WADDEN SEA ECOSYSTEM No. 29

The Wadden Sea Quality Status Report – Synthesis Report 2010

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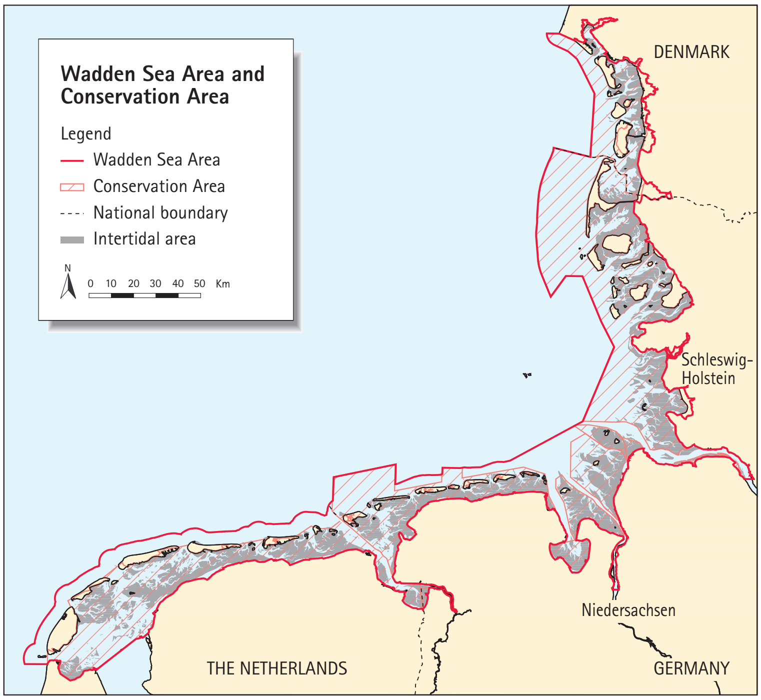


Figure 1.1: Map of the Wadden Sea Area and Conservation Area.

The Wadden Sea is subject to a comprehensive nature protection scheme on national and regional levels as well as to extensive protection and management arrangements between the countries in the framework of the Trilateral Wadden Sea Cooperation. Also, several European directives play a part (*e.g.*, Natura 2000).

Significant new developments since the QSR 2004 are the designation of the Danish Wadden Sea as a National Park (2010), the adoption of a revised Wadden Sea Plan (2010) and the inscription by UNESCO of the Dutch and German parts of the Wadden Sea as a World Heritage Site (2009).

1.1 Trilateral Wadden Sea Cooperation

Since 1978, the Trilateral Wadden Sea Cooperation (TWSC) between Denmark, Germany and The Netherlands has been dealing with the joint protection of the Wadden Sea ecosystem. Central elements of the trilateral arrangements are the guiding principles, common management principles and the common targets upon which common policies and management have been agreed (Wadden Sea Plan, 2010). 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". The Wadden Sea Plan, the policy and management plan for the Wadden Sea Area proper, which includes the central objectives and principles of the Wadden Sea Cooperation, was agreed at the 8th Trilateral Wadden Sea Conference at Stade in 1997. The Trilateral Monitoring and Assessment Program (TMAP), associated with the implementation of the Wadden Sea Plan, was launched on the same occasion.

The Wadden Sea Area covers about 14,700 km²; the Conservation Area is about 11,200 km² (Table 1.1).

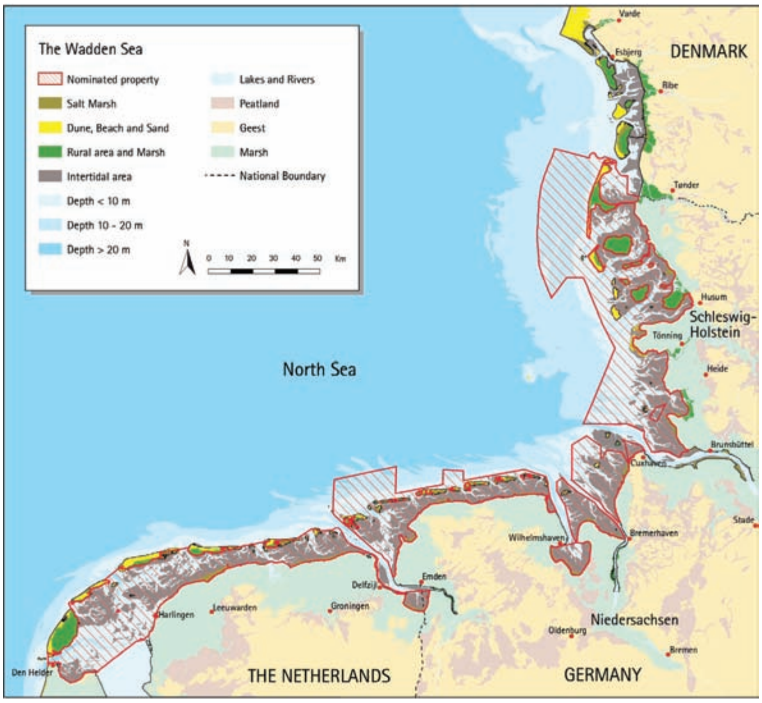
1.2 World Heritage Site

In June 2009, the World Heritage Committee inscribed the Dutch and German parts of the Wadden Sea on the World Heritage List under natural criteria (viii) geomorphology, (ix) ecological and

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

Table 1.1: 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.

Figure 1.2:
Map of the Wadden Sea World Heritage Site (CWSS, 2009).



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).

1.3 International protection regimes

The European Union's environmental legislation is of specific significance for the Wadden Sea and has increased in importance during the past two decades. The legislation is trans-boundary and, increasingly, covers all environmental policy areas. It also has direct implications for Member States' legislation. Of the comprehensive list of environmental legislation, the Habitats, Birds (Natura 2000) and Water Framework Directives are the most relevant 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.

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, because it deals specifically with the interface of land and sea and management of conditions at that interface.

The Wadden Sea countries are contractual parties to several international agreements, conventions and treaties, in particular the Convention on Wetlands of International Importance [especially as waterfowl habitat] (Ramsar Convention), the Convention on Biological Diversity (CBD), the Convention on the Conservation of Migratory Species of Wild Animals (CMS, Bonn Convention) also comprising 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 Cetaceans of the Baltic, North East Atlantic, Irish 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).

1.4 National protection regimes

In 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 under the Nature Conservation Act 1998, supported by additional designations.

In Germany, the Wadden Sea is protected as national parks established in 1985, 1986 and 1990 in Schleswig-Holstein, Niedersachsen and Hamburg respectively.

In Denmark, the revised Statutory Order for the Danish Nature and Wildlife Reserve was enacted in 1998. In 2008, the Danish parliament formally agreed to establish the Danish Wadden Sea National Park, which covers almost 146,000 ha. The national park was inaugurated in October 2010, together with the enactment of the Statutory Order.

A comprehensive overview of the national protection and management regimes is given in the QSR 2009 Thematic Report No. 1 "The Wadden Sea – Protection and Management".

2. Human Activities and Impacts

The Trilateral Monitoring and Assessment Program (TMAP) has a predecessor which operated from 1966-1985. This was the International Wadden Sea Working Group, a private organization of Danish, Dutch and German Wadden Sea scientists who aimed at better protection of the Wadden Sea. In 1983 their collective knowledge was published in the three volumes of 'Ecology of the Wadden Sea' and in 1985 these 124 Wadden Sea scientists published a document 'The management of the Wadden Sea'. Because this private working group suffered from a shortage of money, only a Dutch version ('Het beheer van de Wadden') was actually printed. This little-known booklet contains a table in which the threats to the Wadden Sea system are listed and ranked according to the severity of the problem. The ranking is based on: 1) the speed of recovery after occurrence of a human impact, 2) the maximum geographical extent of the effects of an impact, 3) the frequency of the impact. In the following paragraphs these threats or impacts are listed and discussed in a sequence of decreasing impact, as defined in the 1985 document. So, the first human activities listed were supposed to have the largest (potential) impact on the Wadden Sea system. For better understanding some of the activities are brought under the same heading.

This ranked list of human activities illustrates very well the progress which has been made in 25 years of managing the Wadden Sea as a nature reserve. It also shows the areas where little progress has been made. At the same time it makes clear which human activities and impacts still played an important part between the QSR 2004 and the QSR 2009.

2.1 Reclamations and dams between islands and mainland

In 1985, reclamations of salt marshes and intertidal flats were considered to be the largest threat to the Wadden Sea ecosystem, mainly because the impact was seen as irreversible. At that time reclamations of part of the Wadden Sea were still being discussed. Nowadays, Wadden Sea policy in all three countries makes any reclamation highly improbable. Instead, summer polders along the coast of the Wadden Sea are changed to salt marshes and intertidal flats by removing (part of) the surrounding seawalls.

Dams to the islands were also seen as a very serious threat in 1985. Again, this is a discussion of the past.

This changed attitude to reclamation and dam-building shows that the largest threats to the Wadden Sea have been eliminated. This is due to a strong involvement of nature conservation NGOs and a consequent governmental policy on protection of the Wadden Sea.

2.2 Damaging effects of water pollution

The 1985 report put effects of various forms of water pollution high on the list of threats to the Wadden Sea. PCBs, oil pollution, pesticides, heavy metals, discharge of wastewater with high concentrations of organic matter from agricultural industries, and eutrophication were listed in an order of decreasing impact. Since that time pollution problems have greatly diminished. For example, the huge loads of waste water sluiced by agricultural industries into the eastern Dutch Wadden Sea have completely disappeared. PCBs, pesticides and heavy metals all have strongly decreased and nowadays occur in mainly low quantities (see chapter 3.2). Oil pollution is still present and continues to constitute a problem. Eutrophication of the Wadden Sea was increasing in 1985 but has been decreasing in later years. This reduction of pollution problems is due to an active environmental policy of all states bordering the North Sea. However, some forms of pollution continue to occur in smaller quantities and their presence is still being monitored (see sections 3.1 and 3.2).

2.3 Dredging and extraction of sand and shells

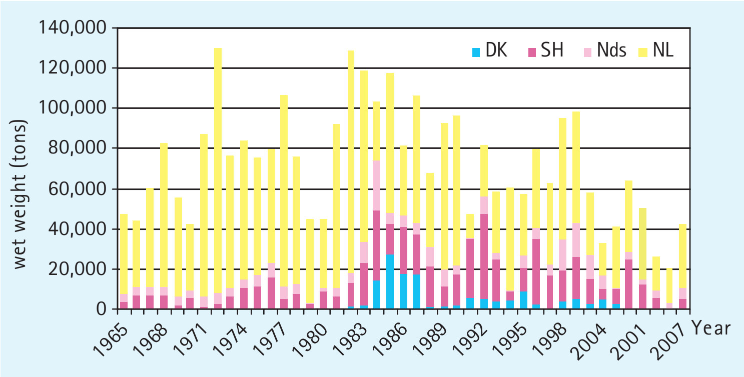
Dredging and extraction of sand and shells figured high on the list of 1985 threats. Since 1985 extraction of sand and shells has been strongly regulated and has been confined to the deeper parts of the Wadden Sea and the North Sea. In parts of the Wadden Sea, sand can only be extracted in combination with dredging; otherwise it has to be brought in from the North Sea.

Dredging of shipping lanes has been increasing since 1985 to accommodate ever larger vessels on their way to the major ports in the Wadden Sea area. At present it constitutes a major problem especially in the estuaries of Ems, Weser and Elbe. Dredging causes water turbidity which cuts light penetration of the water column.

2.4 Cultivation of mussels, oysters and fish

Cultivation of blue mussels occurs in Germany and The Netherlands. The culture is based on the availability of small seed mussels which are fished on wild banks and subsequently sown on the culture plots for growth to marketable size. Since 1985 the collection of seed mussels has had an increasing impact on the presence of wild mussels. Around

Figure 2.1: Landings of blue mussels in the Wadden Sea 1965–2007 (in tons wet weight). (Source: Nehls *et al.*, 2009, QSR 2009, Thematic Report No. 3.5).



1990 an unprecedented low was reached in the Dutch Wadden Sea. At present, regulations to prevent overfishing and damage to natural values are in place in all Wadden Sea countries.

Cultivation of European flat oysters is an activity of the past: this oyster species is now extinct. Its market position has partly been taken over by the Pacific or Japanese oyster, an alien species introduced into the Wadden Sea around 1985. Some experimental fishing is carried out on the now-abundant oyster beds.

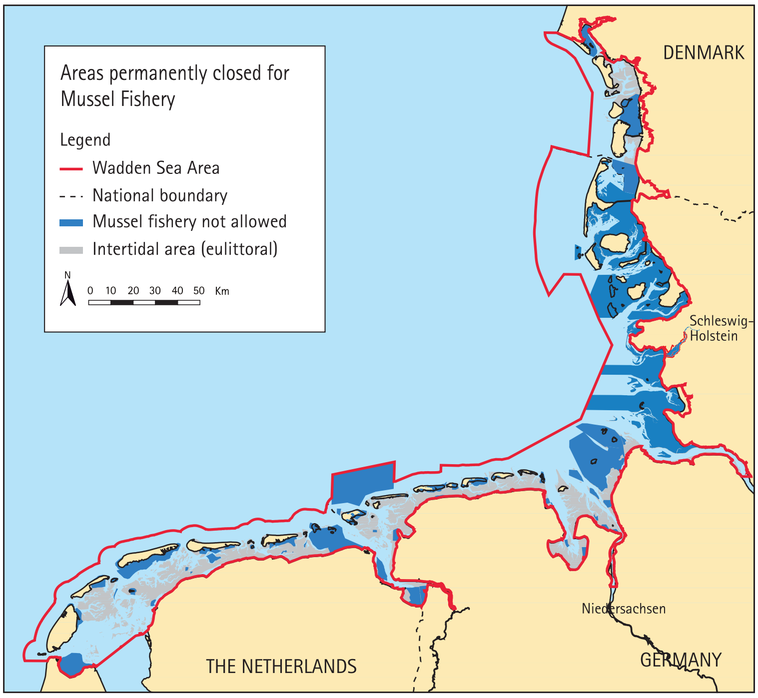
Cultivation of fish does not play an important part in the Wadden Sea.

Amount and abundance of natural spatfall of blue mussels is always varying. Hence, catches of blue mussels show strong fluctuations per year and region. Because of low seed availability, in recent years low catches were reported, accompanied by a decreasing or failing spatfall and declining mussel harvest (Fig. 2.1).

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. 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. Blue-mussel fishing is regulated in all three countries and in certain areas is not permitted at all (Fig. 2.2).

In The Netherlands the mussel culture was also restructured. Starting in 2008, a programme started to gradually phase out fishing of seed mussels from the sea floor. Instead they were collected from ropes and nets suspended in the water. It is foreseen that in a number of 20% increments, all seed mussels will ultimately be obtained from suspended ropes and nets. Presently, shortages of seed mussels in the Dutch Wadden Sea are compensated by seed mussels imported from the

Figure 2.2: Areas in the Wadden Sea region permanently closed for mussel fishery in 2008.



German Wadden Sea, and mussel cultures off Sylt have even been supplied with imports from the British Isles in recent years.

2.5 Extraction and transport of natural gas and crude oil

Natural gas was extracted from under the Wadden Sea from locations on the mainland (Groningen field) since about 1960. In 1981 licenses were issued for gas extraction directly from the Wadden Sea area in The Netherlands (Zuidwal, Ameland). In the outer part of the Ems estuary gas was extracted from German territory. At that time the impact of gas extraction was not very clear and serious consequences were predicted. Hence, a monitoring program was established at the Ameland site in 1982. The results of this monitoring program were used in discussions about extracting gas from new fields in the Dutch Wadden Sea after 1994. It was finally decided to grant a new license for gas extraction from underneath the Wadden Sea near Lauwersoog. The impact of this activity is closely monitored; if the subsidence of intertidal flats and salt marshes exceeds a certain threshold value, the extraction will be stopped. So far the subsidence of the flats seems to be compensated by sedimentation of sand and mud. Hence, ecological effects seem negligable.

Crude oil is extracted from the Dithmarschen part of the Wadden Sea. Due to strong safety precautions no oil pollution incidents have occurred. The oil was initially brought to the mainland by tankers, but since 2005 this has been done via a pipeline. No incidents have been reported.

Natural gas from the Wadden Sea, the North Sea and the Wadden Sea islands is transported through pipelines. The construction and situation on the seabed of these pipelines had a considerable impact on the tidal flats and channels but monitoring has shown that the original ecosystem conditions were restored in 5-10 years.

The State Parties confirmed their commitment not to permit exploration and extraction of oil and gas at locations within the boundaries of the Wadden Sea World Heritage Site.

2.6 Fisheries for fish, cockles, blue mussels and shrimp

In the 1985 report, fishing for fish and brown shrimp was believed to have a stronger negative impact than fishing for cockles and seed mussels. Based on a major research effort, this point of view has changed to the present notion that shellfish fisheries are more harmful than fisheries for shrimp.

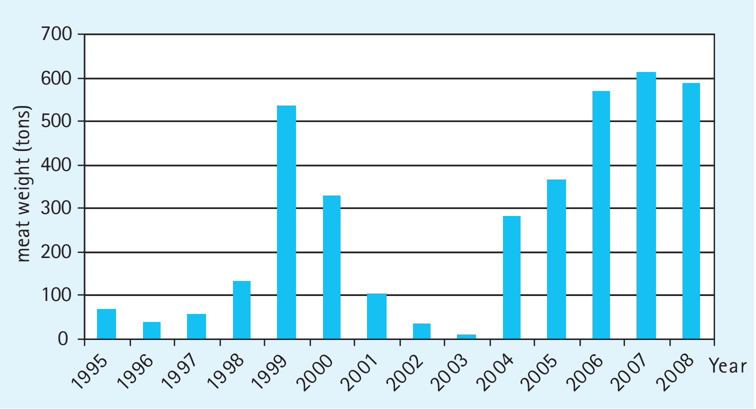
In the period between QSR 2004 and QSR 2009 fishing in the Wadden Sea hardly involved fish. Brown shrimps and blue mussels were the main catches. Starting in 2005, the mechanized fishing of cockles, which proved particularly harmful to the tidal flat ecosystem, was prohibited in The Netherlands; in Germany and almost all part of the Danish Wadden Sea it was already banned. In The Netherlands also the mussel culture is being restructured. Landings of brown shrimps were high in the period 2004-2008.

2004 was the last year in which mechanized fishing for cockles was allowed in The Netherlands (Fig. 2.3). Nowadays cockle-fishing is prohibited in most of the Wadden Sea. Only a manual cockle fishery is still allowed in The Netherlands 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 (Fig. 2.4).

In all three Wadden Sea countries, fishing of brown shrimps (*Crangon crangon*) is carried out in the offshore coastal waters and in almost all

Figure 2.3: Landings of cockles in the Wadden Sea 1977–2007 (in tons wet weight) (sources: DTU Aqua, Fischerblatt, RIVO, PVIS), (QSR 2009).

Figure 2.4: Cockle catch (meat weight) by hand rakers in the Dutch Wadden Sea (information from Rakers Association, OHV, presented by Bert Keus) (QSR 2009).



gullies and channels within the Wadden Sea. Only in the Danish part of the Conservation Area, in 95% of the area of the Hamburg National Park and in the zero-use zone of the Schleswig-Holstein National Park in Germany is shrimp fishery not allowed. Generally, there are no substantial differences in policies and practices within the Trilateral Cooperation Area, except for Denmark where shrimp fishery is prohibited within the line of barrier islands. Landings are recorded by country and kept separately. Record landings were found in 2005 for all three Wadden Sea countries. However, German landings declined in 2006, posing the question as to whether the lower catch was caused by reduced fishing activity or reduced stock.

The Netherlands

In the Dutch part, shrimp fishery is carried out by 204 licensed vessels. Of these, 90 vessels operate 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 (Fig. 2.5.). Fishermen estimated that roughly half of these landings are fished in the Wadden Sea.

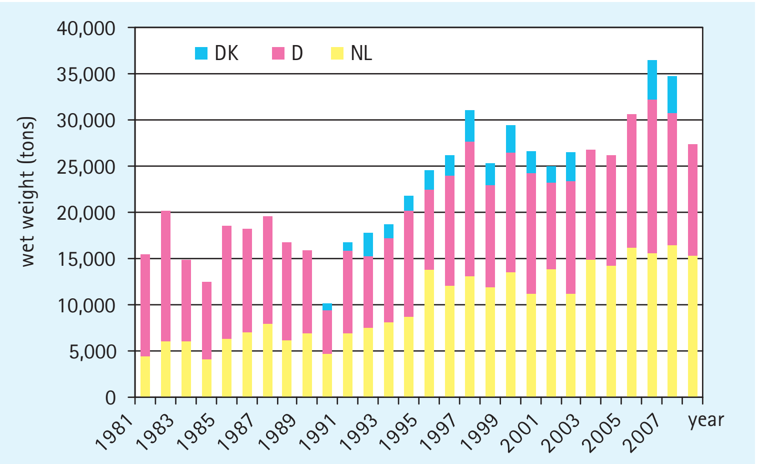
Germany

In Germany, the shrimp catch has on average been 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.

Denmark

In the last 15 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 15 years, the Danish landings have been on average

Figure 2.5: Landings of brown shrimps in 1981-2007 (in tons wet weight) (sources: DTU AQUA, Fischerblatt, PVIS) (DK: data for 1991 – 2002 for Danish vessels) (QSR 2009).



around 2,900 t (only Danish vessels) and about 3,400 t annually (including vessels from other EU countries) (in Fig. 2.5, Danish data are total landings including foreign vessels).

2.7 Helicopters and other small aircraft

The 1985 study listed helicopters and small fixed-wing aircraft as causing disturbance of shorebirds and seals. Between QSR 2004-2009, this disturbance decreased, mainly because low-flying aircraft were prohibited.

2.8 Tourism, sailing

Every year many millions of tourists are drawn to the Wadden Sea coast. They constitute an important source of income for the region. For the people living in the predominantly rural regions of the countries bordering the Wadden Sea, there is in most cases no alternative to tourism. Almost 50 million overnight stays, with a turnover of up to 6 billion euro per year, were estimated for the years 2007/2008. However, the available data sources, applied methods and statistics in the countries are too different to allow a reliable quantitative trend analysis and impact assessment for the entire Wadden Sea. To improve the situation, a multi-dimensional market research instrument should be developed with which demand, changes in utilization behaviour, and their 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. These need to set out a clear overall direction but allow for flexible and pragmatic solutions to the many specific challenges posed by the diverse demands of nature protection, tourism and recreation.

The recent designation of the Dutch-German Wadden Sea as UNESCO World Heritage Site is likely to enhance tourists' awareness of the need to protect the Wadden Sea. The development of a sustainable tourism strategy as requested by the UNESCO World Heritage Committee in June 2009 should be used to establish a reliable basis for monitoring and assessment of tourism impacts on the Wadden Sea.

The 1985 report only discussed sailing and intertidal-flat walking. Their impact was rated moderate.

2.9 Military training

Military training was recorded in the 1985 report as having moderate impact, mainly through disturbance of shorebirds and seals. Now, 25 years later, the impact has been reduced even further.

2.10 Shipping

Along the Wadden Sea coast, a number of large ports of international significance form the destinations of many merchant vessels. The waters off The Netherlands, Germany and Denmark are among the world's busiest shipping routes. Merchant shipping is of high economic importance for the Wadden Sea Region, but a shipping accident could have disastrous ecological and economic consequences for the Wadden Sea. Therefore shipping safety, including avoidance of illegal dumping of oil residues, is of utmost importance.

To raise awareness of the vulnerability of the Wadden Sea, the area was designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organisation (IMO) in 2002.

The high risk and potential consequences of accidents, and the PSSA designation, pointed to the need to maintain and where necessary enhance shipping safety and reduce impacts from shipping on the Wadden Sea. The International and European Communities have introduced several important pieces of legislation aimed at protecting the environment from shipping activities. Also further implementation of policies and actions to prevent oil pollution from shipping - both from illegal discharges and from accidents - as well as control and enforcement measures needs to be continued.

2.11 Hunting

Already in 1985 hunting had a minor impact on the Wadden Sea system. This is still true at the time of QSR 2009.

2.12 Scientific research

In 1985 it was concluded that scientific field research was not entirely without effects on the Wadden Sea ecosystem. This situation has not changed in 2009.

2.13 Not listed in 1985: wind energy

In 1985, the Wadden Sea area had hardly any large windmills for energy production. These were not seen as a problem for conservation. This has changed considerably.

In 2009 the construction of wind turbines is prohibited in the whole Wadden Sea Conservation 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

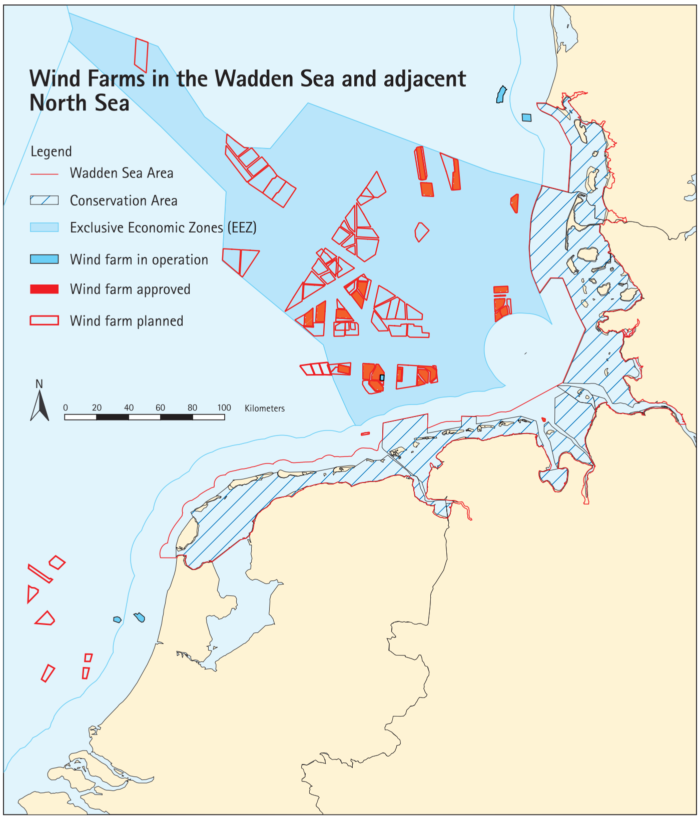


Figure 2.6: Offshore wind farms in the Wadden Sea and adjacent North Sea (status September 2009). Only approved pilot projects and wind farms in operation are shown (QSR 2009, Thematic Report No. 3.6)

force regarding the construction of wind turbines outside the Wadden Sea Area - along the coast and offshore - considering ecological and landscape criteria. In particular, cables crossing the Wadden Sea need attention.

In the Exclusive Economic Zone (EEZ) north of the Dutch Wadden islands, three offshore wind energy projects have been submitted for a license. In Germany, the first offshore wind farm "Alpha Ventus", around 45 km north of the island of Borkum, has been in operation since 2009. A further 18 projects for the German North Sea EEZ are at various stages of planning. In Denmark, three offshore wind farms are currently in operation in the North Sea. The latest one, of about 200 MW, Horns Rev II was inaugurated in September 2009.

2.14 Not listed in 1985: climate change and introduced alien species

The first scientific meeting on the effects of climate change on the Wadden Sea was held in 1988. At that time, climate change was a new subject of scientific research. After more than 20 years the situation has changed considerably. It has been concluded that the effects of climate change are likely to be large. Enhanced temperatures will cause northern species to disappear and enable the settlement of species adapted to warmer climates. Sea level rise, if the predicted rate comes true, may be the most serious consequence of climate change, since it threatens the very existence of the Wadden Sea.

Climate change is treated in two separate chapter in the QSR 2009 focusing on geomorphological and ecological consequences. Effects of climate change may become apparent in many of the monitoring programs targeted at different groups of plants and animals.

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.

However, 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.

Species introduced unintentionally with shipping and other transports, as well as introduced on purpose, are spreading at an unprecedented rate in the Wadden Sea. Many of the introductions benefit from recent warming. This invasion is accelerating and is shifting species dominance in the benthos and the dune vegetation in particular.

3. Monitoring Habitats and Species

3.1 Nutrients, phytoplankton and eutrophication

Eutrophication, caused by increased nutrient loadings, is one of the factors influencing the quality of the Wadden Sea area. Since the earliest nutrient measurements in the Wadden Sea, a clear increase in nutrient loadings and concentrations has been documented. Among the negative effects associated with the increased nutrient loads are Phaeocystis blooms, a decline of seagrass beds, increased blooms of green macroalgae and anoxic sediments. After a peak in the 1980s, nutrient levels have decreased again.

Eutrophication of the Wadden Sea continues to decrease. A main development since the QSR 2004 is a continuation of the decrease of riverine nutrient input. Also, compared to background estimates of autumn NH_4+NO_2 concentrations in the Wadden Sea, present values are still clearly elevated, but have decreased when compared to the QSR 2004.

3.1.1 Nutrients

Riverine nutrient input showed a gradual decrease during the period 1985-2006 (Fig. 3.1). Since 1985, the specific total nitrogen (TN) load to the Southern and Central Wadden Sea decreased each year by 2.1% on average. The specific total phosphorus (TP) load decreased even more strongly than the specific TN load, but in recent years the rate of decrease has slowed 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. In the Elbe and Weser, a slow-down in the decrease in specific TP load has been evident since about 1990.

Salinity-normalized nitrate+nitrite concentrations in the German Bight in winter reflect the decreasing total nitrogen load, and in some Wadden Sea sub-areas a decreasing trend is now apparent.

The salinity-normalized winter nitrate data (at salinity 27) show a downward trend in some areas since the early 1990s. In the Dutch Wadden Sea, a slight decrease was observed from around 50 µM (early 1990s) 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 nitrate concentrations were around 44-49 µM.

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 about 0.9 µM in the western Dutch Wadden Sea, and about 1.1 µM in the Danish Wadden Sea to around 1.8 µM near the Ems and Elbe estuaries. In the western Dutch Wadden Sea only, a further decrease was observed, from 1.4 µM during the early 1990s to about 0.9µM since 2002.

However, compared to background estimates of winter nutrient concentrations (DIN 6 – 9 µM, DIP 0.4-0.5 µM), present values are clearly elevated.

3.1.2 Primary producers

The decreasing nutrient input (TN loads by Rhine, Meuse, Weser and Elbe) had a significant effect on the phytoplankton biomass (as chlorophyll) in the Southern Wadden Sea (Western Dutch Wadden Sea, Lower Saxonian Wadden Sea, Norderney) in summer. 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.

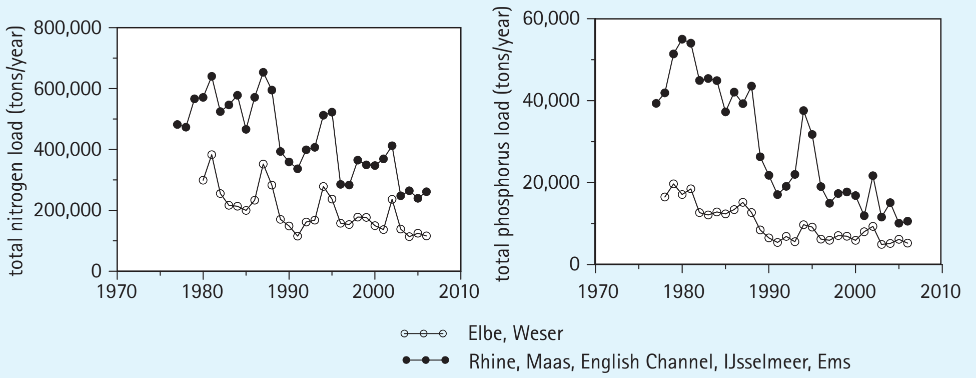


Figure 3.1: Specific nitrogen and phosphorus load (mean annual load / mean annual discharge) to the Southern Wadden Sea (Rhine, Meuse, Noordzeekanaal, IJsselmeer and Ems) and to the Central and Northern Wadden Sea (Weser, Elbe). Data source: DONAR, NLWKN, Lenhart and Pätsch (2001), updated to 2006.

However, the evaluation of present levels against background estimates is difficult because the three Wadden Sea countries use different estimates, time windows and statistics. 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 which are similar to the range in Denmark (1.9 µg and 4.0 µg Chl-a/l, (May-September). In all areas, present values are clearly higher than background values.

In general, summer chlorophyll levels are higher in the Southern Wadden Sea than in the Northern Wadden Sea and are in line with the 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) (Fig. 3.2)

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.

3.1.3 Organic matter turnover

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 (Table 3.1).

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 the view that the observed regional differences are real. Autumn values identify the same eutrophication hotspots and low eutrophication regions as summer chlorophyll. Compared to background estimates of autumn NH_4+NO_2 values, present values are clearly elevated (Table 3.1) but have decreased when compared to the QSR 2004.

The results show that current policies to reduce nutrient input have been successful with regard

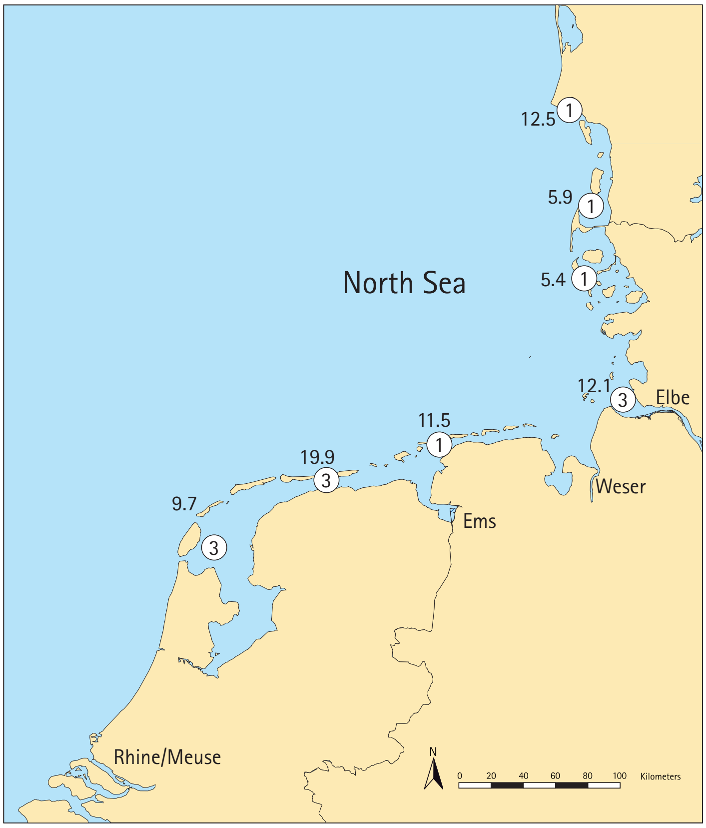


Figure 3.2: Spatial distribution of summer chlorophyll a (May-September) in the Wadden Sea during 2000-2006. Circles indicate the area considered and numbers inside indicate the number of stations used for the mean.

Table 3.1:
Classification of the Wadden Sea into Non-Problem, Potential Problem and Problem Areas based on autumn concentrations of NH4+NO2 (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 between 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 (van Beusekom *et al.*, 2001). All threshold values were formally derived and an uncertainty range of ±1 µM should be added. (Beusekom *et al.*, 2009, QSR 2009 Thematic Report No. 6).

Area	Non-Problem conditions	Potential Problem conditions	Problem conditions	Values QSR 2004 (1997-2002)	„Present" values (2000-2006)
Western Dutch Wadden Sea	<3.0 µM	3.0 µM <> 8.3 µM	> 8.3 µM	9.9 µM	8.2 µM
Eastern Dutch Wadden Sea	<4.0 µM	4.0 µM <> 10.2 µM	> 10.2 µM	19.8 µM	16.8 µM
Lower Sax. Wadden Sea	<3.2 µM	3.2 µM <> 8.2 µM	> 8.2 µM	10.6 µM	9.9 µM
List Tidal Basin	<1.9 µM	1.9 µM <> 4.2 µM	> 4.2 µM	6.1 µM	5.9 µM
Danish Wadden Sea (Gradyb)	<2.5 µM	2.5 µM <> 6.5 µM	> 6.5 µM	10.2 µM	8.3µM

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. However, the target of a Wadden Sea without eutrophication problems has not been reached yet. Therefore it is recommended that policies to reduce nutrient input are continued.

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 formulate region-specific standards for a good ecological status, as for instance demanded by the Water Framework Directive. Further effort is needed to understand the regional differences in nutrient patterns and their implications for the coastal ecosystem, and to improve the temporal and spatial resolution of existing monitoring programs in order to cover the entire seasonal cycle.

For the assessment of the phytoplankton eutrophication status in the Wadden Sea, two metrics are presently discussed in the Water Framework Directive: 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.

3.2. Hazardous substances

The pollution of the Wadden Sea derives mainly from external sources, *i.e.* the major rivers Elbe, Weser, Ems and the IJssel, the North Sea and the atmosphere. Although long-time downward trends are observed for most hazardous substances, there are no significant differences between the situation described in the QSR 2004 and the present situation described in the QSR 2009. Cleaning-up the Wadden Sea is obviously a slow process.

The riverine input of metals (Cd, Cu, Hg, Pb, Zn) in the period 1996-2007 remained at the same level as in 1995 or continued to decrease at a moderate rate (Fig. 3.3). For some metals, the target of background concentrations in sediment has not yet been reached in all sub-areas of the Wadden Sea. Regarding the "effects range level"

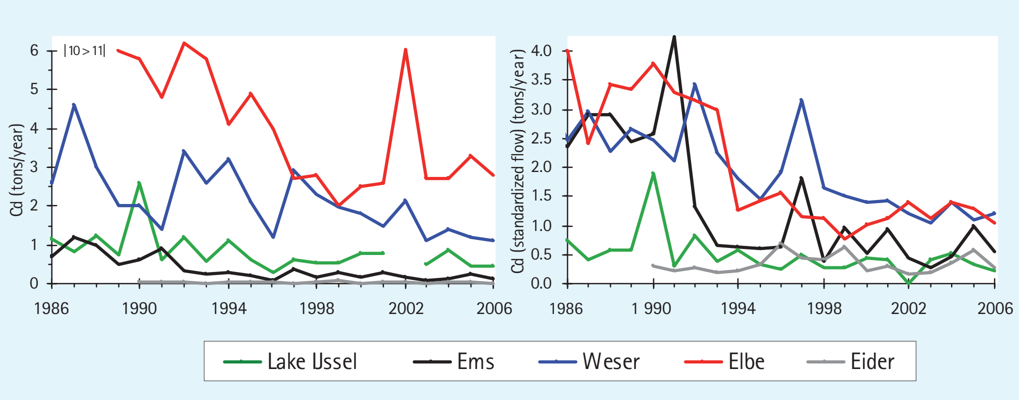
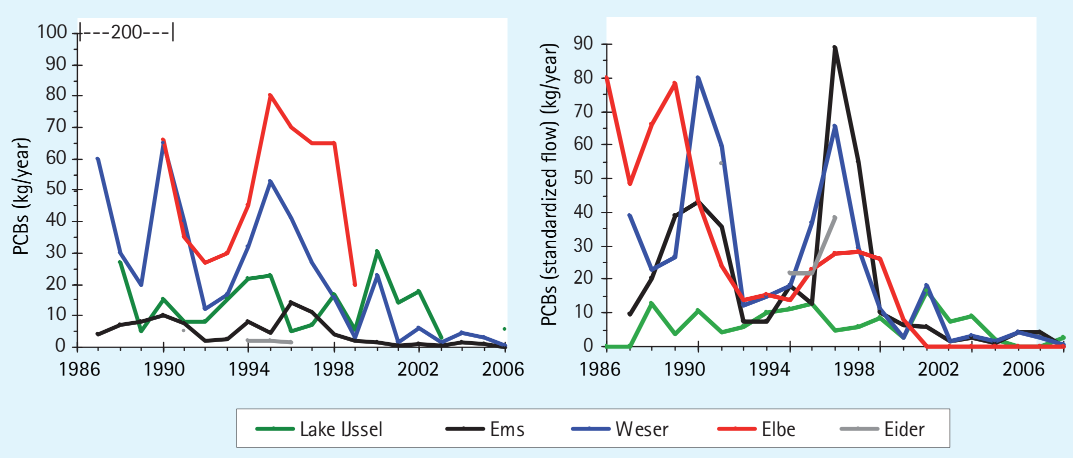


Figure 3.3:
Loads of Cadmium by riverine inputs (tonnes/year). Right panel: corrected for flow differences to a standardized flow of 1010 $m^3 \cdot y^{-1}$ (comparable to the average flow of the Weser). The major decrease occurred until 2002. The rivers Elbe and Weser water concentrations are twice those of Lake IJssel, Eider and Ems (Bakker *et al.*, 2009, QSR 2009 Thematic Report No. 5.1 Hazardous substances).

Figure 3.4: Loads of PCBs by riverine inputs (kg/year). Right panel: corrected for flow differences to a Standardized Flow of 1010 $m^3 \cdot y^{-1}$ (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 (Bakker *et al.*, 2009, QSR 2009 Thematic Report No. 5.1 Hazardous substances)

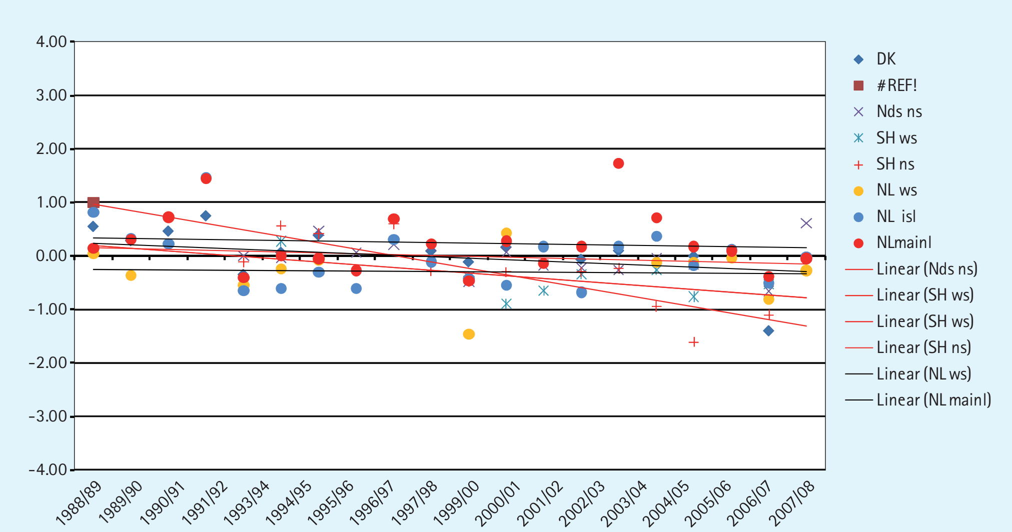


(ERL) by OSPAR, mercury and lead concentrations in the sediments pose a risk to the Wadden Sea ecosystem in the majority of sub-areas. For metals in blue mussels, the target of background concentrations has been reached for copper, zinc and nickel, whereas cadmium, mercury and lead concentrations are above the background. Therefore, continued effort to reduce metal discharges through rivers debouching into the Wadden Sea is necessary.

For a number of xenobiotic (man-made) compounds discharges to and concentrations in the Wadden Sea (Fig. 3.4) have decreased; however, the target (concentrations resulting from zero-emission) has not yet been reached. Some of these substances still pose a risk to the ecosystem. Many newly developed xenobiotics, including hormone disruptors, have a wide occurrence in the Wadden Sea ecosystem, and may have deleterious effects on it. The concentrations of xenobiotic substances in sediment, blue mussels and bird eggs have decreased over the last 20 years due to a reduction in riverine inputs and a phase-out of compounds such as PCBs, Lindane, DDT and TBT. However, concentrations of some compounds such as PCB still exceed background levels. Unexplained peaks continue to occur as well, which may be related to old deposits. Altogether these fluctuations still may have effects on sensitive biota. The target of "concentrations of man-made substances as resulting from zero-discharge" has not been reached due to the remaining diffuse losses and numerous hazardous substances still being in use. This implies that efforts to further reduce diffuse and also global emissions and losses need to continue.

The major sources of oil pollution at sea in the Wadden Sea region are illegal discharges of fuel oil residues, which are a constant threat to sea- and waterbirds. This is confirmed by a clear clustering of recorded slicks around the major shipping lanes in the southern and in the south-eastern North Sea.

Figure 3.5: Logit-transformed oil rates in common guillemots in the areas around the Wadden 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. ns = North Sea, ws = Wadden Sea, isl = islands, mainl = mainland (Camphuysen *et al.* 2009, QSR 2009 Thematic Report No. 5.3).



Although the oil rates among beached birds have decreased since the 1980s they are still high.

The oil rate of the guillemot has decreased since the mid 1980s but is still about three times higher than the OSPAR-EcoQO of 10% set for this species (Fig. 3.5). 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%.

The Wadden Sea coast is hit regularly by oil spills, which cause the deaths of thousands of birds.

Litter in the marine environment is a constant threat to wildlife, a hindrance to human activities, incurs high economic costs, is unsightly and reduces the recreational value of our coasts. It is a worldwide problem that does not stop on the borders of the Wadden Sea. Plastic items make up the major part of litter polluting the marine environment. One of the main sources of pollution is the fisheries industry, with lost or discarded nets, although various forms of packaging account for a large proportion of the litter recorded on beaches in the region. OSPAR beach surveys indicate that litter pollution is presently on the increase in the southern North Sea area and a recent analysis of beached bird data indicates that entanglements with litter are also on the increase in the region (Fleet *et al.*, 2009, QSR 2009 Thematic Report No. 3.8).

3.3 Benthic habitats

Changes of the geomorphology and its driving force, sea level rise, are slow processes and consequently no significant changes have been observed in the short period between the QSR 2004 and the QSR 2009. The same conclusion applies to the area of seagrass beds and the zoobenthic biomass; both are more or less stable. An exception is the Baltic tellin *Macoma balthica* which has strongly decreased. Intertidal mussel beds continued to decline except for the eastern Dutch Wadden Sea.

3.3.1 Geomorphology

The core habitat of the Wadden Sea region is the tidal area with its large extent of coherent intertidal and subtidal flats fringed by salt marshes and beaches, and dissected by branching tidal inlets exchanging half of the tidal volume twice daily with the North Sea. The large intertidal flats came into existence about 5000 years ago when the average tidal range had increased from <1 m

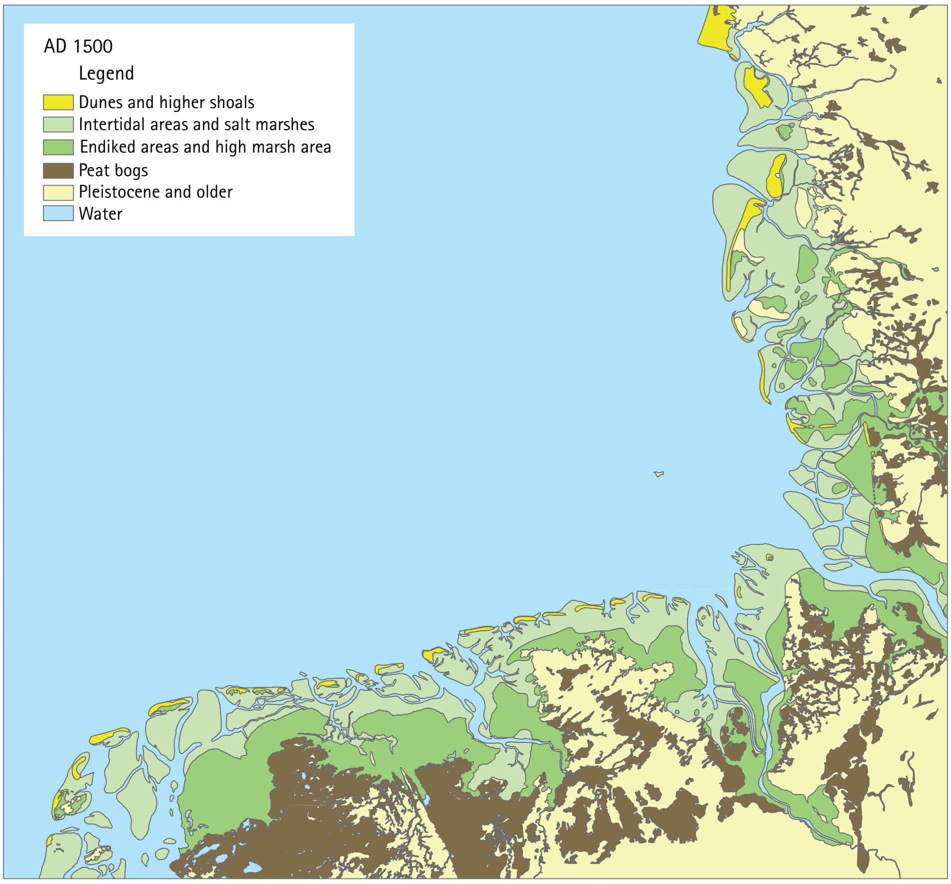
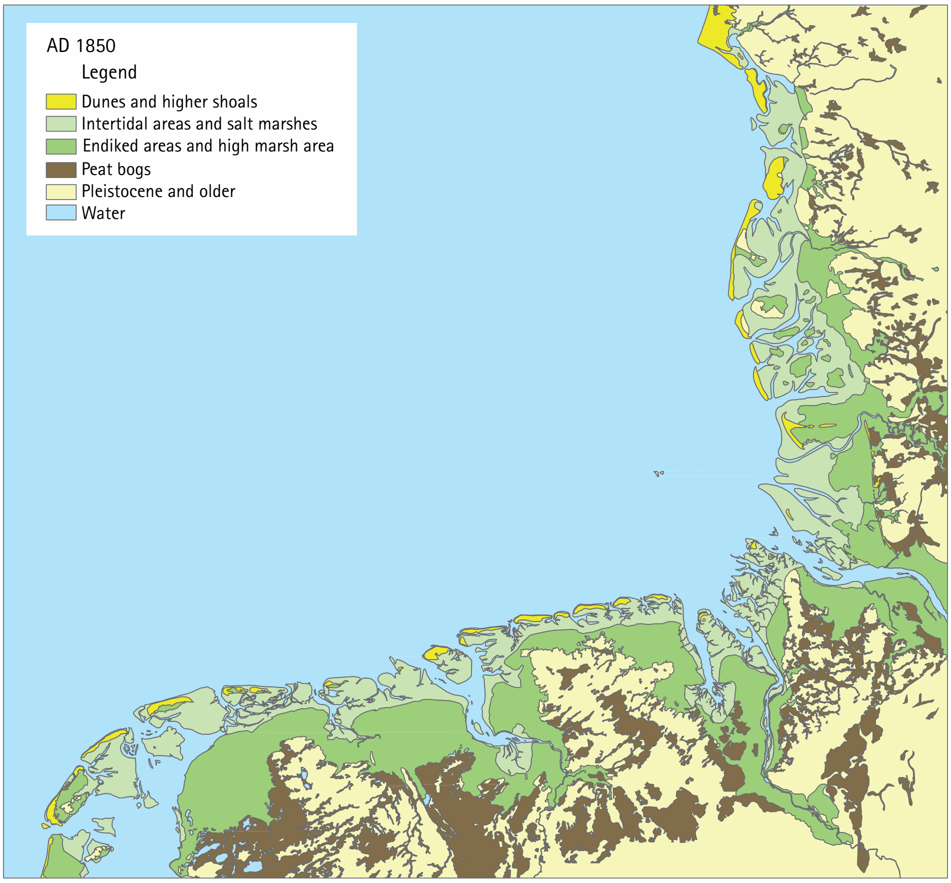


Figure 3.6a: First attempt of the reconstruction of the entire Wadden Sea coast of 1500 based on historical, geological, geomorphological, topographic and soil maps, as well as on previous reconstructions of parts of the Wadden Sea (Wiersma *et al.*, 2009, QSR 2009, Thematic Report No. 9 Geomorphology). The coast of 1850 and 2000 is in Figure 3.6.b).

Figure 3.6b: First attempt of the reconstruction of the entire Wadden Sea coast of 1850 and 2000 based on historical, geological, geomorphological, topographic and soil maps, as well as on previous reconstructions of parts of the Wadden Sea (Wiersma *et al.*, 2009, QSR 2009, Thematic Report No. 9 Geomorphology).



to ~2 m. The further course of geological development differed somewhat between the southern, central and northern Wadden Sea, and intermittently some tidal areas turned into brackish and freshwater marshes or bogs. Traces of this history are still evident and occasionally have effects on present day processes.

The main driving force of coastal morphology is a balance between sea level change and sediment supply from shallow zones of the adjacent North Sea. With the onset of land claim by the 13th century AD, the Wadden Sea entered a phase when human engineering interfered with natural developments and which culminated with large-scale embankments in the 20th century. Compared to 1500, the area of tidal flats decreased by about one third, mainly due to land claim and in the north also because of coastal retreat. Still, the large intertidal area has remained the most outstanding natural feature of the Wadden Sea in a world-wide comparison (Fig. 3.6). With an expected rate of sea level rise of about 1 m at the end of this century, it is questionable to what extent a natural sediment supply from the North Sea could keep up with such a rise in water level. In the early post-glacial phase of the Holocene, sedimentation rates were insufficient to fill up the coastal area at such a high rate of sea level rise. Presumably this is what the tidal area of the Wadden Sea is facing in the coming decades.

Sand nourishments are already carried out to defend the outer coastline of barrier islands. In a similar way, supplementing natural sedimentation rates in the tidal basins could be considered to allow intertidal flats to grow at the same rate as the sea level rises. Accomplishing this without harming the benthic habitats of the tidal area is likely to be a main challenge for the protection of the Wadden Sea in the decades to come.

3.3.2 Seagrass beds and green algal mats

The past geological development and present pattern of sedimentation and erosion are relevant to the distribution of major habitats in the Wadden Sea. For example in the northern region, large meadows of seagrass abound where plants find a firm rooting in peat and clay of drowned land now underlying a thin layer of loose sediment. Conversely, areas where shifting sediments prevail tend to be devoid of seagrass. Seagrass beds are a very sensitive habitat in the intertidal zone. They are very unevenly distributed with small beds of mostly low plant density in the southern and central Wadden Sea whereas, in the northern Wadden Sea, the beds are extensive with a dense cover from July to September. Seagrass beds with a coverage of more than 20% comprise about 11,000 ha with more than 90% of these beds occurring in the North Frisian and Danish part of the Wadden Sea (Fig. 3.7). To what extent this unevenness is natural or caused by eutrophication and other disturbances is still not clear. Climatic differences cannot account for this pattern because seagrass beds of the two species *Zostera noltii* and *Z. marina* thrive all along the Atlantic shores from Scandinavia to northern Africa.

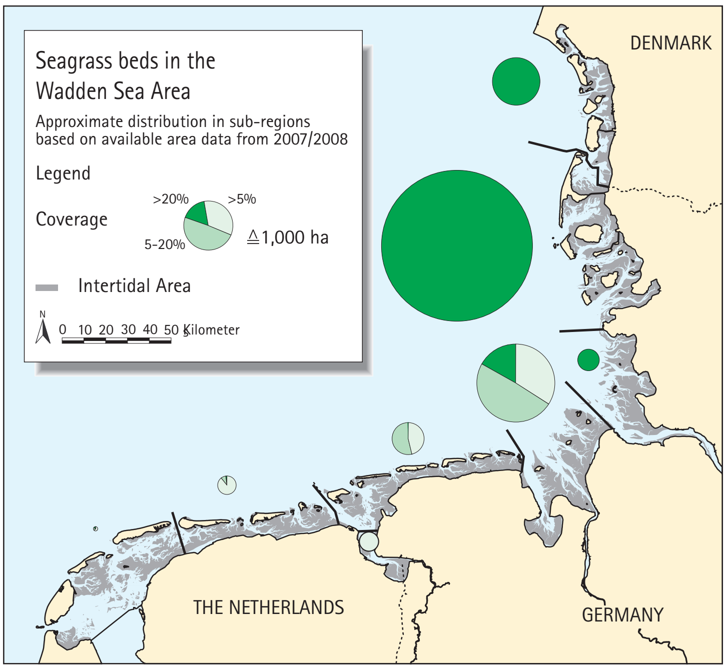
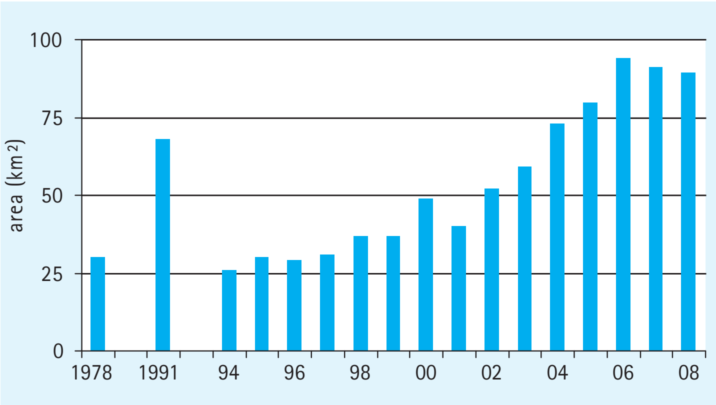


Figure 3.7: Distribution of intertidal seagrass beds (with various densities) in the Wadden Sea (in ha) in different sub-regions in 2007/2008 (van der Graaf *et al.*, 2009, QSR 2009 Thematic Report No. 12).

Figure 3.8: Seagrass bed (more than 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.), (van der Graaf *et al.*, 2009. QSR 2009 Thematic Report No. 12).



After a long-term decline, there has been an increase in seagrass area since the middle of the 1990s. However, this may have come to a halt in recent years. The increase could have been a response to reduced eutrophication stress, improved light conditions, an intermittent decrease in storminess, or a combination of such factors. More research is needed on the cause of seagrass bed development because seagrass provides an important habitat in the Wadden Sea and is used as a main indicator of ecosystem quality. The methods for assessing seagrass beds require further harmonizing in the Wadden Sea. Management should continue to reduce nutrient loads to improve the growth of the two seagrass species which are best adapted to oligotrophic conditions. There is also concern that dredging and dumping of sediments and the subsequent light attenuation has been harmful to seagrass.

Green algal mats attained massive proportions in the summer months of the early 1990s. Subsequently they fluctuated strongly at a moderately high level with a strong peak in 2001. Omitting this peak value, the area covered by green algae, as observed from plane in the Schleswig-Holstein intertidal zone, is significantly correlated with the total nitrogen load of the Elbe and Weser. In spite of considerable scatter, this suggests that the extent of green algal mats may serve as an indicator for the eutrophication status in the Wadden Sea. However, other factors also seem to be important for the extent of green algal mats. For example, a rough sea easily removes green algae from exposed tidal flats. Often, drifting green algae become trapped between groynes of sedimentation fields and then smother any seagrass that is present.

3.3.3 Zoobenthos

Intertidal seagrass and green algae serve as food for brent goose and wigeon in particular, while the benthic fauna of all intertidal flats is important for foraging waders, shelduck and gulls. Particularly the mid tidal zone is rich in zoobenthic biomass. In parts of the subtidal zone quantities of biomass might be even higher. However, the latter habitat has not been sufficiently sampled throughout the Wadden Sea to make a sound estimate.

The deposit-feeding lugworm *Arenicola marina* significantly contributes to biomass on sandy intertidal flats but not on the estuarine mud flats and in the subtidal zone. Suspension-feeding bivalves usually dominate the biomass, *i.e.*, the clam *Mya arenaria* at estuarine sites and the cockle *Cerastoderma edule* at marine sites. Occasionally alien species significantly increase the biomass, *i.e.* the razor clam *Ensis americanus* at the lowest tidal zone and the worm *Marenzelleria viridis* on mudflats in the Dollard. The establishment of such invaders suggests that the resident fauna had been below carrying capacity, probably under top-down control in the food web rather than being limited by food availability.

Over the past decades there are neither consistent temporal trends in total biomass in macrozoobenthos nor in the abundances of 19 species at ten localities spread throughout the Wadden Sea. The zoobenthos in general may not be very suitable for indicating trends in eutrophication. However, the tellin *Macoma balthica* has probably responded with enhanced growth and biomass to eutrophication in the 1980s to the mid 1990s in the western Dutch Wadden Sea. With the exception of the Dollard and a site near Norderney, this major food source for the large flocks of knots is now declining throughout the Wadden Sea.

The recent predominance of mild winters is having a negative effect on recruitment in many bivalves including *M. balthica*. The underlying process seems to be improved survival and early arrival in the tidal zone of predaceous crabs and shrimps which then prey heavily on bivalve spat in subsequent spring and summer. Severe winters cause high mortality or delay in the appearance of these predators in the tidal zone. This may allow young bivalves to survive their early benthic stage. However, there seem to be many exceptions to this pattern.

Many sites show an increase in species richness after mild winters and none shows a decline. This may be seen already as a consequence of global warming. Monitoring of zoobenthos should be generally extended into the subtidal zone, and sampling efforts should be spread more evenly through the entire Wadden Sea. The macrozoobenthos is an important trophic link between the productive microalgae and the coastal birds in the Wadden Sea, and thus serves as a good indicator of ecological quality. This particularly applies to the mussel beds (*Mytilus edulis*) of the Wadden Sea which occur in the lower intertidal and at sheltered sites in the subtidal zone.

3.3.4 Mussel beds

After a strong decrease of intertidal mussel beds in the early 1990s, mussel fishing has been banned from substantial parts of the tidal area. Despite considerable efforts to protect stable mussel beds, most continued to decline. As outlined above, this may be caused by mild winters favouring predators on mussel spat. However, increases of mussels in 2001, 2003 and 2005 in parts of the Dutch Wadden Sea and locally also in Lower Saxony, indicates that factors other than winter temperature need to be considered to explain the population dynamics. The management target to increase the area of mussel beds has only been achieved in parts of the Dutch Wadden Sea. As with zoobenthos in general, more monitoring of mussels in the subtidal zone is necessary for a better understanding of the dynamics. The recent spread of introduced Pacific oysters on intertidal mussel beds as well as in the shallow subtidal will be discussed below in a section on alien species.

Mussels are cultured on the bottom in the subtidal Dutch and German Wadden Sea. For this a total area of 11,000 ha has been reserved, but only about half of that area is actually in use. The main reason for this is that parts of the reserved plots are unsuitable for mussel culture for hydrographical and geomorphological reasons. Young mussels are harvested from natural beds for transfer to the culture lots. In recent years, the scarcity of these so-called seed mussels was partly compensated by imports from the British Isles. Experiments are underway to collect young mussels on ropes and nets suspended in the water. These are out of reach of the benthic predators and survival of young mussels is much higher there than on the sea floor. Collecting spat in this way is common practice on many coasts in the world and has the potential to eventually free natural mussel beds from the disturbances caused by dredging for seed mussels in the Wadden Sea.

3.3.5 Subtidal habitats

Roughly one half of the tidal area consists of subtidal flats and deep gullies. This habitat is not as unusual as the large coherent intertidal flats of the Wadden Sea which supply the huge flocks of birds with food. However, on a European scale it is certainly important, with diving birds and marine mammals exploiting the subtidal habitats. Shrimp, crabs and fish commute between the inter- and subtidal zones. Many invertebrates and some macroalgae have partial populations in both zones. Very often the intertidal serves as a nursery and the adults occur subtidally, although the reverse occasionally occurs as well (*i.e.*, the worms *Nephtys hombergii* and *Phyllodoce mucosa*).

In previous centuries, beds of the European oyster Ostrea edulis in the shallow and deep subtidal zone have been overexploited. This species no longer occurs in the Wadden Sea. Also almost all reefs of the colonial tubeworm *Sabellaria spinulosa* , which once occurred in the deep gullies in the Danish and German Wadden Sea, are gone. Direct destruction with heavy chains to remove these obstacles which affected trawling for shrimp may have caused the decline. Other factors such as sediment dredging to ease shipping may have played a role as well. Repeated small disturbances by bottom trawling may prevent re-colonization. However, experimental studies should explore this issue.

Beds of subtidal seagrass *Zostera marina* in the northern and western Wadden Sea vanished in the wake of an epidemic disease in the 1930s and they never recovered. As with the native oyster beds and *Sabellaria*-reefs, the lack of recovery is not well understood. It is possible that the mere absence of factors which have caused the decline is not sufficient to trigger a recovery. In the westernmost Dutch Wadden Sea, the construction of the Afsluitdijk in 1932, causing changes in the hydrography, may have played a part as well. But even without these conspicuous biogenic habitats, the subtidal is a zone of high biodiversity, probably because of the relative shelter against strong surf from the open sea and high food availability in the shallows. There are indications that benthic biomass is even higher on shallow subtidal flats than in the mid intertidal.

Together with requirements of European Directives on ecological qualities, all this highlights that more research and monitoring needs to be done in the subtidal part of the Wadden Sea. For the intertidal and terrestrial parts, aerial photographs have been of great help to map the distribution of habitats. In the subtidal part, acoustic methods may help in an analogous way. With sidescan sonars towed behind a ship, the strength of the returning acoustic beam is measured and provides information on objects protruding from the sediment. Multibeam sonar systems have been mounted on the hull of a research vessel. The time between emission and the backscatter to the receiver is measured. This instrument provides highly accurate bathymetric records and can even be used for sediment classification. However, it cannot be used at very shallow subtidal flats. A combination of methods in addition to acoustic devices, such as underwater video, sediment coring and conventional oyster dredges, is required for surveying the subtidal Wadden Sea. This is regarded as an urgent task to improve nature conservation, as is restoring the Wadden Sea below low tide level where possible.

3.4 Aquatic alien species

The number of alien species in the Wadden Sea continues to increase. An important new addition to the range of alien species since the QSR 2004 is the American comb jelly *Mnemiopsis leidyi*. It is thought to cause major changes in marine ecosystems. The Pacific oyster *Crassostrea gigas* has continued its invasion of the Wadden Sea.

Alien species have been transported by human means across their natural boundaries, interact with native species, and may irrevocably alter ecosystem functions and the services ecosystems provide to humanity. The introduction of alien species for aquaculture or by shipping is not a new phenomenon. However, in recent years, such aliens are beginning to play a predominant role in the Wadden Sea ecosystem and can no longer be neglected as agents of change (Fig. 3.9). Just to name some of these changes: Dense swards of the introduced *Spartina*-grass extend salt marshes and displace other pioneer plants and intertidal flat organisms. Larvae of Pacific oysters *Crassostrea gigas* settle on mussels, grow faster and larger, and finally turn intertidal mussel beds into oyster reefs. After a few years, these in turn provide shelter for Pacific shore crabs of the genus *Hemigrapsus*. On the shells, an Australasian barnacle *Austrominius modestus* dominates native ones. In the shallow subtidal zone, clumps of these oysters provide anchorage to a more than 3-m long Pacific seaweed *Sargassum muticum*. On these branching algae cling Pacific ghost shrimp *Caprella mutica* and drifting American comb jelly *Mnemiopsis leidyi* also becomes entangled in this kelp forest. Overall, it constitutes a completely new habitat in the Wadden Sea.

Figure 3.9: Razor clams *Ensis americanus*, introduced with ballast water, are washed up on a bed of Pacific oysters *Crassostrea gigas* that were introduced for farming in the Wadden Sea near Sylt (Photo: K. Reise).

At least 50 introduced alien algae and invertebrate species have established with permanent populations in the Wadden Sea. Some remain rare, others first boost and then bust, and some achieve continuing dominance. In most cases they constitute additions, fill apparently empty niches, and provide new habitat structures. At times they benefit native species, but they may also harm or displace them. It is impossible to simply categorize aliens as bad or good. Their interactions with natives and among each other, their effects on habitats and on human health may vary between sites and with time. More subtle are introductions of genetically different individuals which then interbreed with residents. It is also possible that new reciprocal adaptations have evolved in the course of interactions between alien and native species. All these introductions and their consequences are essentially irreversible developments, changing the biota of the Wadden Sea forever. Their number is rapidly increasing and none of them has gone again or is likely to do so.

This conspicuously advancing tide of alien invaders is primarily facilitated by a global exchange of aquaculture organisms and by more, larger and faster ships carrying more alien organisms. Establishment is eased by the common availability of floating objects such as buoys and pontoons where introduced species may settle in the absence of benthic predators. Also, hard coastal defence structures often constitute gateways for alien species. A breakthrough for aliens is now provided by the recent trend of warming by an average of 1.5°C in the past 30 years.

Most donor regions of introduced species are at coasts with a warmer climate than it used to be in the Wadden Sea. Either newcomers now meet easier conditions to become established, or aliens which were already introduced a long time ago now no longer suffer from severe winters and benefit from warmer summers. The combined effect of increasing global trade and global warming has triggered a revolution in the biotic composition of the Wadden Sea compared to the earlier rates of changes. Alien species introductions are a global phenomenon and some alien species become universal. For instance, the Pacific oyster is spreading to almost all coasts within temperate zones, heading a progressing homogenization of the world's coastal biota.

This tends to undermine the biotic uniqueness of the Wadden Sea, calling for a global management to reduce the rate of introductions. Treatment of ballast water and control of hull fouling, halting the use of alien species in open aquaculture facilities, and banning any other form of intentional introductions are obvious steps to be implemented in the framework of international conventions. The Trilateral Wadden Sea needs a common approach to the prevention, management and monitoring of aquatic and terrestrial alien species introductions. Monitoring and early detection is necessary because eradication is only feasible at a very early stage of invasion. Above all, a strong effort is required to raise more awareness among professionals and the general public as a prerequisite for effective precautionary measures.

3.5 Salt marshes

The QSR 2009 revealed an increase of nearly 1,600 ha (about 5%) of salt marshes in the Dutch and German parts of the Wadden Sea when compared to the QSR 2004. However, changes in the vegetation between the QSR 2004 and the QSR 2009 feature a decrease in the pioneer zone and an extension of late successional and climax stages.

Salt marshes occupy the upper parts of the intertidal zone and the supralitoral, *i.e.* the interface between land and sea and extend vertically from well below the mean high-tide level up to the highest water mark. They constitute precious and irreplaceable habitat for a wide range of organisms, although the number of species per unit area may be relatively low. With about 40,000 ha (Table 3.2), salt marshes of the Wadden Sea make up about 20% of the total area of salt marshes along the European Atlantic and Baltic coasts.

3.5.1 Area of salt marshes has increased

The QSR 2009 revealed an increase of the total extent of salt marshes in The Netherlands and German parts of the Wadden Sea when compared to the QSR 2004 (39,680 ha and 40,620 ha, respectively, Fig. 3.10). The new marshes comprise mainly young natural salt marsh including embryonic dunes and driftline vegetation. This increase occurred predominantly on both the islands and the mainland coast of Schleswig-Holstein.

Landform	The Netherlands	Lower Saxony	Hamburg	Schleswig-Holstein	Denmark [1]	Total (ha)
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 summer-polder	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 3.2: 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. (Esselink *et al.*, 2009, QSR 2009 Thematic Report No. 8).

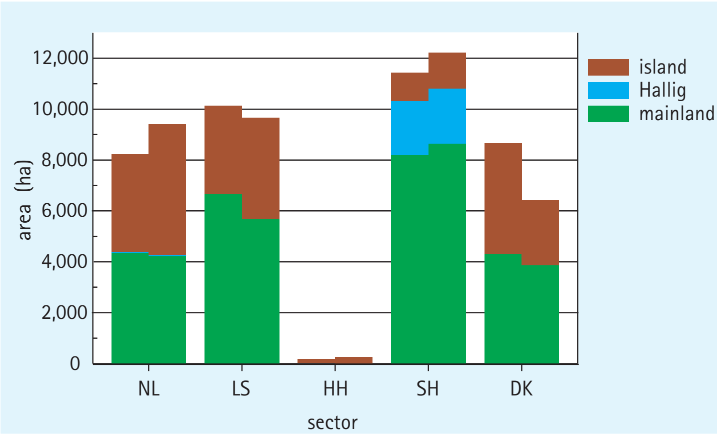


Figure 3.10: Comparison of the extent of salt marshes in different parts of the Wadden Sea during the 1995/2001 (left-hand bars) and the 2002/2007 (right-hand bars) salt marsh surveys. For Denmark, the data from the consecutive surveys were not comparable and did not include pioneer salt marsh. Data of the 1995/2001 survey after QSR 2004 (Esselink *et al.*, 2009, QSR 2009 Thematic Report No. 8).

3.5.2 Vegetation development and ageing

The main result from the comparison of vegetation changes in the QSR 2009 is a decrease of the pioneer zone and an extension of late successional and climax stages in many salt marshes across all Wadden Sea regions. These climax communities are usually formed by almost monospecific stands of the dominant plant species (namely *Elytrigia atherica* community on the high salt marshes, *Phragmites australi*s community in brackish marshes, and *Atriplex portulacoides* community in low salt marshes). Hence, climax communities have a low species and structural diversity. See Fig. 3.11 for examples without or reduced live-stock grazing from The Netherlands and Fig. 3.12 for examples from Germany. The examples also show that the changes take not years but decades.

Not only does ageing affect the floristic diversity on the salt marsh, but also the diversity 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. Thus extension of climax plant communities at the expense of early succession communities will inevitably also lead to a decline of the specific invertebrate diversity in a salt marsh.

The salt-marsh succession may be driven by three factors, namely: (1) an increase in marsh elevation by sedimentation (dominates in the foreland-type salt marshes), (2) an increase in plant nutrients, especially nitrogen (main factor in sandy back-barrier marshes), and (3) cessation of livestock grazing. A lack of natural spatial dynamics may form another important factor for the observed overall trend of ageing. The contemporary Wadden Sea salt marshes have to a large extent been dictated by human activities.

Within that framework recommendations are (1) a reduction of artificial drainage which may increase abiotic variation and a retardation of the ageing processes in wet parts, (2) creation of wide salt marshes (in combination with de-embankments as indicated in the next paragraph) which have the possibility to develop wet parts, (3) superimposed on the abiotic conditions, discussion on the target type of community for conservation, including plant and animal species composition, structure of the vegetation being affected by livestock grazing (intensive grazing with a homogeneous sward, moderate grazing with a heterogeneous sward, no grazing with a homogeneous sward at the long term), or 'laissez faire' without further discussion.

3.5.3 Salt-marsh restoration

In the QSR 2004, an increase of the area of salt marshes was assessed as management target and de-embankment of summer polders was considered an appropriate measure. Over 800 ha of salt marsh have been restored so far. In addition to

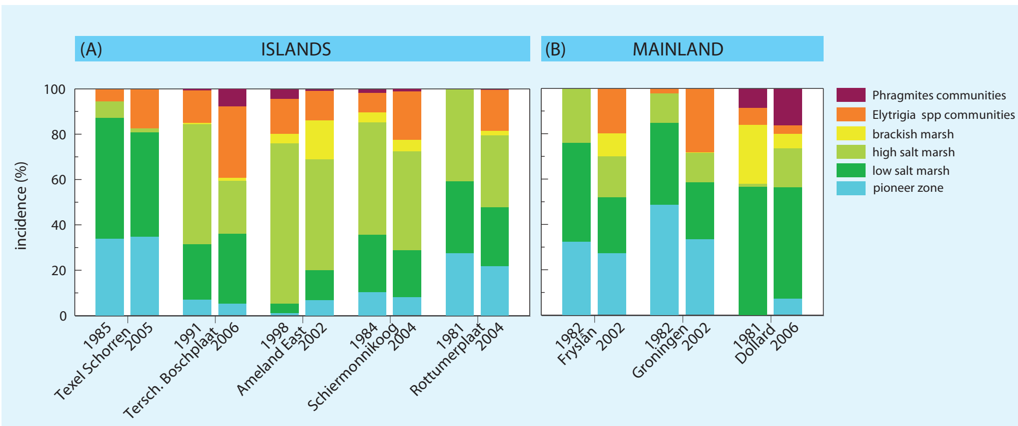


Figure 3.11: Vegetation change in three mainland salt marshes and on five barrier islands in The Netherlands Wadden Sea over an approximately 25-year period. The graphs present the incidence (%) of the main vegetation zones and climax communities (Dijkema *et al.* 2007). Data from vegetation mapping 1978 – 2006 by RWS-DID (Esselink *et al.*, 2009, QSR 2009 Thematic Report No. 8).

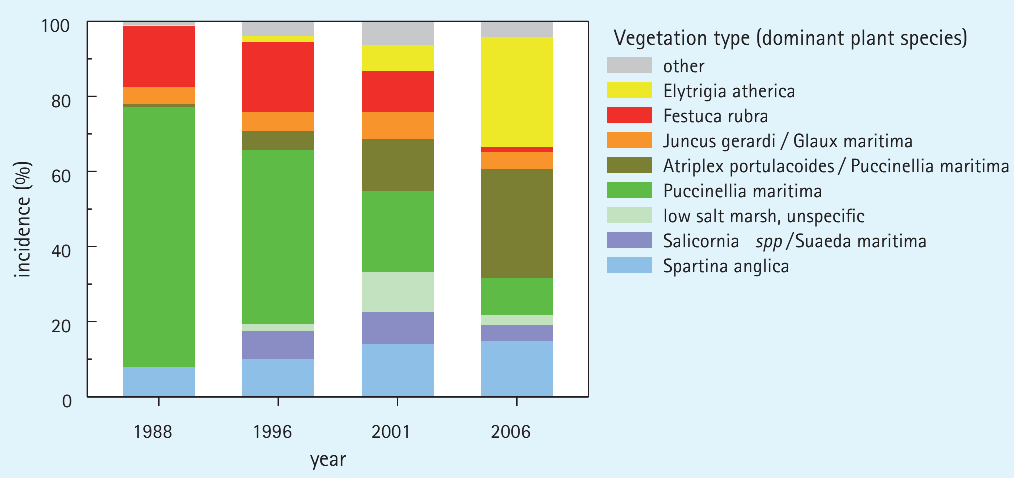


Figure 3.12: Vegetation development on the Hamburger Hallig from 1988 until 2006 based on vegetation surveys of the total area. Note that the whole area was grazed intensively with sheep until 1991, when three management regimes were introduced in different parts of the area. Vegetation types are according to TMAP typology. For graphical reasons, vegetation types with a limited distribution (incidence < 5% in all years) were merged into one collective group (other) (Esselink *et al.*, 2009, QSR 2009 Thematic Report No. 8).

the total area, de-embankment of summer polders 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 narrow salt marshes. Removal of artificial sand dikes may restore washovers and rejuvenate salt marshes on barrier islands (see next paragraph). Through de-embankment, sedimentation gives the area the possibility to adapt to the expected sea-level rise and climate change. The composition and structure of the vegetation depends on the grazing regime, as in existing salt marshes.

3.6 Beaches and Dunes

Since the QSR 2004, no progress was made in 1) increasing the dynamics of dune systems, 2) reduction of atmospheric deposition, and 3) in reduction of groundwater extraction.

Beaches and coastal dunes together constitute one morphogenetic habitat system and play an important role in the Wadden Sea. They build the barrier islands and provide habitats for many, often highly specialized, species. In their shelter, salt marshes can develop. At the same time, they are important for coastal defence and as recreation areas.

3.6.1 The status of the dune fauna

It is increasingly acknowledged that the fauna in the dunes plays an important role. Of course, livestock is introduced into many dune systems. This is done partly to enhance the dynamics and partly to retard or stop succession towards climax stages. The effects on the geomorphology and vegetation are often part of monitoring programmes. However, the status of natural fauna elements including birds, mammals and invertebrates, is largely unknown. Programmes that monitor the effects of management practices should be extended to include the fauna.

3.6.2 A new geo-ecological concept of Wadden Sea barrier islands

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 of the geo-ecological functioning of Wadden Sea barrier islands has been developed (ten Haaf & Buijs 2008; de Leeuw *et al.* 2008; Löffler *et al.* 2008, see details in Lammerts *et al.*, QSR 2009 Thematic Report No. 15). 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. 3.13):

(1) Island heads:

The development of island heads depends on the sedimentation and erosion processes in the tidal deltas between the islands. Periodically bare beach plains grow together with islands: at the north side when the sand comes from the outer (ebb) delta, at the south when it comes from the inner (flood) delta. On the island heads, green beaches may develop in places where the beach plain is partly cut-off from the sea by embryonic dunes. The vegetation of green beaches is characterized by a combination of pioneer species from salt marshes and dune slacks. Salt marshes may also develop on the leeside of embryonic dunes or dune ridges.

(2) Dune-bow complexes:

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. Different dune ridges merged to large

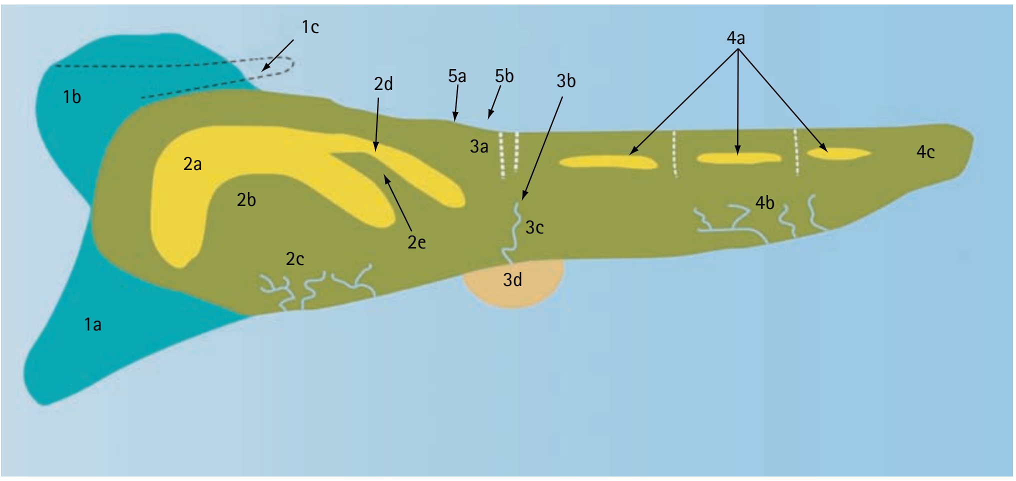


Figure 3.13: New geomorphological model of a barrier island with its characteristic main units and sub-units (for explanation see text and QSR 2009 Thematic Report 2009 No. 15). Salt marshes may be found in sub-units 2c, 3bc, 4b and 5a. This representation of the model is characteristic for the Dutch and Lower Saxony barrier islands (Lammerts *et al.*, 2009, QSR 2009 Thematic Report No. 15).

parabolic dune systems which include grey dunes, heath lands, dune slacks, scrub and woodland. 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. Large parts of these salt marshes have been turned into agricultural areas through embankment.

(3) Wash-over complexes:

A wash-over consists of a north-south oriented part of the beach plain accompanied at both sides by natural dune ridges. Wash-over complexes that are formed on the North Sea side of the island gradually merge with salt-marsh vegetation on the Wadden Sea side. However, this connection has often been closed by artificial sand dikes. The wash-over complex itself can either be bare, covered with algae or with pioneer salt-marsh or dune vegetation comparable to green beaches. A dynamic wash-over 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 wash-over complex to the south.

(4) Island tails:

The island tail consists of a beach plain at the eastern side of the island. 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, and may grow into larger dune complexes that are separated from each other by wash-overs. 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 island salt marshes is well above historic reference values . 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 dominate the northern fringe of these marshes.

(5) Beach and foreshore

The beach and foreshore at the North Sea side are important elements as a transport route for sedimentation and erosion. The beach can harbour embryonic dunes. Periodically, extensive areas of green beach may develop, and then may disappear quickly when large-scale dynamic processes are less favourable.

The next step could be the extension of this model to all barrier islands in the Wadden Sea. Moreover, experimental tests are needed to validate the model.

3.7 Offshore Area

No major geomorphological changes in the offshore zone have been recorded. A comprehensive monitoring programme for the offshore zone is lacking in TMAP. Bird monitoring in the offshore zone of the Wadden Sea has been started only by Schleswig-Holstein in 2004. There is insufficient monitoring data to draw conclusions on biological changes.

The Offshore Area of the Wadden Sea Cooperation Area is defined as the near-shore zone between the barrier islands and the line three nautical miles off the baseline (respectively 12 nautical miles when the conservation area exceeds this line). The boundaries of this 4,000-km² area are artificial. However, with its slope from about 15 m depth up to the island shores and ebb delta shoals in front of the inlets, this zone constitutes an important transition from the Wadden Sea proper to the open North Sea. In this zone, the most violent breakers occur, and many ships have been wrecked during storms in this turbulent sea. Waves mobilize sand from the bottom, and the net transport processes of sand may play a key role for the sediment budget of the Wadden Sea. The permanent exchange of water masses, sediments, planktonic drift and animals migrations between the tidal areas and the offshore zone justify the inclusion of the latter in the Cooperation Area.

Among the multiple anthropogenic pressures in the offshore zone, offshore wind farms, ship traffic, fisheries and sand and gravel extractions are of primary concern. The increasing interest in building wind farms brings another risk to both seabirds and marine mammals in the North Sea. Wind farms are not allowed in the Nature Conservation Area, but some have already been established and others are planned close to this area, and can, therefore, influence parts of the same populations that use both the offshore area and the tidal area. Off the northern part of the Danish Wadden Sea at Horns Rev, a 160 MW wind farm has operated since 2002 and a 200 MW wind farm was opened in 2009. Follow-up studies on the 160 MW wind farm have shown that bird species such as divers avoid the farm while common scoters occur there in smaller densities, gulls and terns occur in the same densities and cormorants in larger densities than in the surrounding waters. Birds on migration through the area initiate a change of their route by 3-4 km to avoid the wind park. Thus the parks influence the birds' utilization of the offshore area, but up to now not seriously. However, the cumulative effects of more wind parks in the North Sea may aggravate the situation.

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 as probable causes of future changes. Upcoming coastal defence measures (including sand and gravel extraction and beach nourishment) might impact the natural sediment dynamics at least on a regional spatial scale.

Crustaceans, bivalves and polychaetes are the most important benthic organisms in the offshore zone. With respect to nutrition of seabirds, bivalves (mainly *Spisula* and *Ensis*) 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. There are significant proportions of the respective biogeographic populations of common eiders, sandwich terns and lesser black-backed gulls in the offshore water of Germany alone. There is insufficient monitoring data to draw conclusions on biological changes.

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.

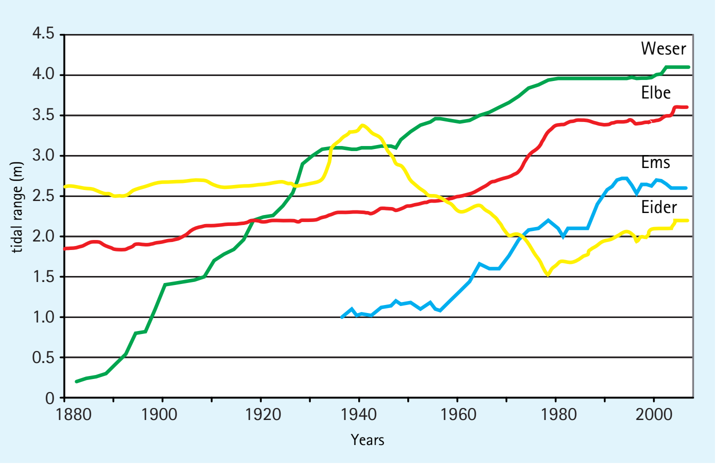
3.8 Estuaries

The estuaries constitute the part of the Wadden Sea in the worst ecological condition. Although the Wadden Sea estuaries are subject to many strong, human-induced pressures, the available monitoring data from TMAP is insufficient to prove any significant ecological change since the QSR 2004. On a longer time-scale, water quality in most estuaries has improved whereas many other characteristics show a declining quality.

Estuaries are tidal river mouths with a free water exchange with the sea. They are characterized by tidal brackish and freshwater areas forming the transition zone between rivers and high-salinity tidal waters. There are five such estuaries in the Wadden Sea Area with 'open access' to the Wadden Sea, namely the Varde Å in the Danish Wadden Sea Area, the Eider, the Elbe and the Weser in the German Wadden Sea Area, and the Ems in the German and Dutch Wadden Sea Area.

The estuaries are of high relevance for the Wadden Sea ecosystem because they are the pathways along which nutrients, toxic substances and silt from the rivers reach the Wadden Sea; and because they serve as migration, nursery and feeding areas for animals. 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 for migrating species (in particular birds and fish), but additionally they are inhabited by various characteristic brackish-water and estuary-endemic species. The brackish salt-marsh vegetation along the shores produces more biomass than any other

Figure 3.14: 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) (Schuchardt and Scholle, QSR 2009 Thematic Report No. 16).



salt marsh. With proper management, this attracts large numbers of ducks and geese.

Most of the river outflows (especially the smaller ones) in the Wadden Sea Area have sluices or storm surge barriers that prevent or reduce natural mixing of fresh and salt water and the establishment of transition zones. The estuaries of the rivers Elbe, Weser and Ems constitute the seaward access routes to the major German and Dutch sea ports and are among the most industrialized regions of the Wadden Sea Area. The industrial development along these rivers and their estuaries has resulted in significant alterations in morphology, hydrography (including tidal amplitude), flora and fauna, amongst others as a result of deepening of channels and embankment of river banks, including the resulting loss of brackish marshes. The increase of the tidal range of the estuaries (Fig. 3.14) may serve to illustrate the strong human influence on the state of the estuaries. A gradual increase reflects the ongoing narrowing and deepening, while the ups and downs at the Eider have been caused by barrage construction.

Large sections of the foreland and water areas of the estuaries have been designated as Natura 2000 sites, thus creating the basic conditions for sound ecological management. However, restoration of brackish marshes and meadows along the estuaries has so far not been achieved. That is also the case for tidal forests and marshes in the freshwater tidal part of the estuaries. On the other hand, loads of nutrients and several contaminants have been reduced during the past 20 years (see Figures 3.1, 3.3, 3.4). Water quality should be improved much more, however.

The ecological importance of the upper Ems estuary and especially its tidal freshwater reach has drastically deteriorated over the past 20 years. The water quality is affected in particular by a huge increase of suspended solids and by oxygen depletion. Consequently the aquatic fauna has strongly declined. These developments have occurred mainly as a result of deepening of the upper estuary for shipyard purposes. In addition, a storm surge barrier (also in use as a temporary tidal weir to enable passage of newly built ships) has been constructed; its effects have not been well studied.

During the past 20 years the Weser ecosystem has undergone fewer changes than that of the Ems. However, further deepening of the estuary has occurred and the resulting increase of the tidal amplitude is very large. The tidal freshwater reach of the Elbe estuary shows bad water quality (especially oxygen deficiency). High dredged volumes and further deepening of the fairway have further changed the ecological system. The Varde Å estuary has morphologically changed least, but its forelands have been subject to intensive agricultural exploitation for decades. Hence, a joint agricultural and environmental project for the extensive meadows around the estuary of Varde Å was initiated during the years 1998-2002, and extensification is now taking place in almost 2400 hectares of marshland.

Apart from the large estuaries there are few natural transitions between fresh and salt water left, such as several tributaries of the large estuaries. These should be conserved. Some progress has been made modifying sluice regimes, building fish passages and restoring brackish marshes, thus increasing the opportunities to develop habitats and species depending on natural transition zones.

All taken together, the estuaries constitute the part of the Wadden Sea with the worst ecological condition. It will require a huge effort to preserve, let alone to augment the ecological values still remaining in and along the estuaries. Such an effort will no doubt be hampered by a tendency to further increase the draught of the vessels heading for the ports along the Ems, the Weser and the Elbe, requiring further deepening of the channels. Climate change will also affect the ecological situation in the estuaries due to changes in the freshwater flow regime, accelerated sea level rise, rising temperature and others. Because of climate change adaptation, measures will become necessary with respect to *e.g.* coastal defence. This may lead to additional impact on the estuarine ecosystem.

3.9 Fish

Few conclusions can be drawn on changes in fish populations since the QSR 2004 because the TMAP did not include a fish monitoring program. However, the inclusion of fish since the QSR 2004 is an important step in itself. Below is an analysis of the state of the Wadden Sea fish fauna based on various sources.

Based on a number of unrelated fish monitoring programs, the QSR 2004 described and assessed the temporal trends and spatial distribution of 20 fish species and the brown shrimp (*Crangon crangon*). Because of the unrelatedness of these monitoring programs, 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. Following the Trilateral Ministers Conference 2005, a TMAP ad hoc expert group on fish monitoring was established in March 2006. For the first time, the QSR 2009 provided a comprehensive and harmonized analysis of the fish fauna of the entire Wadden Sea.

The Wadden Sea estuaries and rivers are subject to substantial anthropogenic pressures, which are reflected in the aquatic biotic communities and in the fish fauna in particular. Among the most relevant anthropogenic factors influencing the habitat conditions in river systems are dams, sluices, weirs and riverbed maintenance. In the estuaries, dredging and the disposal of dredged material, coastal protection and flood defence and the direct or diffuse input of substances from industry and agriculture are main threats. In the Wadden Sea proper, shrimp fishery and mussel culture also affect the fish fauna. Many fish migrate between the Wadden Sea and the North Sea. The latter is subject to increasing human impacts by 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.

Next to past overexploitation, the migrant (diadromous) fish currently seem to suffer most from bottlenecks in the upstream parts of (some) estuaries, where water quality is low and essential habitats are failing, resulting in some species (almost) missing (sturgeon, allis shad, salmon, houting) and low abundance of others (twaite shad, sea lamprey, river lamprey). Only sea trout, smelt, eel and flounder, although decreased in number, are more common in the estuaries. Unhindered migration for almost extinct species such as the houting and salmon, good water quality, suitable spawning habitats and favourable conditions for larval growth are essential to restore or maintain vital populations of diadromous fish in the estuaries and river systems in the Wadden Sea. Attempts to re-introduce the exterminated sturgeon have not been successful up to now. The houting belongs to the most endangered fish species of the Wadden Sea/North Sea and is a prioritized species under the EC Habitats Directive. Previously, it was common in the Wadden Sea Area and adjacent river systems, but today it is only found in the Danish part of the Wadden Sea Area (and maybe also in Schleswig-Holstein) and in certain adjacent rivers. The actual conservation status is unfavourable.

Most of the larger fish species occurring in the past, now are rare or even absent from the Wadden Sea. This applies in the first place to slowly reproducing species such as thornback ray, sting ray, and several species of small sharks. Their decline is probably related to the intensive demersal fisheries in the North Sea, since these species spend part of the year in the North Sea to visit the Wadden Sea, especially in summer. But cod and whiting have also decreased in the Wadden Sea; in this case there might also be a relationship with increased water temperatures in the North Sea due to global warming.

Flatfishes such as 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 (= plaice in their second calendar year of life), 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.

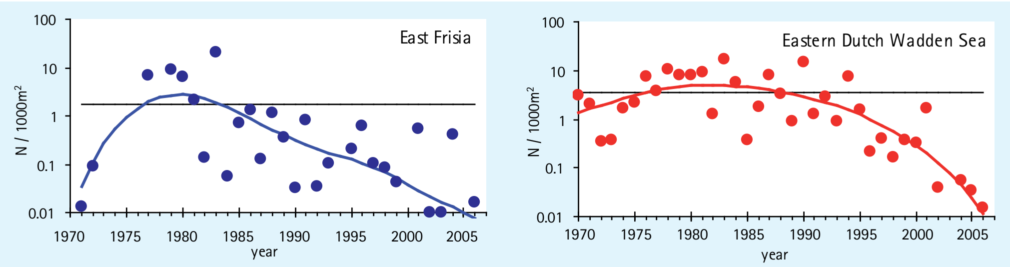


Figure 3.15: Catch density (N/1000 m²) of cod in East Frisia (left panel) and whiting in the eastern Dutch Wadden Sea (right panel). The trend is indicated by a drawn line, whereas the horizontal black line indicates the long-term average abundance (Jager *et al.*, 2009, QSR 2009 Thematic Report No. 14).

An offshore shift in the spatial distribution of young plaice appeared to occur in the Dutch Wadden Sea in the 1990s, which is attributed primarily 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. 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 from the 5-m-depth strata towards the deeper areas as well as from inshore areas towards the further offshore areas. This is an indication that, throughout the Wadden Sea, young plaice have either changed their preference towards deeper and more offshore areas or that an earlier exodus occurs. Whether it is caused by faster growth and/or differences in environmental conditions needs still to be proven.

The observed distribution shifts of juvenile flatfish indicate changed conditions in the Wadden Sea nursery, which may have become less favourable due to higher water temperatures during summer. Similar to the observed phenomenon in juvenile flatfish, brown shrimp also appear to have undergone a distribution shift to more offshore, and also to more northerly waters.

Increasing water temperatures have a positive effect on the occurrence of more southern species such as the anchovy. Exotic or alien fish species, introduced from outside the North East Atlantic seas, are still rare in the Wadden Sea.

The estuarine resident species, *i.e.* those species spending the major part of their life cycle in the Wadden Sea, are 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.

In contrast to the estuaries, there is no existing fish index or tool to assess the status of the Wadden Sea fish fauna. Some fish species are not adequately covered in the current monitoring programs. Although the number of fish species and the species composition seem to have remained fairly stable over the last decades, the abundance of several fish species has decreased to levels below the long-term average. The factors (natural or anthropogenic) causing these changes are still largely unknown.

3.10 Birds

Since the QSR 2004, nearly half of the breeding birds have continued their decreasing trends in parts of the Wadden Sea. For migratory birds, decreasing trends for several species have changed to stable or increasing numbers, especially for Arctic-breeding species. However, some bird species are still decreasing. There are some indications that overfishing, as well as insufficient large roosting and moulting areas affect numbers and distribution of migratory birds.

3.10.1 Birds in the Wadden Sea area

The Wadden Sea region is one of the most important breeding areas for birds in Western Europe, especially for those species connected to coastal areas such as beaches, salt marshes and polder areas with extensive grassland. Despite the large areas of these habitat types in the Wadden Sea, and despite these landscapes being considered as well conserved and protected, large numbers of the breeding bird species are decreasing, and some species will soon be on the edge of extinction from the Wadden Sea area.

For the migratory birds, the Wadden Sea is of outstanding importance, and is one of the most significant staging and wintering sites in the world. Between 10-12 million birds rest here during autumn, moulting their feathers after the breeding season and refuelling their fat reserves before flying further on to the Mediterranean Sea, to West Africa and for some even further to South Africa where they spend the winter. During spring they return to build up their body reserves for the flight to the breeding areas that stretch from Canada in the west over Iceland and Scandinavia to European Russia and Siberia in the east. This shows that birds from a huge area of the northern hemisphere depend on the Wadden Sea. Large numbers of the migratory birds are supported by the tidal areas that constitute large and reliable feeding grounds.

The results for several of the breeding bird species show that the situation is critical. Large decreases are observed, and for several species this can probably be attributed to management of the Wadden Sea salt-marsh habitats. For the migratory species, decreases are also documented but, except for the mussel eating birds, these decreases can probably not be tied to conditions in the Wadden Sea habitats. However, some of the migratory species are also showing increases and these, together with some of the decreasing species, seem to be bio-geographical changes involving a much larger scale than the Wadden Sea.

3.10.2 Breeding birds

Since the QSR 2004, 13 species of breeding birds have continued their decreasing trends in many parts of the Wadden Sea, 8 species are increasing, and 7 species are stable. Many breeding bird species dependant on the salt-marsh areas and extensively managed grasslands are declining (Fig 3.16). Several reasons for the declines are mentioned, such as increased predation by foxes, effect of climate change (some species are also decreasing outside the Wadden Sea), and salt-marsh management. Several of the breeding wader species depend more or less on grazing or mowing of their breeding habitats. The monitoring results for the salt marshes show large areas that are left ungrazed and which are following the succession pattern to a climax stage dominated by tall plants. These habitat types are obviously not suitable for breeding wader species, and could contribute to their decreasing numbers. Increased summer floodings may also cause losses of fledglings.

Change of climate during recent years affects several bird species breeding near the shoreline

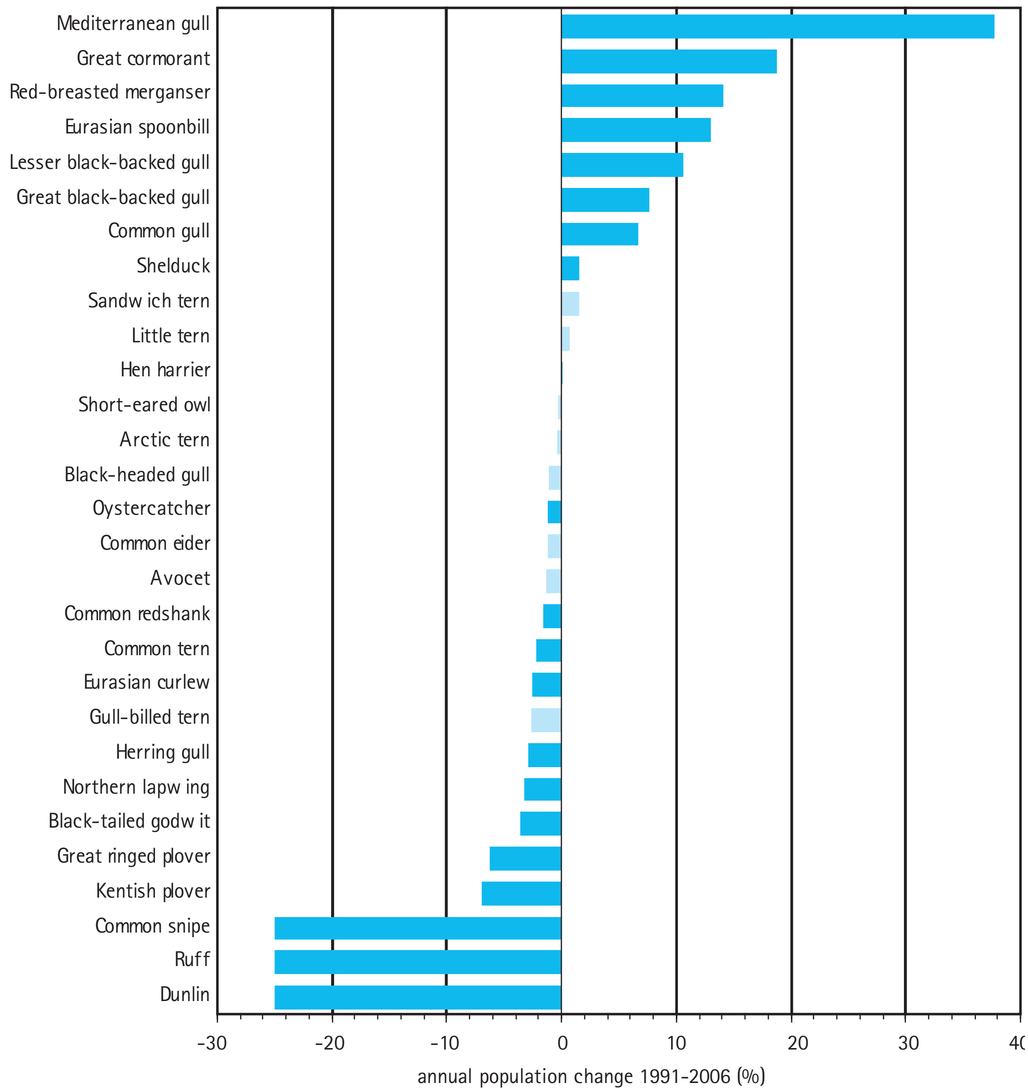


Figure 3.16: Trends in breeding birds 1991-2006, expressed as the rate of annual population change (in %). Non-significant changes are marked light-blue. Population changes in common snipe, ruff and dunlin are estimated from the data of the total counts in 1991, 1996, 2001 and 2006 (Koffijberg *et al.*, 2009, QSR 2009 Thematic Report No. 18).

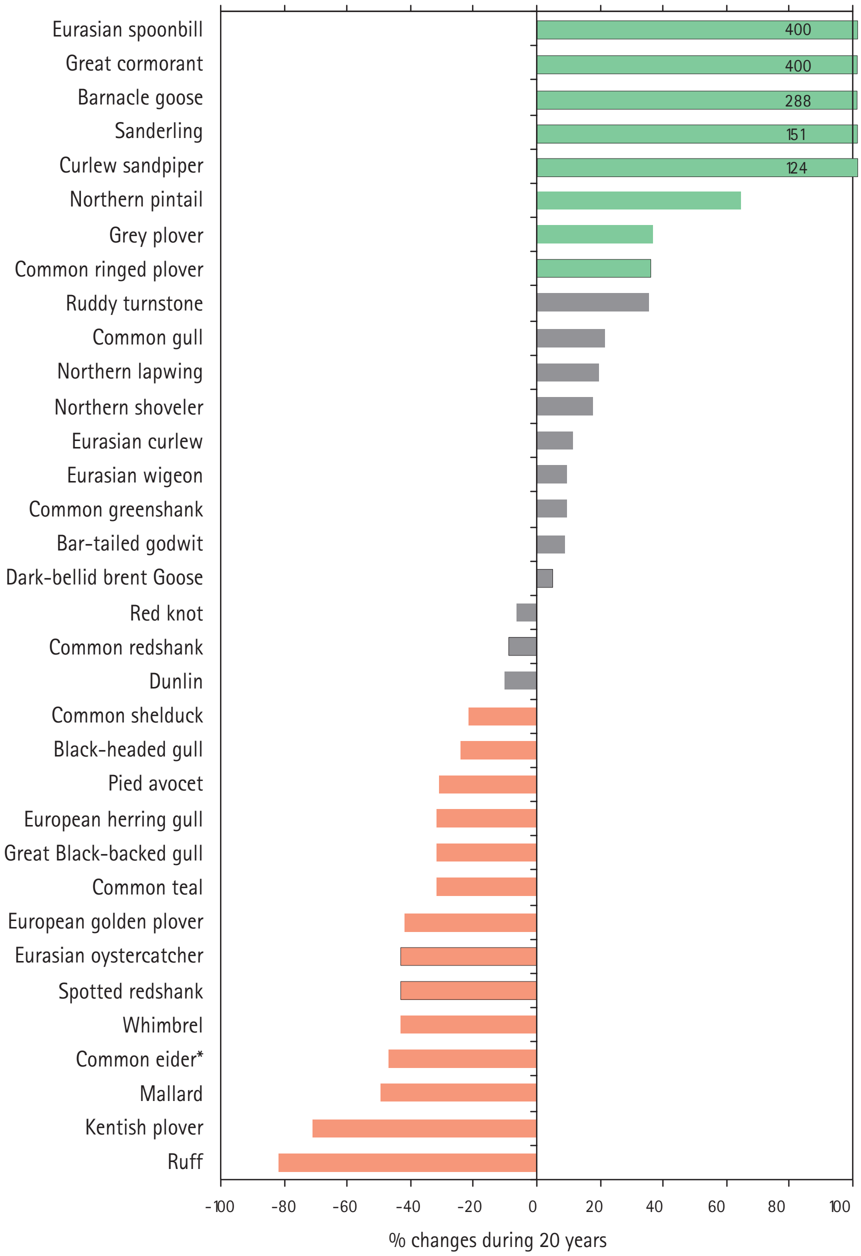
and on the beaches. High water levels during the breeding season increase the risk of destroying bird nests and eggs, causing losses in recruitment. For several species these breeding failures cannot be prevented but for gulls and terns, artificial sand-fields or barge-vessels can be established as breeding sites or platforms.

The negative trends in some populations of breeding birds have become more dominant compared to the QSR 2004. These are most obvious in waders, in shellfish-eating species, and in beach-breeding species, and suggest that the conservation status of many species has become worse recently. The background to this decline is only partly known and is related to less favourable food availability, poor breeding performance, increased predation, and disturbance by outdoor recreations, the latter in the case of beach-breeding species. The impact of other factors, such as changes in salt-marsh management, climate change or changes in the ecosystem, is largely unknown yet.

3.10.3 Migratory birds

Since the QSR 2004, 14 species of migratory birds have decreased, 8 species have increased and 12 species show stable populations. A few years ago, the Arctic species generally showed decreasing trends, but several of these species have now stabilized (Fig. 3.17). The present results show that the species still declining are those breeding in North, Central and Western Europe. Except for

Figure 3.17: Changes in numbers of 34 migratory waterbird species in the Wadden Sea over 20 years (1987/88-2006/07). Green columns indicate species with significant, increasing numbers; grey indicate species with stable numbers and orange columns indicate species with significant, decreasing numbers. *Data for common eiders are from 1992/93-2006/07 (Laursen *et al.*, 2009, QSR 2009 Thematic Report No. 19).



the shellfish-feeding species these bird species do not show a common preference for the same habitat types, indicating that the causes are not to be found in the Wadden Sea ecosystem. The shellfish-feeding bird species have shown a long-term decline in The Netherlands due to intensive mussel and cockle fisheries. The mechanized cockle fishery was terminated in The Netherlands in 2004. Recently the blue mussel biomass has increased in The Netherlands. However, this has not stopped the decreasing trends for the shellfish-feeding species, indicating that other factors are probably involved.

The analyses of the migratory birds suggest that large-scale changes have taken place. During recent years several species arrive earlier and stay longer in autumn in the Wadden Sea area than in former years. Also, several species arrive earlier in spring from the winter areas and leave the Wadden Sea later than before. Species showing these changes in periods of occurrence are geese, ducks and waders, using quite different habitat types. These longer stays during autumn and spring could indicate an increased biomass due to a milder climate. For the Dutch Wadden Sea at least, a general increase in the winter biomass for macrozoobenthos was found. For the biomass in spring there are no trilateral monitoring results, but surveys in the Danish Wadden Sea show increasing macrozoobenthos biomass during recent years. This could support a longer stay for wader species during spring. The longer stay of most of these species gives no management problems, but in some areas the increasing goose numbers cause damage to farmers' crops, especially during winter and spring. Since the goose numbers increase in all parts of the Wadden Sea region, a trilateral approach of goose management, such as proposed by the Wadden Sea Forum, is necessary.

It can be concluded that long-term trends for migratory birds reveal some improvement in the development of several species. Species which show an increasing trend have also increased in their overall flyway population. Species with decreasing numbers mainly breed in North, Central and Western Europe, many of them using inland polder areas and mussel beds for feeding in the Wadden Sea. There are some indications that overfishing, as well as insufficiently large roosting and moulting areas, affect numbers and distribution of migratory birds. A management concept should be developed on a species flyway scale and this should also take into account changes caused by climate conditions.

3.11 Marine mammals

Since the QSR 2004 the number of harbour seals in the Wadden Sea has increased strongly – by about 25%. Even stronger was the increase of the grey seal population, which almost doubled. Less is known about the harbour porpoise; numbers seem to be stable at least.

The harbour (or common) seal, the grey seal and the harbour porpoise are indigenous Wadden Sea species. Marine mammals, as top predators and often long-lived species, have an important indicative function for the quality of the Wadden Sea ecosystem. These species and other top predators (*i.e.* several bird species) that overlap in habitat needs, demand special attention. Because of their longevity and dependence both directly and indirectly on large areas, they can be vulnerable to disturbance and pollution.

In the years after the virus epidemics in 1988 and 2002, the population of the harbour seal has shown a rapid recovery. During coordinated flights in the entire Wadden Sea Area in 2008, a total of 20,250 seals was counted, the highest number ever counted in the Wadden Sea during the moulting season.

Grey seals have relatively recently re-colonized the Wadden Sea. Currently the species is regularly seen in all countries, including the Danish Wadden Sea area, which seems to be the last area to be colonized. The maximum number of grey seals counted during the moult in 2008 in the Wadden Sea and at Helgoland, was 2,224 animals.

Estimates in 2005 of harbour porpoise numbers, for the total North Sea area, amount to 335,000 animals. The main concentrations seem to have shifted from the northern North Sea southwards. As porpoise may migrate into coastal waters and close to the Wadden Sea, numbers recorded have been strikingly augmented in the early 2000s. German studies show hot spots of abundance and frequency (Sylter Außenriff, Borkum Riffgrund and the area north of Helgoland). Knobsände off Amrum and the island of Sylt show a relatively high density of mother-calf groups (the suckling period of this species lasts approximately 8 months). It can be concluded that this area is important for rearing harbour porpoises.

The present conservation status of harbour seals, grey seals and harbour porpoises in the Wadden Sea Area is determined by several environmental factors, including disturbance as a result of various human activities (such as recreation, construction of offshore wind parks, fisheries, air traffic and some military activities)

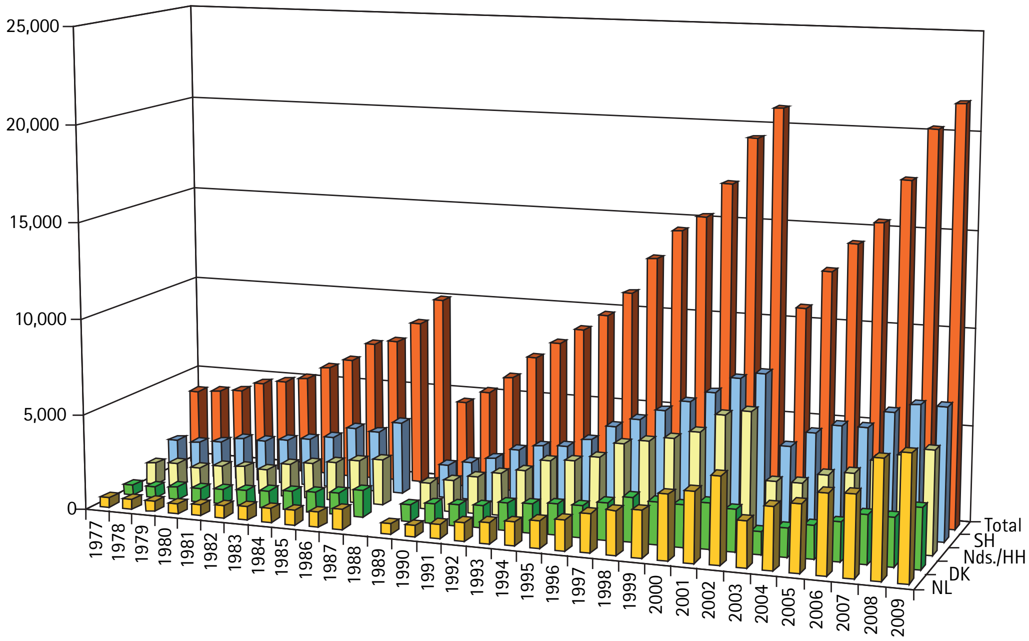


Figure 3.18: Number of counted harbour seals in the Wadden Sea 1975 - 2009; NL = The Netherlands, DK = Denmark, NdS/HH = Niedersachsen and Hamburg, SH = Schleswig-Holstein, Total = entire Wadden Sea (Reijnders *et al.* 2009, QSR 2009 Thematic Report No. 20).

and food availability. At present, the harbour seal population does not show any indication of density dependence.

Pollution is presently not a major issue for marine mammals in this area. At current levels the seal species do not seem to be affected in their population growth. Attention to possible new sources of pollutants should remain, however.

Though probably still not at the population level of around 1900, the harbour seal population has recovered well from the very low numbers observed in the mid-1970s after hunting was forbidden, and after the 1988 and 2002 epidemics. The total population size indicates that the present harbour seal population can be regarded as viable. Data are lacking to estimate the natural reproduction capacity directly, but comparison with harbour seal populations elsewhere leads to the conclusion that the reproduction capacity of the Wadden Sea harbour seal population is at a satisfying level. Still, juvenile mortality is relatively high (approx. 35% instead of 20-25%), despite the good protection of the main resting and nursing places.

For both the grey seal and the harbour porpoise, data are lacking to enable to assess whether the current stocks dependent on the Wadden Sea area are viable, or to adequately estimate the natural reproduction capacity. In both cases the current stocks seem strongly dependent on the stocks occurring elsewhere in the North Sea.

The numbers of grey seals and harbour seals observed in the Wadden Sea have increased over the past years. The question may arise whether and at what point the population may reach the carrying capacity of the area when biological regulating processes will occur (resulting in lowered reproduction and survival, a stagnating growth rate, increasing prevalence of parasites and diseases). General issues of concern with regard to marine mammals are increasing disturbance through noise (*e.g.* offshore wind farms) and disturbance (*e.g.* increase of unregulated recreational activities). In particular, insights into the cumulative effects of the various factors are lacking.

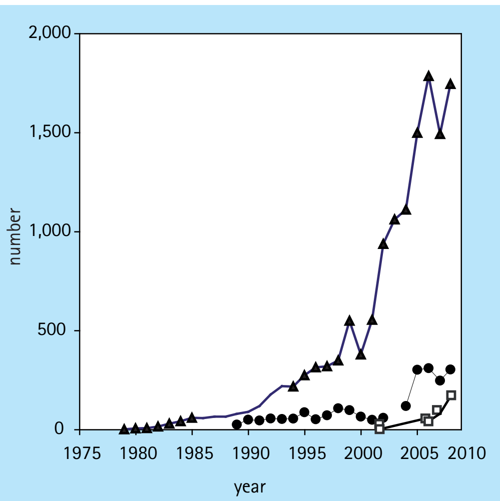


Figure 3.19: Counts of grey seals in the Wadden Sea during the moult (March/April). ▲ data for The Netherlands (source: IMARES); ● data for Schleswig-Holstein and Helgoland (source: National Park Schleswig-Holsteinisches Wattenmeer; □ data for Niedersachsen (source: Nationalpark Niedersächsisches Wattenmeer). (Reijnders *et al.* 2009, QSR 2009 Thematic Report No. 20).

4. The Main Issues

The guiding principle "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way" (Ministerial Declaration Esbjerg, 1991) is based on the observation that the present level of quality of the Wadden Sea is affected by ongoing disturbances and developments which interfere with the natural processes and threaten the sustainability. Therefore, a Trilateral Wadden Sea Plan (WSP Stade, 1997 and updated 2010) has been adopted with specified environmental targets. This is combined with a Trilateral Monitoring and Assessment Program (TMAP) which measures indicators of the actual status of the Wadden Sea ecosystem. Periodically, this status and the corresponding targets are compared in a Wadden Sea Quality Status Report. In the updated version of the Wadden Sea Plan an ecosystem approach is explicitly adopted and as overarching themes climate change, alien species and shipping safety are addressed. Below, the authors focus on some main issues with an outlook on possible long-term developments in the Wadden Sea region.

4.1. Maintaining a great natural heritage

The Dutch and German parts of the Wadden Sea Conservation Area have been given the rank of a World Heritage by the UNESCO World Heritage Committee in June 2009. This recognizes on a global level the outstanding natural values which are under excellent nature conservation management supported by a broad societal consensus. Compared to other coasts of the world which are also inhabited by highly developed agricultural and industrial societies, the geo-morphological shape and the ecological conditions of the Wadden Sea have been well preserved. Maintaining this high level of environmental quality for the coming generations would be a great achievement.

The Wadden Sea's most outstanding natural feature is the large extent of its intertidal sand and mud flats, interacting with adjacent salt marshes and beaches. This is its core value already expressed in its name, which implies that one can wade across this sea when the tide is out. Thus, maintaining the tidal area (intertidal and subtidal area) with its morphological dynamics and its food supply for the spectacular flocks of coastal birds deserves highest priority. The tidal area is sheltered by a sandy barrier against a rough North Sea. This furthers special living conditions, but many biota commute between the tidal area and the offshore zone in order to select the best opportunities, depending on season and life stage. On the landward side, the intertidal flats transcend into salt marshes and into estuaries. Birds especially commute between the intertidal flats for foraging and the salt marshes for breeding and resting, while many fish migrate into or through the estuaries. Offshore zone, sandy barrier islands, salt marshes and estuaries surround the tidal flat area and interact with it in many ways. Each habitat is essential for the functioning of the Wadden Sea ecosystem as a whole. However, these habitats are not as universally outstanding as the tidal flat area. In addition to natural habitats, there are also interactions with the neighbouring rural areas which are therefore partially integrated into management and monitoring.

Figure 4.1: Dike built in 1980/81 at the Danish-German border of the Wadden Sea to shorten and strengthen the line of defence. The embanked area is maintained as a semi-natural wetland. In front of the dike, a foreland has been developed to dissipate wave energy. Further off the dike, natural saltmarsh succession has commenced (lower left), (Photo: K. Reise).

Throughout its existence over the past 5,000 years, the tidal area has undergone considerable changes, with marshes advancing and retreating in line with the balance between sea level change and sediment supply. In the last millennium, human engineering increasingly impacted the landscape of the Wadden Sea. Following an early period of reclaiming and draining peat areas and embanking salt marshes, the intertidal area grew again because storm surges breached seawalls and flooded embanked marshes. Due to a subsiding land level, the intruding tidal waters could not be easily kept out again. Tidal flat areas in the westernmost Dutch Wadden Sea, Dollard, Jadebusen and in the Northfrisian region now extend where once an agriculturally exploited marshland had been. With advances in coastal defence, the size of the tidal area began to decrease again until land claim was halted, towards the end of the past century (Fig. 4.1). The cessation of claiming land from the sea was triggered by the fading need for more agricultural land and its economical feasibility in the European economy and at the same time by a growing appreciation of the natural values of the tidal area.

The changeable extent of the tidal area makes it impossible to derive objectively a reference size of the area from the past which could then serve as an environmental target. It is therefore best to set a target that the present-day size of the area should not be diminished. This is an important decision because sea level is expected to rise faster in the wake of global warming. Under the present rate of sea level rise most tidal flats and salt marshes seem able to keep pace with sea level rise. It is not known exactly to what extent natural sedimentation can compensate for the acceleration of the rising sea level to keep the size of the tidal zone constant. If a sediment deficit arises studies should explore how sand nourishments could compensate such a development and could contribute to maintaining the outstanding natural values. Spatial planning to adapt coastal zones to higher levels of the sea may include buffer zones which in addition to their purpose for defence could develop into zones of high natural value.

Targets for the tidal area in the Wadden Sea Plan do not refer to the size of the area per se but to "a natural dynamic situation in the tidal area" and "an increased area of geomorphologically and biologically undisturbed tidal flats and subtidal areas". This implies that it is best to avoid disturbing the natural dynamics of the area by harmful activities – dredging and stabilizing channels, dumping sediments, changing natural erosion and sedimentation patterns or the seafloor level, by dredging or raking away biogenic structures or by removing organisms. Levels of turbidity, contamination and eutrophication should also be minimized.

Although to a casual observer the tidal area may appear to be OK, all the disturbances of the natural dynamics listed above are evident, as outlined in this report. To a large extent, these are concessions to human needs and rights in the area. The challenge for the future is to fulfil human requirements and still lower the level of interference with the natural dynamics. For example, instead of widening and deepening channels to accommodate the growing size of ferries which commute between mainland and islands, new types of ferries should be designed which do not

Figure 4.2: While exposed beaches at Sylt are regularly replenished with sand nourishments to combat erosion, its more sheltered Wadden shores are still enforced with new hard structures. More sustainable in the face of sea level rise would be dunes and beaches created with sand borrowed from the North Sea (Photo: K. Reise).

require expanded channels with larger ports and longer revetments. This would be a substantial contribution to improving natural sediment dynamics in the tidal area. As another example, the bottom cultures of the mussel fishery are supplied with so-called seed mussels which traditionally have been dredged after settlement as wild beds. Now, promising experiments are being conducted with collectors of young mussels. Such collectors are ropes or nets suspended above the bottom. Supply of seed mussels from such collectors could free the natural beds from recurrent dredging and their dynamics could proceed in an undisturbed way. Hopefully, other disruptions to the natural dynamics can eventually be resolved by ingenious inventions. There should be incentives and awards to promote such endeavours.

The targets for the tidal area to have more natural mussel beds, more worm reefs, more seagrass beds and favourable food availability for birds cannot be regarded as fulfilled. However, management may not be able to do much in these cases. The reasons for a lack of recovery are not clear enough to take immediate action and food shortages for shellfish-feeding birds may have to do more with climatic developments than the fishery. Present monitoring is largely confined to the intertidal part of the tidal area. This severely limits our understanding of population dynamics in many benthic species. More emphasis on the subtidal shallow areas and gullies is necessary in monitoring. To promote epibenthic biogenic habitats, more experimental research is needed.

When touristic and military facilities began to invade the barrier islands of the Wadden Sea, many kinds of hard core defences were used to stabilize the shoreline positions. Some sandy beaches were partially displaced by artificial rocky shores. Thus, the use of sand nourishments were a great achievement. Sand sucked up at offshore source areas is carried to the shore by ship and pipeline. It is either directly sprayed upon eroding beaches or it is deposited in front of the beaches to protect the island shores. There is still a large potential for coastal defence with sand nourishments. For example, at Sylt the exposed beaches facing the North Sea are supplied every year with about one million m^3 of sand to balance natural erosion. On its other side, where the island is facing the tidal area, beaches are still replaced by more hard structures (Fig. 4.2). These spoil the landscape and reduce natural biodiversity. Maintaining natural shores at barrier islands would require more sand nourishments rather than enforcing and extending hard structures of defence.

Salt marshes along the mainland coast are almost all of the artificial foreland-type. The natural salt marshes have disappeared with past embankments. Foreland grew at the expense of intertidal flats by means of sedimentation fields surrounded by brushwood groynes, combined with digging ditches for drainage. The original purpose of such land claim for agriculture has given way to coastal defence and conservation purposes since the 1970-80s. Forelands absorb wave energy which otherwise would hit the seawall. Except for a few sites, the present extent of foreland is regarded as sufficient. Occasionally, existing foreland is protected against erosion. Overall, a status quo between areas of foreland and intertidal flats is now maintained.

Estuaries as a whole are in a very bad shape. Small ones have either been closed with sluices or storm-surge barriers reducing tidal flow. Large estuaries have been converted into shipping channels for ever larger vessels. This increased the tidal range, caused silting up of side-arms, oxygen deficiencies at the bottom, a high load of suspended particles and it requires constant dredging. These problems are so severe that grand solutions have to be thought of – as radical as shifting port functions from inshore to offshore locations. Such a partial shift of port activities out of the estuaries and away from the shallow coast could release estuaries from the burden of accommodating incompatible functions. The estuaries should not be adapted to the growing size of vessels and the volume of trade. Rather, the mode of cargo transfer should be adapted to conserve the shape and form of the coast. Solutions should be sought to conserve the natural values rather than satisfy the immediate human need.

In conclusion, maintaining the great natural heritage of the Wadden Sea is a very challenging task. The current size of the intertidal zone cannot be taken for granted. Mitigating the level of interference with the natural dynamics of the tidal area requires innovative ideas. Maintaining barrier islands relies on proper ways to enhance artificial sand supply, while the unsustainable situation in the estuaries needs radically new solutions. Maintaining the natural heritage would require considerably more than conventional nature conservation and asks for a joint effort of all coastal agencies.

4.2. Healing the old wounds

The historical conversion of episodically flooded marshes and regularly flooded tidal flats into embanked agricultural land cut through the coastal gradient across which matter had been exchanged in natural processes between land and sea. There was no natural seaward growth of the tidal area, so this loss was not compensated for. In particular, brackish transitions between freshwater marshes and salt marshes, once common all along the mainland coast, are nowadays relegated to estuaries. Forelands are not relicts of former salt marshes but have been created in front of seawalls (see above). Forelands mostly look very different from natural salt marshes because of their parallel ditches, the vegetation grazed down to a lawn and a deviating species composition.

As a success of nature management, large artificial forelands are gradually developing towards a more natural state as brushwood groynes at sheltered localities go unrenewed, drainage ditches are neglected and livestock grazing pressure is reduced. Summer dikes have been removed at several locations to allow pasture land to revert to salt marsh meadows. The adopted policy and management is based on sound science and comprehensive monitoring. It has over the years advanced to a great success in regaining natural salt marsh vegetation and the associated fauna. This is a classic case of a win-win situation for coastal defence and nature conservation and is a path which should be continued.

Dunes on the Wadden Sea islands suffer from past stabilization programs. Where salt marshes

Figure 4.3: One of the last free moving dunes in the Wadden Sea area is approaching a busy road. Will winds continue to shift this dune across the island of Sylt or will it be stopped by artificial planting? (Photo: K. Reise).

Figure 4.4: Grey seals once driven out of the Wadden Sea are now recolonizing their former habitat. This constitutes a great success of dedicated nature protection (Photo: K. Reise).

have developed in the shelter of such dunes, these also lack the influence of natural disturbances. This promotes ageing. Plant succession as such is a natural process. However, the dominance of late successional or climax-stages is a result of preventing or repairing physical disturbances such as strong winds and wash-overs. On some islands, trampling by visitors has introduced some small-scale disturbances that have remobilized drifting sand. For the sake of coastal protection, this has been stopped. Eutrophication, decreased grazing and invading bushes and trees have led to a more dense vegetation than there would have been under natural conditions. To restore more natural and dynamic states, a new and promising geo-ecological concept has been developed for barrier islands. This approach has still to gain more public support and needs to be fine-tuned to individual islands. It is a promising first step to reverse the degrading development of dune landscapes and back-barrier salt marshes. Re-introducing more dynamics on the barrier islands would also contribute to their long-term persistence (Fig. 4.3). Similar concepts should be developed for tidal basins and estuaries.

Coastal birds and their eggs were severely over-exploited when a large market for coastal products grew in the expanding cities within reach of the Wadden Sea region. A tipping point was reached at the onset of the 20th century. The sad condition of coastal bird populations was realized and sanctuaries for breeding colonies were secured. Finally, large-scale egg collecting and hunting ceased, together with control of chemical pollution. These initiatives have surely increased the colonial breeding bird species as gulls and terns and also spoonbill and cormorants are increasing. However, despite protection and conservation large parts of the breeding bird species are decreasing, and some species are about to get lost from the Wadden Sea area. A recently observed threat is the increasing number of floodings of salt marshes during the summer period when the fledglings can not yet fly, and are drowned. For the migratory species that especially rely on the huge areas of intertidal flats, large changes in numbers occur. However, except for the shellfish-feeding bird species, they do not show a common preference for the same habitat types, indicating that the causes for the changing numbers are not only to be found inside the Wadden Sea ecosystems, but rather in geographical ranges involving larger regions than the Wadden Sea area. The increasing goose numbers have in part resulted from successful conservation strategies, namely livestock grazing, and huge flocks of these big birds can be seen all over the Wadden Sea area.

Similarly, the recovery of seals after a ban on hunting, the avoidance of disturbances at resting and haul-out places, declining contaminants, together resulted in counts of about 20,000 harbour seals and about 2,000 grey seals in the past year (Fig. 4.4). Seal watching has grown into an important recreational activity and decreasing disturbance distances of seals facilitated this development. Two virus epidemics interrupted the recovery of harbour seals and highlighted that even the best management cannot protect against threats from outside.

There is still a large potential for habitat restoration and population recovery in the Wadden Sea. Among fish, only the houting in the Danish part of the Wadden Sea and its tributaries received the benefit of a well-planned and comprehensive management to achieve a recovery. A good next candidate would be sturgeon which was fished to extinction in the estuaries of the Wadden Sea early in the last century. Reintroducing and protecting such a large and conspicuous fish would draw public attention to the poor state of fish populations in the Wadden Sea compared to what it could be. However, little can be done within the confines of the Wadden Sea unless fishery pressure is reduced in the North Sea.

In conclusion, important steps have been taken to reintroduce a more natural development for salt marsh and dune habitats. The recovery of seal populations is a great success, demonstrating that a consequent pursuit of the respective targets is the right way to go and should be extended to other old wounds as well.

4.3. Mitigating external disturbances

As with coastal regions in general, the Wadden Sea is wide open to external influences from both, the land and the sea. Eutrophication and pollutants have received much attention in the past and their mitigation is one major objective of the European Water Framework Directive. Riverine loads of nutrients are declining at a rate of about 2% per year. Compared to assumed background levels, the eutrophication status is still elevated in the tidal area, salt marshes and dunes of the Wadden Sea. There are apparent sub-regional differences and the signals differ for groups of phytoplankton, benthic macroalgae, turnover of organic matter and dominant grasses in the salt marshes and dunes. No alarming blooms of algae or of sediments turning anoxic up to the surface have been observed during the last decade. The question arises: how low should we go with the reduction of nutrient loads and contaminants? Pre-industrial conditions may be out of reach. Would the money needed to achieve such a target be used better to mitigate other threats? These are important questions which require comparisons between relevant impacts and consideration of their interactions in order to arrive at a sound decision.

Figure 4.5: Watchman of the beach modelled from gloves of sailors and fishermen and other debris washed ashore on a stretch of less than one kilometre (Photo: K. Reise).

Litter in the countryside has become a rare sight and much effort goes into recycling of garbage. By contrast, huge amounts of plastic packaging continue to spoil beaches after a storm. Particularly embarrassing is the high share of debris from fisheries. On a short stretch of coastline, one can easily find enough orange rubber gloves to model a dragon or a fisherman on the beach (Fig. 4.5).

Many fish and birds are migrating species for which threats have to be assessed at a scale larger than the Wadden Sea to identify the factor most limiting the populations. In fish, particularly in top predators, this is usually the fishery in the North Sea which would overrun any attempts of conservation within the Wadden Sea. In birds, hunting pressure along the migration routes and the breeding success in the Arctic or in Eastern Europe may often be crucial for population development. In such cases, more awareness of the fate of fish and birds has to be raised in the respective countries to influence international policies.

Raising more awareness is also required in the case of introduced alien species. Particularly in the epibenthos of the tidal area but also in dunes adjacent to housing estates, alien invasions have increased in the last couple of years to such an extent that aliens often predominate in biotic communities. They originate from distant coasts and have arrived directly by human carriers or indirectly when introduced to other European coasts from where secondary dispersal has brought them into the Wadden Sea. The latter has been by far the prevailing route of immigration. This highlights that preventative measures such as ballast water treatment, control of hull fouling, banning the use of exotic organisms in open aquacultures and seaside aquaria, can only be effective if all coastal countries implement adequate prevention according to international conventions. Parliaments of the Wadden Sea countries should be urged to ratify such conventions.

Once alien aquatic organisms have arrived, only immediate action has a chance to eradicate immigrants. Dispersal with the currents and broadcasting of vast numbers of spores or larvae severely limits the prospects of successfully controlling such invaders. Some invaders are poorly integrated into the food web and hence may affect the performance of the ecosystems. However, the main issue is an ongoing homogenization of coastal biota on a global scale. Successful universal invaders produce a growing similarity between distant biota which once had no species in common. This process has received little attention in the past because most of the introduced coastal organisms are small and inconspicuous. With the invasion of Pacific oysters, this has changed (Fig. 4.6). Wide intertidal flats will never be as before. A common management strategy on the issue of alien species is needed.

The Wadden Sea region is expected to be challenged by an accelerating rise in sea level. As this is a consequence of increasing greenhouse gas emissions, one could assume this region would be at the forefront of climate change mitigation. This is not the case. Power plants using fossil carbon particularly abound in the Wadden Sea region. Gas extraction amounts to 10 billion m^3 per year in the Dutch Wadden Sea, and in the German part about two million tons of oil is extracted annually. There is no indication that this might become less in the coming years. Islands such as Sylt and Texel make no effort to reduce traffic with cars using combustion engines. This paradox may produce a rather bad image.

Although the Wadden Sea is supplied almost continuously with wind which could drive large numbers of wind turbines, the policy to keep wind turbines out of the Conservation Area is justified because of the high density of coastal birds and the importance of preserving an unspoiled land- and seascape in a touristic area. However, the adjacent rural areas accommodate one of the highest densities of wind turbines. The offshore area next to the Wadden Sea is planned to deliver as much as 20,000 to 25,000 MW per year from giant wind turbines by 2030. This industrial neighbourhood will inevitably entail a burden to the Wadden Sea and care is necessary to minimize the effects on the protected nature area. For example, effects of cable crossing through the conservation area should be minimized by bundling these on a single line.

In conclusion, for the wide open Wadden Sea external disturbances play a major role in the performance of the geo-ecosystem. Efforts over the past decades to reduce the influx of excess nutrients and contaminants have improved the ecological quality, but residual problems remain. No success has been achieved so far in stemming the amount of litter washed ashore. The implementation of international strategies is necessary to improve situations of migrating birds and fish. Fish migrating between the tidal area of the Wadden Sea and the North Sea are particularly under-represented in the ecosystem. This distorts the food web and thus ecosystem functioning. On the other hand, too many alien species are invading the Wadden Sea and international conventions to reduce their dispersal by human carriers are not yet implemented. Unlimited alien invasions are undermining efforts of restoring past diversity and are seriously changing the biotic composition in the ecosystem.

Figure 4.6: Vast areas of tidal flats have been overgrown by invading Pacific oysters. These have been intentionally introduced to the island of Sylt for sea ranching but these oysters have reproduced to such an extent that they are now out of control (Photo: K. Reise).

4.4. Adapting to global change

The Wadden Sea cannot be a museum in a changing world. Mean annual sea surface temperature has increased by 1.5°C within the past 25 years in the inner North Sea and the Wadden Sea. Rising temperature entails an increased frequency of mild winters and hot summers, more precipitation during winters and more weather extremes at any time of the year. In the shallow Wadden Sea, water temperature follows air temperature very closely and this is predicted to rise further by almost 2°C in the next decades. This corresponds to water temperatures now encountered on the French coast south of Brittany. Although the Wadden Sea and the Atlantic shores of France have many coastal species in common, there will still be a considerable change in species composition and abundances. The warmer stage will have a number of new actors and their interplay will be different from what we are used to.

To make predictions in this biotic realm is almost impossible. The speed of northward dispersal by southern species and genotypes may exhibit a wide range and we know almost nothing of specific dispersal rates under conditions of a rapid increase in temperature. From present observations, so-called mismatch phenomena between prey and predator will intermittently abound. More southern species will immigrate than Boreal species will leave the Wadden Sea. Introduced alien species often find themselves in a pole position because they originate in most cases from coasts warmer than the Wadden Sea. They may occupy niches before other species arrive by natural dispersal from adjacent southern regions. Compared to previous times, there will be a revolutionary rate of change in the coastal biota. Intensified monitoring will be necessary to keep track of these changes (Fig. 4.7). Otherwise we will lose any understanding of what goes on in the interplay of life and cannot explain the novel phenomena in the ecology of the Wadden Sea.

However, at the regional scale nothing can be done to mitigate this kind of change. The best precaution for not losing too many species and genotypes in a period of rapid change is to maintain or restore a wide spectrum of habitats. A more complex array of habitats will lower the chance of a loss in genetic diversity within populations, prevent competitive exclusion between species and extirpations of plants, prey and hosts by grazers, predators and parasites, respectively. Therefore, faced with climate change, efforts to prevent displacements of natural habitats and to restore degraded habitats deserve a high priority.

An expected rate of sea level rise in the order of one metre at the end of this century will presumably cause a much greater challenge to the Wadden Sea region than the mere change in temperature or precipitation. Sea level rise affects the safety of the people; may squeeze salt marshes; and may drown the intertidal flat zone in front of defended coastlines. It will raise the input of hydrodynamic energy and be followed by a loss of mud relative to sand and a loss of seagrass as sand waves arise in the tidal zone. The barrier islands will be affected most by erosion. In spite of these dim long-term prospects, one metre of sea level rise within a century is still in an order of magnitude where adaptations to the consequences seem possible.

Figure 4.7: The Asian crab *Hemigrapsis sanguineus* is currently spreading throughout the Wadden Sea and may potentially displace the native shore crabs. Monitoring and research is needed to keep track of such invasions and its ecological effects (Photo: K. Reise).

Other than with weather or the outcome of multiple biotic interactions, sea level is reasonably predictable in the long term. This allows a careful planning of the adaptations, learning by experience, and most importantly, there is time to harmonize cultural, socio-economic and geo-ecological consequences. Probably the most difficult problem is that our society has not yet learned to cope with such slow but relentless changes – changes which demand timely adaptations so that subsequent generations will not be faced with more to do than they can handle.

The present coastal configuration is not sustainable. Large parts of the embanked land lie below sea level and cannot rise in concert with the sea. Salt marshes in front of the seawalls and in back-barrier position may, in large part, be adapted to rise with the sea. It is known that net surface elevation change (sedimentation minus compaction) of salt marshes depends on the position in the tidal basin, elevation, distance to the source of sediment input, and structure of the vegetation as affected by grazing. For tidal flats, the adaptation is very uncertain and may depend on the size and shape of tidal basins as well as a variable sediment supply from the adjacent North Sea. Keeping island shores in position will require more and more effort. Concepts such as the geo-ecological model of barrier islands (see paragraph 3.6.2) will be helpful.

In due time we should shift from online coastal defence, with its focus on strengthening seawalls and beaches, to a coast growing with the sea with a focus on sand nourishments from offshore to inshore and attempts to trap sediments behind seawalls for raising the surface of embanked land. Both parts of this strategy require spatial planning and learning by experience. For the islands and the tidal area, the aim is to keep them more or less as they are, while in the low-lying embanked mainland structural adaptations to survive hazards would be an option. Without such adaptations, the Conservation Area would risk losing its universally outstanding natural values, and the rural area would run an ever-higher risk of disaster if its protective seawalls were ever breached.

Sand nourishments should be done with the least possible energy demand or by tapping energy from offshore wind parks. Sand extraction should be limited to offshore areas. Sand should be supplied in a way that minimises interference with the natural sediment dynamics. At present there is insufficient knowledge as to how islands and the tidal area can be maintained with sand nourishments. This ought to be an area of research with high priority. Raising the level of embanked marshes may be even more challenging than finding proper strategies for sensible sand nourishments.

In conclusion, the inevitable change in species composition in the wake of global warming is best accommodated with a high diversity of habitats. This aspect is already sufficiently covered by the existing targets. Adaptation to the expected rise in sea level seems possible by sand nourishments at the barrier islands and in the tidal area. Without such gradual adaptations to the consequences of climate change, the Wadden Sea natural heritage is at risk in the long term.

4.5. Towards excellence in integrated management

Integrated management taking into account ecological, socio-economic and cultural values requires informed, involved and committed societies in the three Wadden Sea countries. Joining the forces of the Trilateral Wadden Sea Cooperation and the Wadden Sea Forum to represent the interests of the stakeholders promises to meet the challenges of the major issues, particularly the envisioned adaptations to global change. The UNESCO World Heritage nomination dossier for the Wadden Sea, the Wadden Sea Quality Status Report 2009, the insights and recommendations from the 12th Scientific Wadden Sea Symposium and the Wadden Sea Plan 2010 provide a sound basis for a common management approach towards solving the main issues. It has been proven successful to treat the Wadden Sea as a coherent system and to imbed the Conservation Area into a wider regional structure of the adjacent land and the Exclusive Economic Zones in the North Sea belonging to the Wadden Sea countries.

Accelerating sea level rise, increasing temperature and introduced alien species complicate the interpretation of signals received from indicators thought to be specific for certain targets. Warming seems to facilitate pelagic and benthic grazing pressure on phytoplankton, suppressing blooms which otherwise would indicate that nutrients are still at a level too high to tolerate. Increased benthic grazing pressure follows from invasive alien species, notably the Pacific oysters and American slipper limpets which have benefited from warming. Identifying effects caused by the mussel fishery is hardly possible any more because mussel recruitment is affected by warming and intertidal mussel beds are overgrown by Pacific oysters. Both warming and alien species contribute to an increasing number of species. High species richness would otherwise have been taken as evidence of successful conservation management. The crux is that these rapid changes lower our understanding of the ecological system and increase the risk of misinterpreting indicators. The only way out is to intensify research and monitoring. Monitoring should be long term and at a large scale, e.g. that of the tidal basins between islands. This is a better way to quantify cumulative impacts of exploitation instead of the present ad hoc small-scale and short-term "research".

Global warming inevitably entails sea-level rise, albeit with some time lag. However, breeding birds have recently faced higher summer floods on salt marshes than in the past. Moreover, there is already a rising high tide level in the German Bight which is higher than the global rate of mean sea level rise. This gives a foretaste of what may come under global temperature rise. Predictions on the magnitude of sea level rise until the end of this century are still unreliable, but the direction is not. Falsely assuming that sea level will not rise as predicted and thus rejecting adaptive measures may have more serious consequences than falsely assuming the reverse. Adaptations such as sand nourishments within tidal basins collide with the target of a natural dynamic situation. What is "natural" is hard to define under conditions of a global change triggered by anthropogenic greenhouse gas emissions (Fig. 4.8). Probably we have to relax the geomorphological target under these circumstances and focus on the main issue of not losing intertidal flats.

The overriding consequences of global change demand a more integrated approach to the targets than has been taken up to now. A more hierarchical approach may be considered to ease management decisions. More importantly, adaptations in the Wadden Sea region to cope with changing precipitation patterns and with sea level rise have effects on coastal defence and many cultural, social and economic values. These have to be considered alongside geo-ecological concerns. The Wadden Sea community has already started along this path but there is a tremendous challenge before us. Although sticking to the path will be difficult, doing so offers the prospect of successfully conserving the Wadden Sea's sublime nature and wildlife, thereby making the region even more worthwhile to live in.

Figure 4.8: Well integrated management is required to meet multiple targets. The salt marsh (lower left) has received dredged sediment from an adjacent harbour site which is silting up. Construction of brushwood groynes for land claim disturb a seagrass bed (dark patch in centre), and in the shelter of these groynes, the introduced *Spartina*-grass is spreading into the mud flat. Protecting natural values at such a shore will be a growing challenge when sea level rise accelerates in the coming decades (Photo: K. Reise).

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

Recomendations from the

12th International Scientific Wadden Sea Symposium

Wilhelmshaven, 30 March – 3 April 2009

General Preamble

Nature conservation and management in the Wadden Sea should, as formulated in the trilateral Guiding Principle, aim "to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way". Much has already been achieved in recent decades but the Wadden Sea is still facing issues of concern such as retarded recovery of biological diversity, the loss of salt marshes, and ongoing contamination with new chemical substances. There is also the need to develop strategies to deal with the consequences of global developments such as climate change and invasive alien species. Finally, in terms of policy and management, there is an increasingly complex system of international, European and national legal instruments and agreements which can both lead to confusion and/or work at cross-purposes. Therefore, there is an urgent need for a better integration in research, monitoring and management with timely involvement and participation of all stakeholders (researchers from various disciplines, government agencies, NGOs and other sectors). A similar holistic and integrative approach should be applied when exploring possibilities for EU-funding.

The Twelfth International Scientific Wadden Sea Symposium discussed these issues under the title 'Science for Nature Conservation and Management'. Given that the trilateral Wadden Sea Cooperation serves as an example in the wider European or even global context, the symposium considered the following recommendations to be of strategic importance for the three Wadden Governments.

Recommendations to the Trilateral Governmental Conference 2010

1. Develop one comprehensive scheme for the conservation and sustainable development of the trilateral Wadden Sea in order to implement the various EU Directives more effectively. Such a scheme will serve as an example for the wider EU. In this context it is important that:
   a. The trilateral Wadden Sea is considered as a sub-region according to the Marine Strategy Framework Directive and
   b. the definitions of "Good Ecological Status / Favourable Conservation Status / Good Environmental Status" as respectively required by the Water Framework Directive / Habitats and Species Directive and the Marine Strategy Framework Directive have to be harmonised to ensure that also the implementation of these Directives is harmonised.
   c. the Ecosystem Approach should be applied to Wadden Sea policy and management.
   d. we must build on existing trilateral structures, agreements and instruments, including monitoring and data handling.
2. Extend the trilateral cooperation area by adding the adjacent off-shore conservation areas, because there is a strong relationship between the Wadden Sea and these areas and treat the inshore and near offshore areas as a single system.

3. The monitoring efforts of the trilateral area should not be restricted to the minimum requirements resulting from the Natura2000, Water and Marine Strategy Framework Directives as these do not provide sufficient information for a proper and scientifically sound ecosystem management of the Wadden Sea. Accordingly, the TMAP should be expanded to develop trilateral strategies and methodologies for monitoring and assessing the ecological values of in particular the subtidal area. Furthermore, a large effort should be given to the development of conservation objectives which underpin the whole management process.
4. Where necessary and possible restore the natural structure and functioning both to increase resilience to the impacts of accelerating sea level rise and to enhance sustainable economic development, taking due account of geo-morphological conditions.
5. The natural landscape of the Wadden Sea and the cultural landscape of the adjacent land area must be regarded as complementary parts of the same landscape. Therefore cooperation between the cultural and environmental heritage should be improved.
6. Governments need to join and reinforce ongoing international efforts to prevent alien species introductions and develop an alien species management strategy for the Wadden Sea.