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Research article

National checklist for aquatic alien species in Germany

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Abstract

More than 140 aquatic alien species (AAS) have been reported from coastlines of the North Sea and the Baltic Sea and from inland waters within the national borders of Germany. The majority of these species has established self-sustaining populations. The most important vectors of introduction are shipping, species imports for aquaculture purposes and species imports as part of the ornamental trade. Several AAS have reached German waters via shipping canals. Many species show a locally limited distribution, but almost half of all AAS have spread successfully across larger areas. Several introduced species are abundant and approximately 20 % of all AAS in Germany can be considered as invasive. Prime source regions are the north-western Atlantic, the Indo-Pacific, and the Ponto-Caspian region. For all source regions considered, the invasion rate has been increasing since the end of the last century.

Key words: Germany, North Sea, Baltic Sea, inland waters, aquatic species introductions, shipping, aquaculture, population status, invasive

Introduction

Invasive alien species may threaten native species, alter habitats, and even affect ecosystem function (e.g. Eno et al. 1997, Nehring and Leuchs 1999, Wolff 2005), and thus represent a significant risk to the receiving environments. Following direct habitat destruction, invasive alien species are considered as the second most important cause of global biodiversity change (CBD 2000).

One of the first summaries of aquatic invaders in German coastal waters was prepared by Gollasch (1996). In 1997 Eno et al. published a summary of coastal aquatic alien species in the United Kingdom. Nehring and Leuchs (1999), Nehring (2000a), and Tittizer et al. (2000) published overviews on "neozoans" of the German macroinvertebrate fauna. In 1999, Reise et al. published a summary of invasive species in the North Sea and several regional updates were published thereafter: e.g. Weidema (2000) for Nordic countries, Nehring (2005) and AeT umweltplanung (2006) for Germany, Jensen and Knudsen (2005) for Denmark and Wolff (2005) for The Netherlands. In 2006 Gollasch published an overview on introduced aquatic species known from European coasts. Here we update the earlier summaries of alien species in German inland and coastal waters. Another data set of aquatic invaders, which contains more comprehensive information for each species listed, is prepared by the authors for the currently ongoing EU-Programme Delivering Alien Invasive Species Inventories for Europe (DAISIE, see http://www.daisie.se for details).

Aquatic alien species (AAS) in Germany

A total of 141 non-native taxa were reported from the waters considered in this overview, i.e. the coasts of the North Sea and the Baltic Sea and the inland waters within the national borders of Germany (Annex). The vast majority of these species were introduced by ship traffic and, intentionally, by stocking or for aquaculture. Species which reached the region on their own i.e. via drift with currents, swimming, or other ways of natural range expansion, were excluded from this overview. Most AAS have been reported from inland waters, followed by the coastal waters of the North Sea and the Baltic Sea.

More than two thirds of the known introduced species have established self-sustaining populations (Table 1). Some species were only recorded over a certain time period (e.g. the Hydrozoa *Bougainvillia macloviana* Lesson, 1830 the Anthozoa *Haliplanella luciae* (Verrill, 1898) and the Bivalvia *Crassostrea virginica* (Gmelin, 1791) and have since become extinct (Annex).

Table 1. Number of aquatic alien species (AAS) known from German waters. The number of AAS which are considered as established is listed separately

Region	All species	Established species
Baltic Sea	34	28
North Sea	62	49
Inland waters	86	82

Intentional fish introductions were predominantly motivated by a perceived improvement to the inland fisheries. About 70 “alien” fish species have been recorded in German waters (Geiter et al. 2002). A two century history of fish stocking and translocation makes it impossible to reconstruct the native range of most alien commercial fish species and their phylogeographic structure might also have been obscured. Consequently, some of these 70 species are considered as cryptogenic (see below). At present, ten fish species have been recognized as aliens and are established in self-sustaining populations with locally restricted distribution.

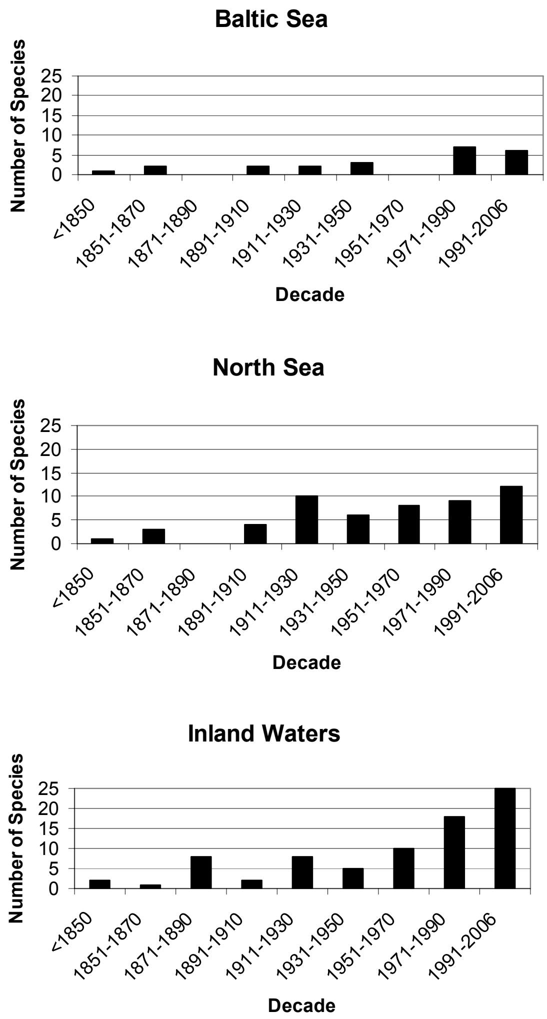

Figure 1. Number of aquatic species introductions into German waters for 20 year intervals between 1850 and 2006

The invasion rate has been increasing in all waters since the end of the last century, with the highest rate of increase found in inland waters (Figure 1). It is anticipated that more species were found in recent years as new findings are usually published with a time-lag. Many of the alien species are at least locally abundant (Table 2) and nearly half of all AAS have spread successfully across a larger area. A few alien species have developed large populations and mass developments have been observed as, for example, for the Chinese mitten crab *Eriocheir sinensis* Milne-Edwards, 1854 in German inland waters (Figure 2).

Major natural hydrographical and topograhical differences exit between the three aquatic ecosystems considered (i.e., inland waters, North Sea and Baltic Sea coasts). These differences are also reflected in a distinct occurrence of alien species.

Some species where only found in single or a few records, i.e. the decapod *Callinectes sapidus* Rathbun, 1896, the anthozoan *Cereus pedunculatus* (Pennant, 1777), the hydroid *Gonionemus vertens* Agassiz, 1862, the horseshoe crab *Limulus polyphemus* Linnaeus, 1758 and the fish *Neogobius kessleri* (Günther, 1861) (Annex).

Table 2. Population status of aquatic alien species known from German waters

Population Status	Baltic Sea	North Sea	Inland Waters
Unknown	1	1	
Extinct	1	4	1
Single record(s)	1	4	
Rare	6	16	33
Local	11	16	29
Common	1	5	10
Abundant	13	16	14
Total	33	62	86

The relationship between salinity and species diversity is well known. In contrast to freshwater and pure seawater, brackish waters are characterized by the lowest number of indigenous species ("Artenminimum" sensu Remane 1934) and seem to provide opportunities for alien species invasions. It has recently been shown for German waters that the brackish areas of estuaries have been invaded more frequently by alien macroinvertebrate species than rocky or sandy sea shores or inland waters (Nehring 2006a). The author also stated that a low indigenous species richness in aquatic communities facilitates invasions of 'new' species, but the frequency and intensity (or size) of the inoculation are critical components in determining colonization success. Brackish waters seem to have many open ecological niches and are often exposed to intensive international ship traffic. Thus, these habitats have the highest potential for species introductions. In addition, estuaries are subjected to a two-sided invasion pressure by alien species via the ocean (e.g., due to shipping) and via inland waters (e.g., canal constructions).

Since the 1980s, polychaetes of the genus *Marenzelleria* have appeared in the North Sea and Baltic Sea. The taxonomic identification of the species, which were introduced with ballast water discharge of ocean going ships, was rather difficult and led to confusions and misidentifications. Sikorski and Bick (2004) showed that at least two *Marenzelleria* species occur in German waters: *Marenzelleria neglecta* Sikorski et Bick, 2004 and *M. viridis* (Verrill, 1873) (former taxonomic determinations and synonyms for *M. neglecta* are: *M. viridis*, *M.* cf. *viridis* and *M.* Type II, and for *M. viridis*: *M. wireni* Augener, 1913, *M.* cf. *wireni* and *M.* Type I). After the first appearance of *M. viridis* in 1979 in a Scottish estuary, the species arrived at the German North Sea coast in 1983 (Essink and Kleef 1986). First individuals of *M. viridis* were found in the German Baltic Sea by 2004 (Bastrop and Blank 2006). Since 1985 *M. neglecta* occurs along the German Baltic Sea coast (Bick and Burckhardt 1989). In 1996 the polychaete was detected in the Kiel Canal (connecting the North Sea with the Baltic Sea) as well as in the Elbe estuary (North Sea) and by 1997 *M. neglecta* had arrived in the Weser estuary (Nehring and Leuchs 2000). Both *Marenzelleria* species spread rapidly and became the predominant polychaete worms in German coastal waters. In the estuaries of the German North Sea coast both *Marenzelleria* species show distinct occurrences due to the salinity gradient (Nehring and Leuchs 2001). *M. viridis* prevails in the mesohaline zone, while *M. neglecta* colonizes mainly the oligohaline zone. In the area between the two zones, both species occur sympatrically.

While many alien species seem to remain insignificant additions to the native biota of Germany, approximately 20 % of the introduced species show invasive behaviour (sensu CBD 2000). The following provides a simple classification, modified after Jansson (1994) and Hopkins (2000), to document the different impacts of introduced alien species in the recipient ecosystem, viz:

- Disruption of existing interactions between species or food web links (e.g., predators, prey, grazers, and competition) - e.g. *Crassostrea gigas* (Thunberg, 1793) (Bivalvia), *Dikerogammarus villosus* (Sovinsky, 1894) (Amphipoda), *Dreissena polymorpha* (Pallas, 1771) (Bivalvia);
- Hybridisation with native and other alien species, resulting in changes of biological and

genetic diversity. Potential candidates in German waters: *Acipenser* spp. (Pisces), *Crassostrea gigas* (Bivalvia), *Lepomis* spp. (Pisces), *Spartina anglica* Hubbard, 1968 (Poacea);
- Introduction of parasites and disease agents. The introduced species may function as a host for pathogens or parasites which affect indigenous species - e.g., *Anguillicola crassus* (Kuwahara, Niimi et Hagaki, 1974) (Nematoda), *Orconectes limosus* (Rafinesque, 1817) (Decapoda);
- Habitat modification - e.g., *Chelicorophium curvispinum* (Sars, 1895) (Amphipoda), *Crassostrea gigas* (Bivalvia), *Hypania invalida* (Grube, 1860) (Polychaeta), *Sargassum muticum* (Yendo) Fensholt, 1955 (Phaeophyceae);
- Impact on species used in fisheries and aquaculture, resulting in decrease of output - e.g. *Anguillicola crassus* (Nematoda), *Eriocheir sinensis* (Decapoda), *Crassostrea gigas* (Bivalvia);
- Impact on resource users may result in harmful consequences on human health and well-being, recreation, and socio-economics - e.g., *Crassostrea gigas* (Bivalvia), *Elodea canadensis* Michaux, 1803 (Hydrocharitaceae), *Spartina anglica* (Poacea).

Figure 2. Mass upstream migration of juvenile Chinese mitten crabs, *Eriocheir sinensis*, in the Elbe River near Hamburg in 1998. Photo Stephan Gollasch

Although we have some information about some of the direct impacts of AAS, the longer-term ecological consequences for native plant and animal communities and the scale on which biodiversity is modified by invasive species is still poorly understood. Analyses of the economic effects of AAS are also needed.

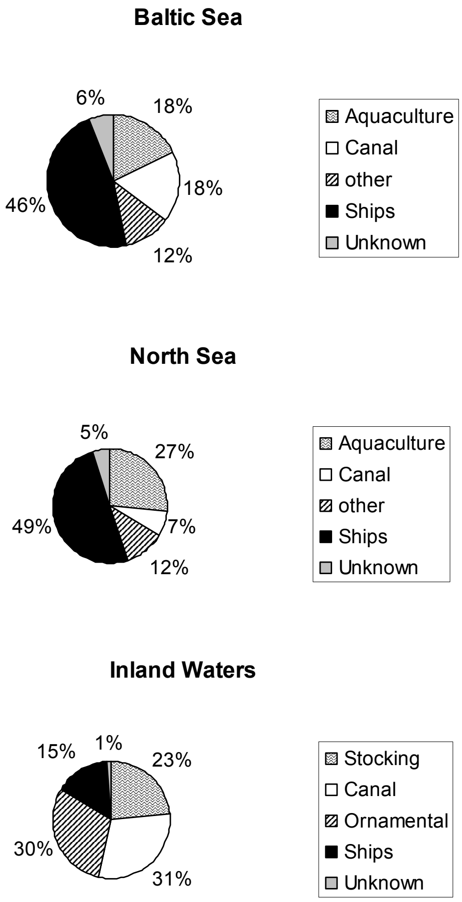

Figure 3. Introduction vectors of aquatic alien species in German waters

The most important vectors for species introductions in the Baltic Sea and the North Sea are shipping and species imports for aquaculture. In inland waters most AAS invasions are attributed to canal constructions facilitating species migrations, to the release of species that have been imported with the ornamental trade, stocking and ship traffic (Figure 3).

Prime source regions for AAS that have invaded German waters are the Ponto-Caspian area, the north-western Atlantic and the Indo-Pacific for the Baltic Sea, the northern Pacific, the Indo-Pacific, the north-western Atlantic for the North Sea, and north America and the Ponto-Caspian area for inland waters (Figure 4).

Cryptogenic species

The native range of some of the species which have been considered as alien is controversial. These species are referred to as cryptogenic species, i.e., species that are neither native or introduced (Carlton 1996). Those species include the polychaetes *Aphelochaeta marioni* (Saint-Joseph, 1894), *Microphthalmus similes* Bobretzky, 1870, *Nereis virens* Sars, 1835, *Polydora ligerica* (Ferronière, 1898) and the Dinophyceae *Prorocentrum redfieldii* Bursa, 1959 (Annex). As those species may be introduced, they were included in the Annex for reasons of comparison.

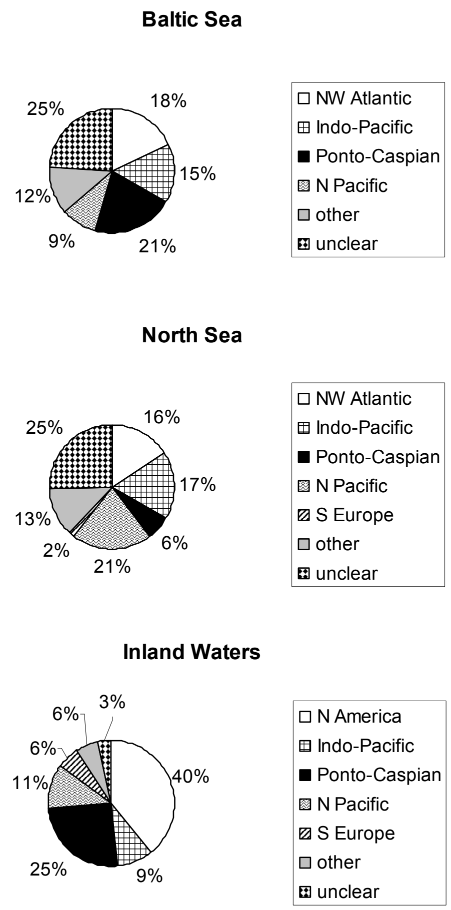

Figure 4. Source regions of aquatic alien species in German waters

Another interesting case is a turbellarian sampled from a ship hull in a German port. After careful taxonomic consideration it was found that this species is new to science and it was described as *Cryptostylochus hullensis* Faubel et Gollasch, 1996 (Polycladida, Acotylea, Plathelminthes). Because this flatworm is only known from this single sample, the native range remains unclear (Faubel and Gollasch 1996). The species was never found again in German waters and is therefore not included in the species list attached.

Species introductions and climate change

We excluded species that reached German waters from their known distribution range by natural means such as range expansion from e.g., the north-east Atlantic or the Mediterranean Sea. It has been hypothesized that temporary or permanent climate change facilitates natural range expansion (Nehring 1998a, Stachowicz et al. 2002). Franke et al. (1999) and Franke and Gutow (2004) reported several nonindigenous species from the North Sea near Helgoland which are known to occur west of the British Channel and/or in the Mediterranean Sea. Examples include the decapods *Palaemon longirostris* Milne Edwards, 1837, *Portumnus latipes* (Pennant, 1777), the Polychaeta *Sabellaria alveolata* (Linnaeus, 1767) and the Bacillariophyceae *Thalassiosira hendeyi* Hasle et Fryxell, 1977.

The cord-grass *Spartina anglica*, a fertile hybrid of the European species *S. maritima* (Curtis) Fernald, 1916 and the North-American species *S. alterniflora* Loiseleur-Deslongchamps, 1807, was introduced into the Wadden Sea in the 1920s to promote sediment accumulation. However, the intended stabilization of mudflats was not always achieved. Recently this alien species has spread naturally into the tidal zone, where it displaces the native glass-word *Salicornia stricta* Dumort, 1868 (Figure 5). This range extension may have been promoted by higher spring temperatures. *S. anglica* may further benefit from climate change and may become more abundant in the near future, resulting in unforseeable consequences for coastal protection (Nehring 2003, Nehring and Adsersen 2006).

Warm water effluents as hot spots of species invasions

Alien species, native to warmer climate regimes, may also have colonised the North Sea in localities with unusual high water temperatures, e.g. near cooling water outlets of power plants. One example is the Pacific polychaete *Ficopomatus enigmaticus* (Fauvel, 1923). This brackish water species was first recorded in the London Docks, United Kingdom in 1922 (Eno et al. 1997), in the port of Vlissingen, The Netherlands in 1967 near a power plant (Wolff 2005) and also in the German Port of Emden in close vicinity of a power plant (Kühl 1977a). Today, *F. enigmaticus* is widespread in coastal areas of all North Sea countries.

Another species which "benefited" from locally heated waters is the freshwater Asiatic clam *Corbicula fluminea* (O.F. Müller. 1756) which was first found in Europe in 1989 near the

Figure 5. The cord-grass *Spartina anglica* (in the background) displaces the native glass-word Salicornia stricta (in the foreground), Wadden Sea near Eider estuary in 2004. Photo Stefan Nehring

Figure 6. Mass occurrence of the Asian clam *Corbicula fluminea* in the Rhine River near Koblenz in 2006. Photo Stefan Nehring

port of Rotterdam, The Netherlands (Wolff 2005). In 1990 it was collected from the German section of the Rhine River (Figure 6), in 1997 from the Danube, and in 1998 from the Elbe (Tittizer et al. 2000). It has been suggested that the successful dispersal of the Asiatic clam in European waters is correlated with winter water temperature minima of 2 °C (Schöll 2000). In Germany, temperatures of inland waters frequently drop below 2 °C in winter and consequently *C. fluminea* should have limited opportunities for establishment. However, industrial and residential discharges of warm water into many German rivers have raised winter temperature almost permanently above 2°C, thereby promoting the establishment of *C. fluminea* in high abundances (Galil et al. 2007).

Species findings attributed to drift

Newly recorded species may also have reached German coastal regions by drift with exceptional water inflow due to rare hydrodynamic situations or storms. In some cases, such as for the Bacillariophyceae *Corethron criophilum* Castracane, 1886 and *Rhizosolenia indica* Peragallo, 1892, the Cirripedia *Lepas anatifera* Linnaeus, 1758 and *Lepas fascicularis* Ellis et Solander, 1786, the Decapoda *Pachygrapsus marmoratus* (Fabricius, 1787) and the clupeid fish *Sardina pilchardus* Walbaum, 1792 this has resulted in a temporary occurrence outside of their native range (Luther 1987, Nehring 1998b, Ehrich and Stransky 2001, G. Meurs (Nationalpark-Zentrum Multimar Wattforum, Tönning, Germany) pers. comm.). These species have not been included in the Annex.

In October 2006 the Ctenophore *Mnemiopsis leidyi* Agassiz, 1865 has been found for the first time along the German part of the Baltic Sea coast (U. Sommer and J. Javidpour (Leibniz-Institut für Meereswissenschaften, Kiel, Germany) pers. comm.). Recently it was also found in Dutch estuaries (Faasse and Bayha 2006, this issue), in the Skagerrak and Kattegatt (Hansson 2006, this issue) and in southern Norway (A. Jelmert (Floedevigen Research Station, His, Norway) pers. comm.), but not yet along the German North Sea coast. This western Atlantic species was possibly transported into the Baltic by easterly directed water currents or introduced by human activities, however, its current alien status is unkown.

Canals as invasion corridors

The natural barriers between river and sea basins that have existed since the end of the Pleistocene have been largely eliminated by canals built during the last centuries. The occurrence of 26 alien species in German waters can be attributed to canal construction. The following examples highlight the importance of shipping canals as invasion corridors.

The opening of the Bug-Prypjat Canal in 1784, which connects the Dnieper-Pripyat system to the rivers Bug and Vistula, was of crucial importance for the early and frequent occurrence of Ponto-Caspian species in northern Europe (e.g., the invasive zebra mussel *Dreissena polymorpha*). After the opening of the Main-Danube Canal in Germany in 1992, which connects the Rhine River and the Danube River, 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 in increasing abundances in the German rivers Main and Rhine (e.g. the isopod *Jaera istri* [Schleuter and Schleuter 1995]). In contrast Bernauer and Jansen (2006) reported that the polychaete *Hypania invalida* decreased in numbers in the upper Rhine River between 2003 and 2004.

In 1995 the Ponto-Caspian amphipod *Dikerogammarus villosus* arrived in the Rhine basin via the Main-Danube-Canal (Tittizer et al. 2000). Since then this new invader has dispersed over large distances in a short period of time and in 2000 the first organisms were observed in the German/Polish river Odra (Müller et al. 2001). This dynamic geographic expansion of *D. villosus* in Germany was facilitated by several man-made canals in northern Germany which created connections to all large river systems (Rhine, Weser, Elbe, Odra). Due to the rapidly increasing population density of this invasive amphipod it became a major component of the macrobenthic fauna in German freshwater systems, eliminating both native and other alien amphipod species (Tittizer et al. 2000, Haas et al. 2002, Nehring 2005).

More Ponto-Caspian species, mainly invertebrates and fishes, are expected to migrate into the North Sea basin via the Main-Danube-Canal. Especially those species which already occur in the upper and middle Danube will likely arrive in the North Sea basin soon.

The Chinese mitten crab (*Eriocheir sinensis*), introduced with ships and first recorded in the Aller River in 1912 (Schnakenbeck 1924, Marquard 1926), was reported from the North Sea coast in 1915 (Schnakenbeck 1924), and from the Baltic Sea in 1932 (Boettger 1933a, Peters 1933). *E. sinensis* was also found in the Kiel Canal in the 1920s (Neubaur 1926) and it is likely that the crab used the canal as the main invasion corridor to migrate from the North Sea into the Baltic Sea (Gollasch et al. 2006). Today the mitten crab can be found in the northern and easternmost parts of the Baltic (Ojaveer et al. accepted). Using the same invasion corridor as *E. sinensis*, the north-American amphipod *Gammarus tigrinus* Sexton, 1939 may have reached the Baltic Sea from inland waters in the catchment of the North Sea, where it was intentionally introduced in 1957 (Schmitz 1960) and first recorded in Germany. *G. tigrinus* successfully spread and reached the North Sea coast by 1965 (Klein 1969) and the Baltic Sea in 1975 (Bulnheim 1976, 1980, Wawrzyniak-Wydrowska and Gruszka 2005).

An east-west (i.e., opposite to the more common direction of invasions) directed migration through the Kiel Canal may have occurred in the case of the decapod *Rhithropanopeus harrisii* (Gould, 1841). This crab was first recorded along the Baltic shores near Kiel and adjacent inland waters (Flemhuder Lake and Kiel Canal) in 1936 (Neubaur 1936), and it was subsequently recorded from the Wadden Sea (Cole 1982, Kühl 1977b, Adema 1991, Nehring 2000b, Van der Velde et al. 2000).

Invasion Myths

The following section focuses on the importance of ships as species invasion vectors. Fact is that shipping continues since centuries and that ballast water is in use for more than 100 years. Some issues, formerly entitled "Invasions Myths" (J.T. Carlton (Williams College, Mystic, USA) pers. comm.), may arise:

"All species, which could have been introduced, are here by now!"

This is not the case. The "window of introduction" theory explains that all factors need to be right to enable a successful species introduction. These factors include e.g. temperature, salinity, food availability, lack of predators and the number of specimens for a founder population. It is believed that a successful invasion only occurs when all factors involved form the right environment for the candidate invader. However, the factors listed are highly varying and one can easily think of thousands of theoretical combinations indicating how rarely optimum conditions may occur in the receiving environment. Further, ship improvements result in larger ballast water tanks, more frequent ship arrivals and shorter voyage durations thereby increasing the survival rate of species in transit. It should be noted that the zebra mussel was first recorded in the North American Great Lakes in the 1980s, but ships from its donor region arrived in the lakes since many decades before the species was introduced, i.e. it took quite some time and probably multiple discharge events until all factors triggering the invasion were right.

"Why do we need to go active right now?"

The number of invaders was increasing towards the end of the last century. Several investigations have shown that since 1950s the number of new records of invaders have clearly increased (Figure 1). Further new free trade agreements and ship improvements (see above) may have increased the invasion rate even further, thereby indicating the need for immediate action with the aim to reduce the number of new alien species arrivals.

"Biological invasions are a natural phenomenon and happen anyway. The only thing we do is to speed up the process"

This is simply not true as there is no natural means to transport a species from e.g. North America to Australia. Biogeographical textbooks describe the Pacific Ocean as a migration barrier as the duration of the zooplankton larval phase is too short to enable a distribution across the Pacific with natural means. Human mediated vectors, such as ballast water or hull fouling transports, are essential for a species to become dispersed across the Pacific. Also, freshwater species cannot reach new habitats separated by marine waters. However, ballast water releases from e.g. the freshwater port of St. Petersburg (Russia) in the port of Hamburg (Germany) may introduce species which could not reach the area by natural means due to the higher salinity in the western Baltic and North Sea.

"Humans should not interfere with species distributions"

Invasion biologists know that biological components and their interaction in an environment are not a stable process. It was also agreed that initiatives should not be undertaken to hinder natural migration activities of species. However, human mediated species introductions should be kept to a minimum as a precautionary approach. Case histories have shown severe, unwanted impacts of invaders which were introduced unintentionally with e.g. ballast water or associated with aquaculture imports. Natural migrations and human mediated species introductions should clearly be treated separately.

"Only 10% of the invaders show a significant impact"

This statement refers to the "10s-rule". The rule was originally postulated based on invasion histories in terrestrial habitats. The figure was revised frequently. No matter how detailed these revisions were it has to be noted that each invasion has its impact on the recipient region. In some cases the impact is quite clear, in other instances the impact is not as obvious. Further, in many cases an impact is only noted when the invader forms a mass development which may occur long time after the initial introduction. In invasion biology it is not the quantity which matters, but the quality, i.e. just one introduced species may severely impact the receiving environment.

"Phytoplankton species are not matter of discussion as these species are distributed world-wide anyway"

It was documented that the number of phytoplankton blooms increased during the last two decades world-wide and it was suggested that this was supported not only by eutrophication but also by biological invasions. The recent occurrence of potentially toxin producing phytoplankton species in the North Sea is a good indication that we should be prepared for additional invaders of this kind.

"Keep the ballast water onboard as long as possible and the species will die over time"

Although many species die during the first days in ballast tanks, scientific studies have shown that after more than 4 months living zooplankton can be found in ballast tanks and under certain circumstances zooplankton species even reproduce in ballast tanks (Gollasch et al. 2000a,b, Gollasch et al. 2002). Further, some plankton species are enabled to form resting stages that survive unfavourable conditions for years or decades. Therefore, keeping ballast water onboard for longer periods of time is not a measure to significantly reduce the risk of species invasions.

"The exchange of ballast water in high seas is an appropriate means to reduce the number of invaders"

The exchange of ballast water in mid-ocean can reduce the abundance and diversity of taxa in ballast water. It is further unlikely that coastal organisms taken up in ports survive open ocean conditions where ballast water is exchanged – and plankton from high seas is unlikely to survive in coastal areas. In contrast to this assumption scientists showed that the exchange of ballast water could increase the species diversity in ballast tanks, especially in many domestic shipping routes, where no deep water exchange zones occur. Also the number of individuals in ballast tanks may increase when ballast water exchange is undertaken in zones with e.g. phytoplankton blooms. Ballast water exchange is therefore recommended as a very first management option, but effective treatment measures are urgently needed to avoid ballast water mediated species invasions in the future.

The future of alien species introductions into German waters and their potential impacts

The publication of recently introduced species in scientific journals is sometimes a time consuming process, and it is likely that by the time this checklist is published new alien species have already invaded German waters.

These may include the *Rapana venosa* (Valenciennes, 1846) (Gastropda), which was observed for the first time in the south-western North Sea in 2005 (Kerckhof et al. 2006), but outside German national waters. This species was already known from European waters and the new findings in the North Sea likely represent a secondary introduction. However, the occurrence of this species in various locations in Europe may also be a result of multiple introductions from its native range. Noting its potential to spread, it is anticipated that this species may be found in German waters soon.

In 1999 Reise et al. prepared an overview of introduced species in the North Sea and concluded that most alien species can be considered "additive" and that they do not cause major unwanted impacts. However, there is evidence to the contrary. For example, the introduced Pacific oyster *Crassostrea gigas* is spreading in the Wadden Sea (Reise et al. 2005) with competitive effects on the *Mytilus edulis* Linnaeus, 1758 mussel beds (Figure 7). The recent spread of *C. gigas* is likely triggered by (a) recent warm summers which support its recruitment and by (b) the absence of cold winters which promote recruitment of *M. edulis*. In northern Europe the Pacific oyster may benefit from global warming and may become more abundant than mussel beds have ever been (Diederich et al. 2005, Nehring 2006b).

Figure 7. Increasing abundance of the Pacific oyster *Crassostrea gigas* on a *Mytilus edulis* mussel bed near List, Sylt Island in 2005. Photo Stephan Gollasch

Because the impact of introduced species is potentially enormous, and very unpredictable, we should be aware of new species introductions. One known source of alien species is ship´s ballast water which can contain millions of organisms and that is discharged in our coastal waters every day. Other vectors of introductions include species that are transported in the hull fouling of ships (Gollasch et al. 2000a, b, Nehring 2001, Gollasch 2002, Gollasch et al. 2002) and canal migrations. The latter have increased in magnitude and frequency over the past decade(s) (Harka and Biro 2004, Nehring 2005, Galil et al. 2007).

Similar to a worldwide trend, the rate of invasion of AAS has also increased in German waters since the 1950s, and will probably continue to rise due to the effects of climate change and further improvements in ship design. It is hoped that measures, such as ballast water treatment to reduce the organism load or the installation of migration barriers such as deterrent electrical systems, salt or freshwater water locks, and air bubble curtains to reduce the uncontrolled range expansion of alien species via canals are taken soon to protect our waters from new species invasions and their potentially detrimental effects.

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Annex

Aquatic alien species reported from coastal areas of the North Sea and Baltic Sea and from inland waters within the national borders of Germany. Species which arrived by drift or other means of natural range expansion were not considered. IAS = an invasive alien species which threatens ecosystems, habitats or native species (sensu CBD 2000)

Species	Year of first record and recipient region			Origin / donor area	Vector	Pathway	Impact or potential impact / invasiveness	References
	Baltic Sea	North Sea	Inland waters					
PHYTOPLANKTON								
Dinopyhceae								
Karenia (= *Gymnodinium*) *mikimotoi* (Miyake et Kominami ex Oda) Hansen et Moestrup, 2000		1966		Pacific	unintentional	ships	bloom forming	Hickel et al. 1971
Prorocentrum redfieldii Bursa, 1959		<1999		unclear	unintentional	ships?	bloom forming	Nehring 1998b, Elbrächter 1999
Raphidophyceae								
Chattonella antiqua (Hada) Ono, 1980		1991		Pacific?	unintentional	Ships	potentially toxic	Elbrächter 1994, Vrieling et al. 1995, Lu and Göbel 2000
Chattonella marina (Subrahmanyan) Hara et Chihara, 1982		1991		Pacific?	unintentional	Ships	potentially toxic	Elbrächter 1994
Fibrocapsa japonica Toriumi et Takano, 1973		1991		Pacific?	unintentional	Ships	toxic / IAS	Elbrächter 1994
Bacillariophyceae								
Coscinodiscus wailesii Gran et Angst, 1931	1977	1977		Indo-Pacific	unintentional	aquaculture	competition, bloom forming / IAS	Hasle 1990, Laing 1999, Wiltshire & Dürselen 2004
Odontella sinensis (Greville) Grunow, 1884	1904	1903		Indo-Pacific	unintentional	Ships	competition	Ostenfeld 1908
Thalassiosira punctigera (Castracane) Hasle, 1983	<1983	1978		Indo-Pacific	unintentional	aquaculture	unknown	Hasle 1983, 1990
MACROPHYTES								
Pteridophyta								
Azollaceae								
Azolla filiculoides Lamarck, 1783			1980s	S America	intentional	ornamental trade	unknown	Hussner 2005
Spermatophyta								
Apiaceae								
Hydrocotyle ranunculoides Linnaeus, 1781			2004	N America	intentional	ornamental trade	competition, habitat modification/ IAS	Hussner 2005
Crassulaceae								
Crassula helmsii (Kirk) Cockayne, 1907			1980s	Australia	intentional	ornamental trade	competition, habitat modification / IAS	Kowarik 2003, Hussner 2005
Hydrocharitaceae								
Egeria densa Planchon, 1849			1980s	S America	intentional	ornamental trade	unknown	Kowarik 2003, Hussner 2005
Elodea canadensis Michaux, 1803			1859	N America	intentional	ornamental trade	competition, habitat modification / IAS	Arndt 1931, Kowarik 2003, Hussner 2005, Wallentinus subm.
Elodea nuttallii (Planchon) St. John, 1920			1953	N America	intentional	ornamental trade	competition, habitat modification / IAS	Kowarik 2003, Hussner 2005, Wallentinus submitted

Species	Year of first record and recipient region			Origin / donor area	Vector	Pathway	Impact or potential impact / invasiveness	References
	Baltic Sea	North Sea	Inland waters					
Vallisneria spiralis Linnaeus, 1753			1966	N America	intentional	ornamental trade	unknown	Kowarik 2003, Hussner 2005
Lemnaceae								
Lemna minuta Kunth, 1816			1983	N America	intentional	ornamental trade	unknown	Kowarik 2003
Lemna turionifera Landolt, 1975			1965	N America	intentional	ornamental trade	unknown	Kowarik 2003
Haloragaceae								
Myriophyllum aquaticum (Velloso) Verdcourt, 1973			1980s	S America	intentional	ornamental trade	unknown	Hussner 2005
Myriophyllum heterophyllum Michaux, 1803			1962	N America	intentional	ornamental trade	unknown	Kowarik 2003
Poaceae								
Spartina anglica Hubbard, 1968		1927		W Atlantic	intentional	planting	competition, habitat modification, hybridisation? / IAS	Kolumbe 1931, Dijkema 1983, Wallentinus submitted
Macroalgae								
Phaeophyceae								
Ascophyllum nodosum (Linnaeus) Le Jolis, 1863		1990s		unclear	unknown	unknown	unknown	Bartsch and Kuhlenkamp 2000, Wallentinus submitted
Colpomenia peregrina (Sauvageau) Hamel, 1937		1905		Pacific	unintentional	aquaculture	unknown	Fletcher and Farrell 1999
Fucus evanescens Agardh, 1820	1989			N Pacific	unintentional	ships	competition, habitat modification, hybridization	Wallentinus 1999, Hopkins 2001
Sargassum muticum (Yendo) Fensholt, 1955		1988		N Pacific	unintentional	aquaculture	fouling, habitat modification / IAS	Wallentinus 1992, Bartsch and Kuhlenkamp 2000, Wallentinus submitted
Rhodophyceae								
Bonnemaisonia hamifera Hariot, 1891		<1959		N Pacific	unintentional	aquaculture	competition	Kylin 1930, Bartsch and Kuhlenkamp 2000
Dasya baillouviana (Gmelin) Montagne, 1841	2002	1960s		W Atlantic	unintentional	aquaculture	unknown	Wallentinus pers. comm., Schories and Selig 2006
Gracilaria vermiculophylla (Ohmi) Papenfuss, 1967	2005	2002		Pacific	unintentional	aquaculture	unknown	Nehls 2004, Schories and Selig 2006
Polysiphonia harveyi Bailey, 1848		1960s		N Pacific	unintentional	aquaculture	unknown	Wallentinus 1999, Maggs and Stegenga 1999
Chlorophyceae								
Codium fragile ssp. *tomentosoides* (van Goor) Silva, 1955		1930s		N Pacific	unintentional	aquaculture	competition, fouling, habitat modification	Bartsch and Kuhlenkamp 2000, Wallentinus submitted
ZOOPLANKTON								
Ctenophora								
Mnemiopsis leidyi Agassiz, 1865	2006			unclear	unknown	unknown	unknown	Javidpour and Sommer pers. comm.

Species	Year of first record and recipient region			Origin / donor area	Vector	Pathway	Impact or potential impact / invasiveness	References
	Baltic Sea	North Sea	Inland waters					
Crustacea								
Acartia tonsa Dana,1848	<1981	1931		Pacific / W Atlantic	unintentional	ships	competition	Klie 1933, Arndt and Schnese 1986
Ameira divagans Nicholls, 1939	1970s			W Atlantic	unintentional	ships	unknown	Scheibel 1974
Cercopagis pengoi (Ostroumov, 1891)	2004			Ponto-Caspian	unintentional	canal	competition, predation	Gruzka pers. com. in WGITMO 2005
MACROZOOBENTHOS								
Porifera								
Eunapius carteri Bowerbank, 1863			1993	Africa, Asia	unintentional	ornamental trade	fouling	Gugel 1995, Nehring 2002
Hydrozoa								
Bimeria franciscana Torrey, 1902		<1952	<1952	Indo-Pacific?	unintentional	ships	competition, habitat modification, predation	Schütz 1963a,b, Cohen and Carlton 1995
Bougainvillia macloviana Lesson, 1830		1895		Antarctic waters	unintentional	ships	unknown	Hartlaub 1897, Broch 1924
Cordylophora caspia (Pallas, 1771)	1870	1858	1899	Ponto-Caspian	unintentional	canal	competition, fouling, predation, habitat modification	Kirchenpauer 1862, Hinkelmann 1899, Schulze 1981, Gruszka 1999
Craspedacusta sowerbyi Lancester, 1880			1923	NW Pacific	unintentional	ornamental trade	unknown	Tittizer 1996, Tittizer et al. 2000
Gonionemus vertens Agassiz, 1862		1947		N America	unintentional	ships	unknown	Werner 1950, Tambs-Lyche 1964
Nemopsis bachei Agassiz, 1849		1942		W Atlantic	unintentional	ships	fouling?	Hartlaub 1911, Kühl 1962
Anthozoa								
Cereus pedunculatus (Pennant, 1777)		1921		NE Atlantic	unintentional	ships	unknown	Müllegger 1921, Pax 1936
Diadumene cincta (Stephenson, 1925)		1928		Pacific	unintentional	aquaculture	competition?	Pax 1936, Kluijver 1991
Haliplanella luciae (= *lineata*) (Verrill, 1898)		1920		Pacific	unintentional	ships	fouling?	Pax 1920, Gollasch and Riemann-Zürneck 1996
Bivalvia								
Congeria leucophaeta (Conrad, 1831)	<1996	<1994	1928	N America	unintentional	ships	competition, fouling	Boettger 1933b, Post and Landmann 1994, Jungbluth 1996
Corbicula fluminalis (O.F. Müller, 1774)			1984	E Asia	unintentional	ships	competition / IAS	Kinzelbach 1991, Meister 1997, Nehring 2002
Corbicula fluminea (O.F. Müller. 1756)			1987	Asia	unintentional	ships	competition / IAS	Kinzelbach 1991, Nehring 2002
Crassostrea angulata (Lamarck, 1819)		1911		unclear	unintentional	aquaculture	unknown	Meyer-Waarden 1964
Crassostrea gigas (Thunberg, 1793)		1991		NW Pacific	unintentional	aquaculture	competition, habitat modification, hybridization ?, parasite carrier / IAS	Utting and Spencer 1992, Reise 1998a,b
Crassostrea virginica (Gmelin, 1791)	<1887	1911		unclear	unintentional	aquaculture	unknown	Möbius 1887, Rady 1913

Species	Year of first record and recipient region			Origin / donor area	Vector	Pathway	Impact or potential impact / invasiveness	References
	Baltic Sea	North Sea	Inland waters					
Dreissena polymorpha (Pallas, 1771)	1828	1835	1824	Ponto-Caspian	unintentional	canal	competition, fouling, habitat modification, parasite carrier / IAS	Dahl 1891, Bentheim-Jutting 1922, Arndt 1931, Thienemann 1950
Ensis americanus (Binney, 1870)	1993	1979		NW Atlantic	unintentional	ships	competition, habitat modification / IAS	Von Cosel et al. 1982, Essink 1985, van Urk 1987, Gürs et al. 1993
Mya arenaria (Linnaeus, 1758)	<1200	<1200	<1931	NW Atlantic	unintentional	ships	competition?	Arndt 1931, Petersen et al. 1992, Reise 1998a&b, Nehring 2000a
Petricola pholadiformis Lamarck, 1818	1927	1896		NW Atlantic	unintentional	aquaculture	competition, habitat modification	Schlesch 1932, Kuckuck 1957, Knudsen 1989, Jensen & Knudsen 2005
Teredo navalis Linnaeus, 1758	<1993	<1808		Indo-Pacific?	unintentional	ships	habitat modification / IAS	Hahn 1956, Schütz 1961, Sordyl et al. 1998
Unio mancus Lamarck, 1819			<1922	S Europe	unintentional	canal	unknown	Tittizer et al. 2000
Gastropoda								
Crepidula fornicata (Linnaeus, 1758)		1934		W Atlantic	unintentional	aquaculture	competition, habitat modification, parasite carrier	Havinga 1929, Ankel 1935, Kuckuck 1957, Minchin et al 1995
Gyraulus parvus (Say, 1817)			1981	N America	intentional	ornamental trade	unknown	Geiter et al. 2002
Lithoglyphus naticoides (Pfeiffer, 1828)			1883	E Europe	unintentional	canal	parasite carrier	Thienemann 1950, Jungbluth 1996, Nehring 2002
Menetus dilatatus (Gould, 1841)			1980	N America	intentional	ornamental trade	unknown	Geiter et al. 2002
Physella acuta (Draparnaud, 1805)			1895	SW Europe	intentional	ornamental trade	unknown	Sukopp & Brande 1984, Jungbluth 1996, Nehring 2002
Physella heterostropha (Say, 1817)			<1927	N America	intentional	ornamental trade	unknown	Jungbluth 1996, Nehring 2002
Planorbella duryi (Weatherby, 1879)			1980s	N America	intentional	ornamental trade	unknown	Geiter et al. 2002
Potamopyrgus antipodarum (Gray, 1843)	1908		1900	New Zealand	unintentional	ships	competition, parasite carrier	Thienemann 1950, Cole 1982
Platyhelminthes								
Dendrocoelum romano-danubiale (Codreanu, 1949)			1992	Ponto-Caspian	unintentional	canal	unknown	Tittizer et al. 2000, Nehring 2002
Dugesia tigrina (Girard, 1850)			1931	N America	unintentional	ornamental trade	unknown	Hauer 1950, Tittizer 1996, Nehring 2002
Kamptozoa								
Urnatella gracilis Leidy, 1851			1960	N America	unintentional	ships	unknown	Franz 1992, Vranovsky and Sporka 1998, Geiter et al. 2002

Species	Year of first record and recipient region			Origin / donor area	Vector	Pathway	Impact or potential impact / invasiveness	References
	Baltic Sea	North Sea	Inland waters					
Oligochaeta								
Branchiura sowerbyi Beddard, 1892			1959	W Pacific	unintentional	ornamental trade	habitat modification	Tobias 1972, Tittizer 1996, Gruszka 1999, Nehring 2002
Polychaeta								
Aphelochaeta marioni (Saint-Joseph, 1894)		1938		unclear	unknown	unknown	unknown	Caspers 1950
Ficopomatus enigmaticus (Fauvel, 1923)		1975		S Pacific	unintentional	ships	fouling	Kühl 1977a, Cole 1982, Zibrowius 1991
Hypania invalida (Grube, 1860)			1995	Ponto-Caspian	unintentional	canal	habitat modification	Kothe 1968, Tittizer 1996, Nehring 2002
Marenzelleria neglecta (= cf. *viridis*) Sikorski et Bick, 2004	1985	1996		NW Atlantic	unintentional	ships	competition, habitat modification, predation / IAS	Bick and Burckhardt 1989, Bick and Zettler 1997, Bastrop et al. 1997, Sikorski and Bick 2004
Marenzelleria viridis (= cf. *wireni*) (Verrill, 1873)	2004	1983		NW Atlantic	unintentional	ships	competition, habitat modification, predation / IAS	Essink and Kleef 1986, Bick and Burckhardt 1989, Bick and Zettler 1997, Sikorski and Bick 2004
Microphthalmus similis Bobretzky, 1870		1962		unclear	unknown	unknown	unknown	Hartmann-Schröder and Stripp 1968
Nereis virens Sars, 1835	1920s	1923		unclear	unintentional?	ships?	predation	Reibisch 1926, Hagmeier and Kändler 1927, Hartmann-Schröder 1996
Polydora ligerica (Ferronière, 1898)			<1932	unclear	unknown	unknown	unknown	Augener 1940, Jaeckel 1962, Hartmann-Schröder 1996
Tharyx killariensis (Southern, 1914)		1972		unclear	unintentional?	aquaculture?	unknown	Hauser 1973, Hartmann-Schröder 1996
Crustacea								
Astacus leptodactylus Eschscholtz, 1823			1910s	Ponto-Caspian	intentional	stocking	unknown	Geiter et al. 2002, Souty-Grosset et al. 2006
Atyaephyra desmarestii (Millet, 1831)			1932	Mediterranean	unintentional	canal	unknown	De Lattin 1967, Tittizer 1996, Tittizer et al. 2000, Nehring 2002
Balanus improvisus Darwin, 1854	1867	1858	<1899	W Atlantic	unintentional	ships	fouling, habitat modification	Kirchenpauer 1862, Hoek 1875, Dechow 1920, Broch 1924, Bäthe 1995
Callinectes sapidus Rathbun, 1896		1964		NW Atlantic	unintentional	ships	predation	Gruner 1962, Kühl 1965
Caprella mutica Schurin, 1935		2004		Pacific	unintentional	ships	clogging of gear?	Schrey and Buschbaum 2006

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	Baltic Sea	North Sea	Inland waters					
Chelicorophium curvispinum (Sars, 1895)	1932	1920s	1912	Ponto-Caspian	unintentional	canal	competition, habitat modification / IAS	Wundsch 1912, Schlienz 1922, Neuhaus 1933, Tittizer 1996, Bernauer et al. 1996, Gruszka 1999, Nehring 2002
Chelicorophium robustum (Sars, 1895)			2004	Ponto-Caspian	unintentional	canal	unknown	Eggers and Martens 2004
Corophium sextonae Crawford, 1937		1997		S Pacific	unintentional	ships	competition	Nehring and Leuchs 1999
Crangonyx pseudogracilis Bousfield, 1958			1992	N America	unintentional	stocking?	unknown	Bernauer et al. 1996
Dikerogammarus haemobaphes (Eichwald, 1841)			1993	Ponto-Caspian	unintentional	canal	competition	Tittizer 1996, Nehring 2002, Wawrzyniak-Wydrowska and Gruszka 2005
Dikerogammarus villosus (Sovinsky, 1894)			1995	Ponto-Caspian	unintentional	canal	competition, predation / IAS	Tittizer 1996, Nehring 2002
Echinogammarus berilloni (Catta, 1878)			1924	Mediterranean	unintentional	canal	unknown	Tittizer 1996, Nehring 2002
Echinogammarus ischnus (Stebbing, 1899)			1977	Ponto-Caspian	unintentional	canal	unknown	Tittizer 1996, Tittizer 1996, Nehring 2002
Echinogammarus trichiatus (Martynov, 1932)			2000	Ponto-Caspian	unintentional	canal	unknown	Podraza et al. 2001, Nehring 2002
Elminius modestus Darwin, 1854		1953		S Pacific	unintentional	ships	competition?, fouling	Bishop 1947, Kühl 1954
Eriocheir sinensis Milne-Edwards, 1854	1932	1915	1912	NW Pacific	unintentional	ships	competition, habitat modification, parasite carrier, predation / IAS	Schnakenbeck 1924, Marquard 1926, Boettger 1933, Peters 1933, Peters and Hoppe 1938, Panning 1938
Gammarus tigrinus Sexton, 1939	1975	1965	1957	NW Atlantic	intentional	stocking	competition, parasite carrier, predation	Bousfield 1958, Schmitz 1960, Klein 1969, Bulnheim 1976, Nehring 2002, Wawrzyniak-Wydrowska and Gruszka 2005
Hemimysis anomala Sars, 1907			1997	Ponto-Caspian	unintentional	canal	competition, predation	Faasse 1998, Ketelaars et al. 1999, Nehring 2002
Jaera istri Vieuille, 1979			1995	Ponto-Caspian	unintentional	canal	unknown	Kothe 1968, Tittizer 1996, Nehring 2002
Limnomysis benedeni Czerniavsky, 1882			1997	Ponto-Caspian	unintentional	canal	unknown	Tittizer et al 2000, Nehring 2002
Obesogammarus crassus (Sars, 1894)			2004	Ponto-Caspian	unintentional	canal	unknown	Eggers and Anlauf 2005
Obesogammarus obesus (Sars, 1894)			2004	Ponto-Caspian	unintentional	canal	unknown	Nehring 2006c
Orchestia cavimana Heller, 1865			1920	Ponto-Caspian	unintentional	ships	unknown	Schlienz 1922, Tittizer 1996

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	Baltic Sea	North Sea	Inland waters					
Orconectes immunis (Hagen, 1870)			1997	N America	intentional	ornamental trade	parasite carrier, habitat modification / IAS	Geiter 1998, Souty-Grosset et al. 2006
Orconectes limosus (Rafinesque, 1817)			1890	NE America	intentional	stocking	parasite carrier, competition, predation / IAS	Schellenberg 1928, Boettger 1934, Sukopp and Brande 1984
Pacifastacus leniusculus (Dana, 1852)			1980s	N America	intentional	stocking	parasite carrier, competition, predation, habitat modification / IAS	Huber and Schubart 2005, Souty-Grosset et al. 2006
Palaemon macrodactylus Rathbun, 1902		2004		SE Asia	unintentional	ships	unknown	González-Ortegón et al. 2006
Pontogammarus robustoides (Sars, 1894)	1994		1994	Ponto-Caspian	unintentional	canal	competition, hybridization, predation	Rudolph 1997, Nehring 2002, Wawrzyniak-Wydrowska and Gruszka 2005
Proasellus coxalis (Dollfus, 1892)		<1987	1930s	Medi-terranean	unintentional	canal	unknown	Gruner 1965, Post and Landmann 1994, Tittizer 1996, Nehring 2002
Proasellus meridianus (Racovitza, 1919)			1930s	W Europa	unintentional	canal	unknown	Thienemann 1950, Gruner 1965, Tittizer 1996, Nehring 2002
Procambarus clarkii (Girard, 1852)			1990s	N America	intentional	ornamental trade	parasite carrier, competition, predation, habitat modification / IAS	Geiter et al. 2002, Souty-Grosset et al. 2006
Rhithropanopeus harrisii (Gould, 1841)	1936	<1977	1936	NW Atlantic	unintentional	ships	competition, predation	Neubaur 1936, Buitendijk and Holthuis 1949, Christiansen 1969, Van der Velde et al. 2000, Kühl 1977b, Cole 1982, Adema 1991, Tittizer 1996, Nehring 2000b
Chelicerata								
Caspihalacarus hyrcanus Vietz, 1928			<2006	Ponto-Caspian	unintentional	canal	unknown	Martens et al. 2006
Limulus polyphemus Linnaeus, 1758		1866		NW Atlantic	intentional	ornamental trade	unknown	Lloyd 1874, Holthuis 1950, Wolff 1977
Bryozoa								
Pectinatella magnifica (Leidy, 1851)			1883	N America	unintentional	ships	unknown	Tittizer et al. 2000, Nehring 2002
Victorella pavida Saville Kent, 1870	1911		1951	Indo-Pacific?	unintentional	ships	competition, habitat change	Kraeplin 1887, Ax 1952
Ascidiacea								
Styela clava Herdmann, 1882		1997		N Pacific	unintentional	ships	competition, fouling	Millar 1960, Reise 1998a,b

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	Baltic Sea	North Sea	Inland waters					
FISHES								
Acipenser baerii Brandt, 1869	1980s	1980s		Russia	intentional	stocking	hybridisation	Spratte and Hartmann 1997, Gessner et al. 1999
Acipenser gueldenstaedti Brandt et Ratzeberg, 1833	<1990s			unclear	intentional	stocking	hybridisation	Gerstmeier and Romig 1998
Acipenser ruthenus Linnaeus, 1758		<1992		unclear	intentional	stocking	hybridisation	Gerstmeier and Romig 1998, Gessner et al. 1999
Acipenser transmontanus Richardson, 1836		<1990s		N America	intentional	stocking	hybridisation	WGITMO 2006
Ameiurus (= *Ictalurus*) *melas* (Rafinesque, 1820)			1990s	N America	intentional	stocking	competition, predation	Welcomme 1988, Spratte and Hartmann 1997
Ameiurus (= *Ictalurus*) *nebulosus* (Lesueur, 1819)			1885	N America	intentional	stocking	competition	Spratte and Hartmann 1997
Carassius auratus (Linnaeus, 1758)			<1560	Asia	intentional	stocking	hybridization	Arnold 1990
Coregonus peled (Gmelin, 1789)			1965	Asia	intentional	stocking	hybridisation, predation	Geiter et al. 2002
Lepomis cyanellus Rafinesque, 1819			1965	N America	intentional	stocking	hybridisation	Arnold 1990
Lepomis gibbosus (Linnaeus, 1758)			1880	N America	intentional	stocking	competition, predation, hybridisation	Welcomme 1988, Spratte and Hartmann 1997
Neogobius kessleri (Günther, 1861)	<2004			unclear	unknon	unknown	competition, predation	Harka & Biro 2004
Neogobius melanostomus (Pallas, 1811)	1999			Ponto-Caspian	intentional	canal	competition, habitat modification, predation	Winkler at el. 2000, Szaniawska and Dobrzycka-Krahel 2004
Oncorhynchus mykiss (Walbaum, 1792)			1882	N America	intentional	stocking	competition, habitat modification, hybridization, predation, parasite carrier	Welcomme 1988, Spratte and Hartmann 1997, Winkler at el. 2000
Proterorhinus marmoratus (Pallas, 1811)			1999	Ponto-Caspian	intentional	canal	unknown	Schadt 2000, Harka and Biro 2004
Pseudorasbora parva (Temminck et Schlegel, 1846)			1984	E Asia	intentional	stocking	competition	Spratte and Hartmann 1997
Salvelinus fontinalis (Mitchill, 1814)			1890	NW Atlantic	intentional	stocking	competition, hybridization, predation	Muus and Dahlström 1968
Umbra krameri Walbaum, 1792			<1997	unclear	intentional	ornamental trade	unknown	Spratte and Hartmann 1997
Umbra pygmaea (De Kay, 1842)		1924	1910s	N America	intentional	ornamental trade	competition	Duncker 1939, Spratte and Hartmann 1997
AMPHIBIAN								
Anura								
Rana catesbeiana Shaw, 1802			1990s	N America	intentional	ornamental trade	predation / IAS	Laufer 2004
PARASITES								
Oomycota								
Aphanomyces astaci Schikora, 1906			1878	N America	unintentional	stocking	crayfish parasite / IAS	Dehus 1990

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Acanthocephala								
Paratenuisentis ambiguus (van Cleave, 1921)	?	?	1987	N America	unintentional	stocking	eel parasite	Taraschewski et al. 1987
Platyhelminthes								
Pseudodactylogyrus anguillae (Yin et Sproston, 1948)	?	?	1980s	E Asia	unintentional	stocking	eel parasite	Buchmann et al. 1987, Sures and Streit 2001
Pseudodactylogyrus bini (Kikuchi, 1929)	?	?	1980s	E Asia	unintentional	stocking	eel parasite	Buchmann et al. 1987, Sures and Streit 2001
Nematoda								
Anguillicola crassus (Kuwahara, Niimi et Hagaki, 1974)	1980s	1980s	1980s	E Asia	unintentional	stocking	eel parasite / IAS	Taraschewski et al. 1987, Minchin and Rosenthal 2002
Annelida								
Barbronia weberi (Blanchard, 1897)			1994	S Asia	unintentional	ornamental trade	predation	Potel et al. 1998
Caspiobdella fadejewi (Epshtein, 1961)			1990s	Ponto-Caspian	unintentional	canal	fish leech	Geissen and Schöll 1998
Piscicola haranti Jarry, 1960			1990s	Ponto-Caspian	unintentional	canal	fish leech	Schimmer 1995, Tittizer et al. 2000
Xironogiton victoriensis Gelder et Hall, 1990			2003	N America	unintentional	stocking	crayfish parasite	Martens et al. in press