapping was done by a combined method of remote sensing, GIS and a very exhaustive field verification (Petersen *et al.*, 2008). The results are very exact in location and vegetation assignment. The older mappings, being the basis of the QSR 2004, had been performed by air picture analyses with very little field verification. As a consequence, a detailed comparison between the old and new mappings cannot be done in a way that sound conclusions on real vegetation changes can be inferred. Also in Schleswig-Holstein, new mappings have been executed between 2005 and 2007. While the islands are mapped on the level of Natura 2000 habitat types (TRIOPS, 2006; Leguan, 2006), St. Peter-Ording (Eiderstedt) is mapped in a detailed level of the TMAP typology (Nature-consult, 2008). The quality of the current data set is much higher than the data of the QSR 2004. Also here, a detailed comparison of old and new maps is not feasible. Moreover the level of detail of the old data sets is low.

For Denmark, recent mappings of dune habitat types according to the EU Habitats Directive are available. The habitat monitoring started in 2004 with monitoring of intensive and extensive stations. Data include vegetation cover, phytochemistry and soil parameters. There is public access to all terrestrial monitoring data, including species and habitat types, which have been gathered since 2004 on http://www.naturdata.dk/.

Table 1 gives a complete update of the QSR 2004 in the sense that earlier mappings are replaced by more recent mappings, when available. On a general level the results do not lead to adjustments of the main conclusions presented in the QSR 2004. However, important differences and changes may be hidden in the overall interpretation. For example, in Lower Saxony the interpretation of new, far more reliable vegetation maps leads to a decrease in coverage of lime-rich fen vegetation (H2.2), housing many Red List species, from 0.9 % to 0.2%. This is significantly lower than in the Dutch islands where no large overall change took place (from 0.9 to 1.0 %). These kind of trends, to be thoroughly analyzed, can only be assessed when reliable chronosequences of mappings from more sites and of a high quality become available. This emphasizes the need of continuation of a common (trilateral) approach of vegetation monitoring.

More than the results concerning content, the most important result of recent mapping activities probably is the increasing quality and quantity of maps available for analyses. For The Netherlands, Lower Saxony and St. Peter-Ording (Eiderstedt), the assessment of real vegetation changes will be possible in the near future. The same is true for Denmark, though the methods deviate from the mapping procedures in The Netherlands and Germany.

Table 1: Distribution of dune types in the Wadden Sea (update of Table 9.2.2 from the QSR 2004). For a translation of most TMAP types see the legend of Figure 1 (for more details on the TMAP typology see Petersen and Lammerts, 2005.)

TMAP types	X.3	X.4	X.5	X.6	X.7	X.7.1	X.7.2	X.8	X.8.2	H.0	H.1	H.2	H.2.2	H.3	H.4	H.5	H.6	H.8	
Natura 2000 types	2110	2120	2130	2140		2160	2170	2180		2190	2190	2190	2190	2190	2190	2190	2180	2190	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	(ha)
NETHERLANDS	2.0	11.0	47.9	9.9	0.7	4.3	0.1	4.4	4.9	0.0	0.6	4.5	1.0	0.5	2.0	2.1	3.7	0.3	11312.4
Texel	0.6	12.9	44.4	9.0	0.6	5.4	0.1	5.7	3.7	0.0	0.4	3.6	2.6	0.4	1.6	2.2	6.1	0.3	3080.1
Vlieland	1.0	11.4	65.0	7.5	0.4	2.5	0.0	0.4	0.3	0.0	1.3	2.4	0.9	2.1	4.4	0.3	0.0	0.0	1046.9
Terschelling	3.0	10.7	40.1	18.4	0.0	0.6	0.3	3.8	11.2	0.0	0.5	5.4	0.6	0.6	1.1	2.0	1.4	0.1	3915.3
Ameland	1.6	6.5	60.0	2.2	2.5	2.1	0.0	8.3	0.0	0.0	1.1	6.7	0.0	0.2	4.2	3.0	0.8	0.8	1997.8
Schiermonnikoog	4.0	14.0	46.9	0.0	0.1	17.9	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.6	2.5	12.2	0.0	1272.3
Niedersachsen	6.2	15.6	41.6	3.7	5.8	5.9	4.7	3.7	0.9	0.0	0.2	3.0	0.2	0.1	2.4	1.5	4.1	0.4	4737.2
Borkum	2.1	11.1	36.8	0.5	6.1	6.5	9.4	5.6	0.6	0.0	0.1	4.4	0.9	0.1	3.7	3.1	9.1	0.1	1241.9
Juist	4.5	18.0	34.7	0.6	15.0	9.3	4.2	1.9	1.0	0.0	0.0	0.6	0.1	0.0	2.3	2.4	1.4	3.8	496.5
Memmert	6.7	24.4	52.1	0.0	0.3	7.1	1.1	0.2	0.0	0.0	0.0	6.0	0.0	0.0	1.8	0.1	0.0	0.2	42.5
Norderney	8.9	19.4	44.6	1.4	1.2	1.5	5.3	2.4	1.3	0.0	0.1	4.3	0.1	0.4	3.9	0.9	4.3	0.1	1078.2
Baltrum	6.4	14.2	52.3	0.1	4.0	10.5	3.3	1.8	0.5	0.0	0.4	3.1	0.1	0.0	0.2	0.9	2.2	0.0	272.4
Langeoog	8.5	16.4	37.0	11.1	5.0	11.6	1.3	3.0	0.0	0.0	0.8	2.5	0.0	0.1	1.3	0.1	1.3	0.0	682.8
Spiekeroog	8.6	16.6	43.3	11.0	4.7	3.3	1.6	6.2	01.8	0.0	0.0	1.0	0.0	0.0	0.2	0.1	1.3	0.1	521.4
Wangerooge	0.6	14.3	44.5	7.0	15.0	3.3	0.6	5.3	2.2	0.0	0.0	1.3	0.0	0.0	1.3	2.0	2.4	0.1	245.6
Mellum	24.8	19.5	54.0	0.0	0.7	0.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	59.0
Minsener Oog	1.1	10.3	83.8	0.0	3.2	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.8	0.0	0.1	96.9
Mainland coast	0.0	3.6	20.9	8.3	3.1	0.2	0.4	10.1	1.2	0.0	0.0	15.8	0.0	0.0	33.1	0.3	3.1	0.0	205.1
Hamburg	9.1	40.2	46.9	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0	1.1	0.0	0.0	2.1	0.1	0.0	0.0	45.1
Schleswig-Holstein	9.9	12.2	24.5	41.9	0.1	0.0	2.5	0.2	0.0	7.9	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	3652.7
St. Peter-Ording	35.0	21.3	7.4	3.3	4.7	0.0	5.9	0.0	0.0	0.0	0.1	0.1	0.0	0.0	22.2	0.0	0.0	0.0	103.7
Föhr	14.9	0.0	85.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7
Amrum	25.5	16.7	33.4	18.0	0.0	0.0	5.3	0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1044.9
Sylt	2.3	9.8	21.6	53.7	0.0	0.0	1.2	0.0	0.0	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2498.3
DENMARK	7.5	2.2	34.8	35.1	0.0	0.0	0.6	0.3	7.7	11.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3077.1
Römö	21.5	4.0	12.2	37.7	0.0	0.0	1.1	0.0	22.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1076.5
Mandö	0.0	0.0	92.6	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27
Fanö	0.0	0.1	43.6	34.2	0.0	0.0	0.3	0.5	0.0	21.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1650.4
Skallingen	**0.1**	**7.3**	**56.6**	**35.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**323.2**
WADDEN SEA AREA	5.8	11.0	40.9	17.0	1.6	3.3	1.5	3.1	3.6	2.8	0.3	3.0	0.5	0.3	1.6	1.4	2.7	0.2	23029.6

Comparing two chronosequential mappings on the island of Texel illustrates the importance of monitoring vegetation changes for nature management and policy. Changing natural processes or management influences can be assessed which makes it possible to adapt management strategies if necessary. On Texel, some of such changes in two succeeding mappings (Figure 1) are clear, especially when looking to the developments between 1997 and 2006 in the dune slack areas on the south side of the island:

1. the areas with reedbed vegetation have decreased between both mappings;
2. there appears to be a clear increase in lime rich fen vegetation in the dune slacks;
3. the area with open water and water vegetation increased considerably;
4. in the dry dunes some productive grass species reached dominance in larger areas.

The changes probably are caused by a gradual rise of the groundwater table due to stopping groundwater extractions for drinking water production. Also, in an ecological restoration project, the outflow of fresh surface water from the system has been restricted. Moreover, the coastline has expanded considerably during the last twenty years as a consequence of increasing sand sedimentation along the southern coastline. This leads to a considerable growth of the fresh water body below the dunes.

Another important factor may be the introduction of cattle grazing which has led to the development of more open vegetation in and along the dune slacks. In the drier parts, on the other hand, it seems that the cover of closed grassland vegetation has increased. This effect in dry dune areas is especially known from old dunes where the topsoils are decalcified. Under these circumstances grazing appears to stimulate the development of closed grasslands with Festuco-Galietum vegetation.

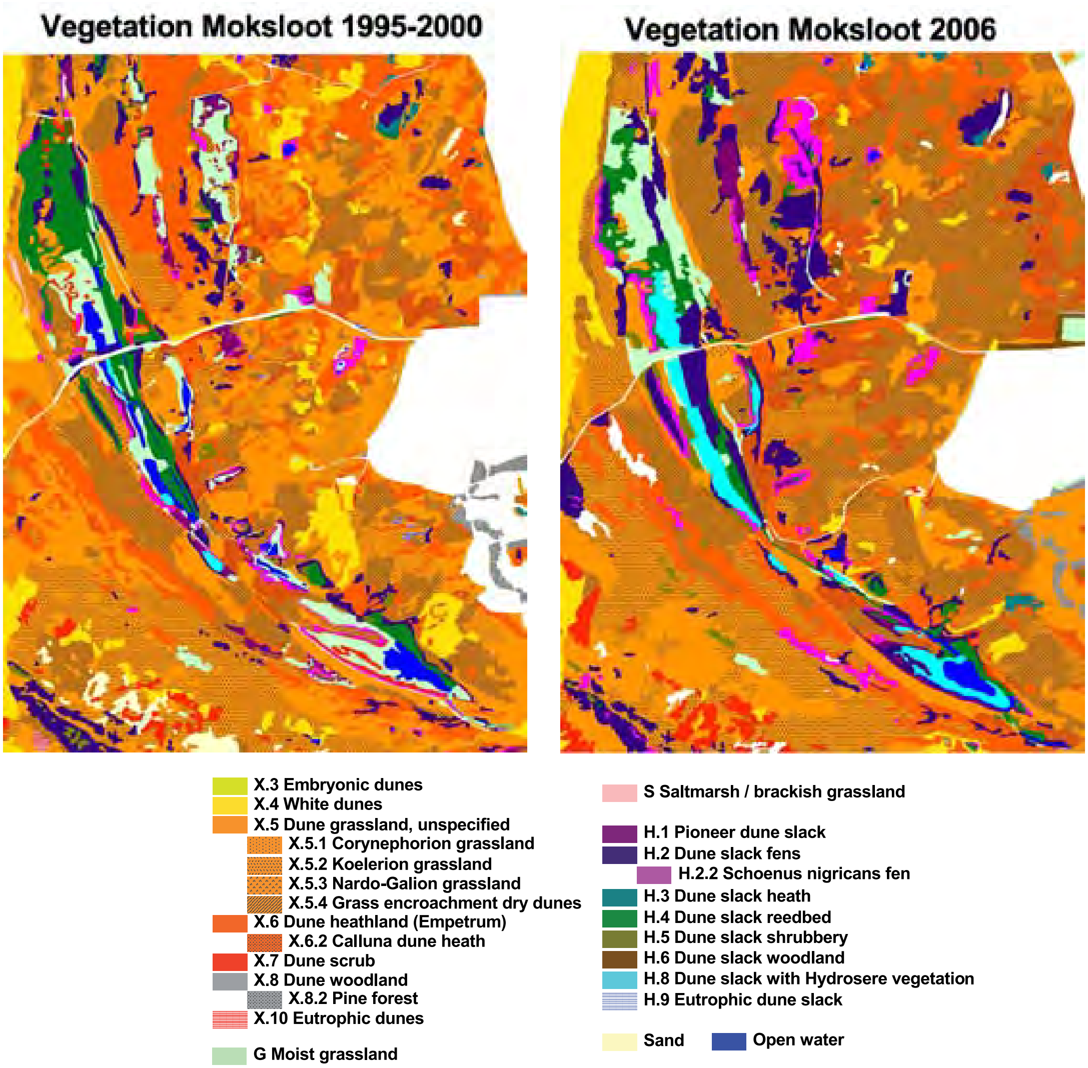


Figure 1: Vegetation maps of south Texel from 1995-2000 and from 2006; local vegetation types are translated to TMAP types.

3. New geo-ecological concepts

Since about a century ago, the nature areas on the Dutch Wadden Sea islands show gradual but large changes in dominating habitat types. In all vegetation series (halosere, hydrosere, hygrosere and xerosere), young successional stages have gradually been replaced by older stages. Grass and bush encroachment caused decreases in the area of open, low vegetation stands and in the number and area of patches of bare sand or mud. As a consequence, small scale biodiversity in dunes and salt marshes, not only of higher plants but also of mosses, lichens and insects, has declined. Nowadays some of the most characteristic species, including some of the birds typical of open dunes, have vanished completely from the islands.

Successional development on the site is a natural process as such. On the Wadden Sea islands, however, vegetation regression, periodical 'destruction' of vegetation-covered surfaces caused by dynamical processes such as water erosion or blowing sand, is an equally natural process. The equilibria between building and degrading forces on different spatial and temporal scales determine the patterns in vegetation and habitat types on the islands. The actual unbalance where old grass and bush encroached areas seem to replace younger successional stages almost completely mirrors last century's dominance of men's stabilization measures over natural processes. Therefore, from an ecological point of view, the rehabilitation of natural dynamics recently is often propagated.

The necessity to implement Natura 2000, as well as the expected climatological changes, stress the need to re-orientate coastal and nature management strategies for the Wadden Sea Islands. In this process, the apparent contradiction between natural dynamics and traced Natura 2000 habitats should be met and the effects of stimulating natural dynamics on coastal safety analyzed. A group of ecological consultants and scientific researchers in The Netherlands responded to the challenge. As a first step they identified the most important driving forces on different spatial and temporal scales. Next they identified five main components with their sub-elements on a 'model island', each controlled by a specific set of more or less dynamic geomorphologic and hydraulic/hydrological processes. The results can be found in a more general publication (Löffler *et al.*, 2008) and two reports with background information: an ecological study (De Leeuw *et al.*, 2008) and a geomorphological study (Ten Haaf and Buijs, 2008).

The model (Figure 2) has been developed for the west-east orientated islands along the Dutch and Lower Saxony coast. On this model island, five main components have been distinguished (Löffler *et al.*, 2008). They are characterized by the specific spatial and temporal scales of the processes determining the speed and frequency of natural successional and regressional changes between and in the sub-elements (numbers according Figure 1):

1. Island Head: The development of the island head depends on the sedimentation and erosion processes in the deltas between the islands. Periodically bare beach plains unite with the eastern island: at the north side when the sand comes from the outer delta and at the south side when it is coming from the inner delta. When there is enough sand available, embryonic dunes and dune ridges may develop, with brackish marshes and dune slacks in between. All these different sub-elements are almost permanently subject to dynamic processes and have a lifespan

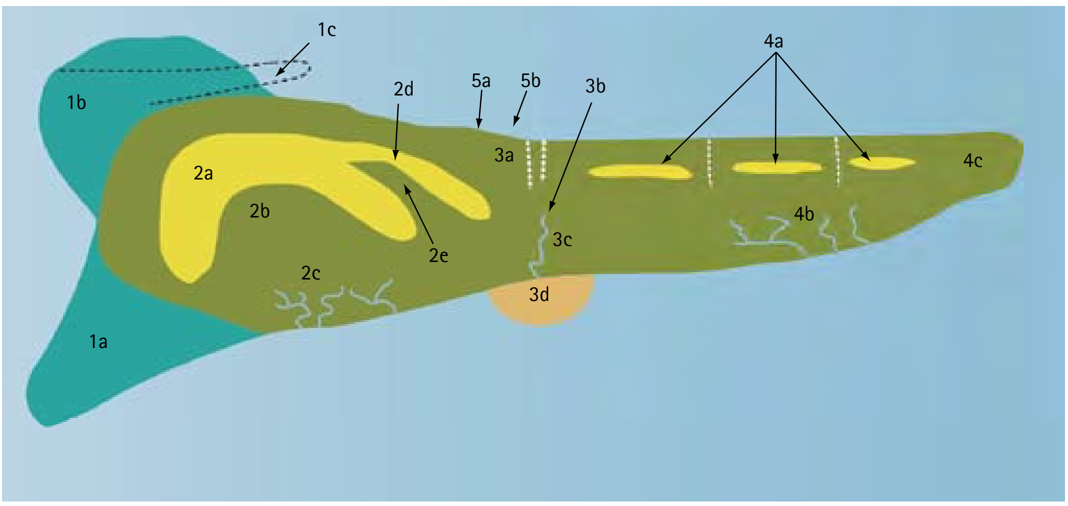


Figure 2: The geo-ecological model island with its characteristic main components and sub-elements (for details see text) (after Löffler *et al.*, 2008).

of 25-50 years. At the inner side, more stable elements can develop: even grey dunes (mostly of the lime-rich type) may temporarily be present. After a while, steep tidal inlets will approach the coast and break down the island head again (on western Ameland about every 60 years; *pers. comm.* Dr. A.P. Oost). The eroded sand then moves along the North Sea coast leading, to periodical sedimentation and erosion there.

2. Dune Bow Complex: The dune bow complex comprises an old central part of the model island, where much sand has been blowing in during long periods of sedimentation. The quantities have been so large that different dune ridges merged to large parabolic dune systems which often have been secondarily reformed to all kinds of dune forms. Until about 1900, stabilization by ongoing succession to scrub and woodland has been retarded by all kinds of intensive human use, such as sod-cutting, mowing, grazing, even periodical burning, *etc.*. Although it takes a long time before organic matter accumulates substantially due to the nutrient poor character of the substrate, dune bow complexes tend to stabilize in the long run. In a natural configuration, it houses a great variety of sub-elements, such as all kinds of grey dunes and heathlands, dune lakes, marshlands and dune slacks, even peat- or bog-forming patches at the inner- and outer dune fringes, *Hippophae*- and *Salix*- shrubs, dune woodland, especially in older decalcified slacks, *etc.*. Salt marshes develop a the Wadden Sea side of stable dune bow complexes and will be there as long as the dunes protect them. However, many of them have been embanked in the past. The sub-elements may have a short lifespan (*c.* 50 years) when subject to secondary dynamics; and up to a very long lifespan of many centuries when stable conditions prevail, *e.g.* in peat-forming systems.

3. Washover Complex: A washover consists of a north-south orientated part of the beach plain accompanied at both sides by natural dune ridges. Here, during high tides, overwash of sea water from the North Sea occurs. An interweaving of several such washovers along the eastern border of a dune bow complex appears to be characteristic for the west-east orientated islands. Most clearly on Spiekeroog, but also on Noderney and Borkum, such washover complexes can still be found in an active state. On the Dutch islands, no active washover complexes are present any more, all of them being closed by sand dikes. The remnants can, however, be quite easily recognized. At the west side, the washover complexes are bordered either by another dune bow complex (on Ameland there even are three dune bow complexes separated by two former washover complexes) or by a large beach plain. Very characteristic for washover complexes is that large sandy areas are covered with different types of algal mats which seem to hamper further succession, probably by forming a resistance to the settlement of higher plants as well as by their vulnerability to erosional processes. Besides these beach plains and the parallel dune ridges, all kinds of sub-elements can be considered to be characteristic for this main component: embryonic dunes, white dunes, dune grasslands, small patches with fen vegetation at the foot of small dune elements, sandy to muddy salt marshes and salt water creeks coming from the North Sea side as well as from the Wadden Sea side (though mostly not interconnected all over the island). Depending on the extent to which these sub-elements are subject to more or less dynamic conditions, their lifespan may be somewhere between 25 and 100 years. All of them undergo long periods with sedimentation (by inblowing sand and locally by inflowing sea water). Some of them are subjected more or less frequently to very short periods of severe erosion during storm tides. As a net result, the washover complex as a whole appears to be a very stable main component, which may be present at the same site even for centuries.

4. Island Tail: The island tail consists of a beach plain at the eastern side of the island. The stability of this main component depends on the dynamics on larger spatial scales than the component itself. In a period of long-lasting sedimentation along the North Sea coast it may develop into a closed dune bow complex. In a period of strong erosion, the whole island tail may disappear again in the long run. However, it seems that it can be present for a long time when it is only subject to periodical net sedimentation and net erosion. The dune sub-elements are comparable to those present on the island head: embryonic dunes, white dunes, partly closed dune ridges with primary dune slack fens, even locally lime-rich grey dunes, *etc.*. Here too, the sub-elements will have a lifespan of about 25-50 years. On the island tails, several individual washovers are also present. As in the large washover complexes, they probably give certain long term stability to the island tails as a whole. Very characteristic for the island tails is the presence of salt marshes. In general, they have a far more muddy character than the brackish marshes on the island heads. It seems that the gradient of pioneer to old salt marshes, intermingled with enclosed permanent wet areas

and natural pattern of creeks, is rather complete when the island tail shows a dynamic structure without artificially closed sand dikes at the North Sea side. In such "natural" circumstances, the area with characteristic salt marsh vegetation however is smaller than behind such dike structures.

5. Beach and Foreshore: From a geo-ecological point of view, the last main component, the beach and foreshore at the North Sea side, can be considered as a very important functional element as transport route for sedimentation and erosion products. Beside that function it can temporarily provide substrate for embryonic dunes and green beaches with very high biodiversity (see also text box on Schiermonnikoog).

The geo-ecological approach, presented here, appears to be very promising as a basis to identify deviations from natural courses in developing successional series. At the same time it also leads to hypotheses of how to restore geomorphologic and ecologic processes in such a way that they fit in again with the temporal and spatial scales of the "original" or "natural" course of succession. Schiermonnikoog shows a fine example of such considerations (see text box below).

Geo-ecological analysis of recent developments on Schiermonnikoog

The pattern of main components on Schiermonnikoog shows a large resemblance with the model island (Picture 1). Since the last 50 years, two very distinguished geo-ecological changes on the island occurred which had significant effects on the ecological functioning of some of the main components (Picture 2):

1. Closing off the Lauwerszee from the Wadden Sea in 1969 reduced the adjacent water catchments in the Wadden Sea. This had a considerable increasing effect on the amount of sedimentation of sand along the west coast of Schiermonnikoog and next led to a huge sedimentation almost all along the North Sea beach of the island. During the last 20 years, large areas on the beach became vegetated.

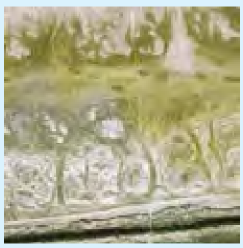
2. In 1959, a huge washover complex east of the dune bow complex was closed by the construction of a sand dike of about 4 km along the North Sea beach.

Where the green beach borders the dune bow complex, it shows a geomorphologic structure and vegetation composition which is completely different from where it borders the former washover complex. North of the dune bow complex, a large green beach with an evened surface developed (Picture 3), housing a homogeneous and very species rich fen vegetation, characteristic of fresh water fed, lime-rich dune slacks (Picture 5). Probably, there is a very high and stable groundwater level caused by the recent seaward expansion of the coastline which led to the growth of the freshwater body below the dune bow system. Of course, at high tides, the vegetation gets inundated with sea water. However, this salt water flows off very fast again because of the permanent saturation with fresh water of the top soil. North of the former washover complex, the geomorphologic structure as well as the vegetation composition, are far more heterogeneous (Picture 4). Because of the absence of a massive dune system in the hinterland, there is no influence of a fresh groundwater body on the beach


Picture 1


Picture 2


Picture 3


Picture 4


Picture 5


Picture 6

and the top soil will run dry in the absence of inundating sea water. Under such conditions the influence of wind blowing may be very dominant and complexes of embryonic dunes with scarce pioneer vegetation developed. If at high tides salt water is flowing over, it apparently grinds away natural creeks through the young dune systems at regular distances, a few large ones west-east and many smaller ones north-south (Picture 6).

It must be realized that as rapidly as the green beaches and the high biodiversity on them developed, they can disappear again in future decades. Their fate depends on the course of the large scale dynamic processes of the main component beach and foreshore. On the basis of old vegetation maps, a reconstruction has been made of the situation before the sand dike closed off the former washover complex. Many of the species rich gradients, now present on the green beach, then were present on the middle of the island in a wind- and/or water- deposition zone of the washover complex (Figure A). After the construction of the dike, the hinterland gradually stabilized. In c. 1995 the younger successional stages had disappeared almost completely (Figure B; also visible on Picture 6). It is very plausible that without the dike and under the actual circumstances, the dominant geo-ecological processes would now also have been very influential up until halfway the island. This would have guaranteed a more lasting presence of pioneer stages up until the centre of the island, also when sedimentation conditions on beach and foreshore turn into erosion conditions. It may be very worthwhile to explore the possibilities to execute restoration measures which bring the concerning main elements of the islands back in phase again with the characteristic spatial and temporal scales of the dominating natural processes (cf. Figure C).

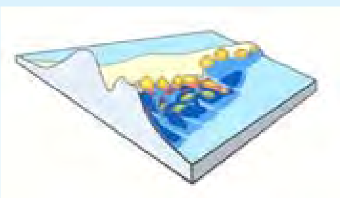


Figure A. Situation 1959

Figure B. Situation ca. 1995

Figure C. After ecological restoration ?

Legend Figures A-C
(Reconstructions A.P. Grootjans)

This geo-ecological approach may also be a sound basis to identify natural sites for (complexes of) Natura 2000 habitats. From the descriptions of the main components, it may be obvious that the right conditions for some habitat types are available in one main component and hardly or not at all in another. This is crucial for the localization of Natura 2000 sites. In general, it may be stated that, for pioneer habitats, the island head and tail are much more suitable than the other main components. On the other hand, the dune bow complex offers better perspectives for some types of grey dunes, dune heath lands, dune woodland, fresh dune marshes and locally some peat- and bog- forming habitats. The approach also may give indications of how and where to stimulate the development of habitats, which are absent now, by restoring the geomorphologic basic conditions. Figure 3 gives the natural position of island habitats projected on the model island. For each individual island this can be further implemented by taking the actual state of the main components into account.

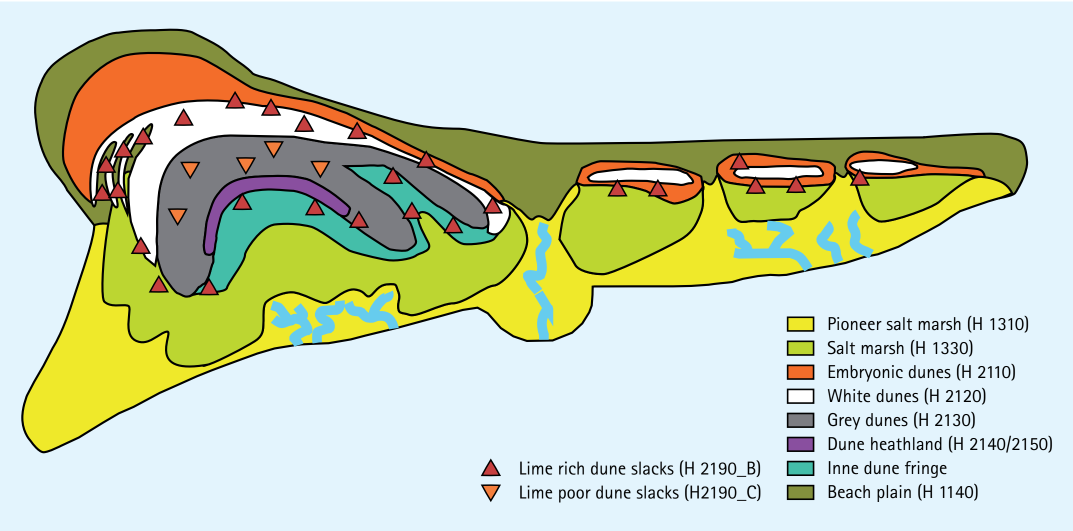


Figure 3: The natural position of Natura 2000 habitats projected on the geo-ecological model island.

4. Groundwater extraction on the islands

In the QSR 2004, the problems concerning groundwater extraction for drinking water production were extensively analyzed. It was concluded that since the 1980s a sound scientific basis has been established to identify and predict the ecological effects on natural dune slacks. It was observed that dune slack vegetation suffered severely when influenced by changes in groundwater regime such as lowering and increasingly fluctuating groundwater tables, as well as changing flow patterns and groundwater chemistry. It also became clear that there were huge differences in the actual practice of groundwater extractions between the islands and also between the countries. Political or managerial considerations of water companies and public authorities probably seemed to lead to very diverse decisions on extraction practices. On small islands with small fresh water bodies huge withdrawal were sometimes allowed, apparently without much regard on ecological effects, while on larger islands a much more cautious approach of smaller groundwater extractions was adopted. It was recommended that priority should be given to:

- organizing the exchange of information and knowledge between all regions;
- assessing the state of the art concerning the magnitudes of groundwater extractions on the Schleswig-Holstein and Danish islands;
- ecologically optimizing the extraction methods (and location choices) on all islands including ecological biomonitoring (Petersen *et al.*, 2003, Petersen and Lammerts, 2005).

In the last few years only little progress has been made concerning this subject. In general, there has not been a decrease in groundwater extractions, as can be seen in Figure 4 showing an updated graph since the QSR 2004. A remarkable aspect is the very large groundwater extraction (2.2 million m^3/year) on Sylt which was not yet included in the last overview. The results of biomonitoring during the last ten years on Norderney and Langeoog, however, have led to some decreasing ecological effect of water extraction. On Borkum, on the contrary, biomonitoring was not applied and the effects on dune slacks have not decreased at all. This is all the more regrettable because on Borkum, of all Lower Saxony islands, the best developed lime-rich fen vegetation in wet dune slacks is present (Petersen, 2000; Petersen and Pott, 2005).

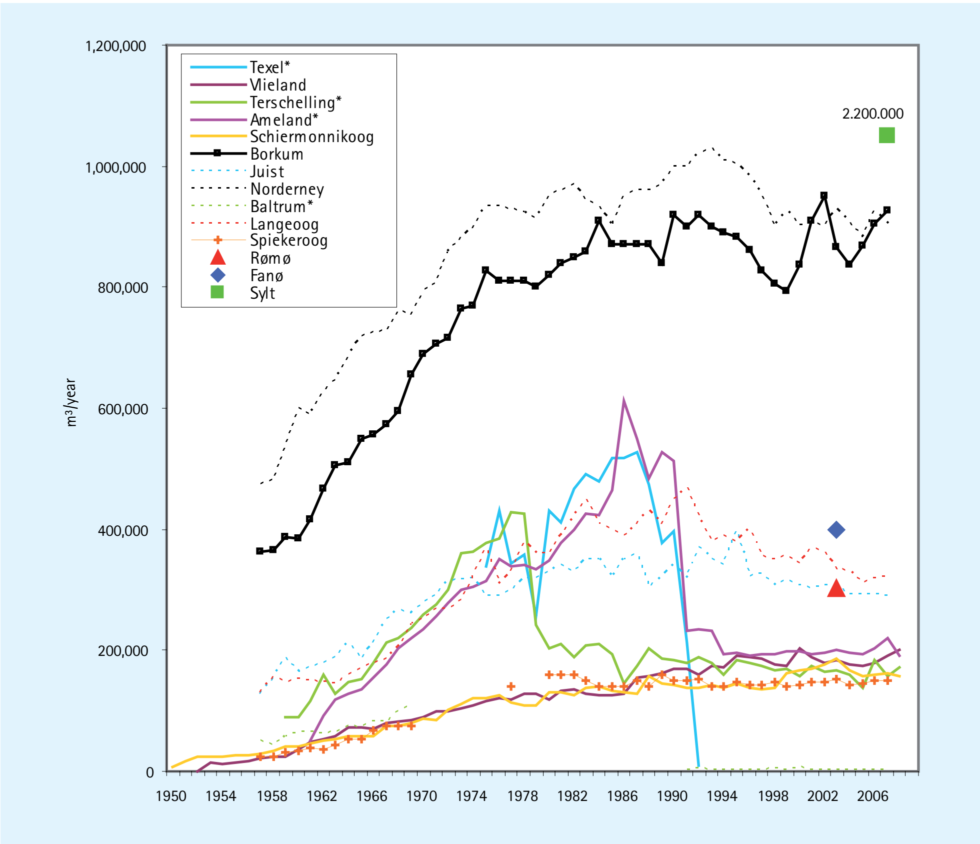


Figure 4: Groundwater extractions on the Wadden Sea islands (in m^3/year); asterisks indicate islands which are totally or partly provided with drinking water from the mainland.

5. The status of dune fauna

In contrast to our knowledge of dune vegetation, the knowledge of dune fauna is still scarce. Studies on the bird fauna predominated during the last decades and we have a thorough knowledge of population trends in birds (*e.g.* Koffijberg *et al.*, 2006). The high importance of the Wadden Sea for hibernation and foraging justified the high priority of birds in conservation and the bird monitoring definitely needs to be continued. Unfortunately, our knowledge of the rest of the fauna is very incomplete. The dune islands of the National Park Lower Saxon Wadden Sea are probably the best studied areas in the Wadden Sea concerning the invertebrate fauna. A comprehensive checklist of the fauna is available (Niedringhaus *et al.*, 2008), which probably covers about 75% of the existing fauna. Although this study represents probably the most complete faunal checklist for a part of a European National Park, some taxa are still understudied (*e.g. Diptera*). Arthropods are by far the most diverse group on the islands, but our knowledge on these species still remains fragmentary. The existing data have mainly been obtained during mapping projects in the 1980s and 1990s, performed by the University of Oldenburg (*e.g.* Haeseler, 1988). The information gathered from these mapping projects included species lists, but also data on habitat affiliation. This comprehensive knowledge on biodiversity on the dune islands is an excellent basis for future studies. On the other hand, the existing knowledge is purely descriptive. A better understanding of the interactions between anthropogenic habitat changes and faunal biodiversity trends is needed to assess observed changes. Data on habitat requirements or population trends of endangered arthropod species is almost completely missing. Continuous monitoring programs should, therefore, be implemented in order to obtain information on the population trends of endangered species. Below three monitoring approaches will be presented.

Approximately 8,000 animal species have been recorded from the East Frisian islands, and it has been estimated that around 10,000 animal species exist (Niedringhaus *et al.*, 2008). Obviously, it will be impossible to monitor all of these species. Hence, a priority list needs to be established, identifying a set of indicator species or high priority species that should be monitored periodically. This list should include *c.* 100 arthropod species that either have their main distribution in the dunes or are highly endangered. This information can be obtained from the checklist provided by Niedringhaus *et al.* (2008) or from the data collected by EIS Nederland. The monitoring frequency should be *c.* 3-5 years, but care must be taken to develop a specific program for each species as some arthropods might have a two year life cycle (*e.g. Decticus verrucivorus*). A major goal of monitoring programs is to gain information on population trends of endangered species. This can help to identify threats or sudden population breakdowns.

A second important approach to obtain data on population trends is to repeat old mapping projects at exactly the same locations and with similar methods. This may provide data on population trends, extinction and colonization processes. A major problem is that no data for the time between two data sets exist, so that the natural population fluctuations cannot be reconstructed. However, based on presence-absence data, the identification of declining species is possible, which can help to update the monitoring species list. The fundamental difference between the monitoring approach and the re-mapping approach is that the first method aims at minimizing the temporal and financial investment and optimizing the information needed for long term management strategies, while the second method will gain data on a higher number of species at much higher costs. An optimal strategy will combine both methods. A re-mapping project might be started at intervals of twenty years, while monitoring should be repeated every 3-5 years.

A third approach, possibly providing the most important information needed for developing a sustainable management, is research on invertebrate responses to dune management. During the last decades, a number of new management techniques has been executed, but the evaluation of these methods has solely relied on vegetation data. As most invertebrates respond to a combination of changes in the vegetation composition, vegetation structure, abiotic factors and biotic interactions with other animal species, the response of the vegetation cannot be simply transferred to the fauna. A research project needs to be started that (1) compares the faunal diversity and particularly the presence of highly specialized or highly endangered species in dune slacks with different management; and (2) studies the faunal succession after new management practices have been implemented. Again, it will not be possible to study all animal groups during such a project, but some highly diverse groups (*e.g. Hymenoptera, Coleoptera, Araneae*) should be included.

In addition to the above monitoring approaches, it may be essential for the conservation of a species to obtain knowledge on its habitat requirements. Key factors for the survival of highly endangered or specialized dune arthropods have to be unraveled in order to optimize management strategies. This knowledge is particularly important for species which occur mainly or only in the dunes of the Wadden Sea, such as the bug *Monosynamma maritima* (Niedringhaus *et al.*, 2008). Autecological data for endangered dune insects are still sparse. A recent example is the study on the habitat preferences of Cepero's ground-hopper *Tetrix ceperoi*, which has its largest Central European populations on the Wadden Sea islands (Gröning *et al.*, 2007). Autecological studies can be included in the monitoring program: The main program should focus on population trends, but at greater time intervals, autecological studies for single priority species can be included.

Last but not least, it is worth mentioning that nowadays some research is executed on the effects of habitat changes in dunes on food webs. Though up until now primarily motivated by the desire to understand the decline of characteristic dune birds, a further development of this approach may be the start of a better understanding of the fate of many more fauna groups on different levels in complex foodwebs. It will probably also provide information on the role of biotic ecosystem processes such as competition and facilitation. These may be important key factors which can be influenced by nature management strategies. Further information on this subject is included in the textbox below.

The importance of food web analyses for understanding effects of habitat change on dune animals

In coastal dunes of the Netherlands – as well as in other parts of Western Europe - increased atmospheric deposition (acidification and eutrophication), lowered groundwater levels, decrease of rabbit populations and changes in land use cause encroachment by tall grasses and bushes. Open and species rich succession stages decreased as well as variety in vegetation structure. The resulting lack of heterogeneity in the dune landscape has negative consequences for the fauna. Since monitoring data from the past are lacking for most animal species it is hardly known which species have seriously declined. However, extinction or strong decline of predators such as red-backed shrike, Northern wheatear, hen harrier and short-eared owl indicates that major shifts in the food web of the Dutch dune system have taken place during the last decades.

It was found that breeding success of red-backed shrike depends on a high availability of large insects and small vertebrates. This makes the red-backed shrike a good indicator of arthropod abundance. To detect which animal species have decreased or vanished from the Dutch dunes, breeding and food ecology of the last red-backed shrikes in the Dutch dunes (1997-1998) was compared with the ecology of a vital population in comparable intact coastal dunes near Skagen, Denmark. This Danish population has a density which is comparable with the situation in Dutch dunes at the beginning of the twentieth century (± 40 breeding pair on 1100 ha) and breeding success is high and stable throughout years. It turned out that prey items in the nestling diet in Denmark were on average twice as heavy as prey items in the Netherlands. Due to the lack of sufficient large prey species in the Netherlands the adults had to put more effort in feeding their nestlings, which resulted in a low breeding success. According to the diet it is concluded that the food web in coastal dunes near Skagen is still fairly intact. Main prey species in Denmark were the scarabid beetle *Anomala dubia*, Wartbiter (*Decticus verrucivorus*), sand lizard (*Lacerta agilis*) and bumblebees (*Bombus* sp.). All these species (groups) declined or disappeared from Dutch coastal dunes prior to the extinction of the red-backed shrikes. In Denmark the massive hatching of grass-root feeding *Anomala dubia* and the breeding season of the red-backed shrike seem to be synchronised. A bottleneck analyses for this beetle species revealed that sand-spray appears to influence the densities of larvae of *Anomala dubia* indirectly. Few or no larvae were found in stabile parts of the dunes, whereas high densities were found in case of sand-spray. The density of larvae is highest in sites where Marram grass *Ammophila arenaria* is vital and makes new shoots. Here, the vitality of root growth probably determines food availability for the larvae. Microclimate (temperature and moisture) in the soil seems to be a relevant factor in speed of larval development. At sites with sand-spray larval development seems to be completed in one year, whereas it takes two years in less dynamic sites.

Also for the last populations of Northern wheatear in Dutch coastal dunes, scarabid beetles as well as other root-feeders such as click beetles (Elateridae) and caterpillars of moth species seem to be very important prey items which contribute up to 70% of the total diet. In many cases these prey items are still present, but the high grass makes them unattainable for the foraging bird species.

The study on the food ecology of red-backed shrike and Northern wheatear proved to be an excellent tool to identify changes in the food web and faunal diversity caused by degradation of coastal dunes. Next to root eating invertebrates (scarabid beetles and click beetles, caterpillars of moths) also thermophilous carnivores (Sandlizard and Wartbiter) and above-ground herbivores and flower visiting insects - mainly (caterpillars of) moths and bumblebees – were showed to be important animal groups which have declined in Dutch coastal dune ecosystems.

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Further information can be found in Kuper et al. (2000), Nijssen et al. (2001) and van Duinen et al. (2005).

5. Target evaluation

An extensive evaluation of the realization of trilateral targets was carried out in the QSR 2004. Below some recent developments concerning the evaluated targets from the Trilateral Wadden Sea Plan (1997) will be discussed briefly:

Increased natural dynamics of beaches, primary dunes, beach plains and primary dune valleys in connection with the offshore zone.

The tendency of some less strict coastal protection leading to a little more wind erosion in the outer sand dikes has continued. However, a management strategy relying on natural geomorphological processes is still far from achieved. In this context, the implementation of the new geo-ecological approaches presented above might lead to a breakthrough in coastal and dune management.

An increased presence of a complete natural vegetation succession.

In the QSR 2004, it was concluded that atmospheric deposition of nitrogen declined and that in the future only local problems would remain. The main problem was thought to be how to get rid of the high standing crop and the large litter layers which had been built up during the periods of highest deposition. Nowadays, there is some doubt about the accuracy of the deposition figures. In the wet dunes, the application of management tools such as sod-cutting and mowing have locally led to regeneration of pioneer stages on mineral soils. The surplus of organic matter in the dry old dunes, however, is still present and increasing. Another problem already addressed in the QSR 2004 involves human influence on the natural hydrological systems, especially groundwater extractions. It is evident that there are still large differences between the countries and between single islands.

Favorable conditions for migrating and breeding birds.

The consequences of habitat changes for migrating and breeding birds were indicated in the QSR 2004. Recent research on the effects of habitat changes on food webs (see above in the textbox on food web analyses) produces promising results concerning the detection of key factors on an ecosystem level, determining the decline of characteristic breeding birds of open dunes such as the red-backed shrike and the Northern wheatear. This approach leads to practical recommendations to nature managers.

6. Recommendations

Management of beaches and dunes are organized in very different ways within and between the three countries. However, to handle the important actual ecological problems in the Wadden Sea dune areas, a trilateral approach will be very fruitful, if not necessary with respect to climate change. For this purpose, an intensification of interchange of knowledge and experience is needed, both on the level of long term management strategies and on the level of practical management measures. A trilateral platform on nature policy and management on the Wadden Sea islands, consisting of scientists of different disciplines (ecology, geomorphology, hydrology, geochemistry) and representatives of nature management authorities will be needed. In the long term, however, this will only be effective when common projects are initiated concerning research, communication and the execution of experiments in the field. Trilateral fund raising from international funds, especially on EC level, may be highly successful in realizing such projects.

Specific recommendations on the basis of this report are:

1. The periodical vegetation mapping on the Wadden Sea islands (once per decade) must be continued. For some of the islands, the quality of vegetation mapping must further be improved to be able to assess vegetation changes and their causes on a comparable level of reliability.
2. The new geo-ecological approach must be further refined by studying for each main component the key processes determining the patterns at the scale of sub-elements. Moreover the approach should be extended to cover also the north-south orientated Wadden Sea islands in Schleswig-Holstein and Denmark. Experiences with the application of the new concepts for nature planning on behalf of the implementation of Natura 2000 should be shared trilaterally.
3. As already recommended in the QSR 2004, it is necessary to organize a trilateral exchange of knowledge on the ecological effects of groundwater extractions, especially on ways to ecologically optimize drinking water production (*e.g.* by extracting from other locations or deeper aquifers, by applying new desalination techniques on sea water or brackish or salt groundwater).
4. In nature management on the Wadden Sea islands more attention should be paid to the role of fauna elements other than birds. General monitoring and mapping projects should give more information on the occurrence of insect species. Specific monitoring may shed light on the direct effects of management techniques on fauna communities. Auto-ecological studies of indicative species and studies on the structure and functioning of food webs will give more insight in the key factors to focus on in nature management. It will be necessary to discuss among faunal specialists and nature managers what the most effective mix of these approaches is and where priorities should be laid.
5. The recommendation for beaches as given in the QSR 2004 (reformulation of the targets of the Wadden Sea Plan, adaptation of the parameters of the TMAP, inclusion of results of research programs and establishment of an expert groups) are still valid and should be reconsidered.

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Estuaries

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1. Introduction

Varde Å estuary
(Photo: John Frikke)

1.1 Characterization of the Wadden Sea estuaries

Estuaries can be defined as tidally influenced transition zones between marine and riverine environments. However, several definitions in the scientific literature as well as in conventions and directives exist (see box below), especially in defining the down- and the upstream border. The definition within the framework of the Habitats Directive (HD) corresponds approximately to the WFD definition (estuaries are called "transitional waters" in the WFD). Especially the trilateral definition is excluding some areas at the downstream border compared to the WFD and HD definition.

> **Some definitions of an estuary:**
>
> Pritchard (1967): "….. and within which sea water is measurably diluted with freshwater derived from land drainage"
>
> Fairbridge (1980): "… is defined as an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, …."
>
> Stade Declaration (1997): "….the estuaries in the trilateral cooperation are delimited on the landward side by the mean brackish water limit, and on the seaward side by the average 10 PSU isohaline at high water in the winter situation".
>
> Water Framework Directive (WFD) (using the term "transitional waters" instead of estuaries): " bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows".
>
> Habitat Directive (HD): "….the downstream part of a river valley, subject to the tide and extending from the limit of brackish water…..".

Most definitions exclude the freshwater tidal reaches, although they form an integral part of the estuarine ecosystem (Fairbridge, 1980; Schuchardt *et al.*, 1993a).

However, in the present review the tidally influenced freshwater reaches are included. Laterally all areas up to the main dike or, where absent, the spring high tide water line are included.

According to the above definition, there are five estuaries in the Wadden Sea region: the Varde A estuary in Denmark and the Eider, Elbe, Weser and Ems estuaries in Germany. The Eider estuary has not been included in the Leeuwarden definition (Leeuwarden Declaration, 1994) due to the storm surge barrier. In terms of structure and function, however, it should be included.

On the one hand, these estuaries are of high relevance for the Wadden Sea ecosystem (input of nutrients and toxic substances, sediment dynamics, nursery and feeding area). On the other hand, the estuaries themselves are a specific habitat, characterized by strong variability and dynamics of key factors, such as salinity, tidal range, turbidity and others. From an ecological point of view they are important, *e.g.* for migration of a number of species, but additionally they are inhabited by various brackish-water and at least estuary-endemic species and are thus of special importance for nature protection reasons. However, in contrast to the Wadden Sea the estuaries are strongly altered by human activities (Reise, 2005).

The estuaries under consideration are mesotidal coastal plain estuaries opening into the Wadden Sea. Morphologically, the river mouth can be divided into two sections: a river-like inner part (including the tidal freshwater, the oligohaline and parts of the mesohaline reaches) between a tidal weir and the outer part. This outer part is characterized by a funnel-like morphology with very extended tidal flats, being part of the Wadden Sea. The Ems estuary differs from this general structure due to the Dollard, a brackish bay, and the Eider Estuary due to the construction of a storm surge barrier and the Varde A, where mixing of river and sea water takes place normally in the Ho Bugt seaward of the narrow river. According to the above definition, this paper deals mainly with the inner parts of the estuaries.

The estuaries vary considerably in size, length and river discharge (see Schuchardt *et al.*, 1999). Except the Varde A, in all estuaries the adjacent lowlands are protected by dikes against flooding, either from the sea or from the river, and they are of great economic importance for shipping, agriculture and industrial purposes and have been altered by human activities.

1.2 Trilateral Policy and Management

Estuaries are an integral part of the Wadden Sea and play an important role in its ecology as has been illustrated in the different Wadden Sea Quality Status reports (Schuchardt *et al.*, 1999; Essink *et al.*, 2005). Thus the estuaries of Varde A, Elbe, Weser, Ems and Eider have been included in the Trilateral Cooperation Area. However, the Eider estuary with its storm surge barrier has not been included in the chapter Estuaries (Trilateral Wadden Sea Plan, 1997). The following trilateral target regarding estuaries has been formulated:

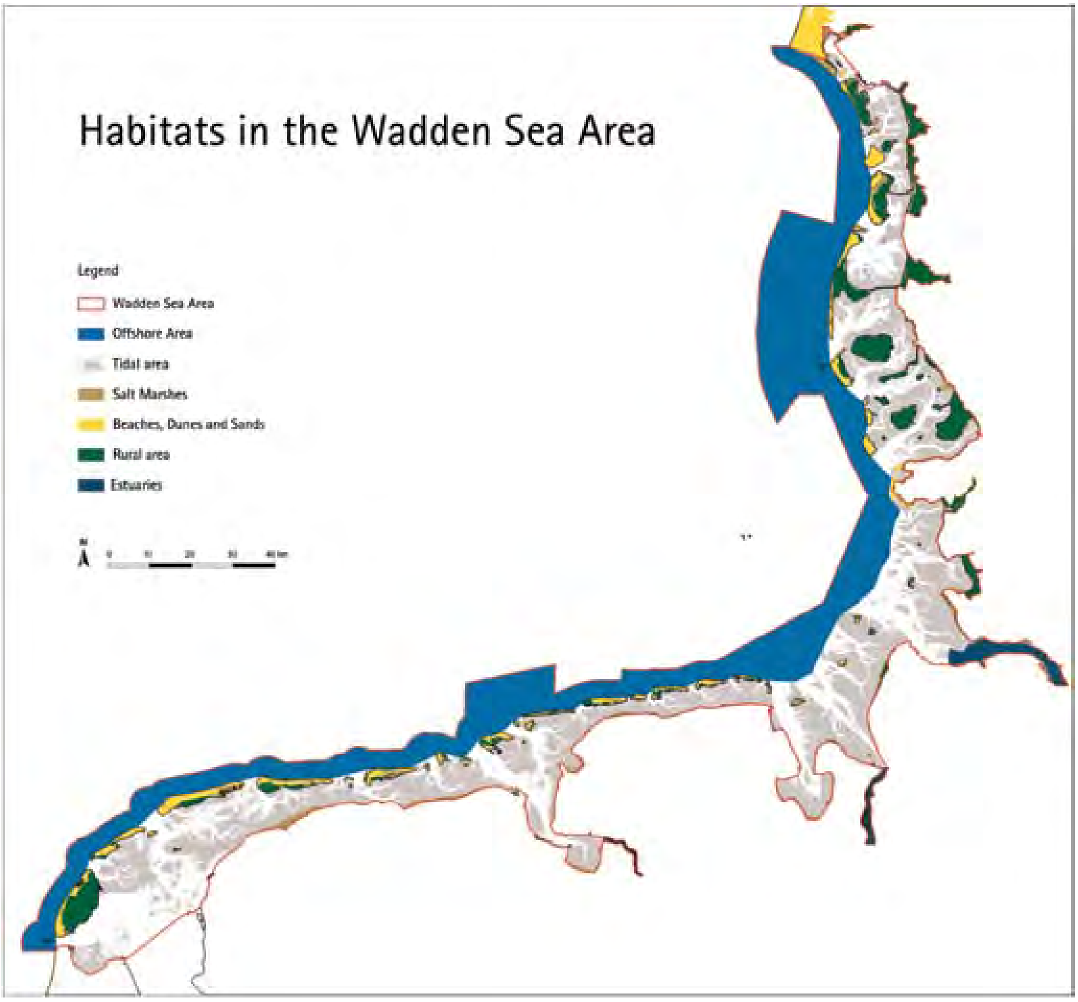

Figure 1: Wadden Sea Estuaries according to the Stade Declaration (1997) : Varde A, Elbe, Weser and Ems.

Valuable parts of estuaries will be protected and the river banks will remain and, as far as possible, be restored in their natural state.

Concerning Trilateral Policy and monitoring, the Trilateral Wadden Sea Plan (TWSP 1997) stated that the relevant parts of the policies formulated for important elements of the Wadden Sea (*i.e.* water, salt and brackish marshes and the rural area) also apply to valuable parts of the estuaries. Additionally it has been formulated that:

- The extension, or major modification, of existing harbour and industrial facilities and new construction shall be carried out in such a way that the environmental impact is kept to a minimum and permanent, or long lasting, effects are avoided and, if this is not possible, compensated. In the Conservation Area, new, not yet approved plans for new construction, as well as for the extension or major modification of existing harbour and industrial facilities, are not allowed unless such is necessary for imperative reasons of overriding public interest and if no alternative can be found.
- The deepening of shipping lanes in the estuaries will be carried out in conjunction with an overall assessment of how to compensate and mitigate the measures.
- The impact of dumping dredged materials will be minimized. Criteria are, amongst others, appropriate dumping sites and/or dumping periods.
- Valuable parts of the estuaries will be protected and river banks will remain and be restored in their natural state, as far as possible.
- The transition zone between fresh and salt water should be as natural as possible.

The Policy Assessment Report (PAR) 2005, prepared for the Tenth Trilateral Governmental Conference (Schiermonnikoog Declaration, 2005), stated that the estuaries of Ems, Weser and Elbe fail to meet the target and that further effort will be necessary to implement the target. The PAR placed emphasis on reduction of natural transitions between fresh and salt water and recommended, amongst other things, a restoration of such gradients. The development of management plans for transitional waters, as required by the WFD, is seen as an opportunity in this respect by the PAR.

Estuaries are not explicitly mentioned in the Common Package of the Trilateral Monitoring and Assessment Program (TMAG, 1997). However, data on estuarine macrozoobenthos resulting from a regular monitoring programme of the Federal Institute of Hydrology (Essink *et al.*, 2005) can be regarded as part of the TMAG.

Currently, monitoring programmes within the scope of the Water Framework Directive (WFD) and the Habitat Directive are under development and include different quality components.

1.3 Findings of the QSR 2004

Based on the findings of the WFD Reports in 2005, which classify all transitional waters as "heavily modified water bodies", the QSR 2004 (Essink *et al.*, 2005) has concluded that most estuaries of the Wadden Sea still do not meet the target, mainly as a result of changes in hydrology, geomorphology and poor water quality.

Although a reduction of the inputs of nutrients and hazardous substances over the last decades has been noted, negative effects on the estuarine ecosystems have been assumed.

2. Ecological status and assessment

2.1 Method and data sources

Schuchardt *et al.* (1993) have evaluated long-term changes in the ecological situation of the inner estuaries of Eider, Elbe, Weser and Ems comparatively and based on a historical reference situation. The simple assessment approach makes use of a few selected indicators for the system. These describe central aspects of the biotope structure and ecosystem functions as well as directly indicate the anthropogenic influence. For pragmatic reasons, however, the data availability also had to be a key criterion. In a current paper, the only-slightly-altered assessment approach was applied again (Schuchardt *et al.*, 2007) so that even the changes in the past 20 years have been documented. These results are presented here in abridged form.

The parameters of tidal range, size of the dike foreland areas, oxygen concentration in the water and heavy metal contamination of the sediments were evaluated comparatively and based on a historical reference situation.

This heterogeneous parameter structure is a reflection of the demand to include both the water quality and the water body structure in the analysis. Biological components were not taken into account since the available database was too narrow. At present work is being carried out on monitoring programmes within the framework of implementation of the WFD, and consequently it will be possible to give consideration to biological components in future.

As far as possible, the comparison is based on quantitative data on the individual indicators, though in some cases only qualitative statements are possible. In this process the status quo situation of each single estuary is compared to a defined historical reference state and, furthermore, the status quo situations of the four estuaries are compared to each other.

2.2 Hydrological and morphological changes

Morphological alterations of rivers and estuaries have strongly affected virtually all estuaries under consideration except the Varde A: the main reasons were coastal protection and land reclamation on the one hand, and adaptation to increasing ship numbers and sizes on the other.

2.2.1 Indicator: Tidal range

The change in the tidal range represents an indicator for changes in water body morphology, particularly due to expansion measures and coastal protection. It is also relevant for changes in the size and characteristics of habitats like tidal flats. There are strong changes, especially in the innermost parts of the estuaries (Figure 2).

Lower Eider

The tidal range in the Eider has risen from approx. 2.6 m at the Tönning gauge towards the end of the last century to 2.8 m today (not given in Figure 2). At Friedrichstadt the mean tidal range at present

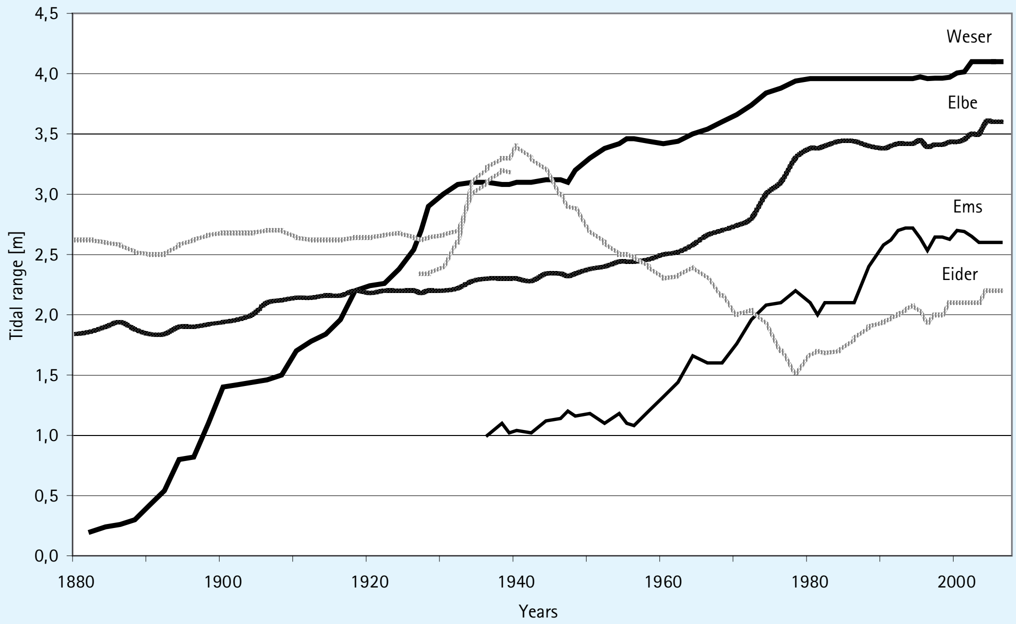

Figure 2: Changes in tidal range between 1880 and 2005 in the Eider (gauges Tönning and Friedrichstadt), Elbe (gauge Hamburg St. Pauli), Weser (gauge Bremen Oslebshausen) and Ems (gauge Herbrum) (5-year running mean) (from Schuchardt *et al.*, 2007).

is 2.3 m. In the meantime, however, changes to 3.4 m and 1.6 m have taken place: after the construction of the Nordfeld tidal weir (1936) a significant increase in the tidal range occurred for over 10 years since the mean low tidal water dropped considerably (Wieland, 1992). From 1944-1970, however, the tidal range fell from approx. 3.4 to 1.6 m as a consequence of the increased sand input from downstream. The current tidal range at the Friedrichstadt and Tönning gauges is the result of targeted flood reduction by means of the Vollerwiek storm surge barrier (Wieland, 1992) and therefore the relatively small change in the tidal range by a few decimetres, based on the situation around the turn of the century, is not an indicator for a slightly altered hydraulic (and ecological) situation.

Lower Elbe

In the Elbe, the tidal range at the Hamburg-St. Pauli gauge has risen from 1.9 to 3.6 m, *i.e.* by a factor of 1.9. The development over time shows a gradual but relatively continuous increase from around 1900 to about 1960 and then a significantly steeper rise until around 1980, *i.e.* during the deepening measures to -11, -12 and -13.5 m chart datum. The deepening to -14.5 m chart datum in 1999 led to a further, relatively small rise that was predominantly weaker than that forecast in the approval procedure (Strotmann, 2004). Among others, Hochfeld (2007) provides an up-to-date overview of the various expansion measures.

Lower Weser

The tidal range in the Lower Weser has risen from 0.2 to 4.1 m in Bremen in the past 130 years, *i.e.* by a factor of 20!. The increase in the tidal range was the steepest during the first three expansion measures between 1890 and 1930, which resulted in very substantial changes in the morphology of the Lower Weser (Busch *et al.,* 1984). After approximately 1930 the rise in the tidal range continued due to further expansion measures, but took place less rapidly. Compared to the first deepening measures, the last (and still the most recent) deepening of the Lower Weser from 1973-77 also led to a less steep rise. However, it was significantly more pronounced than was forecast within the framework of the planning approval procedure (Wetzel, 1987). Due to the deepening of the Outer Weser in 1999 to -14.0 m chart datum and further measures like the backfilling of harbour basins, the tidal range has increased further to a relatively minor extent. The rise predominantly corresponded to the figure forecast in the approval procedure (Lange, 2004).

Lower Ems

In the Ems, the tidal range in Papenburg has risen from approx. 1.4 m around the turn of the century to 3.1 m in the 1980s to 3.5 m today, *i.e.* by a factor of 2.5 (at the Herbrum tidal weir the rise is somewhat lower). The development over time differed from the Weser. As a consequence of smaller-scale measures (river cut-offs), the tidal range increased at Papenburg to approximately 1.7 m until around 1935. A considerable rise did not begin until 1955, after extensive maintenance dredging had commenced. This steep increase in the tidal range continued until 1975 and then stagnated in connection with reduced maintenance dredging (Arntz *et al.*, 1992). A second phase with a steep rise then became perceptible from 1985 to approximately 1995 and encompassed the deepening to 5.7 m and the adaptation to growing new vessel sizes in Papenburg. The tidal range is altered temporarily today due to the damming-up of the Lower Ems through corresponding control of the Gandersum storm surge barrier and weir when the water level is raised for the transfer of newly built vessels (de Jonge, 2007).

2.2.2 Indicator: Dike foreland areas

Foreland areas between the mean spring tide high water line and the winter dikes, frequently flooded, are of special ecological importance. This is not only reflected in the occurrence of specific types of biotope, but also in the large-scale designation as Habitats Directive protection areas or EU bird sanctuaries that has taken place in the meantime. The current use and characteristics of the foreland vary. The change in the foreland areas represents an indicator for a loss in habitat due in particular to coastal protection, agriculture, industrial and settlement development and expansion measures. It is also relevant for changes in the storm tide and suspended matter dynamics as well as the capacity for nutrient retention.

Lower Eider

Dike construction in the Eider lowlands began around 1500 and the dike line was not closed until the end of the 19th Century. Since then, the dike lines have changed very little. In sections, a growth in foreland areas as a result of pronounced sand input can be observed. A comparison of topographic maps from 1889 and 1977 shows that the foreland areas between Tönning and Nordfeld (tidal weir) have not changed significantly. The situation is different in the section downstream from Tönning. A great increase in foreland areas took place here at the expense of tidal flats, due to construction of the Eider barrage.

Lower Elbe

Between 1896 and1905 and 1981 and 1982, the area of the foreland marshes decreased by approximately 52% on the northern bank of the Lower Elbe between Altona and Brunsbüttel and by approximately 75% (an average of about 66%) on the southern bank between Elbbrücken and Cuxhaven (Arge Elbe, 2004). The main reason for this was the extensive construction of dikes closer to the water after the severe storm tide in 1962. Storm surge barriers were also constructed on all tributaries in this context, in connection with relocation of the dike line closer to the water in most cases. This construction of dikes closer to the water after 1962 not only resulted in elimination of the tidal influence in large sections of the foreland areas with their ditch and tidal inlet systems, but also in various branches (the best known example is Haseldorfer Binnenelbe). At present, large-scale dike realignment is the subject of discussion within the framework of the "Tidal Elbe Concept" (Hochfeld, 2007).

Lower Weser

Between 1887 and 1975, the area between the winter dikes decreased from 133 to 78 km^2, while the loss in foreland area amounted to about 50% (Schuchardt *et al.*, 1993). The reason for the losses was shortening of the dike line, separation and backfilling of side arms, industrial locations and, in the 1970s, shifting of dike lines in connection with the construction of barrages on tributaries. The rise in the mean high tidal water, by contrast, did not contribute to a further decline in reed areas, as was determined for the period from 1950 to 2002 (Steege *et al.*, 2005). Currently, foreland areas are used for extension of the Brake port. At Luneplate near Bremerhaven, on the other hand, a polder that can be controlled for the tide is to be opened behind the winter dike as part of compensation measures. Opening of summer dikes and development of tidal polders have taken place at several places, others are in the preparation phase.

Lower Ems

A distinction regarding the loss of foreland areas can be made between two sections in the Lower Ems. While the foreland area has hardly been altered in the section downstream from Papenburg, considerable losses have occurred upstream from Papenburg due to dike construction in 1966. The foreland area (in front of the winter dike, *i.e.* including summer polders) has been reduced by about 70%. Based on the total foreland area, this means a decline of approximately 33% (Schuchardt *et al.*, 1993). Recently use has been made of smaller areas due to the construction of the Ems barrage, among other things. A current assessment within the framework of the Interreg project HARBASINS by Herrling and Niemeyer (2007) showed an approximately 20% loss of supratidal habitats for the section between Papenburg and Pogum in the period from 1898 to 2005.

2.3 Water quality

2.3.1 Indicator: Oxygen concentration

The oxygen concentration in the water in summer represents an indicator for pollution with oxygen-consuming substances and eutrophication, primarily by virtue of direct and diffuse discharges, relocation of dredged material and especially changes in the water morphology. It is a key ecological factor that is decisive for the structure of the biocoenosis. Oxygen deficit situations going significantly beyond those expected in natural form have been documented for the inner estuaries (Flügge *et al.*, 1989).

Lower Eider

Oxygen saturation in the Lower Eider of 55-90% in the summer has been documented for the 1960s (Kühl and Mann, 1971). After expansion of the treatment plant in the town of Tönning, saturation below 70% has hardly occurred from the 1980s to the present (however, this is deduced from limited data, since only individual measurements are available; data: LANU Kiel).

Lower Elbe

The oxygen concentrations in the Lower Elbe have been very well documented since the 1950s (www.arge-elbe.de) (Figure 3). The oxygen concentrations in the upper section of the Lower Elbe may be greatly reduced in summer. In the 1980s, concentrations of less than 3 and even below 1 mg/l were measured over long periods of time. Since the 1990s, concentrations of less than 3 mg/l have been significantly reduced both spatially and temporally (Arge Elbe, 2004). A major environmental relief factor was the reduced primary pollution due to expansion of the treatment plants in Hamburg and, after reunification, in the Upper and Middle Elbe. The reduced toxic inhibition of primary plankton production in the Middle Elbe and the resulting increase in secondary pollution in the Lower Elbe, as well as other measures like backfilling of Mühlenberger Loch and, though this is controversial, further deepening of the Lower Elbe, had polluting impacts (see Arge Elbe, 2004; Neumann, 2004; Kerner, 2007). At present it appears possible that the oxygen concentrations will worsen again.

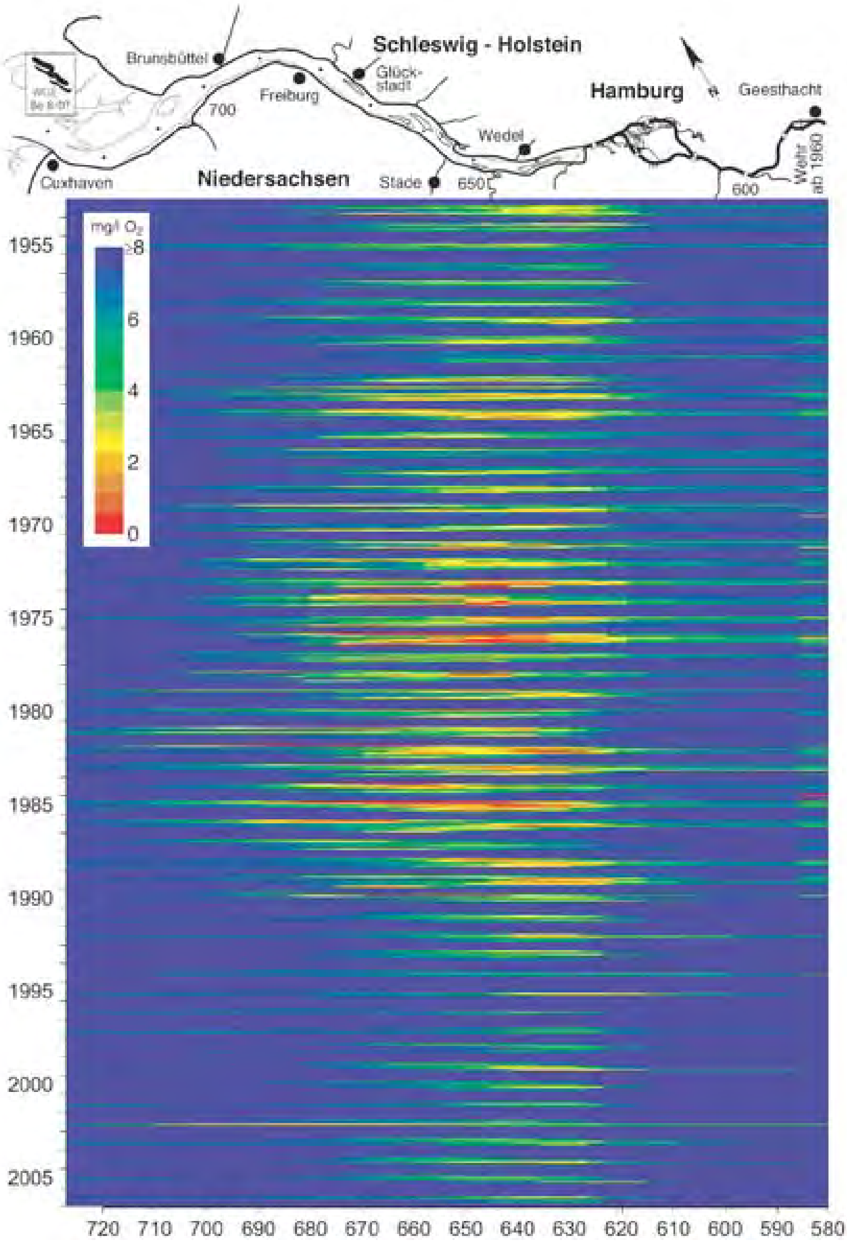

Figure 3: Spatio-temporal plot of the oxygen concentration in the Elbe estuary between Geesthacht (tidal weir) and Cuxhaven. Source: Wassergütestelle Elbe.

Lower Weser

In the Lower Weser, too, extensive oxygen deficit situations, with concentrations below 2 mg/l, were documented before about 1985. Since 1985 (expansion of the Bremen treatment plant), the shortage situations have reduced substantially and this did not change significantly in the 1990s and thereafter (Grabemann *et al.*, 2005); oxygen concentrations below 4 mg/l hardly occur.

Lower Ems

The oxygen concentrations in the Lower Ems have changed substantially since the mid 1980s. This change is well documented by virtue of the fact that a comprehensive measurement network has been set up (Figure 4). Engel (2007) shows both the significant spatial and temporal extent of the oxygen deficiencies in summer in the Leer region and the intensification of the deficiencies: the minimum values have dropped from about 6 to less than 2 mg/l in the past 20 years. Schöl *et al.* (2007), too, show for the Papenburg, Leerort and Terborg measuring stations that the oxygen situation in the Ems estuary has worsened considerably. Since the mid 1990s, oxygen concentrations less than 4 mg/l have occurred to an increasing degree and even concentrations below 1 mg/l are measured. The primary causes identified for this are the extreme increase in suspended matter concentrations, particularly as a consequence of the pronounced deepening of the Inner Ems for ship transfer (resulting in strong tidal pumping) and the intensive relocation of dredged material (Schöl *et al.*, 2007; de Jonge, 2007). Because of the very poor water quality, the biocoenosis (for smelt as an example, see Bioconsult 2007) in the inner Lower Ems has declined dramatically.

2.3.2 Indicator: Heavy metals

Heavy metal pollution of the sediments represents an indicator of the pollutant input into the water body, primarily due to direct and diffuse discharges. Increased concentrations with respect to the geochemical background occur in all water bodies. In the estuaries, concentrations that decline downstream are characteristic and essentially reflect the product of mixing more heavily polluted riverine and less polluted marine sediments.

The summary of the heavy metal concentrations from the 1980s (Schuchardt *et al.*, 1993) shows considerable differences for the various estuaries and the individual heavy metals in the degree to which the natural background values are exceeded. In the Lower Eider the excess was a factor of 2-3, in the Lower Elbe a factor of 3-30, in the Lower Weser a factor of 8-40 and in the Lower Ems a factor of 2-3.

Since around the end of the 1980s, a significant reduction in heavy metal pollution has taken place both in suspended matter and (to a lesser extent) in sediments, especially in the Elbe and Weser but also in the Ems, as a result of increased efforts

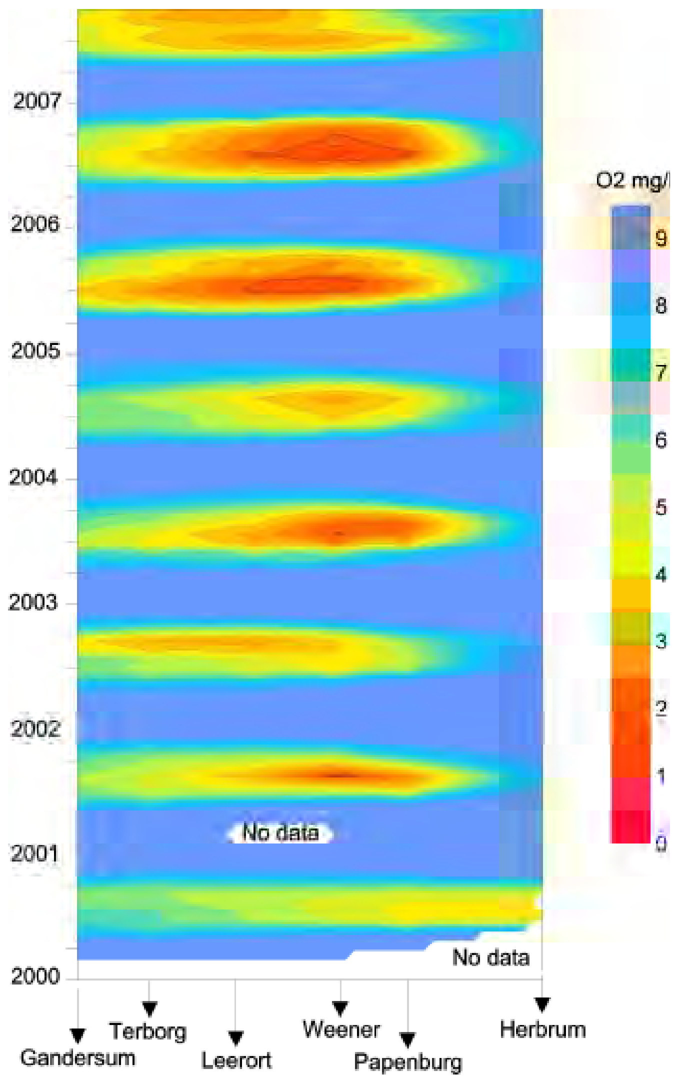

Figure 4: Spatio-temporal plot of the oxygen concentration in the Ems estuary between Herbrum (tidal weir, km -12.7, and Gandersum, km 35. Papenburg is located at km 0). (Source: data NL-WKN; HARBASINS project).

in water protection (Bakker *et al.*, 2005; see also Report No. 5 in the QSR 2009). The reduction in the Elbe was more pronounced than in the Weser, primarily as a consequence of reunification. This also led to a substantial reduction in heavy metal depositions in the North Sea, in some cases to a factor of about 3 (Bakker *et al.*, 2005).

2.4 Long-term assessment

The results of the assessment of the recent ecological situation (1985; Schuchardt *et al.*, 1993b and 2005; Schuchardt *et al.*, 2007) related to a historical reference situation (about 1880) are compiled in Table 1.

The resulting comparison of the ecological situation in the 4 estuaries over the last 20 years clearly indicates that the problem areas identified by us towards the end of the 1980s (compared to a historical reference situation) have fundamentally remained the same, but different developments have taken place for the individual indicators in the various estuaries.

The morphological deformation of the Elbe and Weser estuaries because of their use as major waterways continued and continues even now due to further expansion measures. As a result, the tidal range has increased, though to a relatively weaker extent. This also applies, but to a significantly greater degree, for the Ems estuary as a consequence of several deepening measures. In addition to the impacts on the habitats of the tidal flats and shallow-water zones, the rise in the tidal flow oriented sediment transport above the turbidity zone (Sohrmann, 2006; de Jonge, 2007) is of particular significance. Higher maintenance expenditures and increased turbidity may be the consequences, giving rise to considerations regarding extensive counter-measures parallel to further expansion planning (among others Hochfeld, 2007). For individual aspects such as restoration of flood space, such measures are based on concepts developed by environmental organizations (Claus, 1998).

The enlargement of foreland areas in the estuaries has altered only to a relatively small extent in the past 20 years. The primary reason for this is the absence of further large-scale construction of dikes closer to the water, as took place in particular on the Elbe in the 1970s. However, there are further losses, especially due to port expansion work and industrial location and additional measures are planned. This contrasts to local ecological upgrading by opening summer dikes, for example. Large-scale provision of protective status to the foreland areas, the increasing necessity of flood space and simultaneous growth of foreland areas (also against the background of climate change, Schuchardt and Schirmer, 2005) will presumably require increased action in future, such as opening of summer dikes and dike realignment.

The efforts for greater water quality protection in the past decades also manifest themselves in the inner estuaries. As a result of expansion of the treatment facilities, oxygen-consuming processes have been reduced. Environmental relief is also perceptible for the Weser and, to a lesser degree, for the Elbe, too, where the deficiency was very pronounced in the past years. A significant change in the water quality (indicator: oxygen) in the past 20 years is evident for the Ems estuary. The acute need for remediation is considerably greater here than in the Lower Elbe.

As far as heavy metals as an indicator of the water quality are concerned, an improvement in the pollution situation overall is noted by virtue of the increased efforts for water quality protection.

About 1985	**Eider**	**Elbe**	**Weser**	**Ems**
Morphology / cross-sections	very strong	strong	very strong	moderate
Loss of foreland	none	very strong	strong	moderate
Deficiency of dissolved oxygen	small	very strong	strong	moderate
Heavy metals in sediments	moderate	very strong	very strong	strong
About 2005	**Eider**	**Elbe**	**Weser**	**Ems**
Tidal range	very strong	strong	very strong	moderate
Loss of foreland	none	very strong	strong	moderate
Deficiency of dissolved oxygen	small	**strong**	**moderate**	**very strong**
Heavy metals in sediments	moderate	**strong**	**moderate**	**moderate**

Table 1: Evaluation of the ecological status of the estuaries for about 1985 (above) and 2005 (below) related to a historical reference situation (about 1880) (Schuchardt *et al.*, 1993b and 2007). Categories of change: none, small, moderate, strong, very strong. Changes in status between 1985 and 2005 in bold.

3. Nature protection status

While the outer estuaries as parts of the Wadden Sea have been subject to special protection as a national park for about 20 years already, large-scale designation of the inner estuaries as protected areas, particularly within the framework of the European network Natura 2000, has taken place in conjunction with implementation of the Habitats Directive in recent years. This development encompasses the nature reserves of the EU Birds Directive of 1979 and the protection areas of the Habitats Directive (HD) that were stipulated in a two-stage procedure after a national and EU-wide assessment. The paramount goal of Natura 2000 is to preserve biodiversity in Europe.

3.1 Habitat types of Annex I of the Habitats Directive (selection)

In Annex I, the Habitats Directive designates the types of habitat of Community relevance that are to be protected or restored through implementation of the directive. Primarily the following habitat types are relevant in the estuaries:

1130 Estuaries: The estuaries habitat type encompasses large areas in the inner and middle estuary sections (see below). They include both water body habitats like sublittoral and eulittoral as well as the bordering reeds with varying characteristics that are closely linked via tidal inlets. The limnetic sections can be included.

1330 Atlantic salt meadows: This habitat type is characteristic of the shore sections of the outer estuaries to the extent they are not partially separated from the tidal dynamics through summer polders. Because of the outer boundary of the estuaries according to the Leeuwarden definition, this type of habitat is predominantly located seaward.

91E0 *Riverside forests with *Alnus glutinosa* and *Fraxinus excelsior* and 91F0 hardwood forests: These types of habitat occur in the estuaries only in the form of very small residual stocks. Because of the inner boundary of the estuaries according to the Leeuwarden definition, the potential area of distribution of these habitat types is primarily upstream.

3.2 Species of Annex II of the Habitats Directive

Annex II of the Habitats Directive designates the species of exceptional community significance that are to be protected or restored through implementation of the directive. In addition to migrating fish species, particularly twaite shad (*Alosa fallax*), houting (*Coregonus oxyrhynchus*) and Elbe water dropwort (*Oenanthe conioides*; only Lower Elbe) are relevant in the estuaries.

3.3 Birds Directive

The majority of the HD areas of the estuaries are also EU bird sanctuaries so that management coordinated between the goals of the two directives is necessary. The avifauna of the estuaries is extraordinarily numerous with a wide diversity of species and is composed of bird communities of the open water areas, tidal flats, salt meadows and open greenland areas, reeds, shrub fringes and riverside forests. The estuaries are of great importance for breeding birds as well as for migratory and wintering birds. Numerous species (especially ducks and geese) occur here regularly in stocks of international significance.

3.4 Natura 2000 areas in the estuaries – an outline

An overview on the Natura 2000 areas in the estuaries is presented in Table 2. The predominant portion of the Eider, Elbe and Weser estuaries now belongs to the Europe-wide Natura 2000 network of nature protection areas. The Lower and sections of the Outer Ems are (still) a potential HD area since lawsuits against such designation are pending.

Estuary	Total area (km²)	Area HD (km²)	Area HD (%)	Area BD (km²)	Area BD (%)	Area protected (%)
Ems	228	171	75	124	54	75
Weser	250	230	92	193	77	94
Elbe	471	461	98	299	63	98
Eider	32	26	82	26	82	82

Table 2: Compilation of areas protected according to Natura 2000 in the estuaries Eider, Elbe, Weser and Ems. Area: transitional waters according to WFD; HD: area protected according to the Habitats Directive; BD: area protected according to the Birds Directive. Large parts are protected according to both, HD and BD.

Germany classified the state of preservation of the estuaries in accordance with the HD Directive as unfavourable vis-à-vis the EU Commission. This means there is already today an urgent need to take action coordinated via integrated management plans in order to improve the ecological situation.

Currently integrated management plans according to the HD are under development. More or less in parallel, Water Framework Directive (WFD) management plans are under development. These should be coupled to each other to a greater extent. This also applies to the necessary monitoring.

The river of Varde Å runs into Ho Bugt (Ho Bay) at the most northerly part of the Wadden Sea and this area is unique. It is the only major waterway to the Wadden Sea which has not been altered through straightening or the construction of dikes or locks in the estuary. On account of the original occurrence of a wide range of distinctive bird species and nature types, it has been designated as an EU Bird Protection Area, EU Habitats Directive site and a Ramsar site. However, the wide area of meadowland was used for a very intensive form of agriculture for more than two decades since the beginning of the 1970s. This practice had unfortunate consequences for the water quality of the river Varde Å and the Wadden Sea, and also significantly depleted the conditions for the flora and fauna in the estuary.

Thus a project was established in the years 1998-2002, to secure the area as a dynamic part of the Wadden Sea with its natural flora and fauna, including breeding and resting birds, to reduce the leaching of nutrients into the aquatic environment, and to ensure compensation of the owners or users of the land for any loss of income and to give them a high level of influence. The area covered by the project consists of 2,800 hectares of particularly vulnerable agricultural land, of which about 2,500 hectares is made up of salt marshes and meadows under the provisions of the Danish Nature Protection Act.

The overriding intention of the project is that the agricultural use of the meadows should be extensified through subsidised schemes for environmentally friendly methods. This has been achieved by raising the quality and levels of the groundwater, by stopping the use of fertilisers and pesticides, and by placing special conditions on hay harvesting and grazing.

Individual land owners participate voluntarily in the project, which is conducted on the basis of twenty-year operating agreements. The project is based on more than 400 contracts with more than 250 land owners, and covers an area of almost 2,400 hectares.

The effects of the project are positive and flora and fauna is reacting to the new situation. However, the changes in the conservation status of the area have not been as effective and fast as expected. This is mainly caused by the farmer's choice of traditional cutting and moving of grass instead of choosing practices that involves grazing with cattle (Frikke, 2009).

4. Other brackish waters

Restoration of transition zones between marine and freshwater environments is one of the policy aims for the cooperation area (Policy Assessment Report, Schiermonnikoog Declaration, 2005). Diking and land reclamation all along the coast of the Wadden Sea have eliminated the broad natural transitional zone with creeks, swamps and marshes where freshwater draining from land and seawater mixed and created a chain of brackish water habitats between the big open estuaries. The concentration of drainage systems to form a few sluices ("Siele") with a combination of gates and powerful pumps created small, isolated brackish water environments with very unstable conditions. Little and/or irregular freshwater flow, depending on intermittent pumping, is the main reason for the very poor ecological quality of these biotopes, as stated by Michaelis *et al.* (1992). Most of these show hardly any salinity gradient, but a sharp salinity break. One overview is presented by de Jonge and de Jong (2002). Essink *et al.* (2005) gave an overview on other types of brackish waters such as small tidal creeks in the salt marshes of the Wadden Sea islands with some freshwater input or polders with special water management.

However, there is another type of "estuary", which has not received special attention with respect to its estuarine function: the tributaries of the estuaries of Elbe, Weser and Ems discharging to poly-, meso- or oligohaline reaches (Table 3). Some of these are open to the tide and brackish water environments are present (storm surge barriers), others are dammed up with sluices. These "estuaries", not considered as estuaries with respect to Natura 2000, should be analysed with respect to their ecological functions in more detail.

As mentioned above, restoration of transition zones between marine and freshwater environments and measures to improve the connectivity for migrating species is one of the policy aims for the cooperation area. In the Dutch as well as in the German Wadden Sea, restoration of salinity gradients in small sites has started; further measures are planned (for The Netherlands, see Kroes and Monden (2005). For Lower Saxony, a study on the possibilities for increasing migration between coastal and freshwater is in preparation (Bioconsult, 2009).

Table 3: Tributaries entering the transitional waters of the estuaries Eider, Elbe, Weser and Ems.

Estuary	Tributary	Mouth at km	Salinity at the mouth	Connectivity
Eider	Treene	61	?	sluice
Elbe	Pinnau	660	oligohaline	storm surge barrier
	Krückau	664	oligohaline	storm surge barrier
	Stör	678	oligohaline	storm surge barrier
	Oste	707	mesohaline	storm surge barrier
	Medem	712	polyhaline	drainage sluice
Weser	Drepte	49,5	oligohaline	drainage sluice
	Lune	51	oligohaline	drainage sluice
	Geeste	66	mesohaline	storm surge barrier
Ems	Leda	14	oligohaline	tidal barrier

5. Recent developments and perspectives

The past years have been characterized by dynamic economic development in the estuaries. Further deepening measures and port expansion have taken place, contributing to a further increase in the tidal range, among other things. Parallel to that, however, large areas have been secured for conservation purposes within the framework of the Natura 2000 network. At the same time, a number of improvements have been carried out, primarily in the foreland areas, as part of compensation measures for construction projects (though delayed implementation has been noted for the Lower Elbe – WWF, 2007).

For the near future, too, one can assume that other projects having impacts on the ecological situation will be implemented, of which the most important are the following:

- Ems estuary: closing of the Gandersum storm surge barrier in order to the transfer of ships from the Papenburg shipyard to Emden also in summer; deepening of the outer estuary in The Netherlands as well as in Germany resulting, for instance, in increasing dredging activities; discharge of salt water from cavern construction to the inner estuary; construction of coal-fired power plants in Dörpen, Emden and Eemshaven; raising of dikes and storm surge defence structures. At present, possible remediation concepts for the Lower Ems are the subject of discussion.
- Weser estuary: extension of Brake harbour; deepening of the outer and inner Weser estuary, resulting in increasing dredging activities (Bremen to the open sea; ongoing approval procedure), among other things; raising of dikes and storm surge defence structures.
- Elbe estuary: deepening of the lower and outer Elbe, resulting in increasing dredging activities (Hamburg – Cuxhaven; ongoing approval procedure), among other things; raising of dikes and storm surge defence structures; filling of harbour basins in Hamburg; construction of up to five coal-fired power plants in Hamburg, Stade and Brunsbüttel.

Within the framework of implementation of the WFD and the HD, measures for improvement of the ecological situation are necessary in all German estuaries. They have to be specified in management plans and documented through a monitoring procedure. Another long-term aspect that will also have consequences for the ecological situation in the estuaries in future is climate change. Here it is important to develop a precautionary and long-term adaptation strategy (Schuchardt and Schirmer, 2007).

6. Evaluation of objectives

The objective focuses on giving protective status to valuable areas and regenerating river banks. By virtue of the designation of large sections of the foreland and water areas of the estuaries as HD sites or EU bird sanctuaries, the first part of the objective can be viewed as extensively achieved. For the second aspect, too, *i.e.* regeneration of disturbed bank and foreland areas, several steps have been taken towards meeting the target. Action such as the opening of summer dikes, *etc.*, has been taken primarily within the framework of compensation measures. However, there is still significant need for action here (see also WFD and HD).

Concerning trilateral policy and monitoring, the Trilateral Wadden Sea Plan (1997) states that the relevant parts of the policies formulated for important elements of the Wadden Sea (*i.e.* water, salt and brackish marshes and the rural area) apply also to valuable parts of the estuaries. However, this has not yet been detailed, as already recommended in QSR 1999 (Schuchardt *et al.*, 1999).

In the Wadden Sea Plan (1997), some additional policy aims have been formulated for the estuaries (see 16.1.2). In short:

1 Avoiding and reducing impact due to new construction.

2 Deepening of shipping lanes in the estuaries in conjunction with compensation and mitigation.

3 Minimizing the impact of dumping dredged materials.

4 Protecting valuable sections; restoring river banks (see objective).

5 Naturalization of the transition zones between fresh and salt water.

Regarding (1): Nowadays construction projects, such as port expansion or building of new structures, power stations, *etc.*, take place almost exclusively outside the national parks and HD sites so that direct impact on the cooperation area is avoided. However, further indirect impacts, such as due to heat input, can be expected. The political goal has therefore been achieved in part.

Regarding (2): Avoidance and compensation measures are now an integral element of all approval procedures for further deepening measures in the shipping lanes. However, the type and scope of the measures, as well as the justification for their necessity, remain controversial in most cases. The political goal has thus been achieved in part.

Regarding (3) and (4): Dumping of dredged material is regulated with respect to quantity, pollution and biological effects and an attempt is made to reduce the impacts by means of appropriate dumping site management. However, the amounts of dredged material in the estuaries of the Elbe, Weser and Ems have further increased considerably due to the deepening measures, so that these efforts are impeded in part. The political goal has therefore been achieved only to a very restricted degree.

Regarding (5): In the past years, transition zones have been improved in specific cases thanks to measures taken in the cooperation area. At present, further action on sluices is pending within the framework of implementation of the WFD. Thus there is progress in achieving this political goal and further improvements can be expected by virtue of the WFD.

Overall, it is evident that in some cases there continues to be acute need for action in spite of a number of improvements in the ecological situation. In our view this is primarily due to measures for reduction of the oxygen deficiency and tidal pumping in the Ems and Elbe, projects to secure and restore side arms with their shallow-water zones as well as the restoration of typical estuary habitats in the foreland of all estuaries.

This and other need for action, the further increasing economic significance of the estuaries because of globalization, the implementation of EU directives (WFD, HD) and the required adaptation to climate change make it necessary to coordinate further measures with each other in the form of integrated management plans and at the same time give appropriate consideration to long-term consequences of current activities.

7. Recommendations

The recommendations given in QSR 1999 (Schuchardt *et al.*, 1999) have been repeated for the most part in the 2004 QSR (Essink *et al.* 2005) and most of them are still valid (see below). However, some of the recommendations have been partly fullfilled:

- Existing ecological targets for estuaries in the TWSP must be detailed, taking into account the individuality of each estuary.

This has been (partly) done in the framework of WFD and HD; however, more intensive integration of both directives is necessary.

- Monitoring of ecological long-term changes other than water quality and macrozoobenthos in the estuaries is necessary.

Within the framework of WFD and HD, monitoring of fish fauna in the transitional waters has been started some years ago, according to the design outlined in Scholle and Schuchardt (2009).

Although some of the previous recommendations have been partly fullfilled in the meantime (see above), the following must be repeated and replenished also in the recent report:

- A compilation and integrated analysis of the existing ecological data for the estuaries are lacking.
- The tidal freshwater reaches should be integrated into the Stade Declaration definition of an estuary. The Lower Eider should be included in the estuary definition.
- The downstream borders of the estuary definition according to Stade Declaration, WFD and HD should be harmonized.
- Active restoration of estuarine habitats (especially shallow areas and foreland) is necessary in all estuaries under consideration. Problems linked to the artificial increase of the tidal range have to be given special attention. However, first measures have been taken.
- Consequences of further impact due to further deepening, barriers and harbour extension should be evaluated very carefully, taking into account the historical deterioration of the estuaries and the uniqueness of each estuary.
- Further improvement of water quality is necessary, especially for the Elbe and Ems estuaries. However, the situation in the Ems estuary has worsened and improvement is really urgent.
- Further active restoration of smooth gradients of salinity and tidal amplitude in small creeks along the Wadden Sea coast and the estuaries is important. However, first measures have been taken and further are under planning.

Some additional recommendations can be given:

- The management plans currently being developed within the framework of implementation of the WFD and HD should be coupled to each other to a greater extent. This also applies to the necessary monitoring (see chapter 16.3.4).
- Reduction of tidal pumping is necessary, especially for the Ems, but also for the Elbe estuary. Discussions on this with regard to both estuaries have begun (16.2.3 and Report No. 3.7 on dredging and dumping).
- Several new coal-fired power stations are also planned in estuaries. Both removal and return of the cooling water must be evaluated critically according to cumulative aspects.
- With respect to the restoration of estuarine habitats and salinity gradients the tributaries of the estuaries should also be taken into consideration (*e.g.*, Geeste river) (see section 16.4).
- Long-term strategies for adaptation to climate change should be developed for the estuaries.

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1. Introduction

The Offshore Area of the Wadden Sea Cooperation Area is defined as the near-shore zone between the barrier islands and the line 3-nautical-miles off the baseline. In the tidal inlets this baseline is an artificial line connecting the outer tips of the islands. The area covers about 4,000 km^2, and includes water depths of more than 10 m. The tide causes a daily exchange of water between the Wadden Sea and the North Sea, the extent of which is modified by wind conditions. The Offshore Area forms one coherent geomorphological system with the Tidal Area, which can be demonstrated by sand transport. Also the biology of the Wadden Sea and the North Sea is intimately linked: Phytoplankton is transported from the offshore zone to the Wadden Sea proper and, after dying off, is remineralized. The import of organic matter from the offshore zone is one of the main causes of the food richness of the Wadden Sea. Both cockles and blue mussels may restock the Wadden Sea from populations in deep water refuges in the North Sea after severe winters have decimated the population of the exposed tidal flats. Mobile animals like fish, shrimps and crabs largely leave the Wadden Sea in autumn to survive the winter in the relatively warm waters of the North Sea, after which they return to the Wadden Sea. Without the high productivity in the Wadden Sea, the stock of these species would be greatly reduced (de Jong *et al.*, 1999). Birds and sea mammals demonstrate both a daily and a seasonal shift in their use of the Wadden Sea and the Offshore Area. These few examples illustrate the close connection between the two parts of cooperation area.

In the Wadden Sea Plan the targets for the Offshore Area are formulated as follows:

- An increased natural morphology, including the outer deltas between the islands.
- A favorable food availability for birds.
- Viable stocks and a natural reproduction capacity of the common seal, grey seal and harbour porpoise.

Marine Mammals are treated extensively in the QSR Thematic Report No. 20, both for the Offshore Area and the Wadden Sea.

Anthropogenic pressures in the offshore zone have increased dramatically in recent years. The most important issues in this context are the increasing ship traffic (Report No. 3.2) and offshore wind energy (Report No. 3.6) as well as sand and gravel extractions and dumping of dredged material (Report No. 3.7). Both the Esbjerg Declaration (2001) and the Schiermonikoog Declaration (2005) extensively deal with these issues. The increasing anthropogenic activities in the offshore zone entail a careful marine spatial planning scheme for the near future.

As an important update to the last QSR it needs to be mentioned that several protected areas according to both the EU Birds Directive and the Habitats Directive have been implemented in the offshore area (see chapter 5).

2. Water and geomorphology

Tides are the driving force for a daily exchange of water between the Wadden Sea and the North Sea. The offshore zone up to a depth of about 20 m forms a coherent geomorphological unit with the Tidal Area. Through the tidal inlets in between the barrier islands, sand and silt are transported back and forth between the Tidal and Offshore Areas ('sand sharing system'). The consequence of this dynamic equilibrium is that disturbances will be compensated until a new equilibrium is reached. Sea level rise and bottom subsidence cause a deepening of the tidal basin resulting in an increased net sand import from the offshore zone. Ultimately this sand originates from the seaward shores of the islands. Together with a net sedimentation along the mainland shore, this results in a landward movement of the islands (de Jong *et al.*, 1999).

The speed of sea level rise has increased and is considered to impact the sediment dynamics and sediment transport between the Wadden Sea and offshore zone. The predicted sea level rise is considered to induce a sediment deficit in the Wadden Sea and, above breakpoint (*i.e.* sea level rise is too strong to enable sediment redistribution), the Wadden Sea is thought to develop into a number of tidal lagoons separating former tidal basins from the open sea by barriers (CPSL, 2005). The increasing number of storm events greatly affects many parts of the seaward islands such as the island of Sylt (Reise and Lackschewitz, 2003). Sand extraction and replenishment (or beach nourishment) of eroding coasts has become very important and will be an even more critical issue in the near future. Extraction of sand and gravel is generally carried out in the North Sea outside the 20 m depth contour. The yearly extraction of sand and gravel in the southern North Sea amounts to 45 million m^3 (Lozán *et al.*, 2002). Recovery of the areas where sand was extracted depends on local sediment dynamics, and is fast in areas with strong dynamics. The sand and gravel extraction results in a reduction of benthos biomass and change in species composition, at least temporarily. A complete recolonization of benthos after extraction takes between one month and ten years and sometimes even longer. In most cases, however, it takes a few years. The recolonization depends very much on the nature of the sediment and on water currents. The first species to invade are opportunistic taxa, and after a couple of years species from the original community begin to settle again and develop (Lozán *et al.*, 2002).

3. Zoobenthos and fish

In the coastal waters of the North Sea, the most important zoobenthos groups are molluscs, polychaetes, crustaceans and echinoderms. Despite of *Hydrobia ulvae* which is occurring in highest individual numbers, polychaetes are the most abundant. Molluscs are second in abundance but have the highest biomass.

3.1 Zoobenthos communities

The ICES Study Group on the North Sea Benthos Project 2000 has analyzed zoobenthos samples from the North Sea taken in 2000/2001. Samples were grouped according to their similarity in species composition using PC-ORD and TWINSPAN cluster analyses. This resulted in the identification of nine clusters in the North Sea, largely related to water depths (increasing from South to North) and to differences in substratum types (coarse vs. fine) (SGNSBP, 2004).

At least two of these clusters were found along the Belgian-Dutch-German coast comprising the Offshore Area of the Wadden Sea Cooperation Area. The benthic fauna in these clusters had a relatively low species diversity, with, however, enhanced values in complex biotopes, *i.e.* with mixed substrate from fine to coarse sands, gravel and stones, such as near Borkum Riff and in the outer Amrum Grounds.

Crustaceans and echinoderms dominate the epibenthos community. While the community structure remained rather stable, a high inter-annual variability in dominance as well as a significant change in community structure between winter and summer months was found indicating intensive patterns of migration (Hinz *et al.*, 2004; Reiss and Kröncke, 2004).The dominance of crustaceans in epibenthos communities of the offshore zone have been found reflected in diet of seabirds such as the lesser black-backed gull (Larus fuscus) (Kubetzki and Garthe, 2003; Schwemmer and Garthe, 2005).

3.2 Bivalves

There are two species of the clam genus *Spisula* occuring in the Offshore Area, *viz. Spisula subtruncata* and *S. solida*.

Surveys in The Netherlands since 1995, have shown that *Spisula subtruncata* is distributed all along the North Sea coast off the Frisian Islands south to the Delta area (Craeymeersch *et al.*, 2001). *Spisula* is being monitored in the spring, including 800-1000 stations. The biomass calculated for the North Sea coast off the Wadden Sea varies from 25,000 tons fresh weight in 1996 to about 210,000 tons in 2000. Yearly variations of the same magnitude were also recorded in other areas off the Dutch North Sea coast. However, the variation did not occur synchronously. The yearly commercial landings of *Spisula subtruncata* in The Netherlands in the period 1996-2001, were between 16,000-37,000 tons.

Unfortunately, information on the occurrence of *Spisula subtruncata* in Germany and Denmark is still scarce. In Danish waters off the Wadden Sea, the species was reported for some years, but has disappeared during recent years (P. Sand Kristensen, pers. com.)

The clam *Spisula solida* was investigated in 2000-2001 off the Schleswig-Holstein Wadden Sea (Rumohr, 2002). It occurred at Amrum bank at about 10 m depth off the islands of Sylt and Amrum, off the peninsula of Eiderstedt and at Vogelsand outside the Elbe Estuary. Densities up to 30 individuals per m^2 were found at Amrum Bank, whereas at Vogelsand and in the area off Eiderstedt only 1-10 individuals per m^2 were reported. Due to its low densities, this species is not fished. High numbers of common scoter (*Melanitta nigra*) occur off the German Wadden Sea islands during different periods of the year (see chapter 17.4). However, information on distribution, abundance and even sort of their prey is still much too scarce to draw any conclusions on interactions between birds and their potential prey.

Besides *Spisula*, subtidal mussel beds are of crucial importance both as a habitat structure for an associated benthos community as well as food for benthivorous seabirds (see chapter 13). Most of these mussel beds are located, however, in shallow areas between deeper channels and only few stretch out towards the offshore zone. Mussel beds in deeper areas show a strong inter-annual variability in terms of abundance and biomass, which is mainly caused by storm events. Particularly common Eiders (*Somateria mollissima*) utilize the subtidal mussel beds and consume by far the highest quantities of both eulitoral and subtidal mussels (*e.g.* Camphuysen *et al.*, 2002; Scheiffarth & Frank 2005).

3.3 Fish

Both tidal channels within the core area of the Wadden Sea as well as the adjacent offshore zone are important hatching and breeding sites for different species of fish (see chapter 14). Depth and distance from the coast are the main factors structuring the composition of the typical fish assemblage (Ehrich *et al.*, 2006). Fish are of crucial importance for piscivorous seabird species such as terns, divers and cormorants as well as for marine mammals such as harbour porpoises and seals. Piscivorous bird species, *e.g.* common and Arctic tern, show dramatic failures in breeding success in many colony sites which seem to at least partly be caused by low quality and / or availability of suitable fish species (V. Hennig pers. comm.). These findings are partly contradicted by the effects of overfishing: a reduction of large predatory fish species like cod (*Gadus morhua*) in the offshore zone is considered to have led to a higher abundance of small fish, suitable for piscivorous birds and marine mammals, thus enabling a reasonable reproduction success. It is possible that the loss of large predatory fish species have affected the food web in the offshore zone more than in the Wadden Sea. In consequence, birds and mammals foraging more in the offshore zone would benefit most from these changes. For a proper management, more information on the food basis for piscivorous seabirds as well as on correlations between the birds and their prey need to be achieved.

4. Birds

4.1 Coastal and marine species

Birds using the North Sea off the Wadden Sea have only recently and only partly in Germany (12 nm zone of Schleswig-Holstein and EEZ) been subject to regular monitoring. However, knowledge of the birdlife was derived through different initiatives and in national campaigns in the 1990s and 2000s in both the Netherlands and in Denmark (Camphuysen and Leopold, 1994; Laursen *et al*., 1997), and has grown enormously in recent years, especially to fulfill the obligations of the EC Birds Directive and in relation to site assessments for offshore wind farms and other anthropogenic activities in the open sea. For Germany, numbers and distribution of seabirds and coastal birds within their 12-nautical mile-zone (nm zone) as well as in the EEZ have very recently been published (Garthe *et al*., 2007; Table 1).

Although data are not complete for the trilateral area as data have not been compiled yet for Denmark and The Netherlands, the pattern described for the German coastal zone should be representative for the whole offshore area of the Wadden Sea. The most numerous species in the 12 nm zone of Germany are black-headed gull, common eider and herring gull in summer, and common scoter, common eider and herring gull in winter (Table 1). Viewed from an international perspective, the proportions from the respective biogeographic populations are a very important measure: In summer, 15.1% of common eiders, 12.5% of sandwich terns and 12.0% of lesser black-gull populations occur alone in the German 12 nm zone (Table 17.1). Five more species exhibit concentrations between 1% and 10%. In winter, only the common eider (17.1%) aggregates with more than 10% in the area, common scoter (8.4%), common gull (2.4%), herring gull (1.5%) and great black-backed gull (1.4%) are following next (Table 1).

Beyond the 12 nm zone, thus in the EEZ of Germany, northern fulmar (40,000 ind.), lesser black-backed gull (29,000 ind.) and black-legged kittiwake (8,500 ind.) are the most numerous species in summer, while common guillemot (27,000 ind.), herring gull (15,000 ind.) and black-legged kittiwake (11,000 ind.) dominate in winter (Garthe *et al*., 2007).

The red-throated diver (*Gavia stellata*) is the most common (95%) of the divers, but the black-throated diver is also widespread (*G. arctica*) (Camphuysen and Leopold, 1994; Garthe, 2003). The majority of the divers were recorded between 4-26 m depth (Petersen *et al*., 2003). Aerial surveys during spring in the Danish and German sectors of the North Sea showed that most divers occurred in the eastern parts off the Wadden Sea. 7% of the divers occurred inside, and 93% outside the Wadden Sea Cooperation Area (FTZ and NERI and Elsam Engineering A/S). The largest concentration of divers was recorded off Sylt, outside the Wadden Sea Cooperation Area, in spring.

Common scoter (*Melanitta nigra*), velvet scoter (Melanitta fusca) and common eider (*Somateria mollissima*) use the food resources of the communities of cockles (*Cerastoderma edulis*) and clams (*Spisula subtruncata*) off the Wadden Sea. In October, the common scoter gathers off the Danish Islands, and their numbers increase during autumn to more than 300,000 individuals and their distribution expands to the whole coastal zone of the Wadden Sea (Camphuysen and Leopold, 1994; Laursen *et al*., 1997). The largest concentrations occur off the Frisian and Danish islands, where up to 200,000 individuals can assemble (Laursen and Frikke, 1987; Garthe, 2003). Most of these birds leave for northern breeding grounds, but about 30,000 non-breeding individuals spend the summer in the Wadden Sea area. In late summer, during moulting, large concentrations of common scoters are found in the offshore zone of the three countries. Ongoing studies carried out in connection with planned and established wind farms as well as pilot and regular monitoring data have shown that large concentrations of common scoters occur off the Danish and the Schleswig-Holstein Wadden Sea (Figure 1). The majority of the scoters occurred at water depths between 2-10 m (Petersen *et al*., 2003). Aerial surveys during March showed that 61% of the common scoters occurred inside the Wadden Sea Cooperation Area and 39% outside (FTZ and NERI and Elsam Engineering A/S). This indicates the close connection between the Offshore Area of the Wadden Sea and the adjacent North Sea.

4.2 Connection between the Offshore Area and the Wadden Sea

Winter surveys during more than ten years, of common eiders in both the Dutch and the Danish parts of the Wadden Sea and the adjacent North Sea have shown that the distribution of birds shifts between the Wadden Sea and the Offshore Area. During 1993-2003, in the Dutch Wadden Sea between 1 and 58% of common eiders occurred in the Offshore Area (Berrevoets and Arts, 2003). The figures were high during the late 1990s and peaked in 2000 and 2001 at 48 and 58%, respectively. In the Danish Wadden Sea, the proportion

Table 1:
Estimated numbers of regularly occuring seabird species in the German 12 nautical mile zone in summer and winter. Only species with on average at least 100 ind. are listed. Also, the proportions of the respective biogeographic population are shown.

	Summer		Winter	
Species	Number	% of biogeogr. population	Number	% of biogeogr. population
Common eider	115,000	15.1	130,000	17.1
Common scoter	66,000	4.1	135,000	8.4
Velvet scoter	0	0	210	<0.1
Red-throated diver	0	0	1,800	0.6
Black-throated diver	0	0	150	<0.1
Northern fulmar	ca.120	<0.1	ca.200	<0.1
Northern gannet	270	<0.1	<50	<0.1
Great cormorant	3,900	0.8	1,600	0.3
Razorbill	<50	<0.1	3,100	0.3
Common guillemot	3,700	<0.1	6,500	0.1
Black-legged kittiwake	11,500	0.1	2,800	<0.1
Little gull	<50	<0.1	650	0.5
Black-headed gull	160,000	3.8	16,000	0.4
Common gull	30,000	1.7	41,000	2.4
Great black-backed gull	2,000	0.5	6,000	1.4
Herring gull	110,000	3.4	48,000	1.5
Lesser black-backed gull	46,000	12.0	650	0.2
Black tern	<50	<0.1	0	0
Sandwich tern	21,000	12.5	0	0
Common tern	19,500	1.6	0	0
Arctic tern	15,500	0.8	0	0

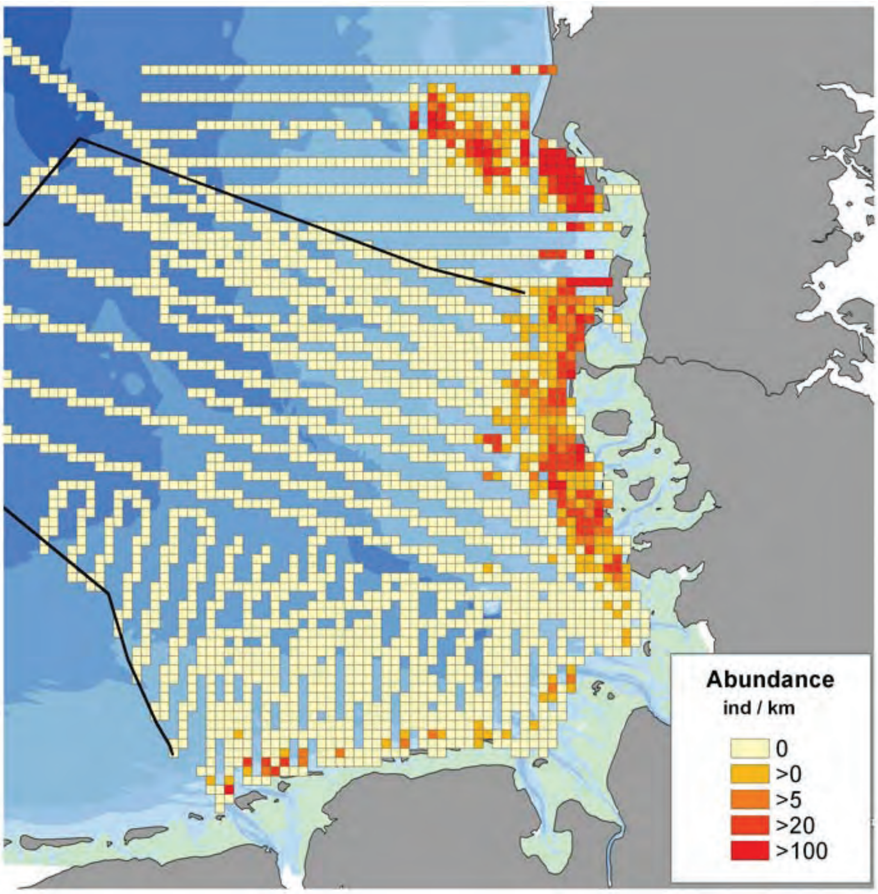

Figure 1:
Distribution of common scoters in winter (December to February, 2002-2009) in the German and Danish part of the Wadden Sea and the adjacent North Sea.

of common eiders in the offshore zone varied between 2 and 77% during 1981-2001, with the highest values during 1984-1987. After 1992, the proportion of common eiders in the Offshore Area fell to 12%. These figures demonstrate a close connection between the two parts of the Cooperation Area. The reason for the observed shift between the two parts of the Wadden Sea is only partly known. Varying abundance of mussel stocks is the most likely explanation. The striking coincidence of intensive mussel fishery and hunting activity is, however, noteworthy, and might additionally explain the changes in distributions. Following a period of intensive mussel fishery, high eider mortality was reported from the Dutch Wadden Sea in the winter 1999/2000 (Camphuysen *et al.*, 2002). In the Danish Wadden Sea, probably two reasons contributed to the change in eider distribution. The proportion of eiders in the Danish Offshore Area peaked with 54% during 1984-1987. During that period intensive blue mussel fishery took place in the Danish Wadden Sea, and common eiders shifted to the Offshore Area to feed on cockles as an alternative food source. However, the common eiders feeding on the alternative diet had a poorer body condition compared to those individuals feeding on blue mussels (Laursen *et al.*, 2009). In 1992, the majority of the Danish Wadden Sea was closed for hunting, which included shooting of eiders between the islands and the mainland coast. After 1992, the proportion of eiders in the Offshore Area decreased to 12%, while in the years before 1992 it was 42% (Laursen and Frikke, 2008). Thus hunting for common eiders had obviously a disturbance effect, displacing the birds to the offshore zone. These facts indicate that there could be more reasons for the shifting of eiders between the Wadden Sea and the Offshore Area. The latter area can play a role both as alternative feeding area and as refuge for the common eiders.

Gulls are another important example for a species group that links the offshore zone with the Wadden Sea: Particularly herring gulls (*Larus argentatus*), common gulls (*L. canus*) and black-headed gulls (*L. ridibundus*) extensively use the tidal flats as foraging habitat (*e.g.* Kubetzki & Garthe 2003). However, a high proportion of individuals of these species can be found in the offshore zone utilizing discards from brown shrimp fisheries (*e.g.* Walter & Becker 1994, 1997). In contrast, for many other species, such as lesser black-backed gull and sandwich tern (Schwemmer and Garthe, 2005; Garthe and Flore, 2007), the Offshore Area is the essential part of their natural feeding areas.

5. Protected areas

While the Wadden Sea and most of its offshore areas have been declared protected areas according to various legal instruments, including the EC Birds Directive (Special Protection Areas: SPAs) and the EU Habitats Directive (Special Area of Conservation: SACs; and previously (proposed) Sites of Community Interest (p)SCI), such areas have only very recently been dealt with in the adjacent open sea of the North Sea. For the Trilateral Area, Germany started this process by declaring an 3,135 km² large SPA adjacent to the Wadden Sea National Park in 2004 ('Eastern German Bight'; BMU,2005; Garthe, 2006). Species of highest conservation concern in this area are red-throated and black-throated divers, and furthermore little gull, sandwich tern, common tern, arctic tern, common gull, lesser black-backed gull, northern fulmar, northern gannet, black-legged kittiwake, common guillemot and razorbill (Figure 2). Similarly, two area have been designated SCIs: The Sylter Outer Reef and Borkum Reef Ground. Both areas are of high importance because of the habitats sand bank and reef, marine mammal species harbour porpoise, harbour seal and grey seal, and fish species twaite shad and river lamprey (only Sylt).

In Denmark, an offshore area of 2463 km² situated in the southern part of the Danish North Sea sector off the Wadden Sea, was designated as an SPA in 2004. The aim of appointing this area is to protect especially Red and Black throated Divers (*Gavia stellata* and *arctica*) and Little Gull *Larus minutus*.

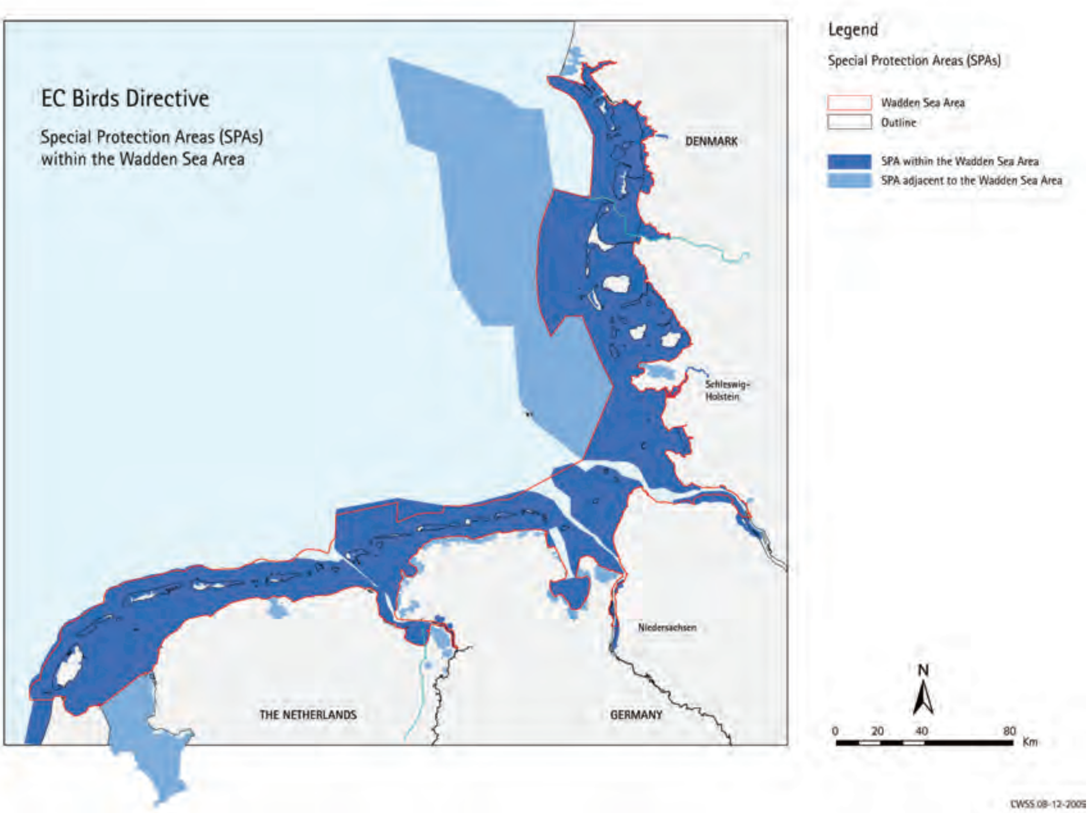

Figure 2: Location of Special Protection Areas (SPAs) according to the EC Birds Directive.

6. Anthropogenic pressures

Anthropogenic pressures in the open sea have dramatically increased in recent years. This is mainly due to economic exploration that affects the sea floor, the open water column and the air space above sea level. Huge plans for further expansion may lead to industrial parks at sea in the near future. The main pressures in the offshore area of the Wadden Sea are:

- Installation of offshore wind farms
- Ship traffic
- Sand and gravel extraction and dumping of dredged material
- Fisheries

Denmark was the first country that installed offshore wind turbines in the offshore zone, already in 2002. Currently, two wind farm sites are operating in Danish offshore waters of the North Sea, while there are two sites in the Netherlands. In Germany the first site is in operation since August 2009. Intense accompanying technical and environmental research has been conducted (and is still ongoing) in all countries mentioned. No wind farm sites are planned in the Cooperation area, however, there are several sites close to it which therefore may influence parts of the same populations of birds that use both the offshore area and the Wadden Sea itself. For more information on the planned offshore wind farm projects see chapter 3.6. Exo *et al.* (2003) list five possible impacts of offshore wind farms on sea birds: 1) risk of collision, 2) short-term habitat loss during construction, 3) long-term habitat loss due to disturbance by turbines, 4) formation of barriers on migration routes, and 5) fragmentation of ecological units, such as roosting and feeding areas. For marine mammals also the habitat loss during construction and during operation is of concern. Additionally, harbor porpoises may be affected by construction noise, which may even cause permanent damage of hearing (Lucke 2008).

The construction of offshore wind farm sites additionally generates a higher intensity of ship and air traffic (mostly in areas with previously low traffic intensities) both during the construction as well as during the operation and maintenance phases.

Dierschke *et al.* (2006) have attempted to quantify the habitat loss due to offshore wind farming for red-throated divers in German waters. This is an important approach to assess cumulative effects of multiple wind farm sites. Marine spatial planning should urgently take into account cumulative effects both of same and between different anthropogenic activities. Innovative tools such as the 'wind farm sensitivity index' for seabirds (Garthe & Hüppop, 2004) are highly useful for spatial planning. This index scales the risk for a large number of seabird species in relation to wind farms. It was concluded that divers, velvet scoter, sandwich tern and great cormorant are at risk most of all, while species such as the black-legged kittiwake, black-headed gull and northern fulmar experience the lowest risk from operational wind farms.

Effects of wind farms had been conducted during in a detailed study at in the Danish sector of the North Sea at Horn Rev, northwest of the Wadden Sea. The study focused on migratory birds flying through and birds staging in the area by use of a BACI-method (Before- and After-Control method). The results showed that birds flying through the areas generally avoided the Horns Rev wind farm. Some species *e.g.* divers and garnet were almost never seen flying between turbines while common scoters rarely did so and cormorants and gulls only showed little avoidance behavior. The bird species staying in the area during the non-breeding season generally avoided the turbines, although there were differences between the species. Divers showed complete avoidance of the wind farm area, while terns and auks were closer to them but never observed inside the wind farms, while common scoters initially showed avoidance but occurred in large numbers in the vicinity, and smaller numbers inside the wind farms (Petersen *et al.*, 2006). After 5 years of wind farm operation wintering common scoters were found within the Horns Rev 1 wind farm site in numbers not different from the numbers found in areas around the wind farm (Petersen and Fox 2007).

In October 2002, the Wadden Sea was designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organisation (IMO). The PSSA covers a part of the Offshore Area. The PSSA classification is given to sea areas that need special protection through actions due to their significance for recognized ecological, socio-economic or scientific reasons, and which may be vulnerable to impacts from international shipping activities (Reineking, 2002). The PSSA Wadden Sea is included on the relevant sea charts and this is expected to increase shipping safety and to reduce environmental impacts. In addition, it will contribute to a more close collaboration between the different shipping authorities, which may reduce or prevent the risk of future disasters (see chapter 4.3).

Despite of the success of designating the Wadden Sea as a PSSA, shipping has still to be regarded as a major threat to the marine environment as it may still cause severe pollution as well as habitat fragmentation for seabirds sensitive to disturbance (*e.g.* divers and different sea duck species). The overall intensity of shipping has increased during recent years (*e.g.* Knust *et al.*, 2003). Ship traffic is actually one of the most important human pressures in the offshore zone as most anthropogenic activities are linked with shipping, *i.e.* fishing, construction and maintenance of offshore wind farm sites, sand and gravel extractions and dumping, coastal protection, military exercises, cargo and ferry traffic as well as recreation. The vast numbers of activities are associated with multiple types of shipping which may have all different effects on the environment. One of the most direct effects is disturbance of marine mammals but particularly of resting and foraging seabirds. Divers and common scoter must be regarded as particularly sensitive to ship traffic as they show highest flight distances and at least scoters may occur in very large flocks which might even intensify their flight reaction (Schwemmer & Garthe, 2006; Bellebaum *et al.*, 2006). Another very important issue is the contamination of the marine environment by shipping. In this respect, the threat of oil spills is the worst scenario; however, constant pollution by chemicals (*e.g.* ship paint) and also marine litter which is very likely to originate from shipping activities and may affect surface feeding seabirds such as fulmars (*Fulmarus glacialis*) is also of great concern (*e.g.* Guse *et al.*, 2005; see chapter 3.2 for more details on shipping).

Another problem for birds using the offshore zone could be sand extraction in the German Bight. The sandwich terns breeding on the Wadden Sea islands in large colonies feed above sand banks in the North Sea especially during the breeding period. Their preferred prey, sandeels, live on these sand banks (Garthe and Kubetzki, 1998). The effects of sand extraction on sandwich terns are not known. Garthe and Flore (2007) also highlight the possible threat by industrial fisheries on sandeels and sprat when trawlers operate near the breeding colonies during the breeding period.

The area involved when extracting sand and gravel (and thus the overall impact on benthos organisms) depends on the extraction technique: Extracting sediment from a surface layer has stronger impact on the benthos community while the digging of deep cones is considered to have a lower impact. Besides reduction of potential food for benthivorous seabird species, gravel extraction may lead to a loss of foraging habitats for diving bird species by lowering the seafloor, which may then exceed the diving capability of birds.

Fishing is of high importance in the offshore zone. As fisheries compete with marine top predators for the same resources, there is potential conflict in fisheries both for invertebrates and fish. A few examples should briefly be mentioned: Fishing of stocks of the clam *Spisula subtruncata* can affect the numbers of common scoter (Leopold, 1993). Severe impacts of cockle fisheries on benthivorous wading birds and common eiders have already been proven in the Netherlands (*e.g.* Piersma & Koolhaas 1997; Piersma *et al.*, 2001; Camphuysen *et al.*, 2002). Studies, however, of the actual effects of fishing on sublitoral clam stocks on common scoters have not yet been conducted.

Many studies have demonstrated that bottom trawling may induce significant changes of the benthic community. For instance, an increase in benthic scavengers such as Liocarcinus spp. that feed on dead or damaged fishes and other discarded species was found (*e.g.* Ramsay *et al.*, 1997; Demestre *et al.*, 2000, Frid & Clark, 2000). Modelling results by Schroeder *et al.* (2008) predict that the benthic communities of large areas of the German EEZ of the North Sea are strongly affected by continuous bottom trawling, as most of the German EEZ is trawled regularly. The high trawling induced mortality of longlived species is largely unaffected by the temporal distribution of annual trawling events while the impairment of short-lived species depends relative strongly on the time of fishing. High losses among sensitive species can only be reduced by substantial decreases in trawling induced mortality (Schroeder *et al.*, 2008).

High quantities of discards originating from different types of fishery are expected to play a crucial role in sustaining breeding populations of scavenging seabird species such as gulls (*e.g.* Oro 1996; Furness 2003). Because many bird species that use this additional food source partly rely on it, negative short- and medium-term effects (redistribution, change in diet, reduced reproductive performance, reduced condition or even mortality; Oro 1999; Hüppop & Wurm, 2000; Votier *et al.*, 2004) are to be expected when reducing disards along with a move towards less detrimental fishing practices and in accordance with changes in the EU Common Fisheries Policy.

Strong overlap in distribution of harbour porpoises and different types of fisheries have recently been found in the German Bight (Herr *et al.*, 2009). These results suggest resource competition between porpoises and industrial sandeel fisheries during different periods of the year. The risk of by-catch in gillnets also exists whereever set nets and diving bird co-occur.

7. Conclusions

The offshore zone is in closely linked with the Wadden Sea as an allochthonous ecosystem in terms of energy and nutrient flow as well as with respect to migration of different species such as plankton organisms, fish and marine top predators. Thus, both systems must be regarded as an entity.

Currently, there are no indications of major geomorphological changes in the offshore zone, however, accelerated sea level rise and altering sediment dynamics must be taken into account to probably course future changes. Upcoming coastal protection measures (including sand and gravel extraction and beach nourishment) might impact the natural sediment dynamics at least on a regional spatial scale.

Crustaceans, echinoderms as well as polychaetes are the most important benthic organisms in the offshore zone. However, with respect to nutrition of seabirds, bivalves (mainly *Spisula* and *Mytilus*) are of highest importance. Fish in the offshore zone are crucial for a variety of piscivorous seabird species. Breeding failures of several species currently indicate fundamental changes in availability and/or quality of fish. Among the seabird species, black-headed gull, common eider and herring gull as well as common scoter are most important. Common eiders, sandwich terns and lesser black-backed gulls show significant proportions of the respective biogeographic populations in the offshore water of Germany alone.

SPAs and SCIs have recently been designated in the North Sea adjacent to the Wadden Sea National Parks and protected areas.

Among the multiple anthropogenic pressures in the offshore zone, offshore wind farms, ship traffic, fisheries and sand and gravel extractions are of primary concern.

8. Target assessment

8.1 Increased natural geomorphology

The sediments of the seabed of the Offshore Area and of the channels and flats in the Tidal Area of the Wadden Sea form a coherent 'Sand Sharing' system. As a consequence of sea level rise, sand will be transported from the coast off the islands into the Wadden Sea. Whereas coastal protection activities on the Wadden Sea islands have continued where necessary, no major changes in geomorphology or its dynamics can be reported since the QSR 1999. One exception is the construction in 1995 of a long cross-shore dam at the northern tip of the island of Texel, which caused sand accretion on both sides of the dam, extending the beach in a seaward direction, as well as geomorphological changes in the ebb tidal delta of the Eijerlandse Gat inlet.

Despite of the fact that currently no major geomorphological changes can be reported, sea level rise as a consequence of climate warming has come on the agenda in many countries. Coastal protection systems will be improved in the near future. Effects on sediment dynamics and benthos communities induced by these sites on a small spatial scale (which may be crucially relevant for the nutrition of breeding birds and chicks) are currently not known.

Conclusions

Apart from coastal protection activities on the Wadden Sea islands (*e.g.* sand nourishment, cross-shore dam at Texel) no evidence has become available regarding any negative development in natural dynamics of the geomorphology of the Offshore Area. However, effect on a small spatial scale have to be kept in mind; but currently no information on this issue is available. Thus the target concerning 'an increase natural morphology' of the offshore area can not be assessed due to the rather rough scale of the information available, but it seems that the natural morphology of the offshore had been maintained.

8.2 Favourable food conditions for birds

Repeated inventories have demonstrated the occurrence of important stocks of the bivalve *Spisula subtruncata* along the Dutch coast, and of *S. solida* along the coast of Schleswig-Holstein. These bivalves are a major food source for diving ducks such as the common scoter and eider. Especially for the eider, these *Spisula* stocks are important for the survival when other bivalve stocks in the Wadden Sea are depleted, either by severe winter conditions or by extensive shellfish fishery. In The Netherlands, there is fishery on *Spisula*, the effects of which on the common scoter and common eider have not been investigated.

From the ICES North Sea Benthos Project 2000 it appears that the macrozoobenthos community in the Offshore Area is part of coastal communities along the Belgian-Dutch-German coast, characterized by low species numbers, but locality enhanced where complex substrate (sand, gravel, stones) is present, such as near Borkum Riff and in the outer Amrum grounds.

- Potential effects of Decreasing Mussel stocks (chapter 11)
- Effects of reduced availability of small fish species
- Missing information on relationships between both piscivorous and benthivorous birds and their prey availability / quality in order to explain negative population trends and low reproduction success.

Conclusions

Sublitoral bivalve stocks in the Offshore Area are important as a food resource for the common scoter, eider and other diving ducks. For the eider, *Spisula* stocks in the Offshore Area are an essential lifeline during adverse conditions in the Wadden Sea.

The Wadden Sea is highly important as breeding and hatching site (nursery) for many fish species. Information on relationships between both piscivorous and benthivorous birds and their prey with respect to negative population trends is missing.

Sublitoral mussel beds are important for a typical associated benthic community as well as food for diving seabirds.

However, the knowledge of the fish stocks and especially the bivalve stocks in the offshore area does not allow a closer assessment of the target to ensure 'a favorable food availability for birds'.

7. Recommendations

Taking into account accelerating sea level rise and higher numbers of storm events, regular analyses in reference sites for parameters that allow tracking major changes in geomorphology should be introduced in the offshore area. This is an important tool for an early warning system which should allow for early management measures with respect to a possible breakpoint in sediment dynamics and sediment exchange between the Wadden Sea and the offshore area (see above).

As the Wadden Sea must be regarded as an allochthonous ecosystem, its functions are highly dependant on exchanges with other systems. Thus, it is important to gain additional knowledge on nutrient and energy flow with the offshore zone.

A management of *Spisula* fishery needs to be developed to ensure compliance with the target 'favorable food availability for birds', especially for common scoter, common eider and velvet scoter. Information on the food resources and correlations between distribution of birds and their prey is particularly needed for sea ducks in the sublitoral in offshore waters.

Basic knowledge on the fish and crustacean fauna as valuable food for seabirds is missing in the Wadden Sea and adjacent offshore area. It is recommended to put more emphasis on this topic in research programs, and also to include this parameter in a regular monitoring program. This information is urgently required to judge the effects of food quality and abundance on seabird population (*i.e.* body condition, reproduction success) and to derive appropriate management measures.

Due to the strong pressure by the current and future multiple anthropogenic activities in the offshore zone, a science-based and integrated marine spatial planning will be of key importance in order to ensure sustainable expansion of human activities in the marine environment. Such planning schemes have to take into account on one side location and ecological effects of offshore wind farms, shipping lanes and sand and gravel extractions / dumping of extracted material, and on the other side biological ressources such as those outlined in this chapter.

The importance of the offshore zone for birds has been demonstrated again in this chapter. It is strongly recommended to continue the monitoring program of birds in the offshore zone of the Wadden Sea that has been started by Schleswig-Holstein in 2004, and to extend it to Niedersachsen, Denmark and The Netherlands.

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WADDEN SEA ECOSYSTEM No. 25

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Breeding Birds

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1. Introduction

Little Tern
(Photo: Jan van de Kam)

In addition to 10-12 million migratory birds, the Wadden Sea also supports large numbers of breeding birds. For several breeding bird species like Eurasian spoonbill *Platalea leucorodia*, oystercatcher *Haematopus ostralegus*, avocet *Recurvirostra avosetta*, Kentish plover *Charadrius alexandrinus*, common redshank *Tringa totanus*, lesser black-backed gull *Larus fuscus*, gull-billed tern *Gelochelidon nilotica* and sandwich tern *Sterna sandvicensis,* the salt marshes, dunes and outer sands of the Wadden Sea are among the most important breeding sites in Northwest-Europe. Several species are included in Annex I of the EU-Bird Directive or listed as Species of European Concern (SPEC). At national level, many Wadden Sea breeding birds represent an important share of national breeding bird populations and are listed as Red List species.

Monitoring of breeding birds in the Wadden Sea has been carried out by the Joint Monitoring Group for Breeding Birds (JMBB) in the framework of the Trilateral Monitoring and Assessment Program (TMAP) since 1991 (Fleet *et al.*, 1994; Melter *et al.*, 1997; Rasmussen *et al.*, 2000; Koffijberg *et al.*, 2006). The monitoring scheme currently focuses on 35 species that are considered characteristic of the Wadden Sea ecosystem. Common breeding birds (eight species) are counted annually in 103 representative census areas evenly distributed over all regions and habitats. Colonial and rare breeding birds (27 species) are difficult to survey with census areas, so they are counted by annual complete counts across the entire Wadden Sea. In the past, a total count of all species, including common species, has been carried out every five years (1991, 1996, 2001, 2006). However, the interval has now been changed to six years, so the next survey is due in 2012). The monitoring scheme aims to assess and detect population size, distribution and population trends in Wadden Sea breeding birds. Fieldwork is standardized and carried out according to trilaterally harmonized methods (Hälterlein *et al.*, 1995) by nearly 500 ornithologists, mainly consisting of staff of NGOs, governmental bodies, site managers and volunteers. A so-called Quality Assurance Meeting (QAM) is organized regularly to provide a platform for exchange of field experience among participants and for discussion of specific counting pitfalls (*e.g.* Blew, 2003).

This chapter presents an update of the QSR 2004 (Koffijberg *et al.*, 2005). It mainly focuses on trends in numbers of breeding birds 1991-2006 and highlights some recent developments and related management issues. Finally an evaluation of the targets of the Wadden Sea Plan (1997) is made and recommendations are given regarding monitoring, research and assessment of management issues.

2. Trends in breeding birds 1991 - 2006

The results presented here were derived from the data that currently are being processed for the next trilateral breeding bird report on the total count of 2006 (Koffijberg *et al.*, 2009). All trend analyses have been carried out with the commonly used package TRIM from Statistics Netherlands (Pannekoek and van Strien 1999). Significance was tested for p <0.05 by use of a Wald test.

2.1 Overall trends

Reliable trend estimates are available for 29 species for a period of 16 years (other species were too rare to allow proper trend estimates). Between 1991 and 2006 nearly half of the monitored species (13) have been subject to declines (Table 1). Furthermore, 8 species have increased whilst 7 species have remained stable. Gull-billed tern, for which the Wadden Sea is the only known breeding site in Northwest-Europe, is the sole species for which no significant trend could be detected. Today, this species is only breeding in the Schleswig-Holstein part of the Elbe Estuary, where recorded numbers fluctuate, although not significantly.

The rate of population change differs between species (Figure 1). With 11 out of 13 declining species, the strongest declines have been observed in waders. Dunlin *Calidris alpina schinzii*, ruff *Philomachus pugnax* and common snipe *Gallinago gallinago* still teeter on the verge of extinction and might well disappear before the next total count in 2012. All three species have also suffered major losses in other parts of their breeding ranges (Zöckler, 2002; Thorup, 2006), and their Wadden Sea breeding sites (mainly in Denmark) are only maintained by taking specific conservation measures (Thorup, 2003). Declines in dunlin are especially worrying as the small population in the Wadden Sea is part of the vulnerable Baltic population of the subspecies *schinzii*.

Of the regularly breeding wader species, Kentish plover and great ringed plover *Charadrius hiaticula* show the highest rate of decline and have abandoned many breeding sites in the past decade. Both species are known to suffer from disturbance by beach recreation (Schulz, 1998; Tulp, 1998). In addition many temporarily used breeding sites (embankments, industrial areas) have been deserted as vegetation succession made habitat unsuitable to breed (Hälterlein, 1998). Besides, natural coastal dynamics – a prerequisite for creating suitable habitat for these species – is lacking at most sites due to coastal defense policies. Conservation measures (*i.e.* prevention of disturbance at potential breeding sites) have been carried out in several parts of the Wadden Sea, but failed to halt further declines. Kentish plover is still thriving only in Denmark, and hopefully further investigations will provide some clues as to what measures could improve the situation for both plovers. Furthermore, management measures in the 'Het Tij Geleerd' program in The Netherlands might be able to restore some of the coastal dynamics and provide new breeding opportunities.

Among the other wader species, black-tailed godwit *Limosa limosa* and Northern lapwing *Vanellus vanellus* have declined as well, demonstrating that the Wadden Sea does not always function as a 'last refuge' as has been suggested earlier (Rasmussen *et al.*, 2000). Even if breeding performance in the Wadden Sea is enhanced by less intensive farming (as shown e.g. on the island of Mandø in Denmark, which supports the best breeding site in Denmark), population trends in both species are highly dependent on the situation in agriculturally-managed marshland areas behind the seawall (Thorup and Laursen, 2008). Here, habitat changes due to intensification of farming and increased predation rates (see below) have had a serious impact on breeding birds. In Denmark, where the coastal marshes are part of the trilateral cooperation area, recent analyses show a decline of 60% in all breeding bird species, including six Annex 1 species that have disappeared recently (Laursen and Thorup, in press.).

Largest increases have been observed in a number of colonial breeding birds, notably Mediterranean gull *Larus melanocephalus*, great cormorant *Phalacrocorax carbo sinensis*, Eurasian spoonbill, lesser black-backed gull, great black-backed gull *Larus marinus* and common gull *Larus canus*. In particular, Mediterranean gull and Eurasian spoonbill have expanded their breeding range from the southwest to the northeast in the past decade and have colonized most parts of the Wadden Sea. In coming years, these species will probably extend their breeding range further north. Great cormorant has shown signs of stabilization in most inland colonies in Europe (Bregnballe *et al.*, 2003) but it still explores new breeding and feeding sites in the Wadden Sea. Only settlement in Denmark has been halted so far, as nests and eggs are controlled annually to prevent successful breeding and expansion of the population (Bregnballe and Eskildsen, 2009). Elsewhere, a lack of safe breeding sites (mainly islands) might become a limiting factor, resulting in a saturation of the current population level.

Table 1:
Summary of trends of breeding birds in the Wadden Sea in 1991-2006. Trend classification of significant trends is expressed as moderate increase (+), strong increase (++), stable (=), moderate decline (-) or strong decline (--). Non-significant trends are indicated by F ('fluctuating'). For 2001-2006 trends have been classified as increasing (INC) or declining (DEC= when difference in indices between 2001 and 2006 were >10%; changes of <10% have been classified as stable (STA). This classification merely gives an indication on recent developments. Not included are little egret, barnacle goose, Eurasian wigeon and pintail, i.e. species that have been added to the list of counted species recently.

Species	DK	SH	NI	NL	Wadden Sea 1991-2006	Wadden Sea 2001-2006 tendency
Great cormorant *Phalacrocorax carbo*			+	++	++	INC
Eurasian spoonbill *Platalea leucorodia*			++	++	++	INC
Shelduck *Tadorna tadorna*	+	+	=	=	+	INC
Common eider *Somateria mollissima*	+	-	+	-	=	DEC
Red-breasted merganser *Mergus serrator*					++	DEC
Hen harrier *Circus cyaneus*			+	-	=	DEC
Oystercatcher *Haematopus ostralegus*	=	-	+	-	-	STA
Avocet *Recurvirostra avosetta*	F	+	=	-	-	STA
Great ringed plover *Charadrius hiaticula*	-	--	--	=	-	DEC
Kentish plover *Charadrius alexandrinus*	+	--	-	-	--	DEC
Northern lapwing *Vanellus vanellus*	F	-	-	-	-	DEC
Dunlin *Calidris alpina schinzii*					-[1]	DEC
Ruff *Philomachus pugnax*					--[1]	DEC
Common snipe *Gallinago gallinago*					-[1]	DEC
Black-tailed godwit *Limosa limosa*	-	+	-	-	-	DEC
Eurasian curlew *Numenius arquata*			F	-	-	DEC
Common redshank *Tringa totanus*	+	=	-	-	-	DEC
Turnstone *Arenaria interpres*	too rare to allow trend classification					
Mediterranean gull *Larus melanocephalus*				+	++	INC
Little gull *Larus minutus*	too rare to allow trend classification					
Black-headed gull *Larus ridibundus*	F	=	=	=	=	DEC
Common gull *Larus canus*	+	+	++	=	++	STA
Lesser black-backed gull *Larus fuscus*	++	++	++	++	++	STA
Herring gull *Larus argentatus*	+	=	-	-	-	DEC
Great black-backed gull *Larus marinus*	F	++			+	DEC
Gull-billed tern *Gelochelidon nilotica*	-	+	-		F	DEC
Sandwich tern *Sterna sandvichensis*	F	-	F	+	=	INC
Common tern *Sterna hirundo*	--	=	-	=	-	DEC
Arctic tern *Sterna paradisaea*	=	=	=	=	=	DEC
Little tern *Sterna albifrons*	+	=	=	+	=	DEC
Short-eared owl *Asio flammeus*			=	-	=	DEC

[1] trend classification not possible due to lack of data; classification is based on results of the surveys in 1991, 1996, 2001 and 2006.

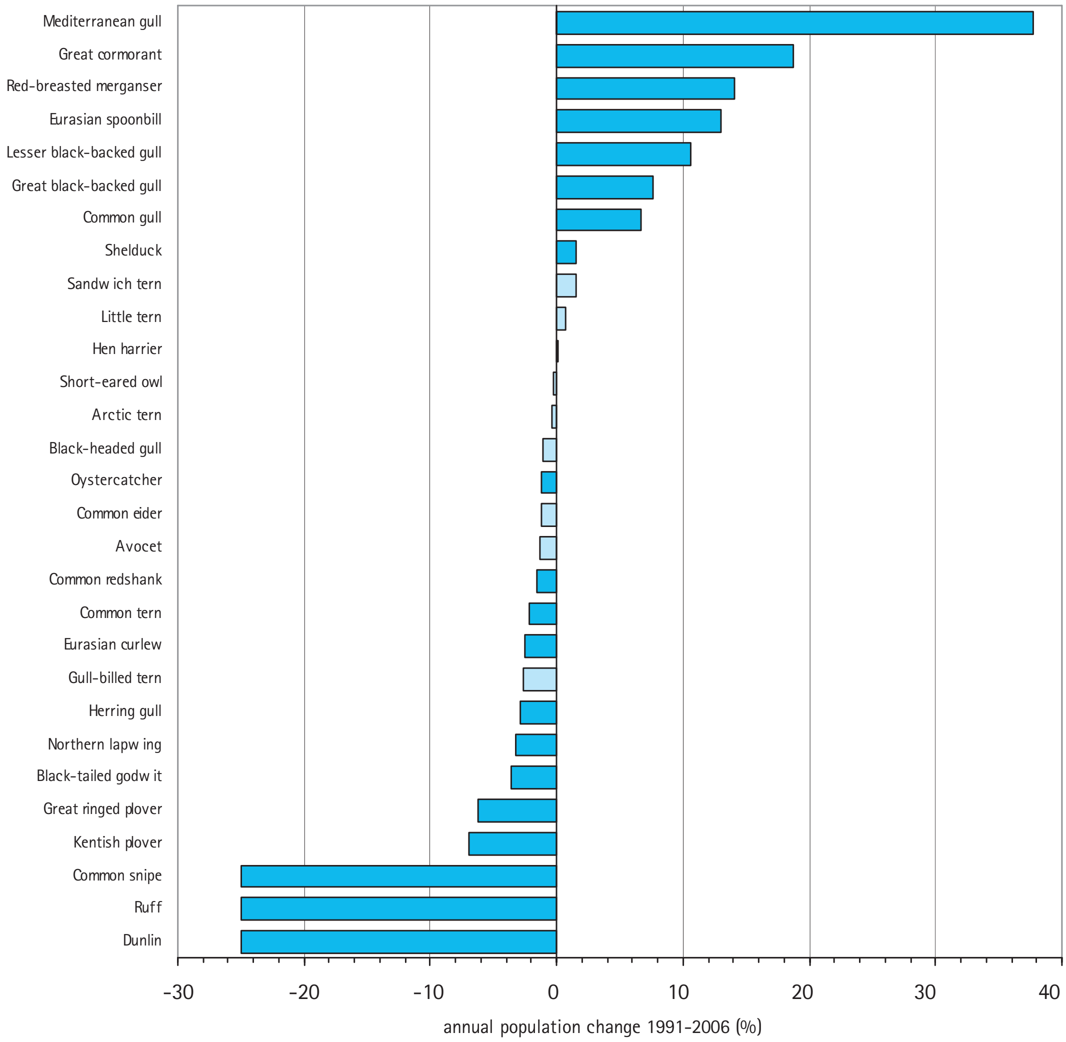

Figure 1: Trends in breeding birds 1991-2006, expressed as the rate of annual population change (in %). Non-significant changes are marked light-blue. Population changes in common snipe, ruff and dunlin are estimated from the data of the total counts 1991, 1996, 2001 and 2006.

2.2 Recent developments

For many species, the trends in 1991-2006 are consistent throughout the whole 16-year period. However, changes in indices between 2001 and 2006 suggest that some formerly thriving species or species with a long-term stable trend are tending to decline recently. This especially applies to common eider, arctic tern *Sterna paradisaea* and little tern *Sterna albifrons*. All three species have shown nearly annual declines since 2001, and their populations have suffered losses of 20-40% in the last five years. In common eider, downward trends have been reported already for a longer term in the important breeding areas in The Netherlands, due to limited mussel stocks that were depleted by fisheries (see below). The small populations of red-breasted merganser, gull-billed tern and great black-backed gull have tended to go down as well recently, but numbers are rather small and it is not clear if the observed trends are part of natural fluctuations or indicate a structural decline. On the other hand, rates of decline in oystercatcher and avocet have been lower from 2001 onwards, indicating that the long-term negative trend in these species seems to have leveled off. Increases in common gull and lesser black-backed gull have leveled off as well, suggesting that existing colonies are at saturation level and that perhaps density-dependent factors are starting to operate.

2.3 Regional differences in trends

Given the large geographical range and differences in management, it is not surprising that many species do not show comparable trends within the four sections of the Wadden Sea (Table 1, Figure 2). Regional differences in trends are important in several aspects. They might provide a first clue

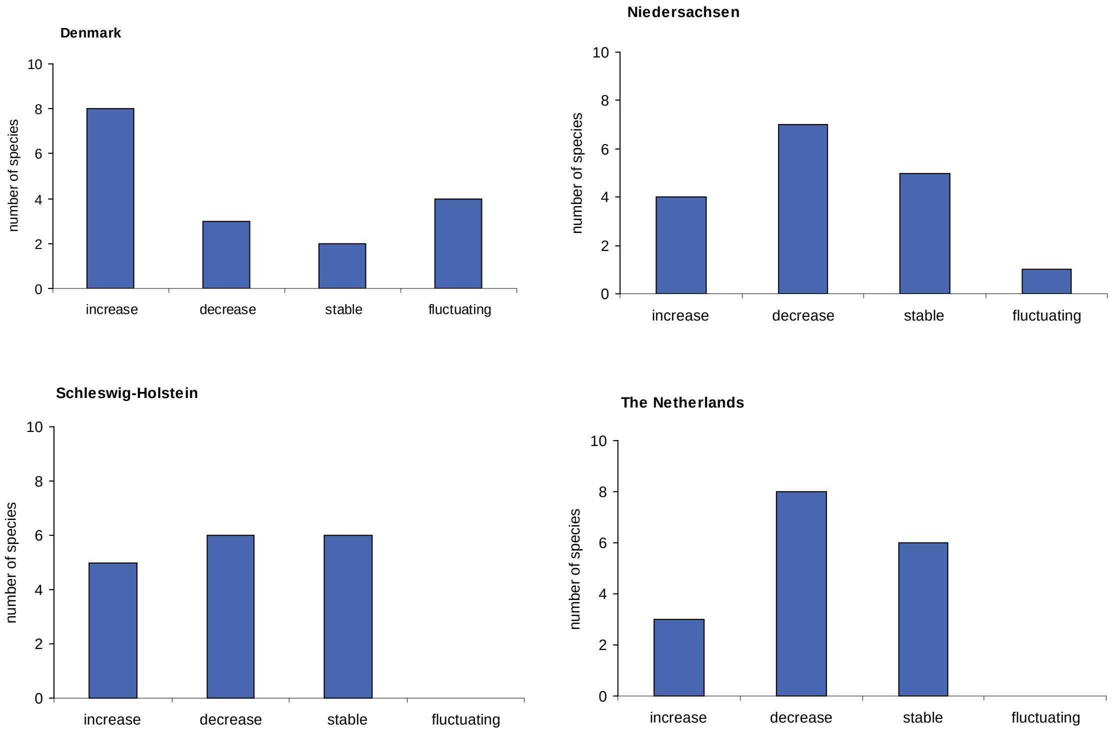

Figure 2: Summary of regional trends 1991-2006. Given is the number of species in each trend category for the four respective Wadden Sea countries. 'Fluctuating' represents non-significant trends. Only species that occur in relevant numbers in all four countries have been included (N = 17).

about the mechanisms that have caused bird populations to decline, especially when also comparing breeding success in the next years (after implementation of this parameter in TMAP has been completed). When analyzing the 17 species that breed all over the Wadden Sea, it is obvious that most populations breeding in the Danish Wadden Sea are generally doing well. The large number of fluctuating trends in this section of the Wadden Sea is probably a result of the small size of the Danish part of the Wadden Sea (and thus smaller breeding populations in many species). In the other three sections of the Wadden Sea different developments are more or less balanced, although in Niedersachsen and The Netherlands declining species are clearly dominating.

In most species no specific pattern in regional trends could be detected. However, remarkable differences in regional trends were found in oystercatcher (increase in Niedersachsen, declining or stable numbers elsewhere), great ringed plover (stable in The Netherlands, declining elsewhere) and Kentish plover (increase in Denmark, declining elsewhere). All three species are declining on the scale of the Wadden Sea. Furthermore, a south-north gradient appears in population trends of shelduck (increasing to stable towards the north), avocet (declining to increasing, apart from small fluctuating population in Denmark) and herring gull (declining to increasing). Further analysis is necessary to unravel the mechanisms causing these patterns.

2.4 Comparison with the QSR 2004

The last QSR 2004 (Essink *et al.*, 2005) included a trend assessment of Wadden Sea breeding birds for 1991-2001. In several species, recent developments have caused trends to change when looking at the whole 1991-2006 period and decreases have become more pronounced (Figure 3). This is mainly due to negative trends in populations of oystercatcher and avocet. Even if the rate of decline has tended to level off recently, populations in both species have declined by 20-30% since 1996. Common redshank has changed its previous status as stable into a declining trend, mainly as a result of declines of up to 40-50% in The Netherlands and Niedersachsen in some recent years. Besides, former increases in arctic tern and little tern have now turned into stable trends, with a recent tendency to decline (see previous section). Thus, several typical Wadden Sea breeding birds, including Annex 1 species (avocet, arctic tern, little tern) and/or species that breed in the Wadden Sea in internationally important numbers (oystercatcher, common redshank) are currently showing negative trends. Of the 14 Annex 1 species breeding in the Wadden Sea, five species show a long term decline, and an additional four species show a recent tendency to decline. Hence, the conservation status of many breeding birds has become worse compared to QSR 2004.

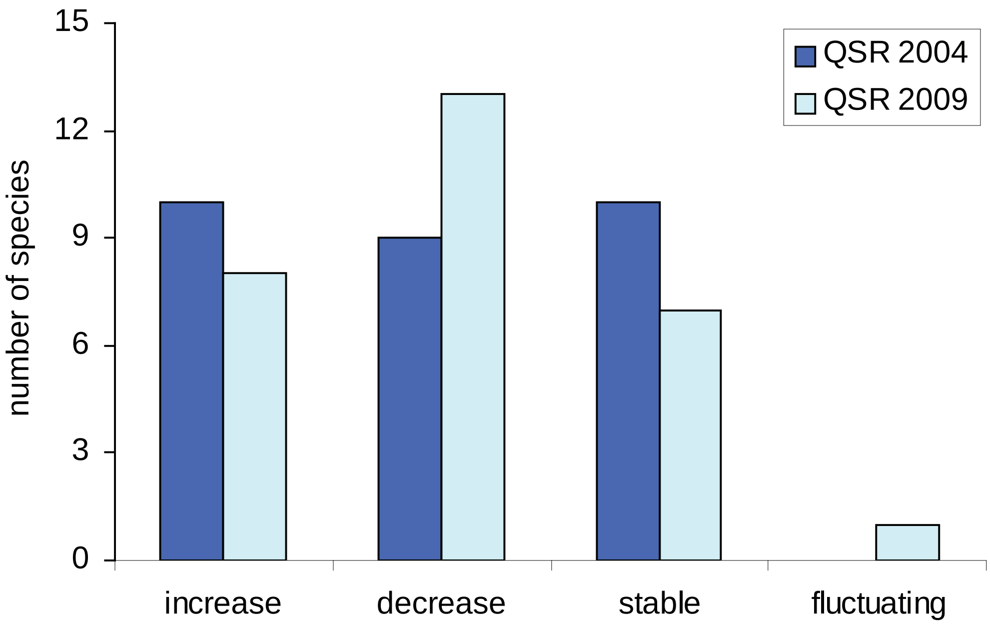

Figure 3: Summary of trends in the Wadden Sea based on assessment in 1991-2001 (QSR 2004) and 1991-2006 (QSR 2009). Compared to the previous QSR, negative trends have become more pronounced.

3. Target evaluation

The current Wadden Sea Plan (1997) puts forward two targets that are considered relevant for breeding birds: (1) favorable food availability and (2) natural breeding success. Two other bird targets, natural flight distances and sufficiently large and undisturbed moulting sites, are aspects that are mainly dealt with in migratory and wintering birds (see Laursen *et al.*, 2009). Being designed as a monitoring scheme, the data from the breeding bird surveys provide excellent information on the state of the Wadden Sea breeding birds, but they do not always provide information on the mechanisms that have caused bird numbers to change. Hence, it is mainly specific research carried out in the past decade, triggered by reports on declines, that has pointed at some processes going on in the Wadden Sea.

Regarding the target favorable food availability, especially shellfish-eating birds received much attention, particularly because of declines in the Dutch Wadden Sea in the 1990s. For oystercatcher and herring gull *Larus argentatus*, downward trends in breeding birds also coincide with negative trends observed in migratory birds (that are part of the same population dealt with in the breeding birds' scheme). Migratory and wintering common eider *Somateria mollissima* have been subject to declines as well, although only breeding bird numbers in the Netherlands (i.e. the core breeding area within the Wadden Sea) have gone down significantly so far. All three species have suffered from the limited stocks of food. This especially applies to blue mussels *Mytilus edulis* in the Dutch Wadden Sea, that were depleted mainly by shellfish fisheries at the beginning of the 1990s (Desholm *et al.*, 2002; Rappoldt *et al.*, 2003; Ens *et al.*, 2004; Leopold *et al.* 2004; Verhulst *et al.*, 2004; Kats 2007). In the eastern part of the Dutch Wadden Sea some recovery of mussel beds has been observed recently, but overall stocks remain much lower than before 1990 and a population recovery in shellfish eating (breeding) birds has not been observed so far. For oystercatcher, Van de Pol *et al.* (2007) have also shown that the chance of flooding (due to more stormy weather) in the breeding season has increased and has had a negative impact on breeding performance. This clearly demonstrates the possible impact of changing weather patterns as part of global climate change (also affecting other breeding birds breeding on the fringe of water and land). In herring gull, the general abandonment of open rubbish dumps will have contributed to the negative trend as well (Koffijberg *et al.*, 2006). Apart from the rather well-investigated shellfish-eating birds, the role of available food stocks in other species groups is largely unknown and has not been investigated in detail so far. In shellfish-eating birds, the long-term decline and low current population level demonstrate that their conservation status is not satisfactory at the moment.

Breeding success is another important target in assessing the status of breeding birds. An important issue that has been pointed at in several recent assessments is the lack of breeding success due to presumed high predation rates. Declines in avocet at least for some sites in Niedersachsen and the eastern Wadden Sea in The Netherlands, seem to be associated with low reproduction rates due to high predation risk, mainly of red fox *Vulpes vulpes* (Willems *et al.*, 2005, de Boer *et al.*, 2007; Melter and Vaas, 2008). Predation is also know to play a role in common redshank (Thyen *et al.*, 2005), black-headed gull (Oltmanns, 2003; Koffijberg *et al.*, 2006) and common tern *Sterna hirundo* (Dijksen and Koks 2003), and also has contributed to the declines in many farmland-breeding waders (Teunissen *et al.*, 2005; Langgemach and Bellebaum, 2005, Thorup and Laursen, 2008). But, its impact at Wadden Sea scale is not clear as breeding success has not been monitored yet and specific studies to quantify predation rates in the Wadden Sea are scant. Birds breeding on the mainland coast are especially susceptible to predation, as usually important mammalian predators like red fox or mustelids are absent on most islands. This probably also explains that species like avocet and black-headed gull are doing better on island-breeding sites (trend 1991-2006: stable) than along the mainland coast (trend: 1991-2006 decline). However, in common redshank only, trends in Niedersachsen differ from the expected pattern (stable on islands and declining mainland), but at the scale of the entire Wadden Sea, populations both on islands and along the mainland coast are going down. Trends in common tern are opposite the picture that would be expected from predation risk: populations on the mainland coast are performing better than those on islands. In this species, food availability might be a better explanation for the observed trends (Brenninkmeijer *et al.* 1997; Stienen *et al.*, 2009; cf. recent declines in arctic tern and little tern), but again, this aspect has not been investigated in detail. Breeding on the fringe of land and water, terns are also susceptible to flooding during the breeding season, as has been demonstrated frequently for breeding sites like the island of Griend in the Dutch Wadden Sea (Stienen *et al.*, 2009; cf. oystercatcher mentioned previously).

Breeding success is an important parameter that has not been monitored trilaterally so far. Hence, a proper evaluation of the target for natural breeding success is not possible yet. The pilot project 1996-97 (Exo *et al.*, 1996; Thyen *et al.*, 1998) showed the importance of this parameter and previous QSR have recommended that breeding success should be monitored (de Jong *et al.*, 1999; Essink *et al,.* 2005). Therefore, the recent decision to include monitoring of breeding success as a parameter in TMAP is a major advance. It will be fully implemented in the breeding season of 2010, but some fieldwork has already started in 2009. In The Netherlands, a monitoring program on breeding success has been carried out since 2005, initially as part of an investigation of shellfish-eating birds (Willems *et al.*, 2005) and now in the framework of a governmental monitoring and research project (de Boer *et al.* 2007). For three of the six species surveyed in The Netherlands (oystercatcher, avocet and herring gull), it was shown that downward trends observed in these species in the Dutch Wadden Sea are indeed triggered by a poor breeding performance. Extension of monitoring of breeding success to other parts of the Wadden Sea would enable a better insight into the mechanisms that cause changes in breeding bird populations (and e.g. the role of predation). It would also help to build understanding of regional differences in the patterns observed and their possible links to management issues or other TMAP parameters like contaminants in bird eggs (Becker and Muñoz-Fuentes, 2004).

4. Conclusions and Recommendations

4.1 Summary and conclusions

Analyses of trends of Wadden Sea breeding birds in 1991-2006 show that 13 of the 29 analyzed species are in decline. Recent counts suggest that (further) declines also occur in common eider, arctic tern and little tern. Declining trends are most obvious in waders: 11 of 13 declining species are in this group and they include both salt marsh breeding species like oystercatcher, avocet and common redshank and more farmland-dependent species like Northern lapwing and black-tailed godwit. Dunlin, ruff and common snipe have nearly gone extinct and their survival is mainly dependent upon management of their remaining breeding sites in Denmark. Backgrounds of the observed trends are only partly known. At least in some species it has been demonstrated that breeding success has been low for many years, but as breeding success has not been monitored trilaterally so far its impact on Wadden Sea level can not be quantified. Depleted food stocks have had a negative impact on especially shellfish-eating species (common eider, oystercatcher and herring gull), but to what extent other species are also affected by food availability is unknown. In Kentish plover and great ringed plover, disturbance caused by outdoor recreation and habitat changes are important limitations that prevent a recovery from the long-term declines observed in both species. At least at local scale, some species have suffered an increase in predation rates (notably avocet, but possibly also other species breeding on the mainland coast), demonstrating how important it is to keep islands free from mammalian predators. The impact of other factors, like changes in salt marsh management, climate change and/or changes in the Wadden Sea ecosystem are largely unknown yet. Compared to the QSR 2004, negative trends have become more dominant, suggesting that the conservation status in many species has become worse recently. The evaluation of the targets of the Wadden Sea Plan shows that at least some shellfish-eating breeding birds are affected by less favorable food availability. Breeding success has not been monitored yet, but at least in some declining species it has been demonstrated in national schemes that declining populations are associated with a poor breeding performance.

4.2 Recommendations

Following recommendations in previous QSR, incorporation of the parameter of breeding success in TMAP in 2009-2010 is one of the most important achievements in breeding bird monitoring in the past decade. It will produce a major gain in knowledge of the backgrounds of changes in bird populations and the cause of the recent declines in many species. Furthermore, following collaboration between the responsible ministry, fishery societies and NGOs, changes have been made to working practices in shellfish (mussel) fisheries in The Netherlands in 2009. These aim to produce a sustainable method of mussel exploitation for human use without affecting food stocks for shellfish-eating birds and to increase the likelihood of mussel beds recovering. For future management, monitoring and research the following measures are recommended:

4.2.1 Management and conservation

- Improve conservation status of beach-breeding species (Kentish plover, great ringed plover, little tern) by prevention of disturbance from outdoor recreation;
- Improve a more bird-friendly management of the most important agriculturally-managed marshland areas behind the seawall;
- Prevent increase of predation risk at island breeding-sites by reducing the possibilities of ground predators reaching the islands (e.g. when improving dams);
- Adapt targets in the Wadden Sea Plan to the conservation objectives in the EU Birds and Habitats Directives;
- Data collection in monitoring of changes in shellfish fisheries;
- Data collection in conservation measures taking place in dune areas.

4.2.2 Monitoring and research

- Initiate studies that deal with salt marsh management and its impact on breeding birds, i.e. link data from different TMAP parameters to get insight into what extent changes in salt marsh vegetation (and management) affect breeding bird densities;
- Initiate studies to assess the current decline in terns, mainly by involving data series on fish monitoring;
- Encourage ringing of breeding birds in the Wadden Sea to enable assessment of mortality rates, emigration and immigration, and their role in population declines.

Furthermore, in coming years years, a system of so-called alert limits will be established. So far, presentation of trend data has been quite basic, using simple symbols to indicate declining, stable, increasing and fluctuating populations. This approach requires some general knowledge of population dynamics in breeding birds. Moreover it is sensitive to annual variation in numbers as it does not take into account the species' biology. In the United Kingdom, alert-limits have been established successfully to indicate trends in bird numbers and initiate conservation action that has to be taken when alerts are flagged (Atkinson et al., 2006). Alerts are pre-defined trend classifications that express population changes within certain time-windows (e.g. 5, 10 or 25 years). When declines exceed certain threshold values (e.g. 25 or 50%), an alert is flagged. Alerts are flagged for short- and long-term changes. Moreover biological filters can be applied to analyze a species' biology (e.g. short- versus long-lived). The use of alerts will be introduced along with regular updates of

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Migratory Birds

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1. Introduction

Photo: Jan van de Kam

For migratory birds using the East Atlantic Flyway the Wadden Sea is of great importance as a staging, wintering and moulting area. At least 52 populations of 41 migratory waterbird species breeding in a large part of the northern hemisphere, from Canada in the west to Siberia in the east, use the Wadden Sea on their movements to the winter areas, that include Western Europe, the Mediterranean, West Africa and as far south as South Africa (Meltofte et al., 1994). Of these 44 populations belonging to 34 species the numbers are of a magnitude that the Wadden Sea can be considered as their most important stop-over site during migration, or their primary wintering or moulting ground (Blew et al., 2005a). When including the turnover rate of the birds, the total number of migrants is estimated at 10-12 million individuals.

The Joint Monitoring of Migratory Birds (JMMB) in the Wadden Sea, carried out in the framework of Trilateral Monitoring and Assessment Program (TMAP), consists of (a) at least two synchronous, complete counts each year, one of them in January, the other one in another month shifting from year to year; (b) frequent (bi-monthly to monthly) spring tide counts at 60 sites; and (c) an additional three counts for geese and aerial counts for shelduck and eider (Rösner, 1993). These surveys allow estimations of numbers, phenology and trends. For a more detailed description see Blew et al. (2005a, 2007) and Laursen et al. (2009a). The trilateral counts were initiated in 1980 and from 1987/1988 a solid counting scheme was established. This paper presents results from 1987/1988-2006/2007, thus covering a period of 20 years.

This chapter is an update of the QSR 2004 (Essink et al., 2005; Blew et al., 2005b) summarizing the results of the latest JMMB report covering the trends of 33 migratory bird species during a 20-year period from 1986/87-2006/07, and the common eider from 1992/93-2006/07 (JMMB 2008, Laursen et al., 2009a); in addition particular assessments are made concerning the ecological targets for migratory waterbirds according to the Wadden Sea Plan (Trilateral Wadden Sea Plan, 1997). The targets for favorable conditions for breeding and migratory birds are:

- Sufficiently large undisturbed roosting and moulting areas
- Favorable food availability
- Natural flight distances
- Natural breeding success*

* only relevant for breeding birds

2. Trend results for 20 years

Considering the results of the trends estimated for the period 1987/1988-2006/2007 for the entire Wadden Sea, eight species show a strong or moderate increase, 12 species are stable and 14 species show decreasing trends (Figure 1). Among the increasing species are the great cormorant *Phalacrocorax carbo*, Eurasian spoonbill *Platalea leucorodia*, barnacle goose *Branta leucopsis*, great ringed plover *Charadrius hiaticula*, grey plover *Pluvialis squatarola* and sanderling *Calidris alba*. Some of the stable species are brent goose *Branta bernicla*, Eurasian wigeon *Anas penelope*, red knot *Calidris canutus*, dunlin *Calidris alpina*, bar-tailed godwit *Limosa lapponica* and Eurasian curlew *Numenius arquata*. Among the decreasing species are common shelduck *Tadorna tadorna*, mallard *Anas platyrhynchos*, Eurasian oystercatcher *Haematopus ostralegus*, Kentish plover *Charadrius alexandrinus*, Eurasian golden plover *Pluvialis apricaria*, ruff *Philomachus pugnax*, whimbrel *Numenius phaeopus* and European herring gull *Larus argentatus*. The trend for common eider *Somateria mollissima* covers only the last 15 years and this is also decreasing.

2.1 Species and trend characteristics

To further study these trends, species have been allocated in relation to population and ecological features by six aspects: total numbers, trend of flyway population, proportion of flyway population migrating through the Wadden Sea, breeding and wintering grounds, and feeding habitat.

2.2 Increasing and stable trends

The three species, which show strong increases during the last 20 years in the entire Wadden Sea, also show increases in their flyway populations (Wetlands International, 2006). Of these, the great cormorant and Eurasian spoonbill are either exclusively or partly fish eaters, while the barnacle goose is an herbivore. In the other four aspects these species differ.

Five species show moderate **increasing trends** in the Wadden Sea, including northern pintail *Anas acuta*, great ringed plover, grey plover, Sanderling and curlew sandpiper *Calidris ferruginea*. All these species winter in tropical Africa while parts of their populations remain in Western Europe and the Mediterranean (Wetlands International, 2006), and all of these species except pintail breed in the Arctic.

Stable numbers were observed in 12 species. More than half of those species also have stable flyway numbers. They also share breeding and wintering grounds in the Arctic, Europe and Africa in similar proportions.

2.3 Declining trends

In total 14 species are in decline in the Wadden Sea. This fraction of species is dominated by species breeding in North, Central and Western Europe, and several of these species also winter there. A large part of the declining species use the polder areas or mussel beds for feeding, and are feeding on terrestrial arthropods, grass, seeds or mussels. However, other species that also feed on grass and seeds, for example the northern pintail and the northern shoveler *Anas clypeata*, are not decreasing, indicating that these food items are probably not the critical factors.

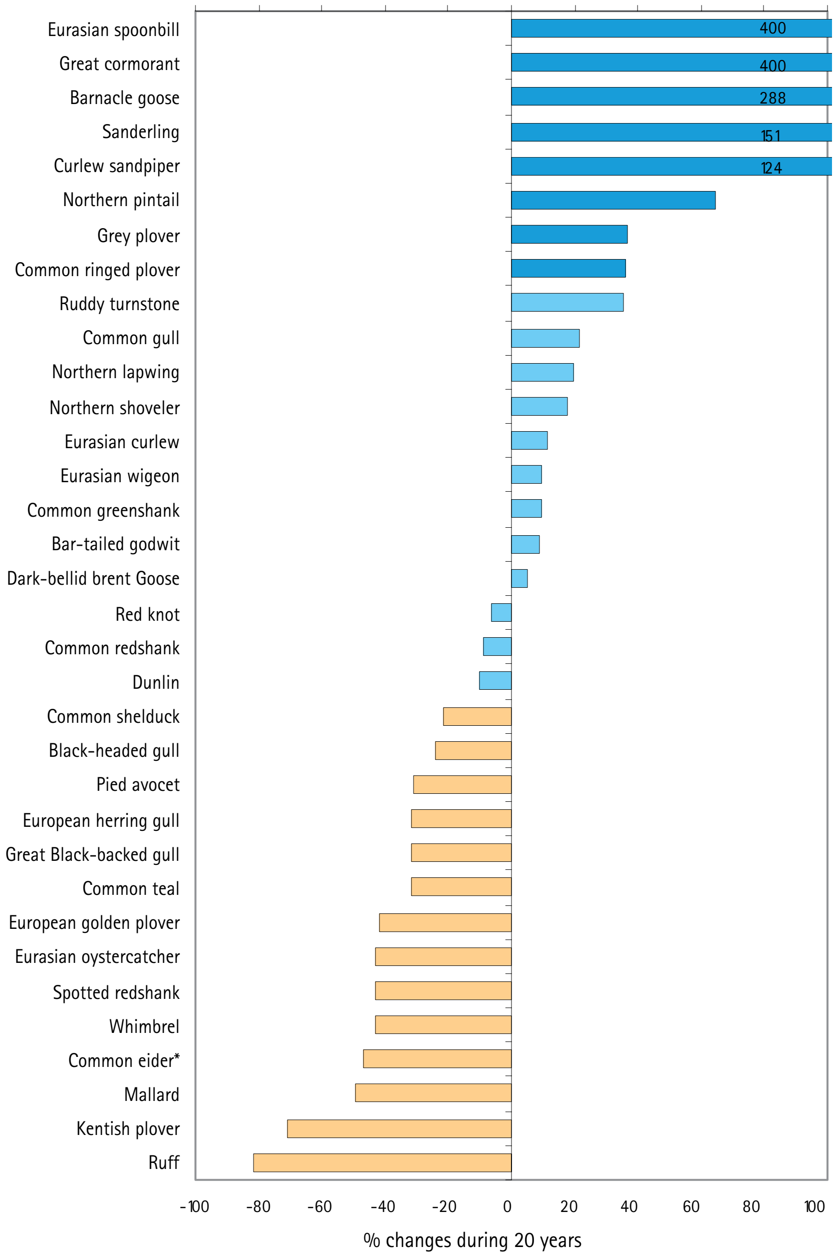


Figure 1: Changes in numbers of 34 migratory waterbird species in the Wadden Sea during 20 years (1987/88–2006/07). Dark blue columns indicate species with significant, increasing numbers; light blue indicate species with stable numbers and orange columns indicate species with significant, decreasing numbers. * Data for Common eiders are from 1992/93–2006/07.

3. Target evaluation

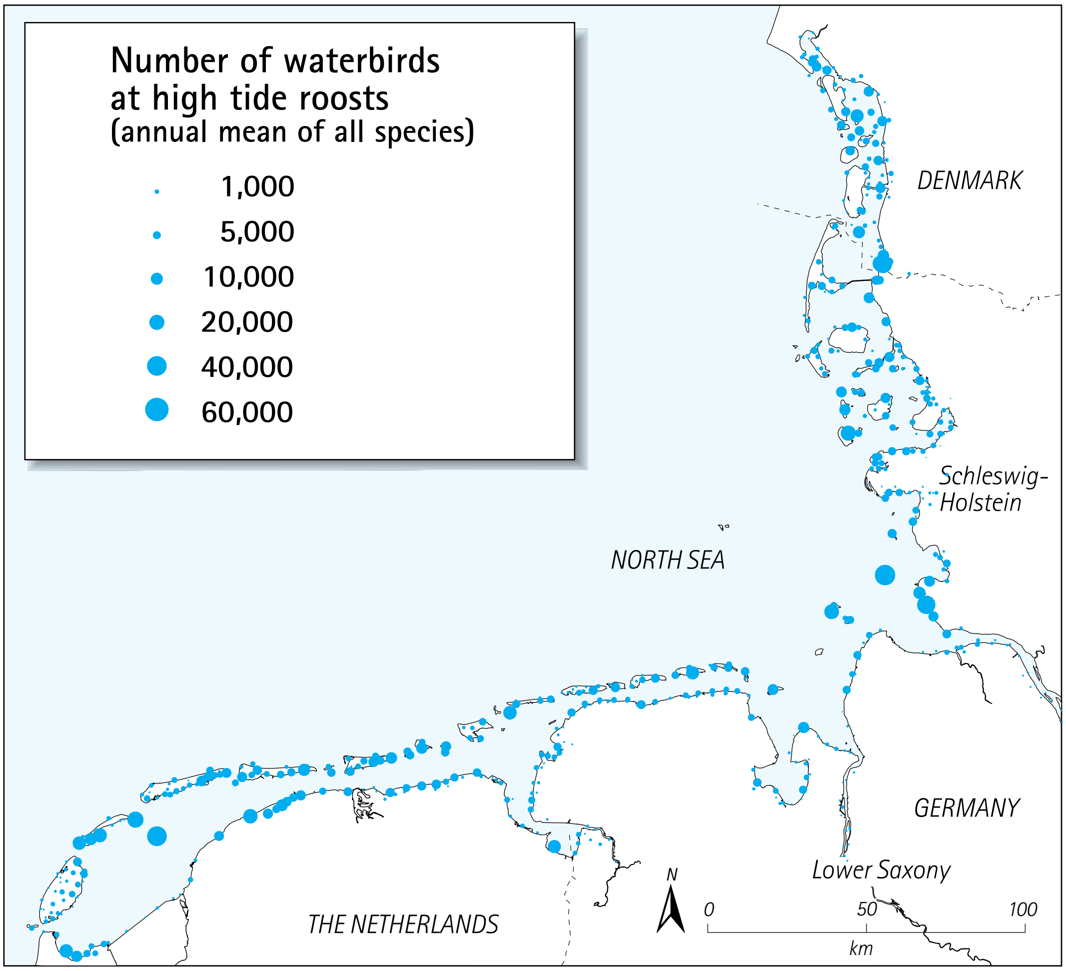
3.1 Sufficiently large undisturbed roosting area

Waterbirds in the Wadden Sea gather at roosting places during high tide, such as sandbanks, salt marshes or inland polders with wetlands. In most cases they roost near to the high-tide-line, following the tides. The safeguarding of these high tide roosts is an issue of conservation and protection of the waterbirds in the Wadden Sea. To assess the possible conflicts between the birds and human interests, the status has been assessed by Koffijberg *et al.* (2003). The numbers and species using a high tide roost in the Wadden Sea are influenced by many factors, including actual water level, distance to nearest feeding areas, preferred roosting habitat, social status of the birds and disturbance levels, both anthropogenic as well as natural predators. As a result, the species use a network of roosts. The largest roosting sites are located where large intertidal mudflats occur at close range and with low level of human activity (Figure 2). These combinations are found for example on small remote and uninhabited islands such as Keld Sand (Denmark), Süderoogsand and Trischen (Schleswig-Holstein), Scharhörn (Hamburg), Memmert and Mellum (Niedersachsen), Griend and Richel (The Netherlands).

3.2 Protection of roosting sites

Human disturbance is in some areas among the most important factors regulating bird numbers at high tide roosts, and it can put an extra stress on the species' energetic balance and their tight migration schedule. Studies have shown that recreational activities are among the most frequent sources of anthropogenic disturbances, and Koffijberg *et al.* (2003) describe that 29% to 42% of all roosting sites are subjected to moderate to heavy recreational pressure. Moreover, data on phenology show that the seasonal occurrence of some species is affected by recreational pressure where birds tend to avoid roosts visited regularly by people in the summer holiday season. As the summer holiday season recently extends more into spring and autumn, it can be expected that more recreational pressure will arise in the future, especially when regarding the timing of migration

Figure 2: Distribution of high tide roosts in the Wadden Sea expressed by the sum of annual means of all species. After Koffijberg *et al.* (2003).



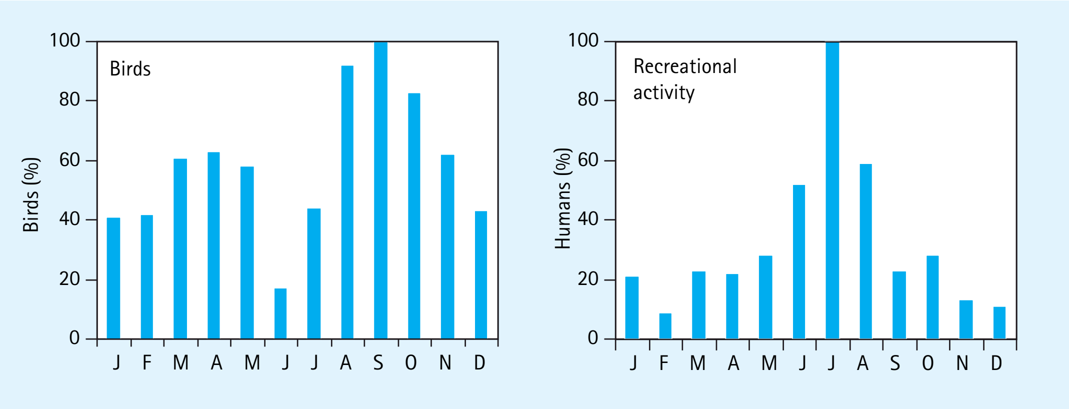


Figure 3: Occurrence (%) of migratory birds and human beings throughout the year in the Danish Wadden Sea. The highest value of both species is set at 100 %. Redrawn after Laursen *et al.* (1997).

of long-distance migrants, for which important numbers use the Wadden Sea as a stop-over in late spring (May) and summer (July-September) (Figure 3).

Hunting activities are considered to be the most disturbing human activity (Madsen, 1998). A moderate to heavy hunting pressure was observed in up to 33% of all sites in Denmark. Laursen (2005) showed a severe impact of hunting in the Danish Wadden Sea on the Eurasian curlew and it was concluded that the gradual hunting restrictions and the final hunting ban in Denmark in 1992-94 resulted in an increase of this species in the entire Wadden Sea at least during winter in the mid 1990s.

Regarding protection regimes, most countries have more than 80% of their high tide roosts inside areas designated as Special Protection Areas (SPA) under the Birds Directive and/or as Ramsar sites; distributional data show that these 80% of roosts are used by more than 90% of the species (Koffijberg *et al.*, 2003). However, in The Netherlands and Niedersachsen, the protection level is somewhat lower since both countries have large proportions of inland agricultural areas among their roosting sites which are subject to limited protection measures. Only in Niedersachsen, Schleswig-Holstein and Denmark are some of these areas included in the SPA, whereas in The Netherlands agricultural areas behind the dikes are not. Especially species as the barnacle goose and the dark-bellied brent goose, Eurasian golden plover and the curlew are known to utilize inland roosts in large numbers. In addition these areas become important for other species during particularly high water levels, when the regular roosting sites are flooded.

3.3 Sufficient large undisturbed moulting areas

Several waterbird species such as swans, geese and ducks moult their flight feathers simultaneously during a period of several weeks between May and September. During this period they are not able to fly, and the birds are extremely vulnerable to predators and human disturbance and therefore congregate in remote places. In the Wadden Sea and adjacent areas in the North Sea common shelduck, common eider and common scoters *Melanitta nigra* gather for their wing-moult in numbers of international importance. Thus, the Wadden Sea countries have a great responsibility for the protection of these species. However, the species moulting behaviors and phenologies differ, thus the management requires a species-specific approach.

The most important moulting sites for shelduck are almost exclusively situated within the southern Schleswig-Holstein Wadden Sea in the outer Elbe-estuary (Kempf and Eskildsen, 2000; Kempf, 2007). Up to 200,000 individuals concentrate at this site during late July and August, but they have shown decreases during recent years. Smaller but increasing numbers (10,000-20,000 birds) are moulting in The Netherlands (Leopold, 2003), where a new roosting site was found at Ballastplaat with 12,500 individuals during 2003-2004 and 23,000 birds in 2005 (Kraan *et al.*, 2006).

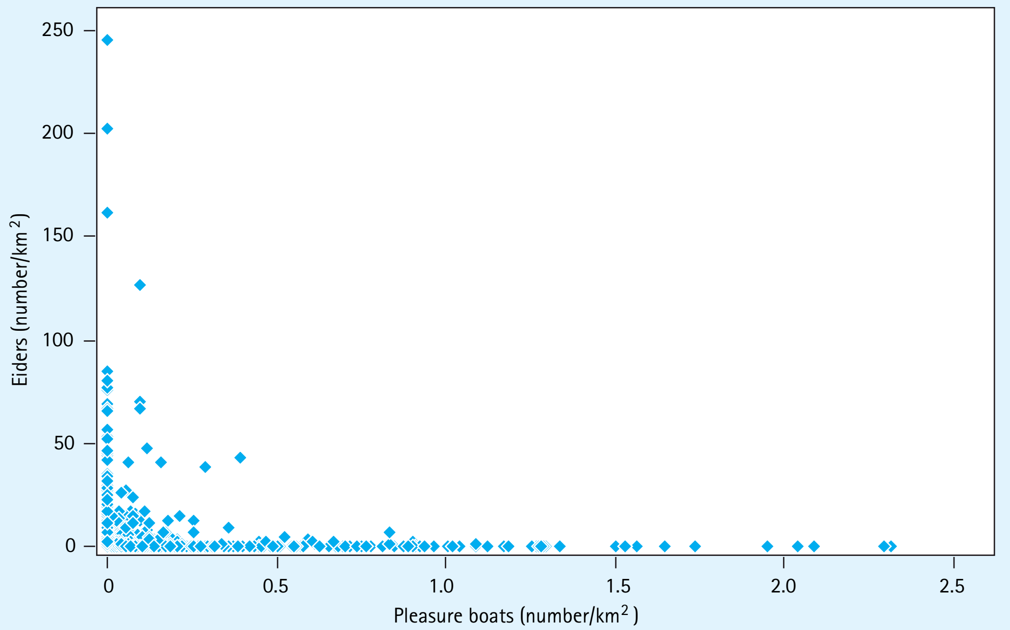
Common eiders moult from July until the end of August and beginning of September. The birds prefer areas with low disturbance levels, rich in shellfish stocks and roosting sites on sand banks. The moulting populations in the German and Danish Wadden Sea add up to 170,000-230,000 individuals during the last two decades (Laursen *et al.*, 1997a, Mendel *et al.*, 2008). However, the numbers have decreased from 1989 and onwards (Desholm *et al.*, 2002), with a steep decline since 1994 in the major moulting sites, the North-Friesian Wadden Sea (Scheiffarth and Frank, 2005). In the Dutch Wadden Sea up to 40,000 eiders were recorded in the 1980s. However, recent information is sporadic and suggests lower numbers. Other concentrations are located in remote areas such as the Randzel area near Borkum, the Hohe Weg near Mellum and the area between Elbe and Weser in Niedersachsen. The East-Frisian Wadden Sea between Juist and Wangerooge however is only sparsely used by eiders during the moulting season, probably due to tourist activities (Nehls, 1999). In Denmark, a negative relationship was demonstrated between the number of moulting eiders and the numbers of boats at sea, indicating that the eiders avoid sites with human activity (Laursen *et al.*, 1997)(Figure 4). In the Königshafen on the island of Sylt it could be demonstrated directly that wind surfing activity drove moulting eiders away from a rich feeding area (Ketzenberg, 1993).

Common scoters have the longest moulting period from June to October, since immature birds, males and females have consecutive moulting schedules. Compared to the other species, phenology and distribution of the moulting birds is less known, since this species prefers to moult in offshore areas and in dispersed flocks. The species is very susceptible to any source of disturbance; for instance the flight distance for an approaching ship is about two km and even longer. Intensive aerial counts in the late 1980s in Denmark reveal that about 110,000 common scoters were located off the Danish Wadden Sea during moult, and counts during the last decade show that at least 40,000 birds are still moulting there (Laursen *et al.*, 1997a; NERI data). Seaside of the German Wadden Sea about 65,000 common scoters are present during the moulting period (Deppe, 2005; Mendel *et al.*, 2008). However, it is likely that numbers of moulting scoters in Germany and The Netherlands are underestimated, making a proper assessment difficult.

3.4 Protection of moulting sites

Several activities such as boating, air traffic and oil spills can disturb birds or can have a big impact on the birds at their moulting sites. In some parts of the Wadden Sea these activities are regulated. Oil spills pose an immense potential threat during the entire year, more so for common scoters than for other sea bird species, since they occur near shipping lanes where most oil spills are observed (see QSR 2009 Thematic Report No. 5). In 1998 about 11,400 eiders and 3,700 scoters died due to the Pallas accident (Günther, 1998). Construction of offshore wind parks within the 12-mile-zone and the associated boat traffic would potentially reduce the area available for the moulting duck species. At least outside the moulting season, common scoters have apparently adapted to the presence of offshore wind parks (Petersen and Fox, 2007). Special Protection Areas (SPA) within and outside the Wadden Sea have been designated and offer a better protection with regard to offshore wind farms and other sources of disturbance. In Denmark, an offshore area of 2,463 km² was designated as an SPA in 2004 to protect especially red and black throated divers (*Gavia stellata* and *arctica*) and little gull *Larus minutus*, but other

Figure 4: Relationship between the density of pleasure boats and moulting eiders (15 July-15 September) recorded during 37 aerial surveys during 1980-1995 in the Danish Wadden Sea. Windsurfers are not included, since they are restricted inside two specific sites. Redrawn after Laursen *et al.* (1997).



species, including the common scoter *Melanitta nigra,* may also benefit. In Niedersachsen, an additional offshore area of 680 km² was designated as a nature reserve in 2007 (also appointed as SPA) to protect birds like sandwich tern *Sterna sandvicensis,* little gull, common gull, lesser black-backed gull and red-throated diver.

3.5 Favorable food availability: grazing and salt marsh management

The Wadden Sea region is an important staging area for the Arctic breeding barnacle goose and dark-bellied brent goose. In particular during spring large proportions (85 %) of both species stay in the Wadden Sea Area to prepare their spring migration to the Arctic breeding areas. Trend analyses of the barnacle goose show a strong increase during the last 20 years; for the dark-bellied brent geese an increase up to 1995 was followed by a decrease thereafter, overall resulting in a stable 20-year trend. Studies of the two goose species' habitat use, phenology and management have shown that the barnacle goose has expanded along the mainland coast and into regions outside the Wadden Sea especially during spring. During winter, the Wadden Sea area has become less important since a larger part of the population is grazing inland in Niedersachsen and the Netherlands (Blew *et al.*, 2005b). In addition, the species' staging period in the Wadden Sea is prolonged by 4-6 weeks into May, which means that the Wadden Sea has become increasingly important for the species to accumulate body reserves (Koffijberg and Günther, 2005). This change in migration strategies is supposedly caused by the extended breeding range to the western White Sea area, resulting in much shorter migration distance and increasing food competition on the Baltic staging grounds (Eichhorn *et al.*, 2009).

The dark-bellied brent goose population has decreased in numbers during a longer period after the mid-1990s due to low breeding success. However, the numbers have become stable and increasing numbers are seen in the core staging areas on the islands in The Netherlands and on the Halligen in Schleswig-Holstein. For both species changes on the breeding grounds can probably explain the change in numbers in the Wadden Sea. However, their feeding opportunities in the Wadden Sea have changed as well during the past decades by abandonment of livestock grazing in the salt marshes of Schleswig-Holstein and Niedersachsen. It is suggested that the number of dark-bellied brent geese could be four times higher during spring if all salt marshes were to be livestock-grazed (Bos *et al.*, 2005). Moreover, competition between the two goose species could also contribute to a change in their distribution (Koffijberg and Günther, 2005).

Other waterbird species as mallard and teal are depending on salt marshes as a feeding habitat, but, like the two goose species, they can also feed in inland polders. However, both species are declining in the Wadden Sea during the 20-year period. Only about 6%-8% of the flyway population of mallard and teal occur in the Wadden Sea, but due to their large population size, the maximum numbers are high, with up to 150,000 mallard and 40,000 teal counted in the Wadden Sea during autumn. A study of the feeding ecology shows that teal feed on seeds of *Suaeda maritima* and *Atriplex littoralis* in the salt marshes (Madsen, 1988). When these food resources are depleted, most teal leave the area and some switch to inland-feeding during night. The numbers of teal counted in the Wadden Sea fluctuate greatly from year to year, and in the Danish Wadden Sea, it is shown that these annual variations are highly correlated to the breeding success (Laursen and Frikke, 2006). Thus it is likely that changes in teal numbers are governed by conditions on the breeding grounds. Guillemain *et al.* (2005) also consider the distribution of teal on a larger geographical scale and argue that the milder climate during the last decade has changed the teal distribution from southern to more northerly areas closer to the breeding grounds. Thus the reason for the change in numbers is not likely to be found in the Wadden Sea.

Three species, Eurasian golden plover, whimbrel and ruff depend on inland marshes in polder areas. All species show declining numbers during the last 20 year period. Up to 6,000 individuals of whimbrels and ruffs only, but up to 130,000 individuals of Eurasian golden plovers, were recorded in the Wadden Sea area, which represents only a small proportion of the flyway population of each species. The habitats they use range from wetland areas used by the ruff to the drier grazed areas used by the Eurasian golden plover and whimbrel, which also use mowed meadows and (dune) heathlands. At present it is not likely that the causes for the decreasing numbers of these species are to be found inside the Wadden Sea region.

3.6 Favourable food availability: benthic feeders and shellfish fishery

Three species, the common eider, Eurasian oystercatcher and the herring gull, have declined in numbers during the past 20 years. These species are all feeding on shellfish, mainly blue mussels *Mytilus edulis* and cockles *Cerastoderma edulis,* which they take in the littoral (oystercatcher and herring gull) or the sublittoral zone (common eider). The red knot, also an obligate shellfish eater, was formerly also recorded as declining (Blew *et al.*, 2005a), but it is now considered as stable, due to increasing numbers in recent years in Denmark and The Netherlands (Laursen *et al.*, 2009a). The common eider is covered by aerial midwinter counts and analyses show strong declining numbers for the Baltic/Wadden Sea population during the 1990s (Desholm *et al.*, 2002); in the Wadden Sea winter numbers have also decreased during the last 10 years.

Blue mussel fishery occurs in all parts of the Wadden Sea, with the largest culture lots and landings being in The Netherlands and Schleswig-Holstein (see QSR Thematic Report No. 3.4). Mechanized cockle fishery was allowed in The Netherlands up to 2004 and in a few areas in Denmark (about 1% of the intertidal area)[1]. Due to depletion of the mussel stocks in Denmark in the late 1980s and low numbers of common eider (Dahl *et al.*, 1994; Laursen *et al.*, 1997b), the management of the mussel fishery was restricted to a few vessels; about half of the Danish Wadden Sea was closed to mussel fishery, and an annual setaside of about 10,000 tons of mussels for the mussel eating birds species was achieved (Kristensen and Borgstrøm, 2005). Due to the impact of the shellfish fishery and observed declines and/or mass mortality in common eider, Eurasian oystercatcher and red knot, a new management scheme was introduced in 1993 for the Dutch Wadden Sea and the Dutch Oosterschelde, including intertidal areas closed for cockle and mussel fishery and a policy of food reservation for shellfish-eating bird species, mainly oystercatcher. The effectiveness of this policy was evaluated after a 10-year period (Ens *et al.*, 2004). During the evaluation period from 1993-2003 there was virtually no fishery on intertidal mussel beds, eventually leading to the return of intertidal mussel beds, especially in the eastern part of the Dutch Wadden Sea. Despite this success, the measurements that were part of the new fishery policy introduced in 1993 were unable to halt the decline in the bird populations in general. Return of the intertidal mussel beds occurred only at the very end of the evaluation period and too little food was reserved for the birds. Instead of reserving the ecological food needs, the policy of food reservation was based on the physiological food needs which were less than a third of the ecological food needs (Goss-Custard *et al.* 2004; Ens, 2006). The results showed that a complex set of factors led to an unfavorable food situation for birds. Both the common eider and the Eurasian oystercatcher suffered because of the low level of blue mussels and cockle after the intense period of fishery at the beginning of the 1990s (Ens *et al.*, 2004; Leopold *et al.*, 2004; Ens, 2006). Storms and severe winters can destroy mussel beds and decrease the food stocks. Eurasian oystercatchers can therefore be forced to switch to cockle stocks for which they have to compete with the cockle fisheries (Rappold *et al.*, 2003). The red knot may be taken as another example: the mechanical cockle fishery not only removed a considerable proportion of the cockles, but also changed the upper sediment layer, which severely reduced the ability of cockle larvae to settlethere. In consequence, the density of small sized cockles, suitable for the knots to feed on became too low to support the usual numbers of knots occurring in the Dutch Wadden Sea (Piersma *et al.*, 2001; van Gils *et al.*, 2006). Whereas shellfish stocks suffer, there are suggestions that kagworm *Nereis diversicolor* may benefit from mechanized cockle fishery (Leopold *et al.*, 2004; Kaan *et al.*, 2007).

The Dutch studies demonstrated that several years with massive die-offs of eiders were caused by food shortage, especially of sublittoral mussels (Camphuysen *et al.* 2002; Ens, 2006). When the eiders are weakened by starvation, parasites can kill the birds (Camphuysen *et al.*, 2002; Kats, 2007). From the Danish Wadden Sea it has been shown that a positive relationship exists between blue mussel stocks and the number of common eiders (Laursen and Frikke, 2008). Danish studies also demonstrated that during intensive mussel fishery in the 1980s the common eiders' body condition was good for those individuals feeding on blue mussels, while individuals feeding on alternative prey (including cockles) had a lower body weight (Laursen *et al.*, 2009b). Experiments on captive eiders indicated that thin-shelled (sublittoral) mussels were the preferred prey and the birds could not maintain their body condition when forced to feed on cockles with poor flesh content (Ens

[1] Gathering cockles by hand (via a kind of rake called "wonderklauw") is still allowed in the Netherlands to a maximum of 5% of the annual stock.

and Kats, 2004). In addition to the significance of the amount of blue mussels, (Nehls, 2001) has shown that also the quality of the mussels (*e.g.* thin shells and the right size interval) is important for the eiders.

For the Eurasian oystercatcher, results from the Dutch Wadden Sea showed that those individuals feeding at sites with mechanized cockle fishery had a poorer body condition and higher estimated mortality than those feeding in areas protected from mechanized cockle fishery (Verhulst *et al.*, 2004). Also, the breeding population of the oystercatcher in the entire Wadden Sea shows declines (Koffijberg *et al.*, 2009). A negative relationship between the consumption of the common eider and the Eurasian oystercatcher in relation to the amount of landed blue mussels in the Wadden Sea was found by Scheiffarth and Frank (2005), demonstrating that there is a conflict between the fishery and the bird species. The decline of the oystercatcher population in the Dutch Wadden Sea was primarily due to the removal of the intertidal mussel beds and to a lesser extent to mechanized cockle fishery (Rappoldt *et al*, 2003). According to recent estimates the current low population of oystercatchers wintering in the Dutch Wadden Sea is in accordance with the carrying capacity (Rappoldt *et al.,* 2008). For the herring gull, the shellfish fishery only partly explains the decreasing numbers. Herring gulls also experienced a decrease in the breeding population in the Wadden Sea region due to their reduced access to waste dumps (since 2004, most dumps have been covered and inaccessible), one of their feeding habitats.

3.7 Favorable food availability: prolonged stay during autumn and winter

Analyses of the species phenology in the Wadden Sea during the last 20 years (period 1987/88-1994/95 compared 1999/00-2006/07) show that during the recent period 61% of the species arrive earlier in autumn and 66% stay longer, before they continue their migration further south and west (Laursen *et al.*, 2009a). Both the Arctic breeding species and those species breeding in more southern latitudes show these differences, and they are more pronounced for the Wadden Sea region north of the River Elbe than for the south-western part. What this means for the management measures is not clear at the moment, but in general many species will spend more time in the Wadden Sea in the coming years, increasing the pressure on its food resources.

3.8 Natural escape distances

Natural escape distances have not been a part of the trilateral monitoring program in the Wadden Sea. However, a study in the Danish Wadden Sea shows that the escape distances are influenced by a number of species-specific parameters, such as wind force and visibility, flock size, body size, and area management *e.g.* if hunting is allowed (Laursen *et al.*, 2005). Comparisons between the escape distances in the Danish and the Dutch Wadden Sea showed that for the Eurasian oystercatcher, Eurasian golden plover, Eurasian curlew, bar-tailed godwit and the black-headed gull the mean escape distances were 1.4-2 times longer in the Danish than in the Dutch Wadden Sea (Laursen *et al.*, 2005, Smit and Visser, 1993). These differences were partly explained by higher human activities (both quality and regularity) in the Dutch Wadden Sea with the birds adapting to these higher disturbance levels, but more importantly to hunting, which during the study period was still allowed in parts of the Danish Wadden Sea; this potentially increased the species' alertness, leading to longer escape distances. A comparison of escape distances between hunted and non-hunted species showed that hunting increased escape distances significantly.

On the other hand, using the escape distance as a management measure is probably not straightforward. Experiments in Britain show that ruddy turnstones which were offered extra food at one site had a longer escape distance and were scanning more frequently for predators and flying further when disturbed, than individuals not offered extra food (Beale and Monaghan, 2004). These results made it difficult to interpret measured escape distances since birds exposed to a heavy disturbance stimulus (such as hunting activity) and birds having a good body condition both exhibit long escape distances.

4. Conclusions

4.1 Trends in waterbirds numbers

Trends for 34 waterbirds are now available for a 20-year period from the Wadden Sea (common eider only for 15 years), and show that 8 species have strong or moderate increases, 12 species are stable, and 14 species are decreasing. Thus, compared to the QSR 2004 there has been some improvement in the development for several species.

Based on a simple assessment, taking some approximations from the species' general biology, it shows that the species with strong increases in the Wadden Sea have also increased in their overall flyway populations. There have been moderate increases in species which winter in tropical Africa and breed in the Arctic. Of those species with stable numbers, more than half also have stable flyway numbers. The 'stable' species are breeding and wintering in the Arctic/Europe and have their wintering grounds in tropical Africa and Europe. Species that are in decline in the Wadden Sea are dominated by species breeding in North, Central and Western Europe. In addition, a large proportion of the declining species uses the inland polder areas or mussel beds for feeding.

Overfishing of mussel beds certainly contributed to the decline of species depending on mussels, but the reasons for the changes in numbers for most other species are not yet known. A more detailed approach to look at possible underlying factors has been undertaken with limited success. While high-quality bird data are available, some of the other factors (benthic fauna, sediments, etc.) are not available in the desired spatial and temporal resolution for the entire Wadden Sea area, preventing sophisticated statistical analyses. Some time series, *e.g.* benthos data, exist but may not be representative for the relevant Wadden Sea regions and some area-wide data series are too short or based on different methods and parameters. Suggestions for improvements has been provided in Ens *et al.* (2009).

4.2 Sufficient large undisturbed roosting areas

National and international protection regimes are covering most parts of the Wadden Sea including the majority of the roosting sites. However, the actual status regarding high tide roosts is not satisfactory (see Koffijberg *et al.*, 2003), and there has not been significant progress since the QSR 2004. The most serious potential conflicts are caused by recreational activity and its disturbance impacts. Outdoor activities take place near large roosting sites and tourist-related activities are reported to be expanding into late spring and early autumn, when some of the bird species are present in high numbers, putting an extra constraint on some of the declining species.

4.3 Sufficient large undisturbed moulting areas

In the Wadden Sea and its offshore area, large numbers of moulting common shelduck, common eider and common scoter occur, and several sites have numbers of international importance. The most important site for common shelduck in the southern Schleswig-Holstein Wadden Sea is considered sufficiently protected (National Park law and mandatory as well as voluntary regulations). Moulting shelducks are monitored in Denmark and Germany, but not in The Netherlands, where large numbers have been reported in recent years (Leopold, 2003), sometimes occupying completely new sites (Kraan *et al.*, 2006). A proposal has now been submitted by the JMMB group to establish an annual survey of the moulting duck species in the entire Wadden Sea.

Common eiders' moulting numbers and locations are available for Denmark and Germany, with sparse data from The Netherlands. Changes in distribution and numbers have been observed in the North-Frisian part of the Wadden Sea, but it is not known whether the numbers had decreased or moved to another site. While most moulting sites are well protected from disturbances, potential sites in the East-Frisian Wadden Sea between Juist and Wangerooge are hardly used by common eiders and it is assumed that the disturbance level, especially from recreational activities (e.g. pleasure boats), is too high.

For common scoter, only few details of the moulting population and distribution in the Wadden Sea and offshore areas exist; still many questions remain with regard to their ecology. Recent studies have been performed in Denmark and Germany within assessments for offshore wind farms. A more correct assessment of the escape distances of this shy species would require an experimental study design to be carried out before proposing concrete 'moulting reserves'.

More information is also urgently needed in relation to the planning of offshore wind farms and the associated traffic of maintenance ships, which can potentially affect the distribution and activity of common scoter at sea during the moulting season (*e.g.* Garthe and Hüppop, 2004; Petersen and Fox, 2007). An evaluation of suggested protection regimes was recently conducted for the German Exclusive Economic Zone of the North Sea (Garthe, 2003). A further assessment of the need of undisturbed moulting sites in and outside the Wadden Sea is needed.

4.4 Favorable food availability for herbivores

There are three herbivorous waterbird species (barnacle goose, dark-bellied brent goose, and Eurasian wigeon) and two semi-herbivorous waterbird species (mallard and common teal) in the Wadden Sea. Of these the barnacle goose shows a steady strong increase, the dark-bellied brent goose and the Eurasian wigeon are stable after a steep decrease in the mid-1990s and the common teal and mallard are decreasing. For none of these species does food seem to be the cause of their decreasing trends. With regard to the goose populations, salt marsh management and the use of inland feeding sites has been discussed, for example, in the Leybucht in Niedersachsen (Bergmann and Borbach-Jaene, 2001; Lutz *et al.*, 2003). The question is whether the salt marshes can or should be managed in a way that can support a maximum number of geese in order to reduce feeding in agricultural areas in contrast to other nature values such as climax salt marsh vegetation communities. This is a discussion occurring in Denmark, where barnacle goose numbers have increased. However, fertilized grasslands will always be of higher food quality and thus more attractive for the geese during some periods than the natural salt marshes. Since these conflicts only arise in a part of the species' yearly life-cycle and involve several countries, they are best solved on the species flyway level. Such a flyway plan had been put forward for the dark-bellied brent goose (van Nugteren, 1997), but has not been endorsed by the countries involved. In the years that have passed since then, barnacle goose numbers have increased further and with them also conflicts (Koffijberg and Günther, 2005). Here, solutions regarding special goose management schemes are to be developed (Laursen, 2002), aiming at a satisfactory co-existence. The Wadden Sea Forum recommends that the best way to deal with geese is a strategic, long-term international approach in which refuge areas for geese are designated. Within these areas farmers should be paid for tolerating grazing geese as well as for improving conditions for the geese, such as reducing disturbance. Outside these areas geese may be chased away or even hunted when necessary (Wadden Sea Forum, 2008).

The declining numbers of mallard, teal, golden plover, ruff and whimbrel that all partly use the polder areas are probably not caused by conditions in the Wadden Sea region, but for at least some of these species the declining numbers are likely to be caused by changes in climate conditions (Laursen *et al.*, 2009a).

4.5 Favorable food availability for benthivores

The QSR 2004 showed that four species depending on shellfish had declining trends. The situation seems to have improved for one of these species, the red knot, but common eider, Eurasian oystercatcher and herring gull are still decreasing. After the intensive mussel fishery in the 1980s and 1990s, regulations have been introduced in all three Wadden Sea countries. In the Dutch Wadden Sea, mechanized cockle fishery was stopped in 2004. At the same time the number of licenses for gathering cockles by hand was increased and the policy of food reservation was abandoned. Irrespective of the size of the stock, hand gatherers may fish 5% of that stock (which is close to the 6% annually fished by the mechanical cockle boats (Ens *et al.*, 2004), thereby probably decreasing the carrying capacity of the Dutch Wadden Sea for wintering oystercatchers (Rappoldt *et al.* 2008). Recently, the Dutch ministry of agriculture, nature and food quality, the mussel farmers and the major nature conservation organizations agreed to completely phase out dredging of sublittoral mussel seed in the years to come. The aim is to develop sustainable mussel fishery in the next decade, probably relying on artificial mussel seed collectors suspended in the water. In Denmark, improved calculation methods were applied and showed that the amount of blue mussels to be set aside for the mussel eating birds must be estimated based on the birds' ecological need, and not based on the physiological conditions; the ecological estimations are 5-7 times larger than the physiological values (Goss-Custard, 2004; Ens *et al.*, 2004; Ens, 2006); consequently during the winter of 2008/2009 a permission for mussel fishery was withdrawn.

Except for hand gathering of cockles in the Dutch Wadden Sea, these are important steps towards the targets of favorable food availability for birds; a further step could be to assess the blue mussel fishery policies in all Wadden Sea regions. However, to do that, regular monitoring of blue mussel stocks in both the littoral and sublittoral zones is needed, using the same or comparable methods in all the Wadden Sea regions.

4. 6 Natural flight distances

Knowledge of flight distances is an important tool in reserve designs (Fox and Madsen, 1997). In the Wadden Sea, moulting species such as the common scoter, common eider and shelduck are strongly affected by human activity during their moult season, which occurs from July to September, in the same period where many people enjoy their summer holidays. The birds gather in remote areas when moulting, and it is especially sailing with small pleasure boats that occurs in many parts of the Wadden Sea at that time of the year, that affects the moulting common eiders and common shelducks. The common scoters occur in more remote offshore areas, where they are vulnerable to larger ships and sailing boats; special concerns for this species are necessary when planning offshore wind farms due to the large associated ship traffic. However, to establish areas for common scoter, it is necessary to know their natural flight distance, and this has to be investigated using an experimental design.

For a number of waterbird species the natural flight distance is also an important aspect when improving the conditions on their roosting sites and when planning tourist activities, zoning regulations, onshore wind farms and other industrial and infrastructural developments. The phasing out of hunting activities, especially in Denmark, has reduced the natural flight distances for geese and considerably increased the number of curlew (Laursen, 2005). This development is an achievement complying with the target of natural flight distances.

5. Recommendations

Recommendations are listed in accordance with the ecological targets of the Wadden Sea Plan.

5.1 Sufficient large undisturbed roosting and moulting areas

Management

- Further develop spatial and temporal zoning for recreational activities;
- Acquire more information on natural flight distances when managing public access close to roosting sites;
- Assess impact of ultra light aircraft;
- Assess impact of small boats and canoes that have become popular and are able to sail in areas where the water depth is only a few cm;
- Provide sufficient protection to high tide roosts not included in designated SPA; especially a problem in The Netherlands;
- Evaluate potential disturbance from offshore wind farms and the associated ship traffic, with special attention for offshore moulting common scoters.

Monitoring and research

- Initiate a trilateral monitoring program for moulting common shelduck, common eider and common scoter;
- Investigate macrozoobenthos communities in the offshore area as food for the common scoter.

5.2 Favourable food availability

Management

- Evaluation of changes in the extent and method of shellfish fishery;
- Monitoring of the shellfish fishery including the seed fishery and the impact on bird species;
- Harmonisation of methods used for assessing and monitoring shellfish stocks;
- Support initiatives to manage goose species on trilateral level to reduce conflicts between farmers and geese;
- Encouragement to manage goose species on the flyway level.

Monitoring and research

- Include parameters (from a birds point of view) for benthos mass and benthos quality in the TMAP to facilitate assessment of bird numbers and their changes;
- Assess causal relationships between occurrence of birds and the availability of food stocks;
- Assess changes in distribution of geese in relation to changes in salt marsh management;
- Initiate studies of the origin/breeding areas of the bird populations using the Wadden Sea, thus allowing an improved assessment for changes observed;
- Introducing an alert system in the reporting system of species trends.

5.3 Natural flight distances

- Investigate escape flight distances of birds during roosting, moulting and under the influence of recreational activity.

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WADDEN SEA ECOSYSTEM No. 25

Quality Status Report 2009
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Marine Mammals

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1. Introduction

Aerial photo of harbour seals on a sand bank (Photo: Sophie Brasseur).

Marine mammals regarded as indigenous species in the Wadden Sea are the harbour (or common) seal *Phoca vitulina*, grey seal *Halichoerus grypus*, and harbour porpoise *Phocoena phocoena*. Several other marine mammal species, both pinnipeds and cetaceans, occur in the Wadden Sea and adjacent North Sea, either as stragglers or as regular visitors. Occasionally five other species of seals are encountered in the Wadden Sea area and adjacent North Sea. These are: harp seal *Phoca groenlandica*, hooded seal *Cystophora cristata*, ringed seal *Phoca hispida*, bearded seal *Erignathus barbatus* and walrus *Odobenus rosmarus*, all of which have a more northerly distribution. Cetaceans documented along the Wadden Sea coast are the white-beaked dolphin *Lagenorhynchus albirostris*, and white-sided dolphin *Lagenorhynchus acutus*. The occurrence (both living and dead) of large cetaceans in the Wadden Sea region since the QSR 2004, notably minke whales *Balaenoptera acutorostrata* and humpback whales *Megaptera novaeangliae*, is remarkable.

This chapter provides an update of the QSR 2004. Therefore it refers only to deviations from trends set out in the QSR 2004 and new information is provided. Issues of concern are given in the context of the Targets set for the harbour and grey seal, and the harbour porpoise in the Wadden Sea Plan as well as in the Seal Management Plans (SMP 1992, 1996, 2002, and 2007). These Targets are:

Viable stocks and a natural reproduction capacity of common/harbour seal, grey seal and harbour porpoise in the tidal areas and the offshore zone.

The present management of the species mentioned in the Targets is laid down in the Seal Management Plan, 2007-2010 (SMP).

(www.waddensea-secretariat.org/management/SMP/seals.html#smp)

Findings of the QSR 2004

The results from the assessment of the Target in the QSR 2004 can be summarized as follows:

Viability

Two components of viability analysis, genetic criteria and risk of extinction, can be used to indicate the persistence of a given population.

The size of the Wadden Sea harbour seal population is far beyond the threshold for inbreeding (5,000 to avoid inbreeding in the long term) and the numbers can therefore be regarded as viable.

It is safe to assume that with the PDV properties as operative in the area during the last epizootic, there is no significant risk of quasi-extinction of the harbour seal population in the Wadden Sea.

The grey seal situation is more complex. Data on life history parameters such as reproductive performance as well as survival in the colonies is lacking. Therefore, no conclusions can be drawn about the self-supporting capacity of these grey seal colonies.

There has never been a harbour porpoise population in the Wadden Sea and numbers observed reflect the distribution of harbour porpoise population(s) in the adjacent North Sea. Data to evaluate the Target for this species is lacking.

Natural reproduction capacity

No quantification can be given for the natural reproduction capacity of either the harbour seal, grey seal or harbour porpoise, because of insufficient knowledge of this parameter. Based on the data obtained for harbour seal populations in the Wadden Sea and the population in the Kattegat-Skagerrak, it is concluded that the reproduction capacity of the Wadden Sea population is at a satisfactory level.

Grey seals on the "Razende Bol" (Photo: Henk van Wijk).

2. Status

2.1 Grey seals

Following a long term decline since the Neolithic, grey seals became extinct in the Wadden Sea and along the Dutch North Sea coast by about 1500 AD (Reijnders *et al.*, 1995). Up until the mid-19th century, only occasional animals were reported on the Dutch, German and Danish North Sea coasts (Mohr, 1952, van Haaften, 1974). No regular pupping occurred until the end of the 1970s when a breeding colony was established near Amrum in the German Wadden Sea. Somewhat later, additional breeding sites were discovered near Terschelling/Vlieland in the Dutch Wadden Sea (1980) and at Helgoland (Reijnders and Brasseur, 2003, Härkönen *et al.*, 2007). Tracking of movements indicate these seal groups to be linked to larger populations in the UK. However, genetic studies are needed to ascertain population structure and determine the relationships between the populations of mainland Europe and the UK. Interestingly, the timing of both pupping (December/January) and moult (March/April) differ substantially between mainland Europe and the UK. Maximum numbers of grey seals counted during the moult in 2008 in the Wadden Sea are 1716 in the Dutch Wadden Sea, 174 in the Niedersachsen part of the Wadden Sea, 98 in the Schleswig-Holstein Wadden Sea, and 206 at Helgoland, amounting to a total of 2194 animals. The respective figures for the 2009 moult counts are 2108 in The Netherlands, 200 in Niedersachsen, 138 in Schleswig-Holstein, and 310 on Helgoland, bringing the total to 2756. This represents an increase of 26% in this last year. Grey seals are not specifically monitored in Denmark, but they are regularly seen in low numbers during harbour seal counts. The development in maximum numbers of grey seals counted in the last decades in the Wadden Sea is given in Figure 1.

Relative strongholds for breeding in the Wadden Sea are the western Dutch Wadden Sea, the Kachelotplate and Amrum in the German Wadden Sea, and Helgoland (German Bight). During counts in the pupping season of 2007/2008, 196 pups were recorded in the entire Wadden Sea: 107 in the Dutch Wadden Sea, 25 at the Kachelotplate, 12 pups off Amrum, and 52 pups at Helgoland. The corresponding figures for the season 2008/2009 are respectively 272, 29, 16, and 70, amounting to a total of 387 pups, which is about twice as much as the year before.

It is noted though that, increasingly, more grey seals are observed in other areas. This is particularly so in the eastern Dutch Wadden Sea and the western part of the German Wadden Sea. In the Netherlands, monitoring is therefore being extended to the probable new areas from 2009 onwards.

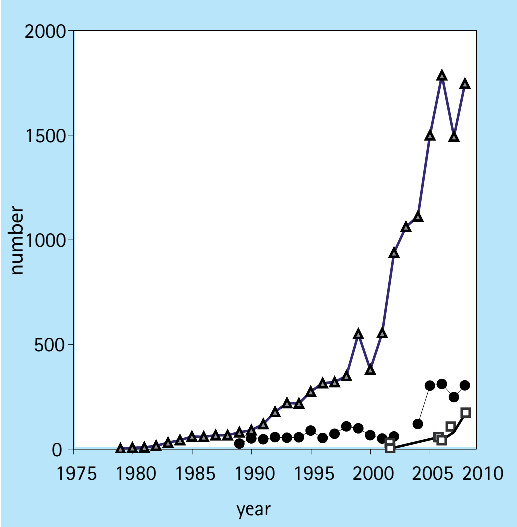

Figure 1: Counts of grey seals in the Wadden Sea during the moult (March/April). ▲ The Netherlands (source: IMARES); ● Schleswig-Holstein and Helgoland (source: National Park Schleswig-Holsteinisches Wattenmeer; □ Niedersachsen (source: Nationalpark Niedersächsisches Wattenmeer).

2.2 Harbour seals

Counts of harbour seals during the moult (August) are used to compare population changes over the years. In 2002, a second PDV-epizootic struck the population and in 2003 only 47% of the expected number of seals was counted: 10,800 animals. Interestingly, the average pup to total ratio in the period 2003-2009 is 27.1% (SD = 3.12), which is much higher than the 21.6% counted following the former epizootic. The surveys for 2003-2009 show that the numbers counted each year increased on average by 12.3% per year, demonstrating a prosperous recovery. Indeed, in 2009 the population counts revealed a total of 21,571 animals. This is clearly above its pre-2002epizootic level of 19,383 animals (Brasseur *et al.*, 2008, 2009). The pup percentage, presently still high, may indicate that the age structure of the population has not yet returned to stable proportions and could still be dominated by adult females. The recruit of young that were born after the epizootic will gradually lessen that influence. The changes in numbers of harbour seals counted in the Wadden Sea are given in Figure 2.

2.3 Harbour porpoise

For the period 2005-2009 five sources are available on harbour porpoise abundance in the Wadden Sea region and adjacent North Sea: the SCANS II North Sea wide cetacean survey in 2005 (SCANS II 2006, SMRU 2008), data from the German MINOS and MINOS+ project (Wollny-Goerke and Eskildsen, 2008; Gilles et al., 2008), a monitoring program in Niedersachsen (Gilles and Siebert, 2008), the

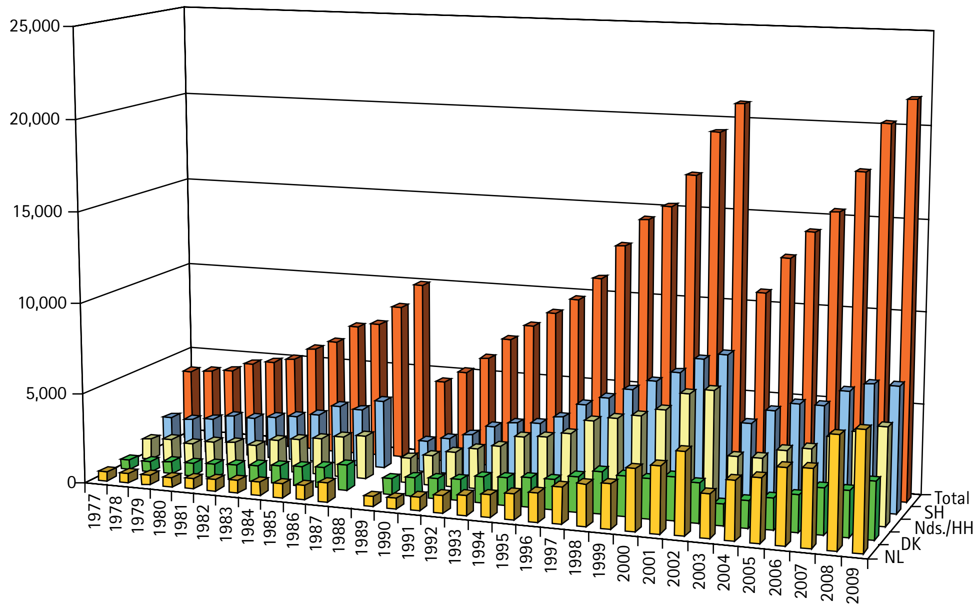

Figure 2: Number of counted harbour seals in the Wadden Sea since 1975; NL = The Netherlands, DK = Denmark, NdS/HH = Niedersachsen and Hamburg, SH = Schleswig-Holstein, Total = entire Wadden Sea

BEMLV project (Scheidat *et al.*, 2006), data from aerial surveys carried out by NERI (Teilmann *et al.*, 2008), and the sea watching data set of the Nederlandse Zeevogelgroep (see Haelters and Camphuysen, 2008).

The SCANS II data showed no difference in the total (North Sea) abundance of porpoises compared to the SCANS I (1994) data. However, in survey blocks north of 56⁰N the average density was about half of its level in1994, whereas for the survey blocks south of 56⁰N, the density was twice the one estimated in 1994 (SCANS II, 2006).

Data from Scheidat *et al.* (2006) and Gilles *et al.* (2008) reveal the highest densities in the German North Sea EEZ, in May 2005, when abundance was estimated at 64,506 animals (95% CI = 36,776-127,036) and in summer 2006, with an estimated 51,551 animals (95% CI = 27,879-98,910). Lowest estimates were obtained in autumn 2005 (e.g. 11,573 animals in October/November).

The Gilles *et al.* (2008) data further showed that the spatial distribution is not homogeneous, but animals have clear preferences for discrete areas. Hotspots were detected at Borkum Reef Ground and Sylt Outer Reef. Similarly, the Danish monitoring data showed that the highest densities were

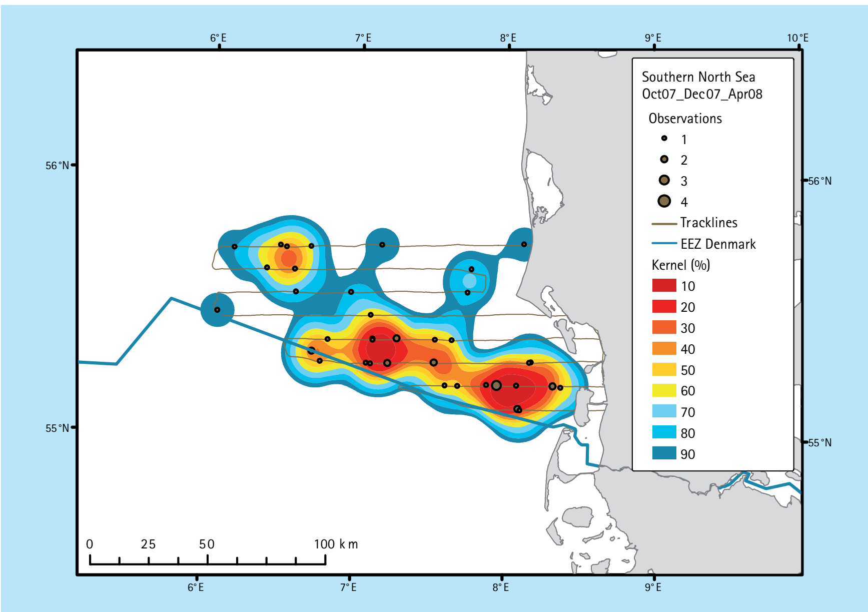

Figure 3: Combined data from three aerial surveys in October, December, 2007 and April 2008 with observations and kernel density contours. The color scale from blue over yellow to red shows increasing concentration of harbour porpoises.

found in the southern part of the Danish North Sea along the German border (Figure 3). Hotspots were also identified here, with one close to the Danish Wadden Sea (Teilmann *et al.*, 2008). The Danish data also showed a strong seasonality in sightings, with maxima in the summer period (Figure 4).

The Dutch sea watching data set demonstrates that the increase in harbour porpoise sightings in Dutch coastal waters mentioned in Reijnders *et al.* (2005) continued. A maximum sighting rate (sightings per hour) was obtained in 2006, thereafter it decreased spectacularly in 2007 (Figure 5) and continued in 2008 (C. Camphuysen, pers. comm.). There is a distinct spring peak in the sightings, with a slight decrease in June followed by a higher level from July onwards (Haelters and Camphuysen, 2008).

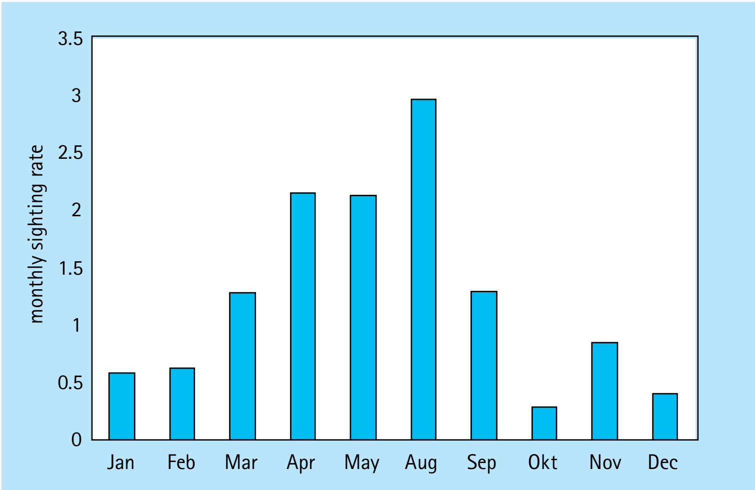

Figure 4: Monthly sighting rate from aerial surveys in the Danish Southern North Sea. Note that June-July is missing from the plot since no surveys were conducted in these months (after Teilmann et al., 2008).

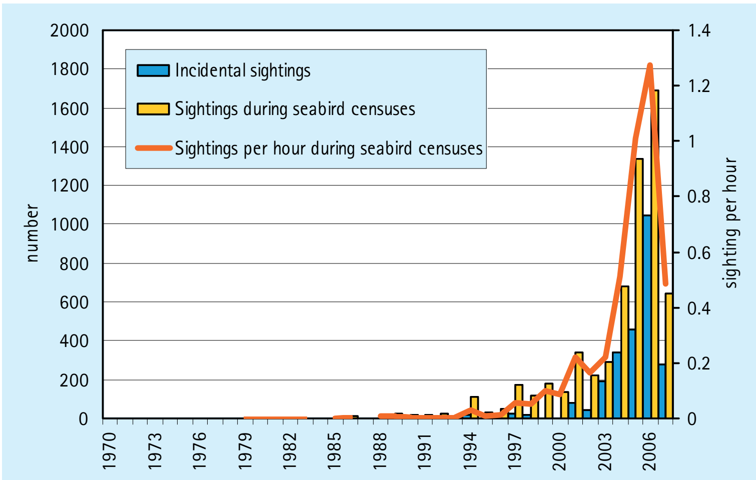

Figure 5: Sightings of harbour porpoises in Dutch coastal waters (coastal observations only), including systematic sightings from seawatchers (number of animals reported, yellow, left y-axis), effort corrected sightings from seawatchers (animals hour^{-1}, orange line, right y-axis) and incidental sightings reported by others (number of animals reported, blue).

3. Factors influencing the status

3.1 Infectious diseases

The health status of seals in the countries bordering the Wadden Sea was monitored through examination of live and dead individuals. Post mortem examinations, including histology, immuno-histochemistry, microbiology, serology and parasitology have been performed since the first epizootic in 1988. Most pathological findings concentrate around the respiratory and alimentary tracts and these findings are compared for three periods: pre-1988, between the epizootics in 1988 and 2002, and 2002-2005.

With respect to parasites in harbour seals, both lungworm infestation and intestinal parasitation were higher between the two epizootics and after 2002, compared to pre-1988. Lower acantochephalan (intestine parasites) and heartworm were also found (Lehnert *et al.*, 2007; Siebert *et al.*, 2007). Bronchopneumonia, gastritis and enteritis all increased after the 2002 epidemic, compared to 1988-2002, but this may have been influenced by the 2002 Phocine Distemper Virus epizootic (Lehnert *et al.*, 2007; Siebert *et al.*, 2007). Bronchopneumonia due to parasitic and/or bacterial infections was the most common cause of death during 1988-2002 and onwards. Septicaemia became the most frequent cause of death or most severe health impact after the second seal die-off (Siebert *et al.*, 2007). Bacteria most frequently causing bronchopneumonia, gastroenteritis, polyarthritis, dermatitis, hepatitis, pyelonephritis, myocarditis and septicaemia in harbour seals and harbour porpoises were isolated and comprised α/β-haemolytic streptococci *Escherichia coli*, *Clostridium perfringens, Erysipelothrix rhusiopathiae, Staphylococcus aureus* and *Brucella maris* (Siebert *et al.*, 2007; Prenger-Berninghoff *et al.*, 2008; Siebert *et al.*, 2009).

A comparison of bacteriological findings in harbour porpoises from different regions of the North Atlantic revealed that organs from animals originating from Greenlandic and Icelandic waters showed clearly less bacterial growth and fewer associated pathological lesions than animals from the German North and Baltic Sea and Norwegian waters (Siebert *et al.*, 2009).

No case of morbillivirus was reported after 2002. But a recent outbreak of a disease, leading to increased mortality of harbour seals in Europe, began in 2007. As in 1988 and 2002, it started on the small Danish island of Anholt and spread to other major seal colonies in the Kattegat and Skagerrak over the next months (Härkönen *et al.*, 2008). Clinical signs of diseased seals and gross pathological findings were similar to those observed in 1988 and 2002. Clinical observations included a dorsally misshaped silhouette with intermittent hump formation in the shoulder region, and restricted movement. In the final stage, animals showed respiratory distress and hemoptysis (Härkönen *et al.*, 2008). Preliminary histopathological findings of four seals displayed multifocal acute catarrhal bronchitis, chronic interstitial pneumonia, severe atelectasis, moderate follicular hyperplasia and acute lymphocytolysis. It was suggested that an unknown virus was most likely the pathogen causing the epidemic. As harbour porpoises showed similar pathological findings, a cross-species infection could not be ruled out (Härkönen *et al.*, 2008).

In conclusion, changes in the prevalence of parasitic and bacterial infections have occurred. But the general health status of harbour seals in the Wadden Sea appears to have improved compared with earlier decades. In particular the health of pups (0-6 months old) has improved after 2002 (Siebert *et al.*, 2007). However, the increasing prevalence of lung and intestinal parasites warrant the continued monitoring of the health status of seals.

3.2 Disturbance

Wind farms

Offshore wind farms may affect marine mammals in different ways: through noise related to construction and operation, and through the physical presence of wind turbines, the shipping of material and people during construction and maintenance. Much of the research into possible effects of offshore wind farms on marine mammals in the south-eastern North Sea has until now been focused on seasonal distribution patterns of seals and porpoises to identify preferred areas and investigate possible spatial overlap with planned offshore wind farms (Brasseur *et al.*, 2004; Wollny-Goerke and Eskildsen, 2008; Teilmann *et al.*, 2008). The only extensive studies on the construction and operation of offshore wind farms hitherto are studies in Danish waters: the Horns Rev area in the Danish North Sea, and Nysted in the Danish Baltic Sea (Teilmann *et al.*, 2006; Carstensen *et al.*, 2006). The results of many of the Dutch studies are expected in 2009 and 2010.

This chapter restricts our assessment to the Horns Rev study, of an area approximately 20 km northwest of the Danish Wadden Sea (Tougaard *et al.*, 2006 a, b).

Porpoises' habitat use before, during and after construction of the wind farm was studied by ship-based surveys and by passive acoustic monitoring. The conclusions were that there was a negative effect of the construction as a whole, but that strong reactions up to 15 km away were observed during pile driving operations. No significant effects were found during operation. Compared to the wind farm in the Baltic Sea, the effects on the porpoises were much weaker in the North Sea. Whether this difference is related to area characteristics or to differences in behaviour of the two populations is unknown. Caution should be used when extrapolating results between wind farms at different locations.

Harbour seals were provided with satellite transmitters to study how they used the area in and around the wind farm area before and after the construction of the wind farm itself. No statistically significant differences in habitat use were seen in the wind farm area and the reference area. However, this should not be interpreted as no influence. With the accuracy of the seal locations obtained via satellite, no detailed analysis of behaviour was possible. Studies should continue because more detailed data on seal and porpoise habitat use are becoming available and, simultaneously, techniques are being developed to model the acoustic underwater world and the possible changes induced by wind farm noise. These new methods enable both more accurate tracking of seal movements and other behaviour, assess the possible impact of noise from wind farms, and moreover provide better opportunities to study and apply mitigation measures.

Recreation

Recreational activities in the Wadden Sea and adjacent waters can adversely affect marine mammals there. Seals will be particularly affected because they use the coastal waters and sandbanks for whelping, feeding, moulting and resting. Serious disturbances can make certain areas unsuitable for seals and in the southern Netherlands this has even led to impairment of recovery of a depleted population (Brasseur and Reijnders, 2001). The detrimental impact of disturbance on seals was recognized by the responsible management authorities and protected areas were established in all Wadden Sea areas in the mid-1980s. This concern is explicitly addressed in the Seal Agreement - concluded between Denmark, Germany and The Netherlands in 1991 (under the Bonn Convention) - and obliges the signatories to create a network of protected areas to "ensure the preservation of all areas essential to the maintenance of the vital biological functions of seals". Momentarily, almost all of the haul-out sites are protected from disturbance during the summer. That is beneficial for harbour seals, but does not cover the demands of grey seal which have their pups, breed and moult in winter/early spring. It is envisaged that this caveat may be adequately addressed when the proposed Natura 2000 Network is designated. One concern though is the increasing, unregulated "seal watching" industry. This is not yet adequately addressed at a trilateral level, and is indicated as a priority action in the current Seal Management Plan. The way the issue has been tackled in Schleswig-Holstein may form a template for the whole Wadden Sea. A combination of protection zones, restrictive shipping regulations and voluntary agreements with shipowners conducting seal watching tours seems to be a promising tool to make seal watching tours ecologically acceptable.

Noise

Marine mammals evolved in a diverse natural sound environment and their hearing sensitivity is well adapted to signals that are biologically significant to them. Pinnipeds and cetaceans produce and receive sound over a great range of frequencies for use in communication, predator avoidance and to interact with their environment. Some toothed whale (odontocete) species have the capability to use echolocation for foraging and orientation in their underwater environment (Tyack and Clark, 2000). For these species, sound is the most important sensory modality, and they rely on hearing for survival.

As far as is known, the three marine mammal species resident in the Wadden Sea area all share the sophisticated and very acute sense of hearing of marine mammals.

Sound in general can have diverse negative effects on marine mammals. It can cause acute or chronic stress (Fair and Becker, 2000); it may impede the perception of other biologically meaningful sounds ("masking") (Richardson *et al.*, 1995; NRC, 2003; Janik, 2005; Madsen *et al.*, 2006); it can trigger behavioral reactions (NRC, 2005; Southall *et al.*, 2007; Nowacek *et al.*, 2007); and even lead to direct physiological or physical impairment and injury (Ketten *et al.*, 1993; Finneran *et al.*, 2002; Kastak *et al.*, 2008). Most of these processes are still poorly understood in marine mammals.

Based on the available information of the sound emissions from pile driving and other intense sound sources on the one hand, and known effects of intense sound on terrestrial as well as some marine mammals on the other hand, it can be hypothesized that both seal species as well as harbour porpoises will be able to perceive these anthropogenic sound emissions and are likely to be impacted by them to varying degrees.

So far, the only available data on behavioural reactions in harbour porpoises to impulsive sound have come from visual and acoustic (T-POD) observations during the construction of wind turbines at Horns Rev, Denmark, where a significant effect on the presence and swimming behaviour was observed at a distance of up to 15 km from the sound source (Tougaard *et al.*, 2003). In the BROMMAD study (Gordon *et al.*, 2000), by contrast, no obvious behavioural reactions were observed in free-ranging harbour porpoises in response to airgun exposures.

Recent studies have shed some light on other sound-induced effects, namely masking and the acoustic tolerance of harbour porpoises to impulsive sound. Results from a dedicated study showed that the operational sound emitted by a 2 MW wind turbine would only mask the acoustic perception of harbour porpoises at close ranges (Lucke *et al.*, 2007). In another study, intense impulsive sounds were tested for their potential auditory effect in a harbour porpoise (Lucke *et al.*, 2008). The animal's auditory tolerance was tested by systematically increasing the received levels of an intense sound stimulus (an airgun impulse). At a sound pressure level of above 200 dB re 1µPa and a sound energy of 164 dB re 1µPa^2·s the animal's hearing threshold shifted temporarily, thus providing the first scientific basis for a noise exposure criterion for this species. Future studies might shed light on the effect this type of pollution might have at the population level of the different marine mammal species.

Taking

"Taking" is defined here as the removal of living seals from the natural environment to check the health condition of the animal. The decision is then taken to either (1) release the animal in its environment; (2) to euthanize it; or (3) to try to rehabilitate the animal and subsequently release it into the wild. Most often "taking" relates to seal pups found without mothers, or to weak or sick seals.

It is clearly stated in the Seal Management Plan (1991-1995), pursuant to the Seal Agreement (concluded in 1991), that taking of seals is prohibited. This was later on further defined and explicitly declared in the so-called Leeuwarden Declaration (LD § 60) by the Trilateral Management Authorities at their 7th Trilateral Ministerial Conference (CWSS, 1994). They agreed "to reduce the taking of seals to the lowest level possible". These decisions were made because 1) taking was not necessary any more to maintain the harbour seal popula-

Table 1: Estimated percentage of born harbour and grey seals that were taken alive from the Wadden Sea in 2000-2005, excluding 2002

Country / species	NL Harbour seal	Nds Harbour seal	SH Harbour seal	DK Harbour seal	Total Harbour seal	NL Grey seal
%	16.2	5.9	5.8	5.1	7.7	44.9

Table 2: Percentages and numbers of seals rehabilitated at seal stations in the period 2000-2005 excluding 2002, and number of released seals.

Country / species	NL Harbour seal	Nds Harbour seal	SH Harbour seal	DK Harbour seal	NL Grey seal	Other areas Grey seal
% rehabilitation	99.9	82.3	30.3*	0	99.7	62.1
n	792	429	702	110	592	58
% released	92.0	86.7	88.3	0	97.1	100.0
n	791	353	213	0	590	36

* 2003 – 2007: 40 – 46 % (Borchardt, unpublished)

Table 3: Percentage of harbour and grey seals in the Wadden Sea that have been in human care between 2000 – 2005, excluding 2002

Country / species	NL Harbour seal	Nds Harbour seal	SH Harbour seal	DK Harbour seal	Total Harbour seal	NL Grey seal
%	14.9	4.2	1.5*	0	4.6	43.5

* 2.7 % in 2003 – 2007 (Borchardt, unpublished)

tion, because by then the population was in a good state and large enough to be considered as not vulnerable anymore; 2) taking can have negative effects on the wild population, namely interfering with natural selection and population regulation; and 3) released animals can carry exotic pathogens to the wild population so that diseases suppressed by medical treatment in the seal station can harm the wild population.

Abt (unpublished manuscript, 2006) has analyzed the data about seal taking from Denmark (DK), Schleswig-Holstein (SH), Niedersachsen (Nds) and the Netherlands (NL) in the years, 2000-2005. The vast majority of seals taken are pups. To calculate the level of taking, the number of taken animals was related to the number of newborn seals in each year. The year 2002 was excluded, because this year was atypical due to the second Phocine Distemper Virus outbreak.

Among the seal pups taken, authorised seal stations try to rehabilitate only a certain percentage. Those percentages are given in Table 2.

From the percentages of seals taken, accepted for rehabilitation and released, it is possible to calculate the percentage of animals in the wild which have been in human care.

Table 3 shows that in Denmark no seals are rehabilitated and released, and seals are taken and released on a relative low level in Schleswig-Holstein and Niedersachsen. In the Netherlands the level of taking is relatively high for harbour seals, and strikingly high for grey seals: nearly every second grey seal has spent some time in a seal station.

Despite the declarations of the trilateral official authorities and repeated statements in successive Seal Management Plans aiming to reduce taking to a low level, this management goal is not being achieved equally in the different Wadden Sea regions. It is being fulfilled in Denmark and Germany, but not in The Netherlands. The high proportion of seals passing through the Dutch seal stations might have negative impacts, especially on the health of grey seals. Basically there are two extremes in seal management: while the focus in Denmark is on the wild population, in The Netherlands it is in practice focused on the individual seal. The latter is contradictory to the general trilateral objective and the agreed Target: to guarantee the natural functioning of the ecosystem.

The population can only achieve a good health status if natural selection processes can occur. From a biological and wildlife management point of view, human activities should not interfere with these basic processes. Even if animal welfare is considered, human handling of seals should be restricted to a low level.

Bycatch

Bycatch or accidental drowning is considered the most serious threat to harbour porpoises in the North Sea (Vinther and Larsen, 2004; EC, 2004; ASCOBANS, 2000; Reijnders *et al.*, 2009). The European Commission tried to address this by issuing Council Regulation 812/2004, aiming at preventing bycatch through the mandatory use of pingers in certain fisheries, and assessing the extent of bycatch through observer schemes. However, fishing boats of less than 12 m (15 m for observer schemes) are exempt and recreational set net fisheries with trammel/tangle/gill nets presumably continue to catch porpoises (Haelters and Camphuysen, 2009). Bycatch also occurs in coastal waters close to the Wadden Sea (e.g. Siebert *et al.*, 2006, Haelters and Camphuysen, 2009). From early November 2008 till mid-March 2009, a total of 167 dead harbour porpoises were found on the Dutch coast and at least 60 of them were mutilated (Camphuysen and Oosterbaan, 2009). The majority of mutilated porpoises were found around the islands of Texel and Vlieland. The injuries point to these mutilated animals being bycaught (Camphuysen and Oosterbaan, 2009).

Regrettably data are lacking on the actual level of bycatch as well as the sort of fisheries' activities involved. This latter includes the types of fishery, the intensity of activity, the spatial distribution and seasonality. We concur with the generally accepted view that this problem needs to be urgently addressed, for instance as described in Camphuysen *et al.* (2008), Haelters and Camphuysen (2009), and Reijnders *et al.* (2009).

Though probably of a much lower scale, drowning of seals in fyke nets is a known phenomenon. The extent is unclear. In The Netherlands, fyke net fishermen are obliged to put a guard net in front of the fyke to prevent seals entering (Reijnders *et al.*, 2005). This may be an approach worth using in other areas of the Wadden Sea.

4. Conclusions

4.1 Scientific assessment – Issues of concern

Grey seals

The number of grey seals observed in the Wadden Sea area has continued to increase since the last QSR (2004). The earlier concern about the lack of effective protection of their breeding and moulting grounds (especially in The Netherlands) has been largely addressed. The waters north of the Dutch Frisian Islands, encompassing grey seal breeding, moulting and resting sandbanks, have been designated as part of the Natura 2000 network and implementation into national law follows. A remaining concern is the lack of knowledge about some basic aspects of the biology of the grey seal in the Wadden Sea and adjacent North Sea. Knowledge on actual numbers using the area is lacking, and the same holds for numbers of pups born, population structure within the Wadden Sea and genetic relationship with other populations elsewhere in the North Sea. This lack of knowledge prevents the design of a management plan tailored to this species.

Harbour seals

The harbour seal population has prosperously recovered from the last virus epizootic in 2002. Given the observed continued population growth, the question arises as to when the population may reach the carrying capacity of the area. This is an important issue, because when approaching that limit, biological regulating processes will occur. These include lowered reproduction and survival rates, resulting in decreased or stagnating growth, and increasing prevalence of parasites and diseases. This should not be interpreted as a population being in distress but simply a natural regulation process.

Harbour porpoises

A major issue of concern is the growing offshore wind farm industry. Many plans are presented to build wind farms in coastal waters, including some close to the Wadden Sea Conservation Area. This is a potential threat to harbour porpoises and detailed knowledge of distribution, abundance and specific habitat use is necessary to assess the situation. These data are largely missing for the coastal waters north of the western/middle part of the Wadden Sea and it is questionable whether the valuable monitoring of the waters west of the northern and eastern Wadden Sea will be prolonged. These kinds of data are also essential to assess bycatch, the other issue of concern. Next to numbers of animals bycaught, the population structure and the size of the stocks/populations from which these animals are removed needs to be known to assess whether this removal is sustainable.

Another specific issue of concern is the recent bycatch of porpoises along the western Dutch Wadden Sea. Despite the lack of information on how the actual level of bycatch affects sustainability, the frequency of strandings and mutilations are exceptional and unprecedented for this area. It therefore needs to be addressed with high priority.

4.2 General issues of concern

Impact of disturbance, whether exerted through recreational activities (including "seal watching") or noise (e.g. wind farms, shipping, seismic explorations, and military sonar) on marine mammals is hitherto less well studied. Given the increasing use of the Wadden Sea and adjacent North Sea for both professional and recreational use, we consider it relevant to include these aspects in future studies (see section on recommendations for research). Insight into the cumulative effects of the various factors at work is lacking and especially needed. Taking of seals, especially in The Netherlands, is a continuing serious concern. The level of taking, especially grey seals in The Netherlands, is so high that one may question whether the population can still be regarded a natural wild population. This is not only a matter of concern from a wildlife biological point of view, but also raises the question of whether such a level of human handling of wild animals is acceptable from an animal welfare perspective, let alone its undermining of a joint trilaterally agreed policy.

5. Target assessment

5.1 Viability

Viability can be defined as the survival of a population in a state that maintains its vigour and its potential for evolutionary adaptation (Soulé, 1987; Mills, 2008; Sinclair *et al.*, 2006). It is generally agreed that there is no single value that can be globally applied in all situations. Two components of viability analysis may serve to indicate the persistence of a given population: genetic criteria and risk of extinction. From an inbreeding point of view, the short term minimum size of a mammal population with life history parameters such as the harbour seal is considered to be 500 individuals. However, if a population should also be able to survive catastrophes – in other words retain evolutionary potential on the long term – the minimum size is estimated to be at least 5000 animals. The harbour seal population has only increased since the QSR 2004, validating the conclusions in that report that the size of the Wadden Sea harbour seal population is far beyond even the threshold of 5000 animals, and can be regarded as viable.

The situation with respect to the grey seal is still as complex as it was in 2004. Colonies have generally increased considerably, but data on life history parameters such as reproductive performance and survival in the colonies, is still lacking. Immigration from elsewhere is assumed to still have a prominent influence on the development of these colonies, but its extent is unknown. Therefore no conclusions can be drawn about the self-supporting capacity, in essence viability, of these grey seal colonies. The other criterion, risk of extinction, can only be addressed for harbour seals, as data for grey seals is lacking.

For the harbour porpoise population in the Wadden Sea, actual numbers observed probably reflect the distribution of harbour porpoise population(s) or stocks in the adjacent North Sea, rather than a resident Wadden Sea population. Data to evaluate the Target for this species is lacking.

3.2 Natural reproduction capacity

No quantification can be given for the natural reproduction capacity of either the harbour seal, grey seal or harbour porpoise, because of insufficient knowledge of this parameter. It is possible to provide a qualitative indication on the reproductive status of the harbour seal. Though no data is available on a straightforward measure such as fertility amongst the females in the population, comparison of growth rate, expressed as per capita birth rate and death rate in this population with similar data from harbour seal populations elsewhere may provide some insight. Based on the data obtained for the Wadden Sea harbour seal population (Reijnders *et al.*, 1997; Abt, 2002; Reijnders and Brasseur, 2003; Brasseur *et al.*, 2008) and the population in the Kattegat-Skagerrak (Härkönen *et al.*, 2002), it is concluded that the reproduction capacity of the Wadden Sea harbour seal population is at a satisfactory level.

5.3 Summary of the Target evaluation:

The population of harbour seals in the Wadden Sea can be considered viable with a satisfactory reproduction capacity.

The Target regarding grey seal and harbour porpoise cannot be evaluated due to insufficient population data.

6. Recommendations

6.1 Recommendations for management

At the request of the responsible seal management authorities, the Trilateral Seal Expert Group designed an effective aerial survey scheme for harbour seals in the Wadden Sea to tune the Trilateral Seal Agreement and EU Habitats Directive requirements (Meesters *et al.*, 2009). It is recommended that the proposed annual monitoring scheme should be closely followed trilaterally and in particular that the proposed minimum survey frequency should be respected.

The taking of seals in some parts in the Wadden Sea is excessive and it is recommended that takes should be brought into line with the practice in Niedersachsen, Schleswig-Holstein and Denmark, according to the trilaterally agreed policy. For detailed management recommendations see the SMP 2007-2010.

6.2 Recommendations for research and monitoring

Lack of knowledge of grey seal biology in general and in particular knowledge of relationships between colonies in the Wadden Sea and other colonies in the North Sea, should be improved through dedicated research, including population biology and genetics.

It is recommended that monitoring of harbour and grey seal and harbour porpoise populations should be continued and in some cases initiated in order to track population developments and health in order to address the concerns expressed earlier in this chapter.

In addition, priority should also be given to promoting studies on habitat use of harbour seals, including feeding ecology, impact of wind farms on harbour and grey seals and harbour porpoises, and bycatch of porpoises. For details see e.g. the SMP 2007-2010.

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