International shipping – a risk for aquatic biodiversity in Germany

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Summary

Aquatic organisms have been moved around the world by humans for centuries. These aliens have led to a profound alteration of the diversity and structure of many biocoenoses, as the example of the introduction of non-indigenous species into German inland waters and coastal waters of the North and Baltic Sea shows. Here, up to now, 98 aquatic alien species from different taxonomic groups have established permanent populations. First data analyses show that German waters are colonized primarily by alien animal species partly on a considerable scale. About every second species has spread successfully across a larger area yet, about every fifth species can be defined as invasive.

International shipping represents the most important introduction vector of aquatic alien species in Germany. Next to intercontinental ocean shipping, it is also the canals built for inland shipping during the last centuries, that have removed the natural distribution barriers between previously geographically isolated river and sea basins.

Biological invasions in our waters take place in most parts in a hidden manner and therefore are registered only sporadically. There is no indication that these alien species will ever leave Germany again. And, it is highly probable that in the near future new alien species will arrive in our waters. The ecological consequences which arise for the biocoenoses as well as the scale on which the biodiversity is modified is not analyzed, understood or evaluated in detail yet. For a successful implementation of the Convention on Biological Diversity in Germany expertise, comprehensive knowledge and purposeful analyses are urgently needed. Alien species are still a challenge to act and the prevention of further arrivals is the decisive step to take.

Key words: aliens, inland waters, North Sea, Baltic Sea, introduction vectors, management, biosecurity, nature conservation

1. Introduction

Natural barriers such as oceans, mountains, rivers, and deserts that allowed the intricate coevolution of species and the development of unique ecosystems have been breached over the past five centuries by rapidly accelerating human trade and travel. Planes, ships, and other forms of modern transport have allowed both deliberate and inadvertent movement of alien species between different parts of the globe, often resulting in unexpected and sometimes disastrous consequences. Thus, the human-aided spread of species beyond their natural range is a significant form of global change and a major threat to biodiversity. In this connection alien species are considered the most important cause of extinction of animal species on a global scale since the end of the 16th century (Groombridge 1992).

The Convention on Biological Diversity (CBD 1992) calls upon each Contracting Party to prevent, as far as possible and as appropriate, the introduction of, control or eradication of those alien species which threaten ecosystems, habitats or species. To fulfill these commitments, the risk potential for various vectors of introduction, the occurrence and the distribution of alien species as well as the alterations and the consequences caused, must be understood first. A comprehensive analysis of these items is a basic requirement for management strategies regarding alien species.

On the basis of all German aquatic ecosystems (inland waters, North and Baltic Sea coasts), the current state of knowledge on established alien species and the overall importance of different human-mediated vectors for their introduction is evaluated. Following these findings, the need for action and possible measures for a successful implementation of the Convention on Biological Diversity in Germany is elaborated.

2. Aquatic aliens in German waters

The number of alien taxa assumed to have been estabilshed in German waters recently amounts to about 98 species (Appendix). The majority of aliens are benthic macroinvertebrates (60), primarily crustaceans, molluscs, polychaetes and hydroids. Introduced macrophytes comprise of 14 taxa, mostly macroalgae and waterweeds. Among vertebrates, fishes are the dominant group, at least eight species have settled. Many of the alien species are at least locally abundant and about every second alien species has spread successfully across a larger area yet. However, between the three German aquatic ecosystems (inland waters, North and Baltic Sea coasts) major natural hydrographical and topograhical differences exit, which is also reflected in a distinct occurrence of the alien species. Several alien species have become established in inland and coastal waters, because they can adapt to a wide range of salinities including freshwater (e.g. the Caspian zebra mussel *Dreissena polymorpha* and the Chinese mitten crab *Eriocheir sinensis*). While many species seem to remain insignificant additions to the native biota, about every fifth species can be defined as invasive (Appendix). Invasive alien species threaten ecosystems, habitats or species with economic or environmental harm and represent a significant risk of the wholesale homogenisation of ecosystems. Invasive alien species are now considered to be the second cause of global biodiversity loss after direct habitat destruction (CBD 2000).

2.1 Inland waters

At least 62 species are recognized as established aliens in the freshwater environment of Germany. In the ecologically important group of phytoplankton no alien species could be observed yet. For several years, however, *Cylindrospermopsis raciborskii*, a toxic freshwater cyanobacterium of tropical origin, is increasingly found in Germany and in other temperate regions (Mischke 2001). This species shows a distinct distribution pattern and occurs mainly in non-interconnected lakes, ponds and reservoirs. Therefore, it is very likely that *C. raciborskii*, which can develop spore-like dormant forms (akinetes), has reached new areas with the assistance of migratory birds as natural vector (attached to feet or feathers or by internal transport in the digestive system) as it is reported for several other planktonic species (Nehring 1998). Taking into account that its human mediated introduction is unlikely, at present *C. raciborskii* can not be regarded as alien. Information about the occurrence of introduced higher freshwater plants are rare. Currently, six alien species are considered as established. Two of them, the invasive North-American waterweeds *Elodea canadensis* and *E. nuttallii*, are wideley distributed and are found primarily and frequently with nuisance densities in standing waters and in slow flowing creeks and rivers (Kowarik 2003). Among the zooplankton, various "exotic" *Daphnia* species have been observed during the last decades, however, no information on their present distribution and current status of establishment in the area is available. Doubts have been raised about their status as alien species, also. The majority of aliens in German freshwater environments are invertebrates. According to Tittizer et al. (2000), 35 macrozoobenthic species are of allochthonous origin in federal waterways. Additionally, some other alien invertebrate species are found in inland waters (a.o. Geitler et al. 2002), of which seven species have established permanent populations. The most important molluscan invader is the the Caspian zebra mussel *Dreissena polymorpha*. In Germany this invasive species lives in lakes, dam reservoirs and large rivers, as well as in brakkish water bodies connected to the North and Baltic Sea. Increasing water pollution in the mid-20th century strongly reduced *Dreissena* populations. The continuous improvement of water quality since the 1980s has allowed the populations to recover; they nowadays have again attained densities of up to 40,000 individuals per m^2 (Böhmer et al. 2001). Native mussels belonging to the genera *Unio* and *Anodonta*, of which some are listed in German Red Lists, are co-opted by zebra mussels as hard subrate for successful settlement. Those mussels that serve as "hosts" for *Dreissena* are effectively starved, because undisturbed filter feeding is no longer possible (Böhmer et al. 2001). In scientific literature about 26 alien fish species were recorded, for which natural reproduction could not be excluded. However, most of these freshwater species have a questionable invasion status. Only eight fish species are considered as aliens, which occur in self-sustaining populations (Geitler et al. 2002; Kowarik 2003). Most of these species have a limited distribution and do not seem to expand their ranges. But two alien fish species are widespread and known to colonise new habitats by active migration. One example is the North American rainbow trout *Oncorhynchus mykiss*, which has been released into open waterbodies for commercial purposes since the end of the 19th century (Geitler et al. 2002). Various reports of exotic amphibians in freshwaters, being intentionally released by their owners are known. Due to climatic conditions they have no chance to establish permanent populations in Germany yet. However, a first exception to the rule is the bullfrog *Rana catesbeiana*, imported from America as a faunistic addition in private garden ponds and aquaria. For several years this invasive species reproduced successfully in natural ponds and lakes nearby Karlsruhe (LfU 2001). There is a serious risk that native species (a.o. crabs, snails, fish, amphibians) will be displaced by bullfrogs throughout Germany, if this invasive species continue to spread. Therefore every year control measures are conducted to combat the spread of the population nearby Karlsruhe (Reinhardt et al. 2003). Several parasite species are reported as introduced by human activities to German freshwaters, of which five are assumed to be established. The introduced invasive parasitic fungus *Aphanomyces astaci* causes the crayfish plague, which has contributed to the decimation of indigenous crayfish species. The remaining four parasites are associated with fish, e.g. the invasive swim-bladder nematode *Anguillicola crassa*, imported with infected eels from Asia in the 1980s and which occur in the European eel with an infection rate up to 90 % today (Geitler et al. 2002).

2.2 North Sea coast

At the German North Sea coast, along with the Wadden Sea and several estuaries, a total of 43 established alien species are known. Seven alien species belong to the phytoplankton, whereby some of them form mass occurrences every year (e.g. the invasive Indopacific diatom *Coscinodiscus wailesii*), some others are regarded as potentially toxic (e.g. the invasive Pacific flagellat *Fibrocapsa japonica*) (Nehring 2001). The occurrence of alien macroalgae is mainly restricted to the rocky shores of the island of Heligoland. Here six introduced species are recorded which also settle partially in low abundances in adjacent sea areas (Nehring 2001). The invasive cord-grass *Spartina anglica*, a fertile hybrid of *S. maritima* and *S. alterniflora*, was introduced into the Wadden Sea in the 1920s to promote sediment accretion. Recently it is a widespread species and grows as a pioneer plant in the tidal zone, where it displaces several native plants (e.g. the glasswort *Salicornia stricta*) and their associated benthic invertebrate species (Reise et al. in press). Only one species of zooplankton (the pacific copepod *Acartia tonsa*) is among the assumed aliens of the German North Sea coast. Recent summaries of introduced species revealed about 27 alien macrozoobenthic species occurring in the area today (Nehring & Leuchs 1999, 2000; Reise et al. 2002). The share of alien macrozoobenthos species increases from the offshore part towards the coast, and there it increases further on from the open coast towards the estauries. In the latter, the percentage of alien species compared to the total number of macrozoobenthic species amounts to 20 (Nehring in press). Several alien species attain locally high abundances (e.g. the American razor clam *Ensis americanus*), however, significant interactions with native species have only been recorded from small areas yet (Reise et al. 2002). The alien barnacle *Elminius modestus* is capable of marked habitat alteration through the construction of dense crusts on hard surfaces. This overgrowth and pre-emption of space dimish other epifaunal species such as the native barnacle *Balanus balanoides* (Nehring & Leuchs unpubl.). Before the arrival of the invasive Chinese mitten crab *Eriocheir sinensis* in European waters in 1912, no native brachyuran crab migrated between brackish and freshwater habitats. For most of its life *E. sinensis* lives in freshwater. During August adults crabs migrate seawards and gather in large swarms to bread in estuaries. In spring 1998, 850 kg of juveniles (ca. 75,000 crabs) were caught in the Elbe estuary by hand in two hours only (Gollasch et al. 1999). Juveniles and adults mitten crabs create burrows on the river banks that provide a refuge and protection from dessication. In areas where *E. sinensis* is particularly abundant, burrows can cause damages to banks and dykes and might affect flood defences (Gollasch et al. 1999). Up to now, no alien vertebrate species occur in self-sustaining populations on the German North Sea coast. Here, only single individuals of alien freshwater fish species were found occasionally. During the last decades several parasitic protozoans and copepodes have been found in mussels in North European coastal waters. They might have an exotic origin and were possibly introduced by human activities, however, their current status on the German North Sea coast is unkown (Nehring 2001). Only the parasitic swim-bladder nematode (see above) is observed in migrating European eels regulary.

2.3 Baltic Sea coast

In the Baltic Sea, the world's largest brackish-water sea area, only very few primary introductions of alien species are known. This is likely due to the fact that in the Baltic only minor aquaculture activities and intercontinental shipping are existent. The Baltic has been, and still is, subject to secondary introductions from both the North Sea area and adjacent inland waters. It is assumed that only 23 alien species have been able to establish permanent populations on the German Baltic coast yet. In ecologically important groups, such as phyto- and zooplankton, macrophytes as well as parasites, only one to three alien species were recorded (Nehring 2003a; Olenin et al. 2004). The majority of established aliens are invertebrates. Recently, 15 macrozoobenthic species have been identified as aliens in the coastal waters (Nehring 2000; Olenin et al. 2004). The invasive wood boring bivalve *Teredo navalis* was probably brought to Europe from East Asia several centuries ago and is now widespread in the southwestern Baltic region. This species has had major direct negative economic impacts in the Baltic. It caused approximately US$ 25 million damage to wooden installations between 1995 and 2001 along the German Baltic coast (Leppäkoski et al. 2002). The soft-bottom community structure was totally changed by the invasive polychaete *Marenzelleria* cf. *viridis* in nearshore waters when it became a dominant species on sandy and muddy habitats in the end of the 1980s. It reached high biomasses (400 g wet weight m^{-2}) and comprised up to 96 % of the total community biomass (Zettler 1997). It seems that only the planktonic copepod *Ameira divagans,* the macroalgae *Fucus evanescens* and the polychaete *Marenzelleria* cf. *viridis* were directly introduced by ocean shipping to the German Baltic Sea coast. The occurrence of all other alien species was faciliated by the construction of numerours canals on Ponto-Caspian rivers, which allow organisms to disperse to Central and West European river systems, which flow into the Baltic. Or they were at first introduced into the North Sea and arrived the German Baltic Sea coast via Danish Belts or Kiel Canal by active migration or by passive transport in water currents or by ships. Established populations of alien fishes or amphibians could not be observed here to the present day.

Table 1: Established alien species in German waters and their introduction vectors.

	intentional release	aquaculture	shipping: ocean shipping – hull	shipping: ocean shipping – ballast water	shipping: inland shipping/ canal
Phytoplankton	-	2	-	5	-
Macrophytes	7	6	1	-	-
Zooplankton	-	-	-	2	1
Macrozoobenthos	16	4	12	8	20
Fishes	8	-	-	-	-
Amphibian	1	-	-	-	-
Parasites	3	-	-	-	2
total	**35**	**12**	**51**		

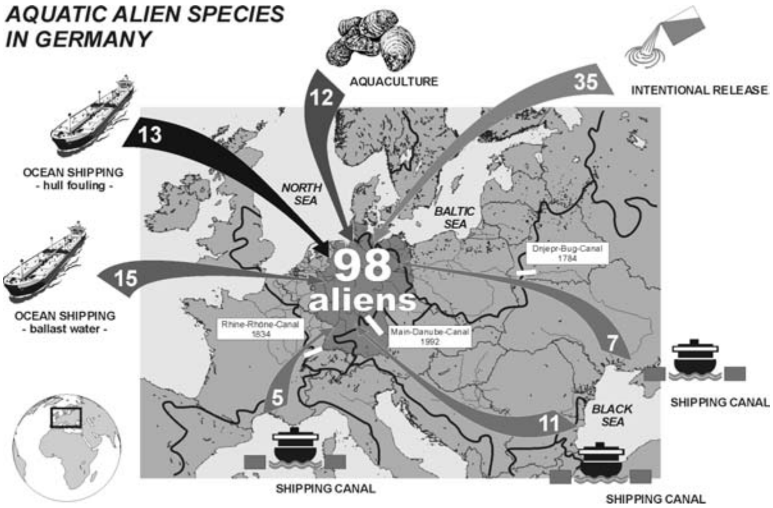

Fig. 1: Number of established alien species in German inland and coastal waters, known or probable introduction vectors, main watersheds, important shipping canals and their opening date.

3. Shipping – the most important introduction vector

Potential areas of origin for species which might become established in new regions, are characterised by comparable environmental conditions. Germany appertains to the boreal, the cold temperate climate zone. Similar environmental conditions can be found in the Ponto-Caspian area as well as on the coasts of South and North America, Japan, Tasmania and New Zealand. However, the long distance prevents an intensive natural exchange of species. Therefore, the majority of organisms from remote areas are dependent on human-mediated vectors, such as intentional release, aquaculture, and shipping (Fig. 1; Table 1).

Within Germany, 35 aquatic alien species are assumed to be intentional introduced, mainly in freshwater habitats. Among them are fishes and also some invertebrate species being stocked for fisheries (e.g. the invasive North American crayfish *Orconectes limosus*). Several invertebrate species were also introduced in creeks and rivers as potential fish food (e.g. the North American amphipod *Gammarus tigrinus*). Emptying of aquaria and the disposal of organisms from private garden ponds into lakes etc. appear to be important sources of introduction for water weeds and amphibians (Kowarik 2003).

The substantial imports of shellfish for aquaculture activities provided a suitable vector for attached macroalgae and their spores, for invertebrates as well as phytoplankton species. Since more than 100 years commercial shellfish transfers across the globe to Northern Europe are carried out (Wolff & Reise 2002). Eleven alien species are believed as being imported as associated organisms with American or Japanese oysters on the German North Sea coast yet. Since 1985 commercial farming activities started up with the invasive Pacific oyster *Crassostrea gigas* in the northern area of the Wadden Sea near the island of Sylt (Nehring 2003b). These oysters reproduced successfully, and in 1991 the first oysters were found outside the culture plot (Fig. 2). Spat settle on any hard substrate in the intertidal zone but preferentially upon wild banks of the

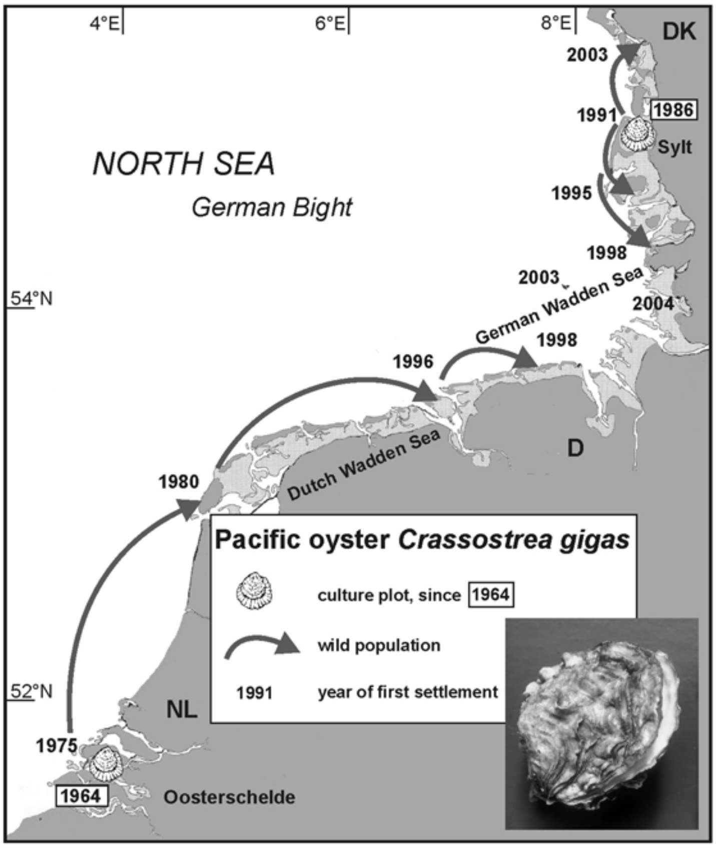

Fig. 2: The invasion of the invasive Pacific oyster *Crassostrea gigas* in the Wadden Sea (Main data source: Reise et al. in press).

native blue mussel *Mytilus edulis* (Reise 1998). Near Sylt development has locally advanced from solitary oysters to coherent reefs. These calcareous reefs are a completely new biogenic structure in the intertidal zone and it can be expected that *Crassostrea* will considerably change the biotic and abiotic characteristics of the Wadden Sea (Reise et al. in press).

International shipping represents the most important introduction vector of aquatic alien species in Germany. About half (52 %) of the 98 species introduced to German waters are associated with this acting mechanism. In the following chapters special attention is given to the main components associated with shipping: canals, ships' hull and ships' ballast water and sediments.

3.1 Canals

The natural barriers between the river and sea basins, as they had stabilised themselves in Europe since the end of the Pleistocene, were eliminated by the canals built during the last centuries. This enables mobile species as well as organisms that are transported by the drag force of water, by biovectors (particularly fishes) or by ships, to spread into new water systems.

The occurrence of 23 alien macrozoobenthic species and their area of expansion in German waters is facilitated primarily by the construction of canals. For instance: the early and frequent occurrence of Ponto-Caspian species in northern Europe (e.g. the invasive zebra mussel *Dreissena polymorpha*), the opening of the Dnjepr-Bug-Canal in 1784, which connects the Pripyat system to the rivers Bug and Vistula, was of crucial importance. After the opening of the Main-Danube Canal in Germany in 1992, connecting the Rhine and Danube basins, this southern corridor is today the most important link between the Ponto-Caspian area and Western Europe. Recently, several Ponto-Caspian species have been found increasingly in the German rivers Main and Rhine (e.g. the polychaete *Hypania invalida* and the isopod *Jaera istri*, Schöll & Banning 1996). In 1995 the Ponto-Caspian amphipod *Dikerogammarus villosus* arrived the river Main. Since then this new invader has dispersed over large distances in a short time and in 2000 first organisms were observed in the river Oder (Fig. 3). This dynamic geographic extension of *D. villo-*

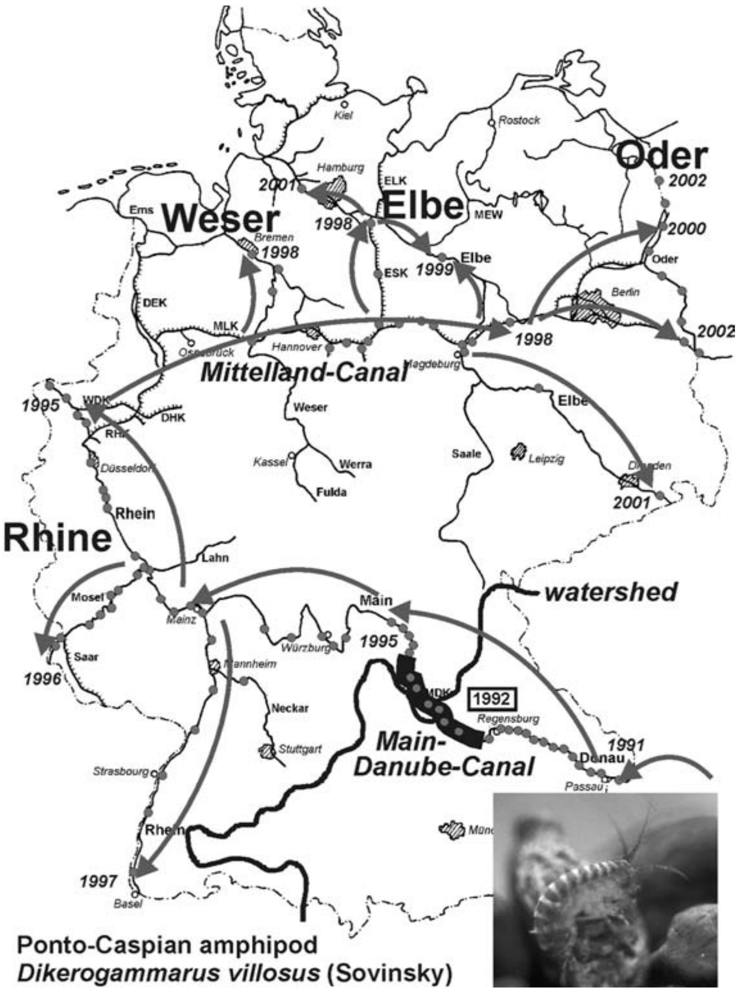

Fig. 3: Spreading of the invasive alien amphipod *Dikerogammarus villosus* in German waters (Main data source: Tittizer et al. 2000).

sus in Germany was fascilitated by the existence of several man-made canals in northern Germany (e.g. Mittelland-Canal), which creates artificial connections between all large river systems (Rhine, Weser, Elbe, Oder). The quickly increasing population density of this invasive amphipod has enabled it to become a major component of the macrobenthic assemblages in German freshwaters, eliminating both native and another alien amphipod species (Tittizer et al. 2000). Some species from the Rhine can also be found in the Danube now (e.g. the clam *Corbicula fluminalis*, Tittizer & Taxacher 1997).

The specific role of inland waterway shipping in the faunal exchange between Danube and Main was clarified by examining the macroinvertebrate colonisation of inland vessels (Reinhold & Tittizer 1999). Six alien species were found on hulls and in cooling water filters, but not in ballast water. These investigations show clearly that the passive transport on ships' hulls represents an important vector for limnic macroinvertebrate aliens (Reinhold & Tittizer 1999).

More Ponto-Caspian species, mainly invertebrates and fishes, are expected to migrate into the North Sea basin via the Main-Danube-Canal within the following years, especially those species that have already been observed in the upper and middle Danube. To reduce the uncontrolled range extensions of alien species by the interconnection of river and sea basins through canals, existing and future constructions, the installation of migration barriers of species (deterrent electrical systems, salt water basins etc.) should be considered.

3.2 Ships' hull

Ships are capable of carrying a wide range of sessile species, their epibionts and paraites on their hulls. Prior to the introduction and widespread use of anti-fouling paints containing Tributyltin (TBT) about one half of the alien animal species introduced into German coastal waters came from fouled hulls of oversea trade ships. With the introduction of the effective biocide TBT in 1970, there has been a reduction of fouled hulls, considerably reducing the introduction of organisms via ship fouling (Nehring 2001). Since then the discussion on the role of ballast water as the important carrier of organisms from overseas has increased (e.g. Carlton 1985; Minchin & Sheehan 1995; Gollasch 2002). However, for the North Sea the vectors ballast water and ship hulls have equivalent importance since 1970 (Nehring 2001). This is probably based on the fact that fouling still occurs today, especially in situations where anti-fouling paint is damaged, difficult to apply, or otherwise ineffective (Fig. 4). And, due to the recent discussion on the ecological effects of harmful biocides and their ban in antifoulants (IMO 1999), the pathway of invasive species introductions via ship fouling can attain a new dimension.

Alternative ship coatings showed that in general fouling is more intensive on these materials than on TBT-containing paints (Watermann et al. 1999a). However, fouling on the alternative products is not as strong as on completely untreated ship hulls and can usually be removed easily. In some cases, it has even been observed that organisms having grown to a certain size on the silicone coating were removed by the water currents in dependence on the speed of the ship. A striking finding was that the two barnacles *Balanus improvisus* and *Elminius modestus*, which had been introduced in former times in the fouling of ships from overseas into the North Sea, occurred in high abundances on the biocide-free coatings. In quantitative terms, *Elminius* ranked in a top position (Watermann et al. 1999a).

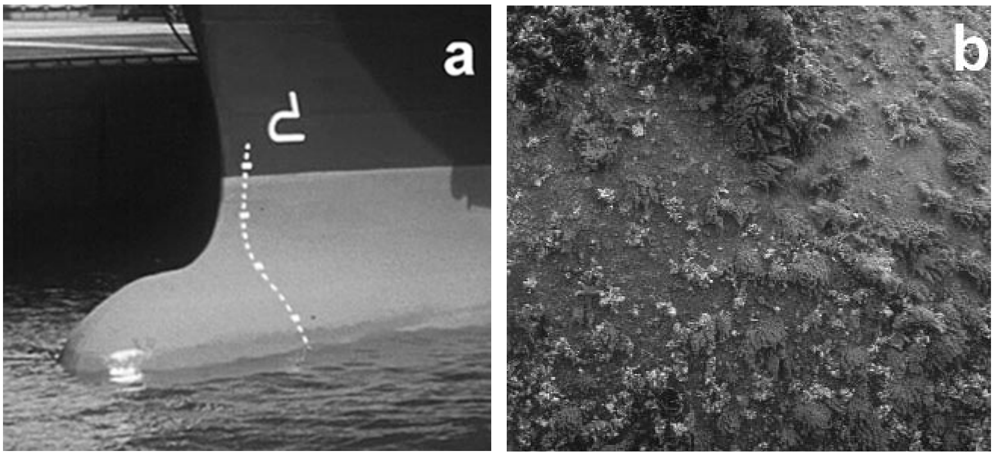

Fig. 4a-b: Ships' hull: a) with effective anti-fouling paint containing Tributyltin, b) with ineffective anti-fouling paint and typical clusters of hydroids, barnacles, serpulid worms, and colonies of bryozoa.

However, these facts have received little attention so far, although they show that increasing introduction of alien animal and plant species into North Sea coastal waters by intercontinental shipping has to be expected if the anti-fouling effectiveness of TBT-free alternatives is lower than in conventional organotin anti-fouling paints (Nehring 2001). Especially the biocide-free silicone coatings, from which fouling growth is easily removable, have an extraordinary high potential for the introduction of alien species. Up to 90 % of the organisms on the silicone coating were directly removed through the water current depending on the speed of the ship (Watermann et al. 1999b). In spite of this "cleaning effect", a silicone coating is about 50 % less efficient compared to TBT paints (Nehring 2001). Consequently, this ecological problem will continue to grow because above all, silicone will be painted on FastFerries, cruise vessels and other high-speed ship types with wide operating ranges in the future. The survival of the organisms in the fouling will indeed increase noticeably when they are transported faster to their new potential colonization areas. In addition, as organotins become replaced by environmentally less toxic paint coatings, coastal areas will become less contaminated by organotins. Such conditions may promote the effectiveness of alien species inoculations (Nehring 2001).

Also the biocide-free mechanically resistant coating of ship hulls will lead to an increasing transportation of fouling species. A crucial precondition for the regular mechanical underwater hull cleaning is the reliable collection and environmentally compatible disposal of the brushed-off biofouling, which is not functional yet. If the removed organisms sink to the bottom of the sea floor several species may survive and successfully establish new populations. Hull cleaning may also encourage the release of spores, cysts and gametes from crushed organisms. Certainly, a controlled disposal of the biofouling can not stop the introduction of alien species, but would probably minimize it.

3.3 Ships' ballast water and sediments

Ballast water has been used since the 1870s to stabilise and trim the vessel and to submerge the propeller when ships are not fully loaded. With the intake of ballast water, organisms and sediments suspended in the water are pumped on board into the ballast tanks. Typically some 30-40 % of ship deadweight tonnage can be carried as ballast water, although ballast capacities on a large bulk carrier may be as much as 60 % of deadweight tonnage. The amount of sediment can reach several hundred tons. The maximum thikkness of sediment known to be transported in ballast tanks was more than 50 cm (Gollasch 1996). Whereas the ballast water favours mainly pelagic species, the sediment hosts ground-dwelling species and increases the number of transported species. If the ballast water is discharged, parts of the sediment and organisms, which survived the cruise will also be discharged. It has been demonstrated that up to 4,000 pelagic and benthic species are transported between continents by ships each day (Gollasch 1996). Each species discharged with ballast water outside their native range has the potential to establish a self-sustaining population, coupled with all ecological and economical consequences. Recent calculations of Gollasch (1996) on the individual entry through ballast water discharges from overseas areas into the ports on the German North Sea coast revealed that 2.7 million individuals are released daily.

However, despite the mass release of alien organisms through ballast water, only 15 established species in German waters were attributed to this introduction vector (Table 1). This is due to the fact that a number of individual factors, primarily related to the biological characteristics of the species and the environmental conditions in the new region, such as temperature, salinity, nutrients, availability of food or native competitors, regulates successful establishment. Nevertheless, as each introduced species poses the potential of unwanted and uncontrollable consequences, their introduction as well as their spreading should be minimized wherever possible.

It is apparent that no single or simple universal solution for shipboard treatment or management to prevent the transfer of viable alien organisms in ballast water and sediments presently exists. Currently, heat treatment, mechanical removal of organisms in combination with UV treatment, and chemical treatment of ballast water are considered the most promising approaches (Taylor et al. 2003). In the meantime some countries, such as Australia, have introduced national ballast water regulations. Given the global nature of shipping, the need for the implementation of an international binding and effective act is obvious. An important measure is the new guideline of the International Maritime Organization on minimizing current risks and side effect to the environment and human health arising from the transfer of species in ships' ballast water and sediments, which was actually adopted as a convention by IMO member States (IMO 2004). The implementation of this new convention will significantly minimize the unintentional introduction of aquatic species, however, a comprehensive prediction of future introductions is impossible. In addition, shipping activities have increased over the past decades with no end in sight and with corresponding increases of amounts of transported and released ballast water. The port of Hamburg has the greatest growth rates among the most important sea ports of Northern Europe today. And up to 2015 a doubling of goods traffic is expected for this biggest German port (PoH 2004). Secondly, the duration of ship voyages will decrease due to technical improvements resulting in faster ships, and consequently will increase survival of organisms transported in ballast tanks. Thirdly, the increasing trade by ships enforced the construction of new ports, as the plannings for the new big German sea port Jade-Weser show, causing additional introductions of species and/or introductions from new regions.

4. Aliens and aquatic biodiversity

The global scale of alien species is becoming more and more evident. As many examples prove, aquatic invasions are irreversible and alien species may be associated with unforeseeable ecological as well as economical risks (e.g. Carlton 1985; Bartley & Minchin 1996; Reise et al. 2002). Even against the background that continuous climate change will probably influence the biocoenosis of North European coastal waters much stronger (Nehring in press), the introduction of alien species enhances the trend of global unification of flora and fauna associated with an irretrievable loss in biodiversity. Today the spread of alien species is now recognised as one of the greatest threats to the ecological and economical well being of the planet. However, impacts caused by aquatic alien species have been documented only for a few species in German waters (see above). Until today scientific interest in alien species is mostly descriptive (e.g., documentation of invasion history, studies on distribution pattern, and abundance assessment; Nehring 2000, Reise et al. 2002, Tittizer et al. 2000). The functional role of these species in aquatic ecosystems and their realized niches in the invaded communities remains to be quantified. In many cases the alien species represent a.o. a new function (e.g., the Chinese mitten crab *Eriocheir sinensis* and its reproduction strategy, see above) or an entirely new habitat type (e.g., the Pacific oyster *Crassostrea gigas* and its reefs, see above) and will thus restructure the community into which they were introduced. Mainly by larval and postlarval drifting as well as by transport on ships' hulls many alien species rapidly extended their distribution, often more than 100 km per year. On basis of this rate of spread studies on local effects often require knowledge of population dynamics on a scale of several hundred kilometers to differentiate the local phenomena from general trends.

In spite of the insufficient scientific analyses until now, it becomes clear that alien species have become dominant members of several food webs in German inland waters, on the North and Baltic Sea coasts. Alien species are able to modify abiotic and biotic conditions for other species, alter composition of both pelagic and benthic communities, and affect organic matter and energy transfer pathways in a variety of food webs, thus acting as habitat and ecosystem engineers. For all that, there is no evidence that alien species have caused the extinction of natives in German waters to date. Furthermore there is no indication that not one established alien species will ever leave Germany again. So the net effect of alien invasions is generally a regional increase in species richness. And, it is highly probable that in the near future new alien species will arrive in our waters. However, the ecological consequences which arise for the biocoenoses as well as the scale on which the biodiversity is modified is not analyzed, understood or evaluated in detail yet. As species introductions are irreversible the extension of their distribution area and increase in abundance is an ongoing process. Therefore, further changes in the ecosystems of German waters and a growing biotic similarity with other regions can be expected. It looks very much that the unique character of German aquatic habitats would still be manifest in the physical environment but not any more in their living components if the problem of alien invasions cannot be solved.

To protect the ecological integrity of our waters, a purposeful management strategy need to be supported. Depending on the alien species of concern, management efforts should be targeted into one of the four categories: (a) acceptence of established non-invasive species; (b) prevention of introductions through enlightenment and regulations; (c) monitoring of occurrence, impacts and spread by monitoring programmes; and (d) minimization of impacts by eradication or control (Nehring & Klingenstein in press). In principle, every action should be based on an individual case decision. The initial step in a management programme must be to distinguish the harmful from the harmless alien species and identify the impacts of the former. However, in aquatic environments we are often faced with the impact at a very late stage when the species might have been there for several generations and already spread their offspring to other areas. Thus, it is almost hopeless to find an efficient method to eradicate aquatic alien species once they have become established. Once the establishment of an alien species is accepted as irreversible, unwanted species can be controlled by reducing density and abundance to keep their impact to an acceptable level. To protect natural biodiversity, however, prevention of further arrivals is the decisive step to take and thus a cruical issue for an international biosecurity strategy.

The need for measures related to alien species has been acknowledged in different sectors since the 1950s. More than fifty international and regional conventions, codes of conduct and other instruments now deal with alien species (for review see SCBD 2001). The Convention on Biological Diversity, currently ratified by over 170 States, is the only globally applicable, legally binding instrument to address generally alien species introduction, control and eradication across all biological taxa and ecosystems (CDB 1992). However, all of these measures lack of extensive efficiency and the rate of alien introductions has clearly increased during the last two decades, with no end in sight. And, up to now no relevant activities centre on the prevention of alien introductions through ship hulls and shipping canals. Thus, alien species are still a challenge to act and new and innovative strategies and actions must be developed.

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APPENDIX

List of established alien species in inland waters and on the North and Baltic Sea coasts of Germany. Origin – known or probable area of origin; Vector – known or probable vector of introduction; Date – year of the first record, or probable time of introduction, in German waters; Distribution – occurring at one or a few localities (+), in part of the area (++), throughout the area (+++); Status – an invasive alien species which threatens ecosystems, habitats or species (X); Key references: (1) Geitler et al. 2002, (2) Kowarik 2003, (3) Nehring 2000, (4) Nehring 2001, (5) Nehring & Leuchs 2000, (6) Nehring unpubl., (7) Olenin et al. 2004, (8) Reise et al. 2002, (9) Reise et al. in press, (10) Tittizer et al. 2000.

	Taxon	Origin	Vector	Date	Distribution: inland waters	Distribution: North Sea coast	Distribution: Baltic Sea coast	Status	Reference
	PHYTOPLANKTON								
	Dinophyceae								
1	*Gymnodinium mikimotoi* Miyake & Kominami	Pacific	ocean shipping - ballast water	1966		+++			4, 8
	Raphidophyceae								
2	*Chattonella antiqua* Ono	? Pacific	ocean shipping - ballast water	1991		++			4
3	*Chattonella marina* Hara & Chihara	? Pacific	ocean shipping - ballast water	1991		++			4
4	*Fibrocapsa japonica* Toriumi & Takano	? Pacific	ocean shipping - ballast water	1991		+++		X	4, 8
	Bacillariophyceae								
5	*Coscinodiscus wailesii* Gran & Angst	Indo-Pacific	aquaculture product	1977		+++	++	X	4, 8
6	*Odontella (Biddulphia) sinensis* Grunow	Indo-Pacific	ocean shipping - ballast water	1903		+++	++		4, 8
7	*Thalassiosira punctigera* Hasle	Indo-Pacific	aquaculture product	1978		+++	++		4, 8
	sum				0	7	3		
	MACROPHYTES								
	Spermatophyta								
	Crassulaceae								
8	*Crassula helmsii* Cockayne	Australia	release	1990s	+				2
	Hydro-charitaceae								
9	*Elodea canadensis* Michaux	N America	release	1859	+++			X	2
10	*Elodea nuttallii* St. John	N America	release	1953	+++			X	2
	Lemnaceae								
11	*Lemna minuscola* Herter	N America	release	1983	++				2
12	*Lemna turionifera* Lanolt	N America	release	1965	++				2
	Haloragaceae								
13	*Myriophyllum heterophyllum* Michaux	N America	release	1962	+				2
	Poaceae								
14	*Spartina anglica* Hubbard [hybrid]	W Atlantic	release	1920s		+++		X	4, 9
	Macroalgae								
	Phaeophyceae								
15	*Colpomenia peregrina* Hamel	Pacific	aquaculture product	1905		+			4
16	*Fucus evanescens* C. Agardh	N Pacific	ocean shipping - hull	1924			+		7
17	*Sargassum muticum* Fensholt	N Pacific	aquaculture product	1988		++		X	4, 9
	Rhodophyceae								
18	*Bonnemaisonia hamifera* Hariot	N Pacific	aquaculture product	1959		+			4, 8
19	*Dasya baillouviana* Montagne	W Atlantic	aquaculture product	1960s		+			4, 8
20	*Polysiphonia harveyi* Bailey	N Pacific	aquaculture product	1960s		+			4, 8
	Chlorophyceae								
21	*Codium fragile* ssp. *tomentosoides* Silva	N Pacific	aquaculture product	1930		+			4, 8
	sum				6	7	1		

	Taxon	Origin	Vector	Date	Distribution inland waters	North Sea coast	Baltic Sea coast	Status	Reference
	ZOOPLANKTON								
	Crustacea								
22	*Acartia tonsa* Dana	Pacific / W Atlantic	ocean shipping - ballast water	1925		+++	+++		4, 7
23	*Ameira divagans* Nicholls	W Atlantic	ocean shipping - ballast water	1970s			++		7
24	*Cercopagis pengoi* (Ostroumov)	Ponto -Caspian	shipping canal and inland vessels	2002			+		7
sum					0	1	3		
	MACROZOOBENTHOS								
	Porifera								
25	*Eunapius carteri* (Bowerbank)	Africa / Asia	release	1993	+				10
	Hydrozoa								
26	*Bimeria franciscana* (Torrey)	? Indo-Pacific	ocean shipping - hull	1952		+			4
27	*Cordylophora caspia* (Pallas)	Ponto-Caspian	shipping canal and inland vessels	1858	+++	++	++		3, 4, 10
28	*Craspedacustra sowerbyi* Lankester	E Asia	release	1923	++				10
29	*Nemopsis bachei* Agassiz	W Atlantic	ocean shipping - hull	1942		+			4
	Anthozoa								
30	*Diadumene cincta* (Stephenson)	Pacific	aquaculture product	1928		+			4
	Bivalvia								
31	*Congeria leucophaeta* (Conrad)	E Atlantic	ocean shipping - hull	1928	+	+	+		4, 7, 10
32	*Corbicula fluminalis* (O.F. Müller)	E Asia	ocean shipping - ballast water	1984	++	++		X	4, 10
33	Corbicula fluminea (O.F. Müller)	Asia	ocean shipping - ballast water	1987	++			X	10
34	*Crassostrea gigas* (Thunberg)	Pacific	aquaculture product	1991		+++		X	4, 9
35	*Dreissena polymorpha* (Pallas)	Ponto-Caspian	shipping canal and inland vessels	1828	+++	+	++	X	3, 4, 10
36	*Ensis americanus* (Binney)	W Atlantic	ocean shipping - ballast water	1979		+++	++	X	3, 4, 9
37	*Mya arenaria* (Linnaeus)	W Atlantic	release (?)	<1800		+++	+++		3, 4
38	*Petricola pholadiformis* Lamarck	W Atlantic	aquaculture product	1896		+++	+		3, 4
39	*Teredo navalis* Linnaeus	Indo-Pacific	ocean shipping - hull	<1800		+	++	X	7, 8
40	*Unio mancus* Lamarck	S Europe	shipping canal and inland vessels	before 1922	+				10
	Gastropoda								
41	*Crepidula fornicata* (Linnaeus)	W Atlantic	aquaculture product	1934		+++			4, 9
42	*Gyraulus parvus* (Say)	N America	release	1981	+				1
43	*Lithoglyphus naticoides* (C. Pfeiffer)	E Europe	shipping canal and inland vessels	1883	++				10
44	*Menetus dilatatus* (Gould)	N America	release	1980	+				1
45	*Physella acuta* (Draparnaud)	SW Europe	release	1895	+++				10
46	*Physella heterostropha* (Say)	N America	release	before 1927	+				10
47	*Planorbella duryi* (Weatherby)	N America	release	1980s	+				1
48	*Potamopyrgus antipodarum* (Gray)	S Pacific	ocean shipping - ballast water	1900	+++	++	++		3, 4, 10
	Platyhelminthes								
49	*Dendrocoelum romanodanubiale* (Codreanu)	Ponto-Caspian	shipping canal and inland vessels	1992	+				10
50	*Dugesia tigrina* (Girard)	N America	release	1931	+++				10
	Kamptozoa								
51	*Urnatella gracilis* Leidy	N America	ocean shipping - ballast water	1960	+				1

	Taxon	Origin	Vector	Date	Distribution inland waters	North Sea coast	Baltic Sea coast	Status	Reference
	Oligochaeta								
52	*Branchiura sowerbyi* (Beddard)	S Asia	release	1959	++				10
	Polychaeta								
53	*Ficopomatus enigmaticus* (Fauvel)	S Pacific	ocean shipping - hull	1975		+			4, 5
54	*Hypania invalida* (Grube)	Ponto-Caspian	shipping canal and inland vessels	1995	++				10
55	*Marenzelleria* cf. *viridis* (Verrill)	W Atlantic	ocean shipping - ballast water	1985		++	+++	X	3, 4
56	*Marenzelleria* cf. *wireni* Augener	N Atlantic	ocean shipping - ballast water	1983		++		X	4, 5
	Crustacea								
57	*Astacus leptodactylus* Eschscholtz	Ponto-Caspian	release	1910s	++				1
58	*Atyaëphyra desmaresti* Millet	Mediterranean	shipping canal	1932	++				10
59	*Balanus improvisus* Darwin	W Atlantic	ocean shipping - hull	1858		+++	+++		3, 4
60	*Corophium curvispinum* Sars	Ponto-Caspian	shipping canal and inland vessels	1912	+++	+	+	X	3, 4, 10
61	*Corophium robustum* Sars	Ponto-Caspian	shipping canal and inland vessels	2000	+				6
62	*Corophium sextonae* Crawford	S Pacific	ocean shipping - hull	1997		+			4
63	*Crangonyx pseudogracilis* Bousfield	N America	release	1992	+				10
64	*Dikerogammarus haemobaphes* Eichwald	Ponto-Caspian	shipping canal and inland vessels	1993	++				10
65	*Dikerogammarus villosus* (Sovinsky)	Ponto-Caspian	shipping canal and inland vessels	1995	++			X	10
66	*Echinogammarus berilloni* (Catta)	Mediter-ranean	shipping canal and inland vessels	1924	+				10
67	*Echinogammarus ischnus* Stebbing	Ponto-Caspian	shipping canal and inland vessels	1977	++				10
68	*Echinogammarus trichiatus* (Martynov)	Ponto-Caspian	shipping canal and inland vessels	2000	+				10
69	*Elminius modestus* Darwin	S Pacific	ocean shipping - hull	1953		+++			4, 8
70	*Eriocheir sinensis* Milne-Edwards	N Pacific	ocean shipping - ballast water	1912	+++	++	++	X	3, 4, 10
71	*Gammarus tigrinus* Sexton	W Atlantic	release	1957	+++	++	+		3, 4, 10
72	*Hemimysis anomala* Sars	Ponto-Caspian	shipping canal	1997	+				10
73	*Jaera istri* Veuille	Ponto-Caspian	shipping canal and inland vessels	1995	++				10
74	*Limnomysis benedeni* Czerniavsky	Ponto-Caspian	shipping canal	1997	+				10
75	*Orconectes limosus* (Rafinesque)	N America	release	1880	+++			X	10
76	*Pacifastacus leniusculus* Dana	N America	release	1980s	+				1
77	*Pontogammarus robustoides* (Sars)	Ponto-Caspian	shipping canal and inland vessels	1994	+		+		3, 10
78	*Proasellus coxalis* (Dollfus)	Mediter-ranean	shipping canal and inland vessels	about 1931	++	+			4, 10
79	*Proasellus meridianus* (Racovitza)	W Europe	shipping canal and inland vessels	about 1930	++				10
80	*Procambarus clarkii* (Girard)	N America	release	1990s	+				1
81	*Rhithropanopeus harrisii* (Gould)	W Atlantic	ocean shipping - hull	1936		++	++		3, 4
	Bryozoa								
82	*Pectinatella magnifica* Leidy	N America	ocean shipping - hull	1883	+				10
83	*Victorella pavida* Saville-Kent	? Indo-Pacific	ocean shipping - hull	1951		+			4, 5
	Ascidiacea								
84	*Styela clava* Herdman	N Pacific	ocean shipping - hull	1997		+			4
	sum				42	27	15		

	Taxon	Origin	Vector	Date	Distribution inland waters	North Sea coast	Baltic Sea coast	Status	Reference
	FISHES								
85	*Lepomis cyanellus* Rafinesque	N America	release	1965	+				1
86	*Lepomis gibbosus* Linnaeus	N America	release	1880	+++				2
87	*Ictalurus melas* (Rafinesque)	N America	release	1990s	++				2
88	*Ictalurus nebulosus* Lesueur	N America	release	1885	++				2
89	*Pseudorasbora parva* Bleeker	E Asia	release	1984	+				2
90	*Oncorhynchus mykiss* (Walbaum)	N America	release	1882	+++				1
91	*Salvelinus fontinalis* (Mitchill)	NE America	release	1890	++				2
92	*Umbra pygmaea* (DeKay)	N America	release	1910s	++				2
sum					8	0	0		
	AMPHIBIAN								
	Anura								
93	*Rana catesbeiana* Shaw	N America	release	1990s	+			X	1
sum					1	0	0		
	PARASITES								
	Oomycota								
94	*Aphanomyces astaci* Schikora	N America	release	1878	+++			X	1
	Nematoda								
95	*Anguillicola crassus* Kuwahara et al.	E Asia	release	1982	+++	+++	+++	X	1, 4, 7
	Annelida								
96	*Barbronia weberi* Blanchard	S Asia	release	1994	+				10
97	*Caspiobdella fadejewi* Epstein	Ponto-Caspian	shipping canal	1990s	+				10
98	*Piscicola haranti* Jarry	Ponto-Caspian	shipping canal	1990s	+				10
sum					5	1	1		
Total number					**62**	**43**	**23**		