4 Is Ballast Water a Major Dispersal Mechanism for Marine Organisms?

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4.1 Introduction

More than 1,000 non-indigenous aquatic species, ranging from unicellular algae to vertebrates, have been found in European coastal waters, including navigational inland waterways for ocean-going vessels and adjacent water bodies. Approximately half of all non-indigenous species recorded to date have established self-sustaining populations (Gollasch 2006). These introductions are of high concern, as many cases have caused major economical or ecological problems (Chaps. 13–19).

Species are introduced unintentionally (e.g. with ships) or intentionally (e.g. for aquaculture purposes and re-stocking efforts). In shipping, the prime vectors for species transportation are ballast water and in the hull fouling of vessels. Further, a considerable number of exotic species migrates through man-made canals. Examples are the inner-European waterways connecting the Ponto-Caspian region and the Baltic Sea. Also, the Suez Canal "opened the door" for Red Sea species migrations into the Mediterranean Sea and vice versa (Gollasch et al. 2006; Chap. 5).

For the purpose of this contribution, the following inventories of introduced species in coastal waters were considered: North Sea (Gollasch 1996; Reise et al. 1999; Nehring 2002), Baltic Sea (Leppäkoski 1994; Gollasch and Mecke 1996; Leppäkoski and Olenin 2000; Olenin et al. 2005), British Isles (Eno 1996; Eno et al. 1997), Ireland (Minchin and Eno 2002), Mediterranean Sea (Galil and Zenetos 2002; CIESM 2005). Other key publications are a book dealing with aquatic invaders in Europe (Leppäkoski et al. 2002) and a review of marine introduced species in Europe (Streftaris et al. 2005). To broaden the scope, additional datasets from outside Europe were also included: from Australia, Japan, New Zealand and North America, including Hawaii, as well as the inventories of introduced species prepared during the Global Ballast Water Management Programme (GloBallast), i.e. from Brazil, China, India, Iran, South Africa and Ukraine.

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4.2 Vectors

Introduction vectors are defined as the physical means by which species are transported from one geographic region to another (Carlton 2001). Vectors include various natural mechanisms of spread and also anthropogenically aided species dispersal. Since man started to sail the oceans, species have been either intentionally or unintentionally in transport. The Vikings were wide-reach seafarers and may have been responsible for the introduction of the infaunal bivalve *Mya arenaria* to Europe (Petersen et al. 1992) – this actually may be the first ship-mediated species introduction into Europe. When returning from North America, Vikings may have kept live *M. arenaria* aboard as food supply. Alternatively, they may have imported the clam in the solid ballast used on their vessels. It is assumed that Viking ships arrived in Europe from muddy estuaries in North America, and these estuaries would have been highly populated with *M. arenaria*. However, it is also possible that there was a gradual re-expansion of *M. arenaria* into Europe after the last glaciation period. Wolff (2005) states that the transfer of *M. arenaria* by the Vikings may have occurred only on an occasional vessel because there was no direct transport route between North America and Europe in Viking times (Marcus 1980). Greenlanders travelled to North America more frequently, and also between Greenland and Norway, but it is unclear whether these trips were undertaken by the same vessels. As a result, *M. arenaria* was probably first introduced from North America to Greenland and thereafter from Greenland to Europe (Ockelmann 1958; Höpner Petersen 1978, 1999).

Historically, aquaculture and stock transfers of aquatic species resulted in a significant amount of taxa being transported worldwide. Dry and semi-dry ballast is no longer in use with merchant shipping but, during former times, this vector is claimed to have introduced a certain number of species worldwide, e.g. *Littorina littorea* to North America (Carlton 1992), *Chara connivens* to coastal areas of the Baltic Sea and several seashore plants into Europe (Wallentinus 2002). Estimations reveal that more than 480,000 annual ship movements occur worldwide with the potential for transporting organisms. Various calculations have been made on the amount of ballast water carried with the world's fleet of merchant ships – it has been estimated that 2–12 billion t of ballast water are transported annually. In ballast tanks and also other ship vectors including hulls, anchor chains and sea chests, ships may carry 4,000 to 7,000 taxa each day (Gollasch 1996; Carlton, personal communication). One reason for this great diversity of organisms in transit arises from the three different "habitats" inside ballast water tanks: (1) tank walls, (2) ballast water, and (3) the sediment (Taylor et al. 2002).

When calculating the number of new invaders per time unit, every 9 weeks a new species is found. It should be noted that this value is regionally very different and, in Europe, there are indications that a new species was found every

3 weeks over the time period 1998–2000 (ICES WGITMO 2004). However, not all species recorded form self-sustaining populations (Minchin and Gollasch 2002). In many cases, it is impossible to clearly identify the introduction vector. In bivalves, for example, introductions may be attributed to larval transport in ballast water releases, adults in hull fouling of ships or imports as (non-)target species for aquaculture activities.

4.3 Relative Vector Importance

Previous studies have shown that the most prominent invasion vectors are shipping and aquaculture activities (Streftaris et al. 2005; Gollasch 2006). An exception from this general trend is the Mediterranean Sea where the dominating invasion "vector" is the opening of the Suez Canal, enabling Red Sea species to migrate into the south-eastern Mediterranean Sea and vice versa. This phenomenon is also known as Lessepsian migration (cf. Ferdinand de Lesseps planned the Suez Canal which opened in 1869). However, this is not considered to be a vector but rather a removal of a migration barrier, and has been included here only for reasons of comparison (Chap. 5).

The relative vector importance is regionally very different. Assessing all available data as outlined above, on a global scale species introduced with hull fouling seem to slightly dominate those associated with ballast water and

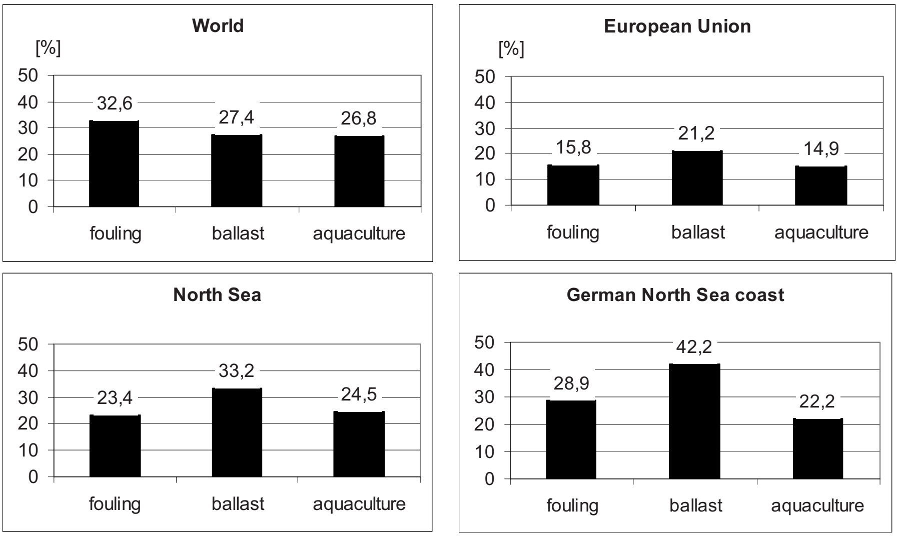

Fig. 4.1 Relative importance of the invasion vectors hull fouling, ballast water and aquaculture efforts per region

aquaculture. In waters of the European Union, ballast water-mediated species introductions prevail and this trend becomes even clearer when extracting the data for the North Sea (Fig. 4.1).

4.4 Ballast Water

Ballast water is in use in shipping to, for example, strengthen structures and to submerge the propeller when no cargo is carried. Ballast water has long been suspected as major vector for species introductions. One of the first assumptions that a species was introduced by ballast water to regions outside its native range was made by Ostenfeld (1908) after a mass occurrence of the Asian phytoplankton algae *Odontella* (*Biddulphia*) *sinensis.* The species was first recorded in the North Sea in 1903. The first study to sample ships' ballast water was carried out 70 years later by Medcof (1975), followed by many others. In Europe, 14 ship sampling studies have been undertaken. More than 1,500 ballast tank samples were taken, of which approx. 80 % represent samples from ballast water and nearly 20 % from ballast tank sediments. Almost 600 vessels have been sampled since 1992. The total number of taxa identified overall was more than 1,000. The diversity of species found included bacteria, fungi, protozoans, algae, invertebrates of different life stages including resting stages, and fishes with a body length up to 15 cm. The most frequently collected taxa were diatoms, copepods, rotifers, and larvae of Gastropoda, Bivalvia and Polychaeta (Gollasch et al. 2002).

The above-mentioned shipping studies have clearly shown that an enormous number of taxa can be found in ballast tanks at the end of ship voyages. However, en-route studies based on daily sampling frequencies showed that organisms in ballast water die out over time. The most significant decrease in organism densities occurs during the first 3 days of the voyage, and after 10 days most individuals were found dead (e.g. Gollasch et al. 2000; Olenin et al. 2000). However, exceptions from this general trend occurred. In one study, most taxa died out during the first days of the ship's voyage but harpacticoid copepods increased in numbers towards the end of the voyage, documenting that certain species reproduce in ballast water tanks (Gollasch et al. 2000).

Species with a high potential to cause unwanted impacts in the receiving environment are frequently transported in ballast water. This refers mainly to phytoplankton species which may produce toxins – these species, when introduced to areas in close proximity to aquaculture farms, are of great concern. Further, human pathogens including *Vibrio cholerae* have been found in ballast water.

One invader well known for its negative impact is the Ponto-Caspian zebra mussel *Dreissena polymorpha*. When very abundant, the mussel may clog the water intakes of power plants and municipal waterworks, one notable example being the North American Great Lakes. Although this species causes fouling problems, it is unlikely that it was introduced to North America in the hull fouling of ships. The oceanic voyage is too long for these freshwater organisms to survive. As a result, certain species, including those causing fouling problems as adults, are introduced as larvae in ballast water.

Ship design continuously improves, resulting in ever faster and larger vessels. Consequently, ship arrivals are more frequent, ballast tanks increase in size and the time an organism needs to survive in a ballast water tank is reduced. As a result, the volume and frequency of ballast water discharges increase, which also enhances the likelihood of species surviving in the new habitat after ballast water discharge. By implication, each new generation of ships has the potential to increase the risk of invasion.

4.5 Risk-Reducing Measures

The vectors shipping, aquaculture and stocking may play a different role in the future, as regulatory instruments are either in place or developing with the aim to minimize the number of new species introductions. In aquaculture and stocking, the International Council for the Exploration of the Sea (ICES) has updated its Code of Practice on the Introductions and Transfers of Marine Organisms (ICES 2005). This instrument provides (voluntary) guidelines to avoid unwanted effects of moved species and unintentional introductions of non-target taxa. ICES member countries planning new marine (including brackish) species introductions are requested to present to the ICES Council a detailed prospectus on the rationale, the contents of the prospectus being detailed in the Code. Having received the proposal, the Council may then request its Working Group on Introductions and Transfers of Marine Organisms (WGITMO) to evaluate the prospectus. WGITMO may request more information before commenting on a proposal. If the decision is taken to proceed with the introduction, then only progeny of the introduced species may be transplanted into the natural environment, provided that a risk assessment indicates that the likelihood of negative genetic and environmental impacts is minimal, that no disease agents, parasites or other non-target species become evident in the progeny to be transplanted, and that no unacceptable economic impact is to be expected. A monitoring programme of the introduced species in its new environment should be undertaken, and annual progress reports should be submitted to ICES for review at WGITMO meetings, until the review process is considered complete.

The International Maritime Organization (IMO), the United Nations body which deals, e.g. with minimizing pollution from ships, has developed two conventions relevant to biological invasions.

1. The International Convention on the Control of Harmful Anti-Fouling Systems on Ships: this Convention was developed as a consequence of the unwanted impact from poisonous antifouling paints based on tri-butyl-tin (TBT) in the aquatic environment. Eventually, the use of TBT was banned and TBT-free antifouling paints are currently being developed and tested. However, it is feared that alternative ship coatings may not be as effective, possibly resulting in more species arriving in new habitats with ship hull fouling.
2. The International Convention for the Control and Management of Ships' Ballast Water and Sediments: although being of limited effectiveness, ballast water exchange in open seas is recommended as a partial solution to reduce the number of species in transit. In the future, ballast water treatment will eventually be required. This Convention was adopted in 2004 and is now open for signature by IMO member states. IMO is currently developing 15 guidelines to address certain key issues in the Convention in greater detail.

4.6 Ballast Water Management Options

Ballast water exchange has been suggested as a management tool for vessels on transoceanic voyages. Ballast water taken onboard ships in ports or coastal areas would be exchanged for deep oceanic water, the background assumption being that, in the open sea, fewer organisms will be present and also plankton species are unlikely to survive in coastal areas when the ballast water is discharged in the next port of call. This water exchange approach is also recommended for cases of vessels travelling between two freshwater ports, as the salinity increase would likely kill any freshwater organisms pumped onboard in the freshwater ports.

The water replacement efficiency during ballast water exchange depends on, e.g. the ballast tank design. Trials have shown that three times volumetric exchange of ballast water results in approx. 95 % removal of phytoplankton cells and approx. 60 % removal of zooplankton organisms. However, the 5 % of phytoplankton surviving may amount to millions of specimens (Taylor et al. 2002).

Since the mid-1990s, roughly 20 initiatives on ballast water treatment have been completed or are still ongoing. The treatment options considered to date include filtration, use of hydrocyclones, heat treatment, coagulation/flocculation, pH adjustment and chemical treatment, including electrolytical generation of agents from seawater and UV.

4.7 Conclusions

The relative importance of invasion vectors is difficult to assess because not all introduced species can clearly be attributed to any one vector. However, shipping seems to be the prime invasion vector today. In shipping, key vectors are ballast water and hull fouling. Their relative importance is regionally very different, being strongly influenced by local economies and shipping patterns. However, as shown above, any ship design improvement which results in larger and faster ships will favour ballast water-mediated introductions. Consequently, the relative vector importance should be revisited over time. Further, trade scenarios and shipping patterns may change over time. When planning mitigation measures aimed at reducing the number of new species introductions, the prime invasion vectors should be addressed first; the findings of such assessments may change over time.

Exotic species will definitely continue to spread, although the timely implementation of the above-mentioned measures may significantly reduce the invasion rate. As newly found species are usually reported with a certain time lag due to publishing procedures in scientific journals, the number of first records in the current decade will likely increase in the future. To solve this problem, a new European journal of applied research on biological invasions in aquatic ecosystems has been launched and will be published frequently to announce new findings of biological invaders (http://www.aquaticinvasions.ru/). Timely publication of new introduced species is not only of academic interest. It may also result in an early warning instrument with the aim to develop eradication programmes of certain species. The success of rapid response measures to eliminate newly introduced species is dependent on early detection. Successful efforts are known from Australia and North America. In Europe, early detection and rapid response scenarios are currently developing.

The management of already established species requires more effective international cooperation of neighbouring states. Following the precautionary principle, emphasis should be placed on the prevention of species introductions because, once established, their secondary spread is difficult or impossible to control. This approach comes particularly into focus noting the impacts certain invasions have caused, including implications for native species, fisheries, aquaculture and human health. It is therefore hoped that the above-mentioned regulatory instruments enter into force soon and will timely be implemented with the aim to reduce future species introductions and their potential negative impacts, resulting in an improved protection of the world oceans. It seems logical to address the most prominent invasion vectors first – as shown above, these are likely ballast water and hull fouling of ships.

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