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Alien Species

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1. Introduction

The dispersal of organisms is a natural process limited by multiple barriers, among which geographical barriers are the most evident. However, for centuries, alien species have been introduced to new areas in which they were previously absent and to which they have been introduced by humans as mediator. With increasing global trade the introduction of alien species, both intentional and unintentional, has increased concomitantly and has increased in complexity. Next to global habitat loss and climate change, this biological globalization has become a key process in altering the biosphere.

Alien species bring both costs and benefits which may accrue to different sectors of society. Benefits are wide-ranging and examples in the aquatic environment include stocking and re-stocking operations, new aquaculture opportunities and tools in coastal protection and reclamation schemes (*a.o.* Minchin and Rosenthal, 2002). By contrast, viewed on a global basis, alien species are one of the key threats to native species and ecosystems and other aspects of biodiversity (Rabitsch *et al.*, 2008). Furthermore, biological invasions may turn into serious threats to humans, their health and economical possibilities. In Germany for example, the economic losses caused by only 20 analysed terrestrial and aquatic alien species are estimated to a level of 156 million Euro annually (Reinhardt *et al.*, 2003). We here consider the effects of alien species on the environmental quality of the Wadden Sea, and thus adopt a nature protection perspective.

The worldwide implications of alien species have been identified by both non-governmental and governmental organizations, and have been emphasized in numerous international conventions and other legally binding and non-binding instruments (Shine, 2006). On the basis of the Convention on Biological Diversity (CBD, 1992), the European Strategy on Invasive Alien Species was finalized in 2003 (Council of Europe, 2003) to combine existing regulations established under the Bern Convention in 1979 and its subsequent agreements, and to offer the signatory states possibilities to deal with alien species. However, until now, most of these measures have so far only been declarations of intentions which lack the extensive detailed planning necessary to prevent alien introductions. Therefore, the implementation of sound strategies and instruments to deal with biological invasions must be an urgent conservation priority.

Especially in the Wadden Sea area, a diverse range of alien species has established permanent populations (Reise *et al.*, 2005). The rate of alien introductions is continuously increasing and no change is as yet in sight. Many of the introduced species have become abundant and several can be regarded as invasive in the sense of having a significant effect on the recipient ecosystem (Jensen and Knudsen, 2005; Wolff, 2005; Gollasch and Nehring, 2006). The guiding principle of the trilateral Wadden Sea policy *"is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way".* Invasive alien species pose a particularly serious threat to such nature conservation interests. Moreover, as concluded in the Quality Status Report 2004, species introductions are irreversible and accumulating over time. This issue may be considered to be more important than reversible effects of overfishing, eutrophication and contaminants. For the Wadden Sea, the net effect of unhampered introductions would be a regional increase in species richness and a growing biotic similarity with other coasts. The unique character of the Wadden Sea would still be manifest in the physical environment but not any more in its living component (Reise *et al.*, 2005). However, up to now a purposeful strategy on how to deal with alien species introduced into the Wadden Sea is lacking (Nehring and Klingenstein, 2005). To respond effectively to threats by alien species, the trilateral policy and management should take the issue of alien species into account to a greater extent.

2. Instruments and impact assessment

More than fifty international and regional conventions, codes of conduct and other instruments now deal directly or indirectly with the spreading of alien species (SCBD, 2001; Shine, 2006). Nearly all of them have their own institutional mechanisms and decision-making procedures. These binding or voluntary instruments often provide the baseline from which domestic legislatures develop policy, legislation and management frameworks to address alien species issues (Council of Europe, 2003). The main international instruments for nature conservation that specifically address alien species includes the Convention on Biological Diversity (Rio de Janeiro, 1992), the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention, Bonn, 1980), the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention, Bern, 1979), and the Convention on Wetlands of International Importance as Waterfowl Habitat (Ramsar Convention, Paris, 1994). However, instruments at all levels use variable terminology, sometimes inconsistently or without adequate definitions. On the other hand, a consensual set of definitions regarding alien species is essential in order to facilitate discourse among the science, policy and management communities dealing with the issue. Thus we propose a set of key terms and definitions as an operating tool (see box below) that does not lead to further confusion. The set is based on terms and definitions mainly used in work done under the Convention on Biological Diversity (CBD, www.biodiv.org).

The aims of the Convention on Biological Diversity, which was adopted in 1992 and enforced in 1993, are the conservation of biological diversity, the sustainable usage of biological resources, and the fair and equitable sharing of benefits arising from the use of genetic resources. Article 8 of the Convention requires all Contracting Parties "*as far as possible and as appropriate, to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species"*. This statement was specified by the decision VI/23 *"Guiding Principles on Invasive Alien Species"* by the 6th Conference of the Parties to the Convention in 2002. Its adoption suggests comprehensive national strategies on the basis of a hierarchical approach (prevention, early detection, measures).

The Bonn Convention highlights in Article III.4.c that the Contracting Parties agree *"to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely*

Definitions

Native species

A species, including genetically distinct populations, occurring within its natural range (past or present) and dispersal potential (i.e. within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans).

Alien species

A species, including genetically distinct populations, occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans); includes any part, gametes or propagules of such species that might survive and subsequently reproduce.

Invasive alien species

An alien species which is known or expected to exert effects on native populations and species, natural habitats and ecosystems beyond of which can be considered to be within the range of average regional conditions.

Introduction

The transfer, by direct or indirect human agency, of a species or genetically distinct population outside of its natural range (past or present) and dispersal potential; this movement can be either within a country or between countries or areas beyond national jurisdiction. Human involvement here does not include habitat changes, global warming, eutrophication, etc.

Intentional introduction

Deliberate transfer and/or release by humans of a species or genetically distinct population outside its natural range (past or present) and dispersal potential (such introductions may be authorised or unauthorised); this includes also species which subsequently escape or which are released into the environment.

Unintentional introduction

All other introductions which are not intentional; this also includes parasites, symbionts etc. of intentionally introduced species.

to further endanger [migratory] species, including strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species." Article V.5.e of this Convention states that Contracting Parties should protect *"habitats [of migratory species] from disturbances, including strict control of the introduction of, or control of already introduced exotic species detrimental to the migratory species".*

The Bern Convention, to which 39 European states and the EC are party, provides a regional framework for implementation of the Convention on Biological Diversity in Europe (Council of Europe, 2003). Article 11.2.b of the Bern Convention states, that Contracting Parties should *"strictly control the introduction of non-native species".* Bern Convention Parties should also inform governments of neighbouring countries if accidental introductions have occurred (Recommendation No. R (84) 14, 1984) and set up mechanisms for inter-State co-operation, notification and consultation in order to co-ordinate precautionary and control measures for invasive species (Recommendation No. 77, 1999).

In 2000, the Bern Convention's expert group on invasive alien species began developing elements for a European Strategy on Invasive Alien Species. The finalized European Strategy, approved by the Bern Convention Standing Committee in 2003 (Recommendation No. 99), is a comprehensive document addressed to nature conservation agencies and all other sectoral agencies with responsibility for activities relevant to the prevention or management of invasive alien species (Council of Europe, 2003). The European Strategy promotes the development and implementation of national strategies, coordinated measures and cooperative efforts throughout Europe to prevent or minimise adverse impacts of invasive alien species on Europe's biodiversity, as well as their consequences for the economy and human health and well-being (Council of Europe, 2003).

The recent Marine Strategy Framework Directive (European Parliament and Council, 2008) extends EU water legislation to the marine environment and follows an approach similar to that of the Water Framework Directive (European Parliament and Council, 2000). It came into force on 15 July 2008 and establishes a comprehensive structure within which Member States are required to develop and implement cost effective measures, necessary to achieve or maintain Good Environmental Status (GES) in the marine environment. GES must be achieved by the year 2020 at the latest. Within the Directive, GES is defined by eleven qualitative descriptors, one of them being "Non-indigenous species". In Annex 1 of the Directive it is mentioned as: "Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems".

For coastal and inland wetlands, the Ramsar Convention has recognized the threat to their ecological character and to terrestrial and marine wetland species if alien species become invasive. In Resolution VII.14 (1999) on invasive species and wetlands Contracting Parties are urged, where necessary, to adopt legislation or programmes to prevent introduction of *"new and environmentally dangerous alien species"* into their jurisdiction and to develop capacity for identifying such alien species. In Resolution VIII.18 (2002) the Conference of the Parties to the Ramsar Convention urged Contracting Parties to address the problems posed by invasive species in wetland ecosystems in a decisive and holistic manner. Further, Contracting Parties are urged to identify the presence of invasive alien species in Ramsar sites and other wetlands in their territory, the threats they pose to the ecological character of these wetlands, and to undertake risk assessments of alien species that may pose a threat to the ecological character of wetlands.

Despite these and other efforts, alien species in the Wadden Sea are still perceived only at a descriptive level. To mitigate present, and avoid future, negative impacts of aliens in the Wadden Sea, legal and organisational implementation in the three bordering countries, Denmark, Germany and The Netherlands are of utmost importance. However, invasion processes ignore political boundaries between countries. Consistent with the ecosystem approach as developed under the Convention of Biological Diversity, inter- and intra-regional cooperation is essential for effective frameworks and development of an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea. Efficiency can be increased by sharing information and intensifying cooperation, ensuring basic consistency in policies, legislation and practice.

The impacts of alien species on ecosystems vary significantly depending upon the invading species, the extent of the invasion, and the vulnerability of the ecosystem being invaded. An initial step towards an alien management plan is to assess and present the evidence that invasive alien species are a major threat to natural biodiversity in that area and that action is mandatory to be taken. The preparation of a preliminary assessment is a crucial step and should be based on existing information, which can be accessed from various sources (literature, databases, *etc.*). Loss and degradation of native biodiversity due to alien species can occur throughout all levels of biological organization from the genetic and population levels to the species, community, and ecosystem levels, and may involve major alterations to physical habitat, water quality, essential resources and ecological processes. These impacts can vary in terms of the lapse of time between the initial introduction and subsequent spread of an alien species, its severity of impact, the likelihood of synergistic interactions with other threatening processes, and the potential for initiation of a cascade of effects ramifying throughout an entire ecosystem (Mooney and Hobbs, 2000; Kowarik, 2003; Reise *et al.*, 2006).

Up to now, concern has been mainly confined to the species level and introductions from outside the Northeast Atlantic biogeographic province. This may be too narrow in perspective. Particularly, benthic species may show considerable genetic structure variation within that region (*i.e.* Luttikhuizen *et al.*, 2003a; Olsen *et al.*, 2004). This may not be surprising for benthic organisms lacking pelagic means of dispersal, but it also seems to occur in species with pelagic larvae, such as the European cockle *Cerastoderma edule* (Krakau *et al.*, submitted) and *Macoma balthica* which even shows genetic differences between the Wadden Sea and adjacent North Sea coastal regions (Luttikhuizen *et al.*, 2003b). Obviously, shifting organisms from one coast to another, a common practice in aquaculture with mussels and oysters, may dilute the adaptations evolved within local populations. It is probable that this practice has contributed to the collapse in many local populations of the European oyster in the 19th and early 20th centuries. We usually lack sufficient genetic information and the knowledge to anticipate the effects of lost subspecific adaptations. This is urgently needed, as is evident from recent transfers of mussels from British coasts into the northern Wadden Sea which may entail the introduction of alien genes. In order to protect intraspecific genetic diversity, alien proveniences of native species (*"gebietsfremde Herkünfte heimischer Arten"*) should be taken more into consideration in authorization procedures in future.

The European Strategy on Invasive Alien Species (Council of Europe, 2003) recommends that all aliens have to be sorted into three categories: (1) a white list of species which are harmless and might even be of use or benefit; (2) a grey list of species which impact is unclear; (3) a black list of species which cause serious harm. However, species lists and the according decision-making needs to be based on transparent scientific criteria that are regularly reviewed and on accurate, precise, generally applicable, and widely accepted assessment protocols. Various methods of performing risk analyses on specific groups of alien species have been employed (*e.g.* Morse *et al.*, 2004; Copp *et al.*, 2005; Hewitt *et al.*, 2006), but there is still no international standardised methodology.

For German nature conservation activities, criteria based risk assessment for evaluating the ecological threat of both alien plants and animals in aquatic (freshwater, brackish and marine waters) and terrestrial habitats are now being developed (Essl *et al.*, 2008). The method allows allocating species (or infraspecific taxa, as appropriate) in one of the three following impacts categories: invasive (Black List), potential invasive (Grey List), and non-invasive (White List). The main focus is on threats imposed by alien species on native species which can be summarized into five general categories:

- Hybridisation with native and other alien species, producing reproductive offspring;
- Competition;
- Predation and herbivory;
- Introduction of parasites and disease agents which affect indigenous species;
- Habitat alteration, resulting in changes of biological structures and water budget.

These threats have to be considered in the context and in conjunction with other effects in the ecosystem such as the provision of a novel and beneficial food supply, a more efficient coastal filter function, diversion of parasites from native to introduced species or the provision of complex habitat structures where none have been before.

The basis for assessment is the net endangerment of native species by alien species, *e.g.* verified by listing in a Red List. Distribution in the assessment area, the applicability of control measures and specific bio-ecologically traits (*e.g.* occurrence in protected areas, reproduction and spreading potentials, facilitation by climate change) serve as additional classification criteria. The German assessment method allows for (1) identifying those species that threaten natural biodiversity and other ecological functions and values, and (2) prioritizing species for management efforts (e.g. mitigation, control, monitoring). While designed for use in Germany and Austria, the protocol can be applied to any other region, and may also be applicable to assess the impact in the non-native range of a species that is also present elsewhere in a region as a native.

On basis of the routine outlined above, a preliminary assessment of alien species occurring in the Wadden Sea shows that presently most of the alien species cause no, or only minor, impacts on the natural biodiversity of the Wadden Sea, but it is also clear that several of them involve far-reaching ecological consequences (in detail see chapter 7.3). However, it should be noted that the impact of alien species, even those that may be invasive, is often insufficiently known because appropriate studies have not been attempted; effects often develop over many years and it is often difficult to distinguish the effects of alien species from those of many other simultaneous, natural, and anthropogenic effects on ecosystems (Reise and van Beusekom, 2008). Apart from ecological consequences by invasive alien species, any alien species invasion constitutes a biological contamination of natural aquatic ecosystems. In coastal waters the macrozoobenthic communities of the mesohaline zone in estuaries are characterized by the highest number of alien species as well as by the highest percentage of alien species compared to the respective total indigenous species numbers (Wolff, 1999; Nehring, 2006) (Fig. 1). The high sum total of aliens may be more significant than the effects of the individual alien species. Also, the interactions between aliens may give rise to an 'invasional meltdown' in the sense that already-established aliens facilitate the establishment of others. The conclusion is that the assessment of ecological quality status needs to be undertaken in an ecosystem context. Specific indices should be established to aid identification of invasive species, as recommended by Arbaicauskas *et al.*, (2008) and Panov *et al.*, (2009) for inland and coastal waters.

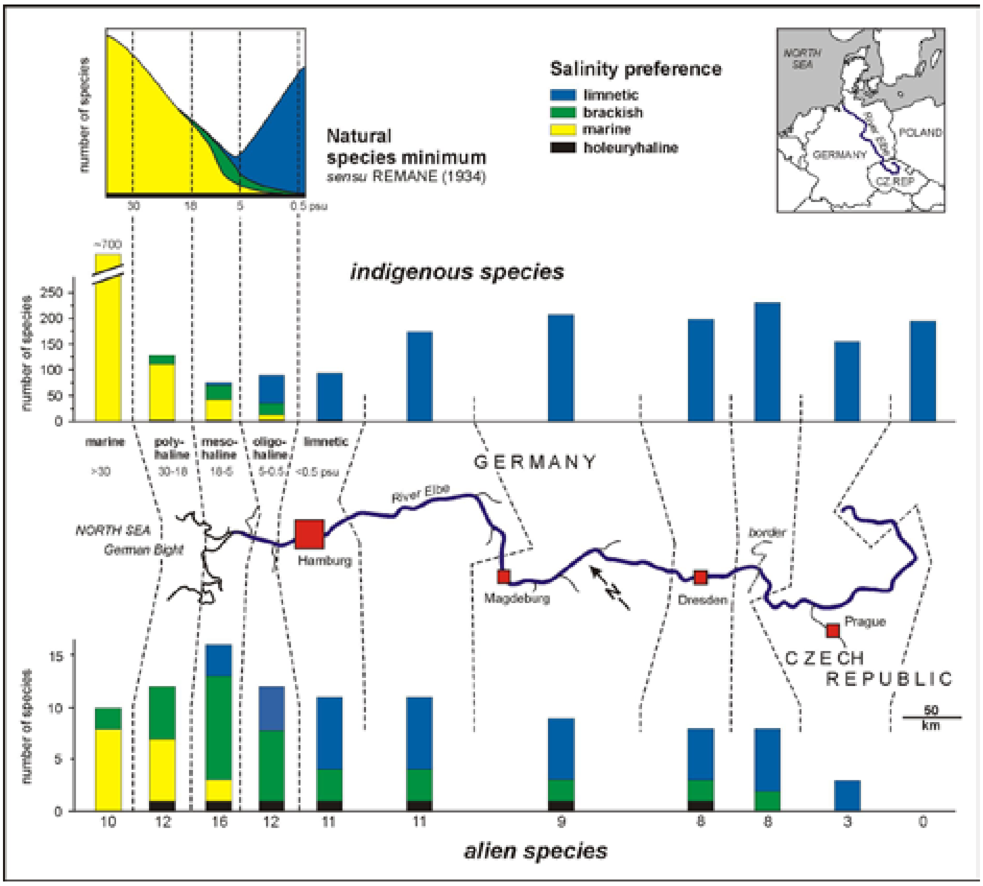

Figure 1:
Estuaries – one hotspot of invasion. It seems that the combination of brackish water with its unsaturated ecological niches and intensive international ship traffic is responsible for the observed high infection rate with alien macrozoobenthic species in the Elbe estuary (after Nehring, 2006).

3. Hotspots of invasion in the Wadden Sea

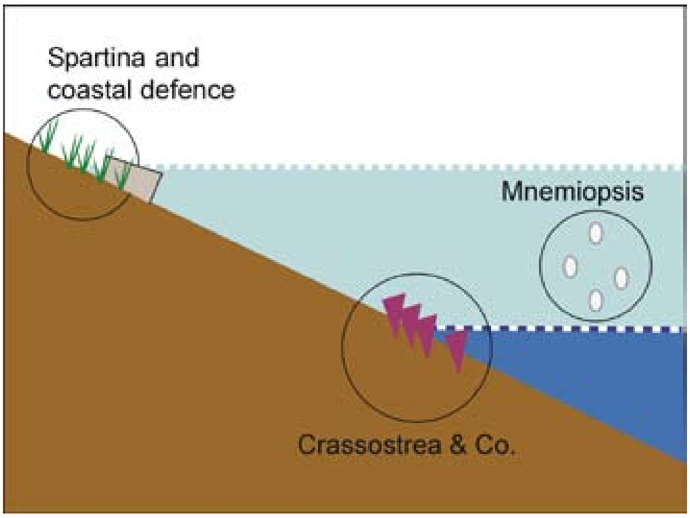

Figure 2: Hotspots of bioinvasions at the vertical habitat gradient in the Wadden Sea. *Spartina* and artificial hard structures around high tide level, *Crassostrea* and other alien suspension feeders with epibionts around low tide level, and alien plankton.

In the Wadden Sea, invasive alien species have not spread randomly across the depth gradient from the upper beaches and salt marshes to the deepest bottoms of the tidal inlets. Instead, there are three hotspots of alien impacts (Fig. 2): The first is encountered around high tide level on sheltered shores. Either the invasive *Spartina* grass dominates the vegetation or introduced hard substrates prevail as a coastal defence or harbour walls. *Spartina* is dealt with in detail below. The artificial hard substrates host rocky shore species which otherwise would be absent from the Wadden Sea but are native to the region (*i.e.* the common sea slater *Ligia oceanica*). These boulder walls may also serve as gateways for alien species which arrived by ship from overseas (Reise and Buschbaum, 2007). Examples are the Asian shore crabs *Hemigrapsus sanguineus* and *H. takanoi* which hide underneath boulders and may potentially interfere with juveniles of the native shore crabs. Since 2007 both crabs are spread throughout the entire Wadden Sea.

Extensive habitats in the Wadden Sea, the vast mud and sand flats around mean tide level, with or without seagrass, are almost devoid of alien species. Only in the estuarine parts the invasive polychaetes *Marenzelleria neglecta* and *M. viridis* temporarily achieved high densities (Fig. 3) (Nehring and Leuchs, 2001; Essink and Dekker, 2002). Also sandy beaches are virtually free of alien invaders. By contrast, the transition from the lower intertidal into the upper subtidal zone alongside tidal channels is again a hotspot where the benthos is becoming dominated by alien species,

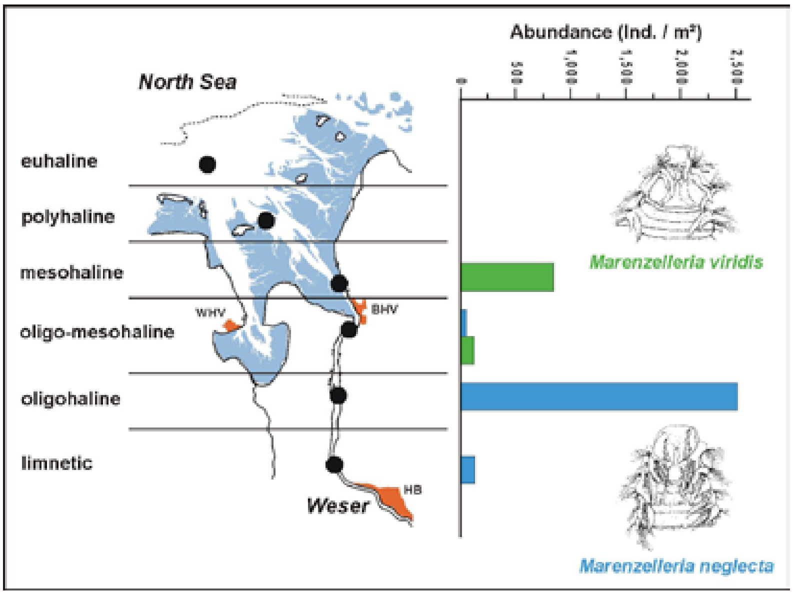

Figure 3: High abundance of two American spionid polychaetes, *Marenzelleria neglecta* and *M. viridis* in the sublittoral of the Weser estuary, differentiated by the salinity gradient (BfG Estuary Monitoring Programme 1999, modified after Nehring and Leuchs,

above all by the Pacific oyster *Crassostrea gigas*, *Ensis americanus*, locally *Crepidula fornicata* and others. This is an invasional meltdown where aliens facilitate each other. At greater depth of channels and in the adjacent offshore zone, the share of aliens is again quite low up to now.

Potentially, a third hotspot may be in the coastal waters flowing in and out of the Wadden Sea with the tides. Some alien holoplanktonic species at times abound including the ctenophore invader *Mnemiopsis leidyi* and larvae of introduced aliens. As well as these three hotspots, one could also regard specific localities as potential hotspots of alien species, where they can be expected to show up first after arrival in the Wadden Sea. These localities include ports, marinas, on buoys and in inner estuaries where the species are introduced with ships and are expected to arrive and have a good chance to get off board or reproduce. Other hotspots are around oyster and mussel cultures. Such localities should be particularly surveyed for early detection of alien invaders (see chapter 4).

3.1 *Spartina* – the most important invasive plant in the Wadden Sea

Already intentionally introduced eight decades ago to aid in land claims and now well rooted with extensive populations along the sheltered shores of the Wadden Sea and adjacent coasts, the *Spartina* grass has become a characteristic feature of the transition zone between marsh and tidal flats (Fig. 4). Nevertheless, it is still not generally known that this conspicuous grass does not belong to the native flora and constitutes an artificial element in the Wadden Sea, just as dikes and revetments, linear ditches and brushwood groins. What is the history and what are the prospects, what the effects on the ecosystem and biodiversity, and what could be done about it?

Grasses of the genus *Spartina* are indigenous to the Americas and the species *S. maritima* to Africa and southwest Europe or possibly has been introduced a long time ago into the latter region. Along other coasts in the world, including the Wadden Sea, various other plants such as species of the genera *Salicornia* and *Puccinellia* used to dominate the pioneer zone of salt marshes. However, this has changed. Today *Spartina* grasses abound at most sheltered shores of temperate climate zones because of deliberate introductions which aimed to enhance salt marsh development. *Spartina* species hybridized, natural vegetation became displaced and coastal landscapes transformed. *Spartina* is a classic example of global biological homogenization through its mixing with once-distinct coastal vegetations.

Particularly widespread are *S. alterniflora* and *S. anglica.* The latter originates from accidental hybridization between *S. maritima* and introduced *S. alterniflora* in southern England. In the sterile hybrid, a doubling of chromosomes happened to occur and a fertile species was born, named *S. anglica* in 1892. This new species turned out to be a more vigorous pioneer of salt marsh vegetation than its parents, strongly facilitating sediment accretion and thereby transforming tidal flats into salt marshes. This has attracted coastal engineers and systematic planting of *S. anglica* commenced in the 1920s, including the introduction at various sites in the Wadden Sea between 1925 and 1944 (Nehring and Hesse, 2008). These plantings were partly successful and *Spartina* spread further on its own. However, disillusionment soon followed the initial euphoria. König (1948) concluded that *Spartina* cannot protect any coast but grows well only where it is protected by the coast itself. Also die-backs occurred, marshes with *Spartina* became water-logged and unsuitable for grazing, and ditching for irrigation increasingly cumbersome. Finally, in the 1960s, even tests with herbicides were conducted in the German Wadden Sea to eradicate *Spartina*, in the end without success.

Figure 4: A belt of *Spartina anglica* between native salt marsh vegetation (*Halimione*) and bare tidal flats with some seagrass (*Zostera noltii*) on the island of Sylt (July 2008).

On vegetation maps for the Wadden Sea, salt marshes were generally categorized into pioneer, low and high salt marsh zones but did not provide information on the areal share of *Spartina*. Only for salt marshes along the Schleswig-Holstein coast, the areal share of a "*Spartina anglica* Typy" was given as 18% for the mainland and 13% for the islands in 2001 (see Stock *et al.*, 2005). However, this does not comprise *Spartina* growing outside that type in the unspecified pioneer and lower salt marsh zone. Thus, there are no data on the areal extent of *Spartina* in the Wadden Sea. Knowledge is confined to a few selected sites showing how this invader spread initially, and that it is still spreading (*i.e.* Vinther *et al.*, 2001; Stock *et al.*, 2005; Loebl *et al.*, 2006). It has been suggested that reductions in domestic grazing and in irrigation works (Stock *et al.*, 2005), climate change in the form of mild winters (Vinther *et al.*, 2001), and warmer and earlier spring times since 1988 (Loebl *et al.*, 2006) have contributed to a renewed acceleration in the spread of *Spartina*.

Global warming may prolong the growth season of *Spartina* in the Wadden Sea because it belongs to plants with a C_4 pathway with physiological thresholds of 4°C for germination and 7°C for effective photosynthesis. Loebl *et al.* (2006) assume that the improved temperature conditions may have helped the grass to grow also on more exposed sandy tidal shores where it has been absent before. However, interactive effects between warmer temperature and increasing hydrodynamics in the wake of accelerating sea level rise may ultimately set a limit to the further spread of *Spartina* in response to global warming, relegating its distribution in the Wadden Sea to the sheltered locations in the upper tidal zone. Thus, a general cover of bare sediment by *Spartina* down to mid tide level, as it commonly occurs at the more sheltered Atlantic shores of North America, may never happen in the Wadden Sea.

Patches and swards of *Spartina* are a strong habitat transformer or ecosystem engineer by accreting sediment, accumulating organic material, penetrating the ground with a dense mesh of roots and rhizomes, and offering a complex habitat structure above the ground which also shades the bottom and calms down hydrodynamics. A multitude of effects has been recorded, varying with the phase of succession, the physical environment and the organisms considered (Table 1).

The role of *Spartina* as food to herbivores is minor compared to being a source of detritus and physically changing the habitat structure. Effects on biodiversity depend on location, the organisms and the scale which is considered. *Spartina* tends to grow in monospecific stands which displace more diverse native vegetation but on a larger scale it adds one more type of habitat patch to the dynamic mosaic of the salt marsh vegetation (Fig. 5). The diversity and complexity of effects of *Spartina* on the environment precludes any

Table 1: Effects of *Spartina* on the habitat and other organisms

Effects	Habitat/Organisms	References
Shoots and roots are food	for foraging geese	Esselink *et al.*, 2000
Shoots provide shelter	for ducks and other birds	Zedler, 1993
Shoots provide habitat	*Littorina, Hydrobia*	Armbrecht, 2008; Bouma *et al.*, 2009
Dense swards prevent	edge erosion of old marsh	see Fig. 7.4
Dense swards accrete sediment	more than other vegetation	Gray *et al.*, 1991
Shade out native plants	*Puccinellia, Salicornia*	Scholten and Rozema, 1990; Gray *et al.*, 1991
Raise the ground too high for	*Zostera noltii*	Reise *et al.*, 2005
Culms increase	abundance of macrobenthos	Rader, 1984
Roots inhibit burrowing fauna	*Arenicola* and other infauna	Armbrecht, 2008; Bouma *et al.*, 2009
Growth phases have different effects	in infauna	Neira *et al.*, 2007
Patch edge and center differ in effects	on bivalves	Dumbauld *et al.*, 1994 in Daehler and Strong, 1996
Inhibit suspension feeders	*Cerastoderma edule*	Armbrecht, 2008
Roots create oxic microhabitats	nematodes	Osenga and Coull, 1983
Accumulation of detritus creates	anoxia and die-back	Nehring and Hesse, 2008
Sediment accretion eventually	facilitates native plants	Dijkema, 1983
Invasion of bare tidal flats reduces	feeding area for shorebirds	Evans, 1986; Goss-Custard and Moser, 1988
Monospecific swards	may be susceptible to epidemics	Thompson, 1991

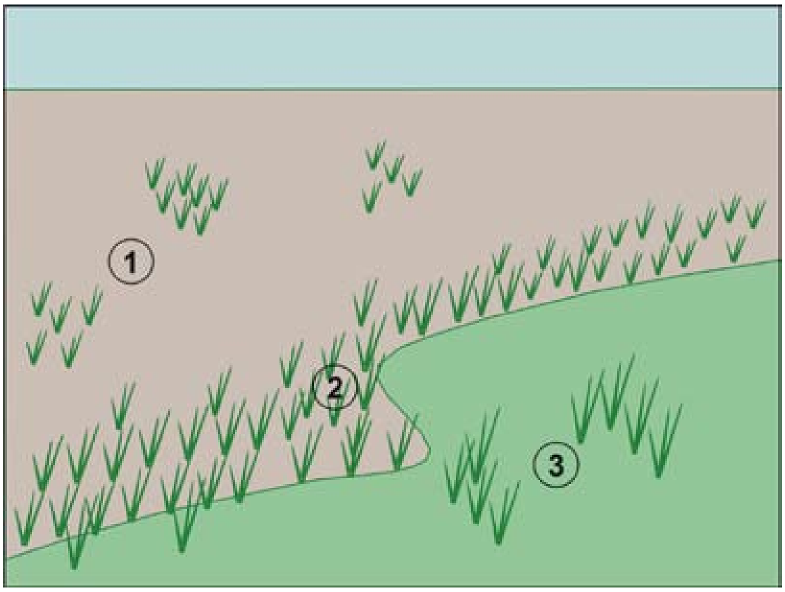

Figure 5: *Spartina anglica* invades (1) upper tidal flats in patches, (2) dominates in swards the seaward edge of salt marshes, and invades (3) the high marsh with dynamic patches. Effects on habitat structures and other species differ at these sites.

simple normative statement whether it is good or bad, and the net balance will vary with time and location. From a nature conservation point of view, however, the magnitude of deviation from natural conditions caused by the *Spartina* invasion is relevant and could justify measures of eradication or control (see chapter 4).

Nehring and Hesse (2008) have reviewed mechanical, chemical and biological methods which have been employed or have been suggested to control *Spartina*. To restore natural processes in the upper tidal zone of the Wadden Sea, it would be desirable to have shores again without *Spartina*. However, methods to eliminate established *Spartina* should fulfil the following requirements:

1. Mechanical elimination must not have disturbing effects on other organisms and natural habitat structures lasting longer than a few years.
2. Applied chemicals must not poison other organisms.
3. Biological agents such as diseases or herbivores must be specific to *Spartina* and not spread to regions where these are not wanted.
4. Must be successful in the long run, be cost-effective and acceptable to the public.

In addition, any management measures should be avoided which promote *Spartina* in the Wadden Sea. The Natura 2000 programme ought to be corrected. The invasive alien *S. anglica* should not fall any more into the natural habitat type *Spartinion maritimae* code 1320.

3.2 Invasional meltdown around low tide level

Similar to *Spartina*, also the Pacific oyster *Crassostrea gigas* is a universal habitat transformer of temperate shores, regardless whether muddy, sandy or rocky (Ruesink *et al.*, 2005). Different from *Spartina*, the invasion of *Crassostrea* began only two decades ago and it is still too early to venture a sound projection on the final outcome. So far, there is hardly any other invaded region which happened to be so readily invasible for this alien oyster as the Wadden Sea. How could that happen, what is the impact like and is there anything which could be done about it? *C. gigas* is spreading above and below low tide level where it is not the only successful alien invader. The interactive effects with other aliens exacerbate the situation. The benthic community around low tide level is often dominated by alien species.

Without the depletion of natural beds and subsequent extinction of the European oyster *Ostrea edulis* in the Wadden Sea and adjacent waters, there would not have been an incentive to introduce alien oysters (Reise, 2007). Early attempts failed to introduce *O. edulis* from elsewhere in Europe, *C.virginica* from Atlantic America and various strains of *C. gigas* from the western Pacific. However, the *C. gigas* introduced into the Oosterschelde estuary in 1964 spread into the wild from 1976 onwards. In the Western Wadden Sea specimens probably originating from seed oysters imported from a French hatchery (Smaal *et al.* 2009) were introduced in the cooling basin of the electricity plant in Texel in the late 1970s (Tyde-

Figure 6: Pacific oysters growing adjacent to an oyster farm at the island of Sylt (August 2007).

man, 2008) and adult specimen were encountered outside that basin in 1983. Spread from there was rather slow at first but since the late 1990s the invasion progressed rapidly throughout the Wadden Sea (for details see Dankers *et al.*, 2004; Reise *et al.*, 2005; Nehls and Büttger 2007; Fey *et al.* in press). Another source of this species was regular farming of *C. gigas* with spat from British and Irish hatcheries near Sylt since 1986. A wild population, started close to that farm in 1991, invaded the Danish Wadden Sea and also spread to the south (Fig. 6).

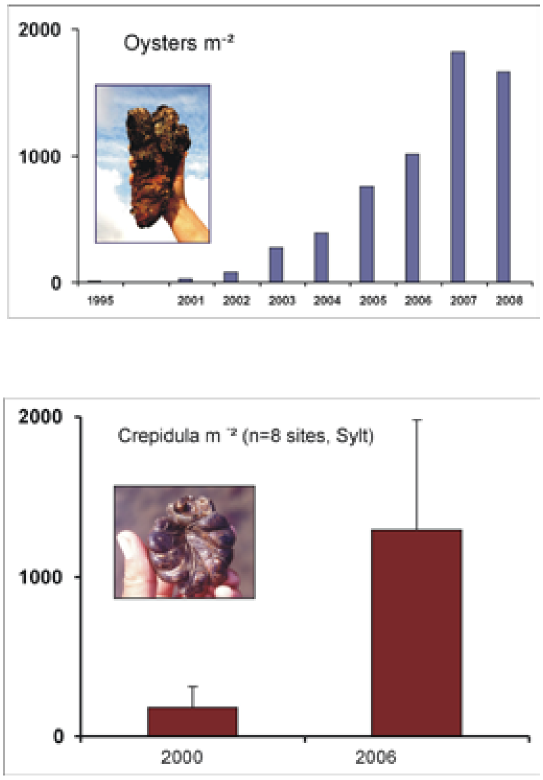

Figure 7: Above: mean abundance of the Pacific oyster *Crassostrea gigas* on mussel beds which since 2005 appeared to be all oysters reefs near Munkmarsch harbour on Sylt. Below: mean abundances of the American slipper limpet *Crepidula fornicata* adjacent to mussel beds in 2000 and to oyster reefs in 2006 at about spring low tide level near the island of Sylt (Reise, unpubl.).

The reproductive success in *C. gigas* has been linked to mean water temperatures >18°C during July and August (Diederich *et al.*, 2005), and particularly strong recruitment was observed in summers between 2002 and 2006. A representative course of oyster reef development on former mussel beds is given in Fig. 7. Oysters settle on any hard substrate but are most common on mussel beds or where these had been before. The vertical distribution ranges from below mid tide level down into the shallow subtidal with a maximum found around low tide level, copying the pattern of mussel beds. Abundances generally attain densities up to 1,000 to 2,000 oysters m^{-2} with a total weight of 30 to 50 kg m^{-2}, but on established reefs they may go as high as 140 kg m^{-2} (Fey *et al.* in press). In 2006, the oyster mass including shells was estimated to be at least 61,000 t in the Wadden Sea (Nehls and Büttger, 2007).

Ecologically, the spread in the Wadden Sea started with a paradox. In spite of strong crowding between *Mytilus edulis* on mussel beds, oyster larvae successfully attached to individual mussels, grew faster and larger, soon smothered their basibionts and began to dominate the beds (Fig. 8). Mussels have not reversed this hostile takeover by settling on top of the oysters and smothering them in turn. Instead, mussels settled in the understory between the much larger oysters, escaping predators. Oyster larvae, by contrast, settled preferentially on top of their older conspecifics which gives rise to reef formation (Diederich, 2005). There are also wide areas with scattered clusters of oysters. These are mostly dislodged from the reefs, continue to grow and may serve as nuclei for new beds where bare sediment had been before.

There are probably no more mussel beds without any oysters in the entire Wadden Sea. Will the Pacific oysters eventually displace the native mussels? Up to now, the observations are inconclusive (Nehls *et al.*, 2006; Nehls and Büttger, 2007). Within and between mussel beds, all combinations of high and low abundances have been encountered. Also the temporal development provides no clue. Since 1998, mussels increased in the Dutch and decreased in the German and Danish Wadden Sea, while oysters proliferated everywhere. The decrease in mussels commenced already before the oysters began to increase significantly. The area of mussel beds in Dutch Wadden Sea has remained relatively stable over the last years while oyster reefs and mixed beds are increasing (Fig 9).

Long-term experience with mussels indicates that severe winters have regularly resulted in population expansion in the subsequent summer (Nehls *et al.*, 2006). This has been linked to a gap in predation pressure caused by high predator mortality and/or their retarded development. However, such gaps may also occur for other reasons as the development of the mussel population in the Dutch Wadden Sea shows. Thus, the climatic trend alone, with no more severe winters since 1996, will not suffice to predict the future proportions of mussels to oysters in the Wadden Sea. The microspatial pattern suggests that mussels have a chance to coexist under the dominance of oysters (Fig. 8).

The spectrum of species associated with mussel beds and oyster reefs is roughly the same but strongly varies with location (Markert *et al.*, 2009).

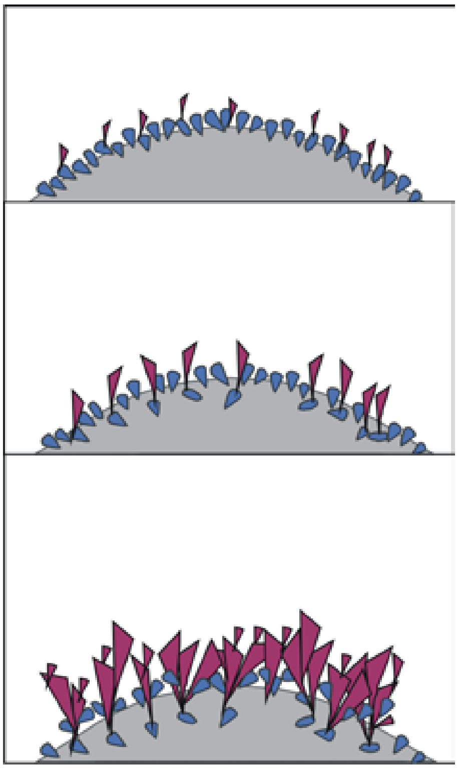

Figure 8: Succession of the conversion of a mussel bed into an oyster reef in the Wadden Sea within 3 to 5 years. First, Pacific oysters settle upon mussels. Then new mussels settle in the understory, while settling oysters attach to the tops of live and dead oysters, creating an oyster reef.

A field experiment with mussels and oysters revealed that differences in the habitat matrix generated by these two bivalve aggregates entailed different abundances of associated infauna and epifauna (Kochmann *et al.*, 2008). Further, a cover with fucoid algae common on sheltered mussel beds rarely develops where oysters prevail. As a coastal filter the oyster reefs may be a functional analogue to the mussel beds but the structural

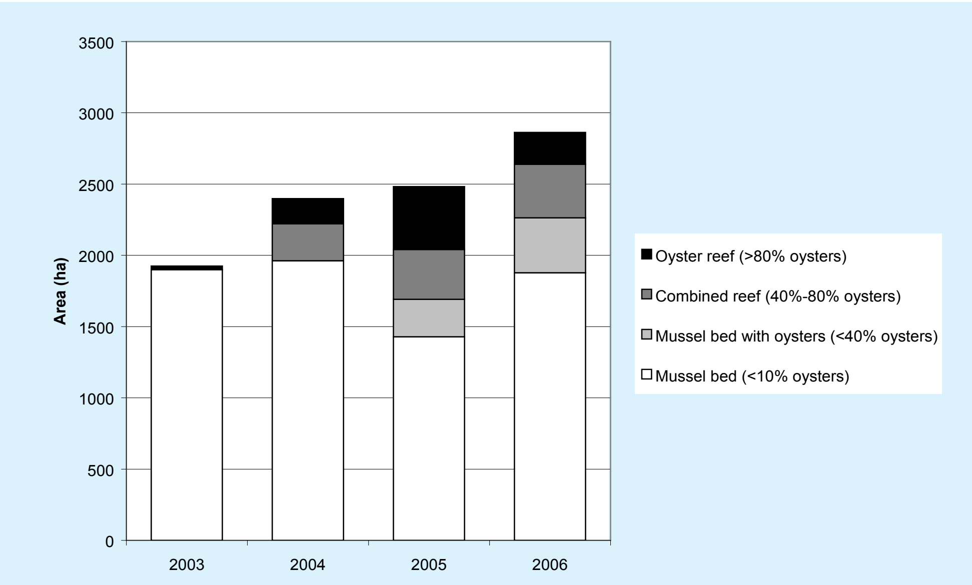

Figure 9: Area of intertidal mussel beds and the "takeover" by the Pacific oyster in the Dutch Wadden Sea (Fey *et al.* in press).

Figure 10: Stack of the American slipper limpet *Crepidula fornicata* (left) and stacks scattered on shallow subtidal bottom forming a dense bed of limpets (Sylt, September 2008).

effects differ. In particular, the Pacific oysters are still poorly integrated into the food web of the Wadden Sea. Birds like eider, oystercatcher and herring gull which particularly feed on mussels may run into a shortage of food because most oysters are too large for consumption or fused into clusters, and shells are too strong for the birds to break them open (Blew and Südbeck, 2005; but see also Cadée, 2008 a,b).

May the Pacific oysters cause food shortage in native suspension feeders by competition? In line with such a process, native bivalves did decrease over the last decade (Beukema and Dekker, 2005; Nehls *et al.*, 2006). As pointed out above, the trend of warming is more likely to be the cause. This entails an increasing predation by shrimp and shore crabs on bivalve spat rather than competition with the alien suspension feeders. Further, one should note that *C. gigas* is not the only suspension feeder that invaded the Wadden Sea. Concurrently with the increase in oysters, the American slipper limpet *Crepidula fornicata* increased in abundance (Fig. 7). It was already introduced into the northern Wadden Sea seven decades ago with *O. edulis* imported from the Oosterschelde, and switched from the fading oyster grounds to subtidal mussel beds near Sylt (Thieltges *et al.*, 2003). There it now abounds in the shelter of mussel beds or oyster reefs, forming a halo virtually paved with stacks of individuals attached to each other (Fig.10) (Nehls *et al.*, 2006; Thieltges *et al.*, 2009). Also around low tide line, the razor clam *Ensis (directus) americanus* attains its highest densities since the 1980s (Armonies and Reise, 1999). Attached to the empty shells protruding out of the sediment as well as to oysters and slipper limpets, the Asian ascidian *Styela clava* frequently occurs in bunches of individuals with up to 232 m^{-2} just below mean low tide level (Fig. 11) (Liebich, 2007).

Altogether, *Crassostrea, Crepidula, Ensis, Styela* and a few others have launched a striking invasion of alien suspension feeders in the zone around low tide line. The level of primary production may be still high enough to supply them all (Brinkman and Jansen 2007; Reise and van Beusekom, 2008). In addition to competition and predation, parasitism has to be considered as an important biotic interaction altered through alien bioinvasions.

Figure 11: Aggregate of the invasive ascidian *Styela clava* on shallow subtidal bottom (Sylt, June 2007)

Alien molluscs generally have arrived without their parasites, but parasites of native molluscs also infected the alien hosts (Krakau *et al.*, 2006). Experiments have shown that Pacific oysters and American slipper limpets actually mitigate the parasite burden of the native mussels (Thieltges *et al.*, 2009). From the oysters as intermediate hosts, trematodes cannot reach their final hosts because oysters are not (yet) consumed by the birds. Slipper limpets actually prey on cercarial stages and do not get infected. In recent years massive mortality occurred locally in late summer (Dankers *et al.*, 2004). From the French Atlantic coast there are reports of very high summer mortalities in *Crassostrea gigas* (Samain *et al.* 2004). In the Wadden Sea, oyster beds do not disappear after mortality events. The shells remain and new spat fall even solidifies the bed as a whole (Fig. 12)

Slipper limpets attached to mussels have been shown to reduce growth and increase mortality in their basibionts, while they provide protection against predator attacks by shore crabs and starfish (Thieltges *et al.*, 2006). The web of interactions becomes even more complex when the large invasive kelp *Sargassum muticum* is considered (Fig. 13). It forms dense canopies in the shallow subtidal of Sylt with positive effects on the diversity of native species which attach or roam between the manifold branched thalli (Buschbaum *et al.*, 2006; Polte and Buschbaum, 2008). Usually, clusters of oysters and stacks of slipper limpets provide the main anchorage at the bottom for this invasive macroalgae. However, this is often not perfect because the algae attain lengths of up to 3 m in July and the resulting drag lifts the anchorage off the bottom, and both together end up in the wash line on the beach.

Figure 12: Dead Pacific oysters serve as substrate to subsequent settlement which may glue together the empty shells (Photo: N. Dankers).

In conclusion, the Pacific oyster has established firmly in the Wadden Sea. Neither the final population size nor the impacts on native species can be clearly projected but it may cause a change in the ecosystem which may surpass that of *Spartina*. Together with several other alien invaders parallel to or interacting with *C. gigas*, the benthos around low tide level has already been overturned with cascading effects on foraging birds and the functioning of the ecosystem. Thus, efforts to protect *Crassostrea* reefs in the Natura 2000 programme as natural habitat type of community interest (Reefs, code 1170) have not to be put into action.

Figure13: The invasive *Sargassum muticum* forms a dense kelp forest adjacent to the oyster farm at the island of Sylt (July 2007).

Apparently, the spread of *C. gigas* into the wild was not considered to be a problem until the late 1990s. Although *Crassostrea* successfully reproduced in the Oosterschelde since the mid 1970s, it was still assured in 1986 that starting a *Crassostrea* farm near Sylt is not violating National Park law because it was assumed that the Pacific oysters were unable to breed under our latitude and would not spread into the wild. Concern has arisen only after the invading population had passed the line of no return. In view of the sheer number already present, together with its enormous potential of reproduction and dispersal, no mechanical control of this invader is conceivable. Wild aggregates of *C. gigas* may not be commercially harvestable for consumption, and large scale dredging for low quality meat, manure or chalk production would be devastating for the environment. Thus, fishery on oysters would be no sensitive option for the Wadden Sea ecosystem. Seed oysters might be collected but very few are suitable for further culturing because most are attached firmly to clusters and cumbersome to detach. Removal of entire reefs with bulldozers or by dredging from a ship is not feasible on the large scale required for control without harming all other organisms including natives, and the success is likely to be only short term. Other means of control could be the introduction of potent predators or diseases. However, such biocontrols are difficult to keep under control (Hoddle, 2004; Thomas and Reid, 2007). Potential collateral damage to non-target species as well as to cultured oysters is usually impossible to rule out.

However, as a partial reparation for the over-exploitation of the native oysters and the introduction of alien ones, attempts could be made to re-introduce the native oyster *O. edulis*. Other than the mainly intertidal *C. gigas*, this species had occurred subtidally and so may not suffer from spatial competition with *C. gigas* if re-introduced. The maintenance of dense commercial stocks of *O. edulis* may provide the key to a redevelopment of native oyster beds by providing initial brood stock nuclei from which larvae can spread. A problem might be to obtain a genotype similar to the one which once thrived in the Wadden Sea before over-exploitation led to its extinction. Care should also be taken not to introduce the *Bonamia*-disease. Presumably, *O. edulis* living today in Limfjorden (Kristensen, 1997) could be a proper source for the re-introduction. An unintended re-introduction of *O. edulis* has turned into a success in Strangford Lough, Northern Ireland (D. Roberts, *pers. comm.*). However care should be taken as these oysters might be susceptible for Bonamia disease or if resistant they might carry the disease and might form a stepping stone between infected regions (Dutch Delta) and non-infected regions such as Limfjorden.

3.3 Alien invaders in the plankton

In drifting planktonic organisms, an occurrence in the North Sea cannot be set apart from the Wadden Sea. These organisms are largely at the mercy of currents and thus their abundance in the Wadden Sea is highly variable. What evidence is known that aliens in the plankton exert effects on natives or on the ecosystem in the Wadden Sea?

At least nine taxa in the phytoplankton are likely to have been introduced with ballast water or oysters, and of these the diatoms *Odontella sinensis*, *Coscinodiscus wailesii* (Fig. 14) and *Thalassiosira punctigera*, the frequently re-named dinophyte *Karenia (=Gymnodinium) mikimotoi (=aureolum)* and *Fibrocapsa japonica* belonging to the Rhaphidophyceae have been occasionally reported as abundant (Gollasch *et al.*, 2008). To what extent these introduced alien species have effects on other phytoplankton or on consumers has not yet been shown.

As a corollary of the many alien invaders in the benthos, there are times when their larvae are abundan in the coastal waters. As an extreme example, larvae of the American razor clam *Ensis americanus* dominated with 92% all identified bivalve larvae in the plankton samples taken in summer 2004 near Sylt (M. Strasser, *pers. comm.*). As with phytoplankton, the cascading effects in the food web are not known.

In the warm summer of 2006, the lobate ctenophore *Mnemiopsis leidyi* was sighted at several coasts in northern Europe including the Wadden Sea, but may have been introduced several years earlier with ballast water (Faase and Bayha, 2006; Boersma *et al.*, 2007; Tendal *et al.*, 2007). Normally, only specialists care about such comb jellies. However, *M. leidyi* had already a bad name from the Black and Caspian seas. This American ctenophore found ideal conditions after first encounters in 1982, spread massively and was blamed for having caused the collapse of the Black Sea fishery on anchovy by competing for planktonic food (Bilio and Niermann, 2004). After 1995 the same ctenophore also invaded the Caspian Sea, and again this was associated with a dramatic decrease in other zooplankton and fish, in this case kilka, the most common anchovy there. Similar effects were suspected in North European waters.

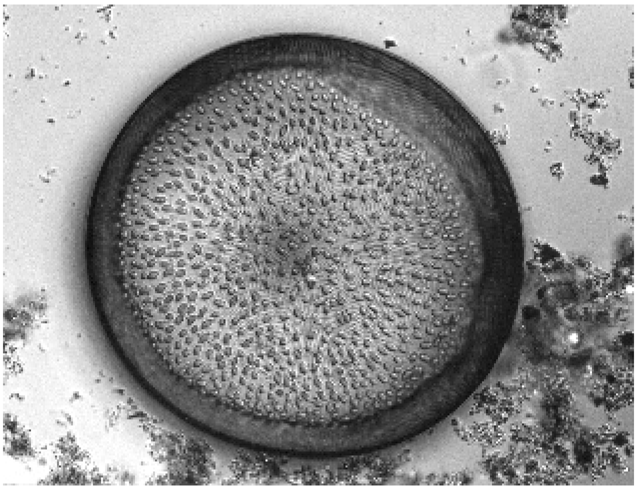

Figure14: The invasive diatom *Coscinodiscus wailesii* forms dense blooms, up to 90 % total algal biomass (Photo: K. Hesse).

However, *M. leidyi* on average remained smaller than in southern waters, mostly <40 mm in length and only a few were found in the Wadden Sea, sized up to 80 mm. From winter to early summer densities were rather low, and then increased up to 60 m^{-3} in August when temperatures were above 17°C (Fischer, 2008). Small size may limit both, reproductive potential as well as predatory impact. Mainly small sized prey is taken such as copepods and barnacle larvae (Müller, 2008). With high abundance only in late summer, effects on larvae of most fish and benthic macrofauna may remain weak, while larvae of species like *C. gigas* which spawn later may become potentially decimated.

It is obvious that no control of pelagic invaders is possible once these have arrived. Prevention of such species from entering the Wadden Sea with their vectors is the only way to keep them out. Treatment of ballast water and careful quarantines with imports for aquaculture must ensure that no life organisms with the potential to survive and reproduce in the Wadden Sea find their way into the North Sea. Such measures need to include benthic organisms or benthic stages as well and therefore the hulls of ships should receive special treatment.

3.4 What next do we have to expect?

Watching at the gate to prevent aliens from entering the Wadden Sea and getting established inside the Conservation Area is essential. This is the most effective precaution against the rising tide of alien invaders. It requires sound knowledge of what is native and what is not. When the Egyptian ibis, which has escaped from zoos into French coastal wetlands, is attempting to nest on a Wadden Sea island, this will be readily noticed and swift action could be taken to prevent breeding. The American horseshoe crab *Limulus polyphemus* is another likely candidate to become established, but is conspicuous and strange enough not to be overlooked. However, there are many other cases which will pass unnoticed without specifically focused surveys.

On the Pacific coast of North America, a vigorous hybrid between the introduced *Spartina alterniflora* and the native *S. foliosa* emerged (Ayres *et al.*, 2004). Detecting such a hybrid introduction into the Wadden Sea may require genetic screening. The same may apply to the native small eelgrass *Zostera noltii* and *Z. japonica.* These are morphologically very similar, and the latter is already spreading in coastal America. No alien species is known from the weedy green algae categorized as *Ulva* or formerly *Enteromorpha.* This may simply reflect the current confusion in the taxonomy of this group. Genetic screening will be necessary to unravel to what extent globalization already has proceeded and then to detect newly invading taxa or genotypes.

Such an effort may seem exaggerated at first sight. However, eelgrass and green algae are used as monitoring parameters to evaluate environmental quality for the European water framework directive. If the taxonomic basis of such parameters is not well controlled, serious misinterpretations could be the result. At present, seed mussels are imported into the northern Wadden Sea from the British Isles which entails the possibility that, in addition to *Mytilus edulis,* the southern sister species *M. galloprovincialis* or a hybrid between the two is imported unnoticed. It

Figure 5: Mature female of *Callinectes sapidus* Rathbun caught in German Weser estuary on 20 July 2007 (Photo: J. Albersmeyer).

is not known what the consequences for survival and for species interactions may arise from such genetic mixing. The invasion of *Crassostrea gigas* is already severe but it could become even worse if in addition other Pacific species such as *C. sikamea* and *C.ariakensis* are introduced. Morphologically these are almost indistinguishable from *C. gigas*. Nevertheless, there are important ecological differences with respect to vertical range and exposure to hydrodynamics.

Some invaders are almost certainly about to invade the Wadden Sea if they are not already present before this volume is published. Some have an impressive career as successful invaders elsewhere, i.e. the Pontocaspian fish *Neogobius melanostomus*, the Pacific whelks *Rapana venosa* and *Ocinebrellus inornatus*, the Asian clam *Tapes philippinarum*, the small mussel *Musculista senhousiana* and the sizable blue crab *Callinectes sapidus* (Fig. 15). Decisions whether these should be met with resistance to prevent establishment should be based on experiments testing the interactions with native species as well as on models predicting the invasional pressure and thus the chances to keep particular invaders out. Thus, in addition to regular surveys by experts, a considerable research effort is needed.

4. Conditions and measures

The significant effects of alien species on aquatic ecosystems require that efforts should be made to prevent and control their further spread. The strategies to minimize impacts caused by alien species are known. However, the countries' abilities to address issues on alien species varies.

Alien policy in the Dutch Wadden Sea

There is no specific alien policy for the Wadden Sea. In October 2007 the Ministry of Agriculture, Nature and Food Quality send a policy statement (Beleidsnota Invasieve Soorten) to the Dutch parliament. It mentions several of the above indicated international agreements and also the IMO ballast water agreement (to be ratified in 2009) but not the RAMSAR convention which is specifically important for the Wadden Sea.

A general conclusion of the statement is that preventing introductions of invasive alien species is the most important and (cost) effective policy option. Possible management options that contribute to prevention are creating public awareness of this problem and making agreements with stakeholders, such as companies that import plants, plant products or animals.

The Ministry of Agriculture, Nature and Food Quality set up an *Invasive Species Team,* consisting of several civil servants. The formal starting date for this team was January 2009. In co-operation with an expert network this Invasive Species Team will work on: a) gathering information on (new) alien species, b) setting up monitoring programs (early detection of new alien species), c) risk analysis (carried out by experts), d) advising the Ministry on invasive species (risks and possible management options), e) informing the public on invasive species (raising awareness). The Invasive Species Team mainly focuses on alien species that (potentially) impact biodiversity. Most of the (alien) organisms that threaten human health or the economy (agriculture) are dealt with in other organizations and ministries. When an initial analysis indicates possible impacts on biodiversity and more information is needed, a risk analysis will be carried out by experts. If needed, further monitoring will be carried out to determine the spread of the alien species. Based on this information the Invasive Species Team advises the Ministry on the possible impacts of the alien species and possible management actions.

Alien policy in the Danish Wadden Sea

In 2008 Denmark prepared a National Action Plan for Alien Invasive Species. The Action Plan gives a number of recommendations on prevention, eradication, control and research on alien species. Regarding the marine environment, prevention is much preferred as eradication most often is impossible. Therefore one of the recommendations is implementation of the Ballast Water Convention.

The Action Plan also includes the first Danish "black list" of species regarded as the "worst" alien invasive species in Denmark. Furthermore there is an "observation list" of species either not yet present in Denmark but known to be invasive in neighbouring countries or present in Denmark but still rare.

Alien policy in the German Wadden Sea

In accordance with the CBD's guiding principles (CBD, 2000), Germany has recently been preparing a national strategy on invasive alien species (Hubo *et al.*, 2007). The overall strategy for alien species comprises two main components: dealing with the problem of alien species already present, and the prevention of further introductions including the response if prevention should fail. Depending on the species, efforts should target one of the five categories: (a) prevention of introductions through education and regulations; (b) monitoring and early detection by effective monitoring programs; (c) rapid measures to eliminate newly introduced invasive alien species; (d) minimization of impacts of established invasive alien species by eradication and control; and (e) acceptance of established non-invasive species.

a. Prevention

Prevention is the first line of defence. In aquatic environments, alien species can be hard to detect and organisms disperse rapidly. It is a well-known fact that the eradication of an introduced species, once it has established in our waters, will be very difficult (and expensive), or even impossible. Therefore, the prevention of introductions (at best at source) is the most effective and least costly management strategy. Moreover, prevention is the only option where different measures for intended and unintended introductions have to be applied (Nehring and Klingenstein, 2008).

As far as intended introductions are concerned, many releases of alien organisms have been undertaken without taking into account the possibility of detrimental effects. Some organizations have developed guidelines and codes of practice (*e.g.* the ICES Code of Practice on introductions and transfer of marine organisms, the EIFAC Code of Practice and Manual of Procedures for consideration of introductions and transfers of marine and freshwater organisms). These instruments should assist key authorities (*e.g.* government agencies, regional authorities, professional associations for fishing) in determining whether an introduction is justified, and advise them on what to do after an introduction has been approved. However, these voluntary rules have lacked efficiency up to now.

As a legal instrument, the European Council enacted in 2007 a council regulation concerning the use of alien and locally absent species in the European aquaculture industry (Council of Europe, 2007). This is a first step in the right direction. However, up to now this directive is not transferred in national legislation in the three Wadden Sea countries. Under the proposed measures, all projects to introduce an alien species, or a native species which is locally absent from an area, would have to be submitted for approval to a national advisory committee which would determine whether the proposed introduction was 'routine' (i.e. from a known source of aquatic organisms classified as low risk) or not. In the case of non-routine introductions, an environmental risk assessment would have to be carried out. Only movements which are assessed as low risk (or reduced to low risk by application of mitigation procedures or technologies) would be granted a permit which can cover a five year period. The proposal requires quarantine procedures for non-routine introductions and also sets out a number of requirements concerning pilot release, contingency plans, monitoring and the keeping of national registers.

An important example of preventing unintended introductions is the International Convention for the Control and Management of Ships' Ballast Water and Sediments, adopted by member States of the International Maritime Organization in 2004 (IMO, 2004). It will enter into force 12 months after its ratification by 30 States, representing 35% of the world's merchant shipping tonnage. Under the Convention, ballast water management will become mandatory in order to minimize the introduction of harmful aquatic organisms and pathogens by this vector. Implementation of the Convention will prove difficult as it involves many legal, biological and technical aspects, including changing the design, construction and operation of ships. Expediently, parties (port or flag state administrations) are given the right to take more stringent measures than prescribed by the convention when consistent with international law. However, up to now this convention is not in force because as of 26 October 2008 sixteen States representing 14.24% of world tonnage had ratified. The sixteen states include just three from Europe: France, Norway and Spain.

The Ballast Water Convention does not prevent all unintended introductions associated with shipping since it only covers ballast water management. But solutions with environmentally acceptable methods for the control of hull fouling are also urgently needed now that effective but ecologically risky TBT based antifoulants have been banned in many countries (Nehring, 2001). And up to now there have been no activities focusing on shipping canals, although this pathway is of highest relevance for alien invasions in aquatic ecosystems, especially in Germany and its estuaries (Nehring, 2006; Galil *et al.*, 2007).

An important additional aspect of preventing unintended and intended introductions is the raising of awareness/enlightenment of politicians, management authorities, companies, scientists as well as the public about alien species, their risks and the possibilities to prevent further introductions. Among presentations in the scientific world and for the public, web-based information platforms offer a great chance to enhance awareness of the alien problem continuously (e.g. the German web-sites www.aquatic-aliens.de, www.neophyten.de). In particular, the many nature guides in the Wadden Sea should attend special courses on alien species. As in the case of oil spills or other environmental hazards, we recommend establishing a trilateral working group of experts, sufficiently funded to specify specific preventative conditions and measures to prevent efficient alien invasions in the Conservation area of the Wadden Sea.

b. Monitoring and early detection

The second line of defence, and high priority, against biological invasion into protected areas, is the monitoring and early detection of alien species (De Poorter, 2007).

Monitoring is of special relevance to obtain information about the invasibility of habitats, and the spreading and establishment of alien species, or about the efficiency of measures (see below).

However, a purposeful monitoring scheme for aquatic alien species is still missing. Such schemes should be based on existing data and instruments (*e.g.* TMAP) as well as the development of new mechanisms such as expert consultation and early detection systems (see below). The European Water Framework Directive (European Parliament and Council, 2000) requires that an integrated monitoring programme be established within each river basin district, including coastal waters. In many cases, these monitoring programmes will be extensions or modifications of existing programmes and will enable collections of the physical, chemical and biological data necessary to assess the status of water bodies. Alien species should be a key parameter in the monitoring design.

Within surveillance and monitoring efforts, the development of an effective early detection system is necessary to detect and to determine the status of newly occurring alien species in the wild. By rapid measures (see below) any potential invasion can be "nipped in the bud" – avoiding impacts on biodiversity and livelihoods, and saving large amounts of management resources. Invasive alien species which are listed on 'black lists' elsewhere should receive special attention. However, in aquatic environments, new introduced species are much more difficult to detect than in terrestrial habitats. Therefore an early detection system and rapid assessment strategy could focus in short time intervals 1) on areas that are likely to be hot spots of entry, such as large estuaries (*e.g.* Ems, Elbe, Weser; see Nehring, 2006), ports (*e.g.* Bremerhaven, and in the near future Wilhelmshaven after the opening of the Jade-Weser-Port; see Gollasch and Leppäkoski, 2001), marinas and aquaculture plots (*e.g.* Pacific oyster farm near the island of Sylt; see Wolff and Reise, 2002), and 2) as the need arises on particularly valuable habitats within protected area sites. And apart from this, an important component of an aquatic early detection system should be the integration of fishermen because many first discoveries of aquatic alien species are made by them (Nehring *et al.*, 2008). We recommend that in the trilateral group of experts (see above) an alien monitoring scheme inclusive early warning system and need of alien research in the Wadden Sea should be specified.

In general, every measure, pronounced in the following categories, should be based on a case-by-case decision depending on the local conditions or situation in accordance with legal codes and regulations. In order to evaluate the success or failure of a management programme, it is necessary to monitor and, if necessary, adapt the efforts undertaken.

c. Rapid measures

Due to the key actions of the European Strategy on Invasive Alien Species, rapid measures are the third line of defence (Council of Europe, 2003). Once an alien species becomes established within a location in an aquatic system, it poses a threat to an entire region due to its rapid dispersal via coastal water currents, shipping canals and rivers (Nehring, 2005). Therefore time is limited during which rapid measures are a practicable option. Its realization and choice of methods will be influenced by ecological, financial, legal and political considerations. Especially for newly introduced alien species, which are defined as invasive after a risk assessment, eradication is the most coherent solution in terms of biodiversity conservation (Genovesi, 2005). However, a basic requirement is the availability of at least one efficient eradication method. If rapid measures are not initiated or do not result in species eradication, the further establishment of the species in the immediate environs can be very costly (Gren, 2008).

To our knowledge, no rapid measures on newly introduced alien species have been carried out in the Wadden Sea to date, although it is conceivable that with the establishment of an early detection system (see above) newly introduced invasive species can be eradicated more promptly and successfully. This has been achieved with *Caulerpa taxifolia* in Californian lagoons (Anderson, 2005). From the Mediterranean Sea, the invasive potential of this algae was already well known. Rapid eradication was made possible because of an early detection by a monitoring programme, freeing up emergency money originally set aside for the case of an oil spill, a public campaign to prevent further introductions from private seawater aquaria, and the engagement of many volunteer divers. In the Wadden Sea, on the other hand, we feel a 'hurrah attitude' of being the first discoverer and the curiosity of how the invader proceeds still dominates over rushing for immediate eradication. We recommend that in the trilateral group of experts (see above) possibilities concerning rapid measures should be considered and recommended.

d. Eradication and control

If an alien species is defined as invasive after a risk assessment and if rapid measures fail or are not practicable, the competent authorities may be able to prevent further proliferation and/or minimize harmful impacts by taking mitigation/control measures – the fourth line of defence. Where it is ecologically feasible and socially acceptable, eradication should be the preferred option over long-term control, because eradication is usually more cost effective and less risky for the environment than control. However, especially in the aquatic environment, it is almost hopeless to eradicate widespread invasive alien species.

Once the establishment of an alien species is deemed irreversible, unwanted species can be controlled, for example by preventing propagation, preventing establishment in new sites or fixing the population size at a certain level to keep their impact within limits. As mitigation measures, control methods should also be selected, while taking into consideration the conservation value of the habitat as well as the efficiency, selectivity and the undesired effects these methods may cause. In the area of the Wadden Sea, only one control activity has so far been carried out to reduce the wild stock of the invasive cord-grass *Spartina anglica*. In the early 1960s, an experiment was initiated to eradicate *Spartina* locally in the Wadden Sea of Schleswig-Holstein (Meyer, 1964). Several herbicides were tested, but the results showed that single treatments were ineffective in the long run. Randløv (2007) advocated a combination of sheep and cattle grazing, and in case these were not possible, the use of a brush cutter to control *S. anglica* in Danish coastal waters was suggested.

It will, for instance, not always be possible to eradicate or control the worst invader, if there are insoluble conflicts with other conservation targets, insufficient resources, or the available techniques are unreliable. In that case, it may be better to focus on several other invasive species that are not as far into the invasion cycle and where there is a good chance of success. We recommend that in the trilateral group of experts (see above) possibilities concerning eradication and control measures should be considered and recommended.

e. Acceptance

The impacts from alien species can be direct, indirect, cumulative and/or complex, unexpected, surprising and counter-intuitive, and they often only show after a considerable time lag. Therefore, from a management perspective, every alien species needs to be managed as if it is potentially invasive, until convincing evidence indicates that it presents no such threat.

Many aquatic alien species which are already introduced and established in the Wadden Sea are innocuous and have obviously no relevant ecological effects (see Chapter 7.2 and 7.3). Such species should be accepted as a new component of our flora and fauna after a critical re-assessment of their effects. Where a species is assessed as harmless it can be included on a 'white list' to simplify management efforts. However, risk assessment may become outdated when conditions change. This may be due to other aliens altering habitat properties, to a change in climate, or to a change in the invader population itself. This requires periodical re-evaluations (Nehring and Klingenstein, 2008).

5. Conclusions

Although our present knowledge about the extent, patterns and mechanisms of aquatic bioinvasions is still in its infancy, it is clear that aliens are a significant force of change in aquatic communities globally. In the highly protected Wadden Sea a multitude of alien species have established permanent populations, several with an invasive or potentially invasive nature. These species pose a serious impact to native biodiversity because they have the potential to alter the natural state of an ecosystem into which they were introduced and may enhance the trend of global homogenization of flora and fauna. Further, alien invasions in aquatic systems tend to be irreversible, and it is certain that in the near future more alien species will arrive and establish permanent populations in the Wadden Sea. Such changes constitute a serious challenge to nature conservation. Who will be moved to protect a habitat entirely dominated by a fortuitous and growing assemblage of alien species? Therefore management of alien species is a priority issue and must be mainstreamed into all aspects of protected area management. This also needs to include the potential genetic mixing by aquaculture practices within genetically structured populations of species native to the Northeast Atlantic coasts.

Up to now no management plan exists in which way the preservation or restoration of the Wadden Sea ecosystem in relation to alien species could be guaranteed. Legal and organisational implementation in the three bordering countries, Denmark, Germany and The Netherlands, lags behind other regions that have developed strategic frameworks to address alien species in a holistic way. In each bordering country, multiple agencies have responsibility for different aspects of the alien species issue. Moreover the various sectors relevant to the management of aliens have vastly different management needs and policy processes associated with them. On the other hand management of alien species needs to be put in an ecosystem context.

The need for an effective coordination and cooperation in the issues of alien species within the Wadden Sea region to conserve the unique Wadden Sea ecosystem has never been greater. Priority should be given to developing an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea, consistent and harmonised with the European Strategy on Invasive Alien Species, with the Natura 2000 programme and with other legally binding and non-binding instruments. This pressing issue will be even more imperative considering that *Spartina anglica* and other invasive alien species will benefit from global warming, thus resulting in further spreading and radial expansion in the near future.

6. Target evaluation

In the Trilateral Wadden Sea Plan (1997) no specific targets were formulated with respect to alien species issues. However, in recent years, invasive alien species have become a high-profile policy topic for the international community which has emphasised the need for cross-sectoral coordination between competent institutions and stakeholders at all levels (Council of Europe, 2003). In the Evaluation Report about the Trilateral Wadden Sea Cooperation, invasive alien species are specified as one emerging challenge which needs an effective Cooperation in the future to conserve the unique Wadden Sea ecosystem (Moser and Brown, 2007). Therefore the object of efforts should be the developing of an alien management plan on the level of the Trilateral Cooperation on the Protection of the Wadden Sea in which specific targets and measures are formulated.

7. Recommendations

There is a need to consider the development of a trilateral policy on how to deal with alien species in the Wadden Sea. Therefore, the development of a trilateral alien management plan is recommended, which should take into account the following:

- Trilateral targets concerning alien species issues must be specified, consistent and harmonised with the European Strategy on Invasive Alien Species and other legally binding and non-binding instruments.
- The Natura 2000 programme ought to be corrected. The invasive alien *Spartina anglica* should not fall any more into the natural habitat type *Spartinion maritimae* code 1320. Efforts to protect reefs of the invasive alien *Crassostrea gigas* in the Natura 2000 programme (Reefs, code 1170) have not to be put into action.
- An inventory should be made of occurrence and distribution of alien species in the Wadden Sea.
- A criteria based risk assessment for evaluating the ecological impacts of alien species in the Wadden Sea should be realized. Subsequently alien species should be classified equivalent to the 'Black, Grey and White List' of the European Strategy on Invasive Alien Species.
- The potential genetic mixing by aquaculture practices within genetically structured populations of species native to the Northeast Atlantic coasts should be a concern in protected area management.
- The knowledge about economic and socio-economic benefits and damages of alien species in the Wadden Sea should be improved.
- A trilateral working group of experts needs to be established, sufficiently funded to help in alien species identifications, to assist in ad hoc risk assessments, and to specify alien monitoring schemes which include an early warning system and need of alien research in the Wadden Sea. Possibilities concerning preventative, eradication and control measures should be considered and recommended.
- A common portal should be installed with searchable lists of alien species occurring in the Wadden Sea, species accounts, species distributions, species fact sheets, a catalogue of experts on alien species and recommended preventative, eradication and control measures.
- To enhance awareness of the alien problem, the many nature guides in the Wadden Sea should attend special courses on alien species.

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