ASSESSMENT AND CONTROL OF BIOLOGICAL INVASION RISKS

Edited by Fumito Koike, Mick N. Clout, Mieko Kawamichi, Maj De Poorter and Kunio Iwatsuki

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Important vectors for marine organisms unintentionally introduced to Japanese waters

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Abstract Ships are recognised as a major vector for the introduction of alien marine organisms, either through hull fouling or via ballast water. It is known that 26 species have been unintentionally introduced into Japanese waters and 42.3% of these are presumed to have been introduced by hull fouling. A notable feature of introductions to Japan is that, hull fouling is considered as the most important vector and there are no species that have been introduced solely by ballast water. This is thought to be due to the fact that ballast water, is usually retained within the ship for long enough to kill the organisms within it. The low importance of ballast water as a vector is also a common feature among importers of natural resources. The most significant source regions for species introduced to Japan are the North East Pacific and the East Asian Sea. Meanwhile, introductions from the North West Pacific, which includes countries close to Japan, are few. Because the risk of introduction from the North West Pacific, where the climate is similar to Japan's, can be assumed to be high, care should be taken with introductions, including secondary ones, from this region. Measures that should be taken to prevent or to reduce future introductions to Japanese waters are discussed, taking into account these factors.

Keywords: ballast water; climate similarity; hull fouling; introduction; Japanese waters

INTRODUCTION

Over many centuries, shipping has inadvertently aided the spread of marine organisms. These species are called introduced species, (or alien species) if they end up in areas where they are not native. Some of these introductions have caused economical or ecological problems around the world. An estimate of the cost to the US economy, including the cost of control measures, of alien marine and freshwater organisms exceeded 2.4 billion US dollars a year (Pimentel *et al.* 2000).

Although similar impacts happened in Japan (Arakawa 1980, Anon 2003), neither the current situation nor the cost of restoration or preventative measures are clear. It is said that world trade has increased 14-fold since 1950 and in this period the number of biological invasions of terrestrial, freshwater, and marine habitats has increased exponentially (Hayes 2003). Since this trend is likely to have occurred also in Japan, it is expected that further impacts will be caused by introduced species, now and in the future. To enable us to take measures to prevent or reduce problems caused by introduced species, it is necessary to clarify the current impacts caused by them and to raise public awareness about them.

As already said, an important way of preventing impacts caused by introduced species is by not introducing them, since this is far less costly than eradication of established alien species (e.g., Carlton 2001a). To do this, it is necessary to elucidate the means of introduction, the life histories, and the habitats of current species introduced to Japan. These results may lead to the development of effective measures and technologies to prevent or reduce introductions.

In this study, the vectors by which introduction occur are reviewed with this in mind and, after consideration of their importance for introduction into Japanese waters, a new measure to prevent or reduce introductions is discussed.

A succession of vectors

Before the 19th century, there were only three vectors for the introduction of marine organisms. They were dry or semi-dry ballast, hull fouling, and intentional movement to provide food (Carlton 1999, 2001a, 2001b). The number of vectors has increased over time, with the diversification of marine transport. During the 19th century, three vectors were added: ballast water, importation for aquaculture and the construction of canals, such as the Suez Canal. In the 20th century, the further diversification of marine use, accompanied by rapid economic development, led to the appearance of many new vectors, so that the total number now exceeds 20 (refer Otani 2004). Based on Carlton (2001a), Williamson *et al.* (2002) assigned the

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known vectors into eight broad categories and showed that commercial shipping and aquaculture are the most important ones. Reviewing many studies, Gollasch (2002) also concluded that these two categories provide the main means of introduction of alien species into aquatic ecosystems. Although aquaculture practices may be considered to be the most important vector for certain regions (see Williamson *et al.* 2002), there are many indications that commercial shipping is the most important vector overall (Eno *et al.* 1997, Gollasch 1999, Steneck and Carlton 2001, Fofonoff *et al.* 2003, Hewitt *et al.* 2004, Otani 2004). Before the development of the use of ballast water in the mid-1800s, the category 'commercial shipping' consisted of two vectors, dry or semi-dry ballast and hull fouling. However, the use of dry or semi-dry ballast has gradually reduced with the increased use of ballast water. After the changeover to ballast water in the 1950s (Carlton *et al.* 1995), the two vectors, ballast water and hull fouling, have become important for the transfer of marine organisms by shipping (e.g., Carlton 1985, Williamson *et al.* 2002).

Ballast water

Ballast water is used to add weight and so stabilise the ship at times when the weight of cargo is insufficient to do so or to adjust ship's trim. This system was developed in the mid-1800s and became extensively used over the next decade or so (Carlton *et al.* 1995). The quantity of ballast water has increased with the steady increase in total seaborne trade (Carlton 1985). At present, "it can be concluded that the average annual ballast water discharge worldwide is nearing 3 billion tonnes, whilst the annual ballast water discharge worldwide has changed by small increments since 1996" (Karaminas 2002). The variation in the quantity of ballast water discharged worldwide is expected to be small because shipping capacity is almost constant (Karaminas 2002). Ballast water has received much attention as a vector since the late 1980s because of the dramatic increase of invasions associated with it globally (Fofonoff *et al.* 2003). As long as the quantity of discharged ballast water stays at the present level, it has to be expected that introductions via ballast water will continue unless some kind of effective measure to prevent introductions by ballast water is developed. It is also known that some species introduced via ballast water have caused various economical or ecological impacts. Examples include the zebra mussel (*Dreissena polymorpha*), in the Great Lakes (Morton 1997), Japanese dinoflagellates in Australia (Jones 1981) and the American ctenophore (*Mnemiopsis leidyi*) in the Black Sea (Haribson & Volovick 1994). In response to this threat by ballast water various approaches to cope with ballast water introductions are now in place at the international as well as regional level (Williamson *et al.* 2002). The best known is "The International Convention for the Control and Management of Ships' Ballast Water and Sediments", adopted by the plenary conference of the International Maritime Organisation (IMO) in 2004. This convention requires management and control of ballast water, and it is expected that introductions via ballast water will decrease drastically as a result of its implementation.

Hull fouling

For a long time, hull fouling was considered to be the most important vector for introductions, but after World War II, it was considered less important as a vector because: (1) the expanded use of increasingly effective antifouling paints, (2) ships spending less time in port, and (3) the increased speed of ships (Allen 1953, Carlton 1985, Fofonoff *et al.* 2003). This assumption led to a strong focus on ballast water as the primary vector for introduction. However, Lewis (2001) referred recently to the importance of hull fouling, mentioning several reasons: (1) in spite of the development of antifouling paint, most vessels carry fouling organisms in their unprotected niches, (2) the expansion of the inter-docking cycle may bring on significant levels of fouling in poorly protected areas, (3) effective antifouling paint, which includes TBT, will be banned in 2008, (4) even at high speed, some recessed places can provide havens for fouling organisms, (5) the shortening of the sailing time between ports works advantageously for some species, and (6) some kinds of ships are stationary or laid up for long periods of time. In addition to Lewis (2001), other investigations describe the importance of hull fouling (Cranfield *et al.* 1998, Lewis 2001, Gollasch 1999, Gollasch 2002, Coutts *et al.* 2003, Godwin 2003, Minchin and Gollasch 2003, Otani 2004).

INTRODUCED MARINE SPECIES IN JAPAN

A short history of research on introduced marine species in Japan

The first review of introduced marine species in Japan appeared in 1980. This research was carried out by Arakawa (1980) and reported on 13 introduced species (Tab. 1). Subsequently, although there was some research on introduced species in Tokyo Bay (e.g., Asakura 1992, Kajihara 1996, Furota 1997,

2002) and in Osaka Bay (e.g., Nabeshima 2002), no nationwide review of introduced species was published until the review of Otani (2002). Referring to Asakura (1992), Otani (2002) added five new species to the 13 already described by Arakawa (1980) (Table 1). However, no Japanese researchers, including Otani (2002), applied criteria to judge whether their species were introduced. In addition, due to insufficient records of occurrence in the past, recent taxonomic rearrangements, and confusion over some species reported in those papers, it was likely that some of the species reported in the past as introduced might not actually be so. When Iwasaki *et al.* (2004) surveyed these problems, based on their questionnaire survey carried out during 2002-2003, they reported 26 unintentionally introduced species (Tab. 1), 15 intentionally introduced species, and 20 cryptogenic species in Japanese waters. The determination of status, whether native, introduced, or cryptogenic, was based on new criteria modified from Ruiz *et al.* (2000).

Table 1 Marine organisms unintentionally introduced to Japanese waters reported in each paper. *: Newly arranged to Cryptogenic species by Iwasaki.

Species	Arakawa (1980)	Otani (2002)	Iwasaki *et al.* (2004)
Annelida			
Hydroides elegans	X	X	X
Ficopomatus enigmaticus	X	X	X
Tentaculata			
*Zoobotryon pellucidum**	X	X	
*Bugula californica**	X	X	
Mollusca			
Stenothyra sp.			X
Crepidula onyx		X	X
Nassarius sinarus			X
Cuthona perca			X
Mytilus galloprovincialis	X	X	X
Perna viridis	X	X	X
Xenostrobus securis		X	X
Mytilopsis sallei		X	X
Petricola sp. cf. *lithophaga*			X
Phacosoma gibba			X
Mercenaria mercenaria			X
Arthropoda			
Amphibalanus amphitrite	X	X	X
Amphibalanus eburneus	X	X	X
Amphibalanus improvisus	X	X	X
Amphibalanus variegatus	X	X	X
Amphibalanus venustus	X	X	X
Amphibalanus glandula		X	X
Pyromaia tuberculata			X
Carcinus aestuarii			X
Callinectes sapidus			X
Chordata			
*Ciona intestinalis**	X	X	
Polyandrocarpa zorritensis		X	X
Molgula manhattensis	X	X	X
Phaeophyta			
Cutleria multifida			X
Chrolophyta			
Caulerpa taxifolia			X
Total	13	18	26

Vectors and source bioregions

This study of the vectors responsible for introduction was restricted to the 26 unintentionally introduced species that Iwasaki *et al.* (2004) reported. Intentionally introduced ones (whose vectors were obvious) and cryptogenic species (where it was unclear whether they were introduced or not) are not discussed.

The vectors and source bioregions of each species introduced into Japan were decided by reference to the general literature (see Otani 2004), except that source bioregions were rearranged into the new bioregions used in Hewitt *et al.* (1999). Vectors were compiled into five broad categories (see Cranfield *et al.* 1998): hull fouling, hull fouling or ballast water, ballast water, fisheries, and others or unknown (Tab. 2).

When the number of introduced species by each vector was calculated using data from Japan, “hull fouling” accounted for 42.3%. Adding the category of “hull fouling or ballast water”, (which accounts for 23.1%), and the category of “hull fouling or cargo fouling”, (included in “others or unknown”), to this number, a total of 69.2% of all the species have been introduced by shipping (Fig. 1). In the category of “hull fouling or ballast water”, there are three species such as the spider crab *Pyromaia tuberculata*, the Mediterranean green crab *Carcinus aestuarii*, and the blue crab *Callinectes sapidus*, which we consider not to have been introduced via ballast water but to have been introduced via hull fouling (Otani 2004). Other than these species, it is considered that the Northern quahog *Mercenaria mercenaria* was probably introduced by hull fouling (Otani 2004). If these species are included in “hull fouling”, the number of species introduced by hull fouling increases. For other vectors, “others or unknown” accounts for 23.1% and “fisheries” accounts for 11.5% (Fig. 1). There were no species introduced through ballast water only.

Species have been introduced to Japan from all over the world. Most introduced species are from the East Asian Seas and the North East Pacific, each with six introduced species (Fig. 2). There are only three introduced species from the North West Pacific, in spite of the very similar climate and the high frequency of seaborne trade.

Table 2 Marine organisms unintentionally introduced to Japanese waters, their vectors, and their source regions. Vectors followed Otani (2004) except for *Phacosoma gibba*. Source regions follow Hewitt *et al.* (eds.) (1999). * Rearranged from Okoshi (2004). Abbreviations: A, Accidental release; B, Ballast water; C, Cargo fouling; H, Hull fouling; F, Fisheries.

Species	Presumed primary vector	Presumed alternative vector	Presumed source bioregion
Annelida			
Hydroides elegans	H	B	East Asia Sea, Australia and New Zealand
Ficopomatus enigmaticus	H	B	East Asia Sea, Australia and New Zealand
Mollusca			
Stenothyra sp.	F		North West Pacific
Crepidula onyx	H		North East Pacific
Nassarius sinarus	F		North West Pacific
Cuthona perca	H		Unknown
Mytilus galloprovincialis	H		North East Pacific, Mediterranean, North East Atlantic
Perna viridis	H		East Asian Sea, Central Indian Ocean
Xenostrobus securis	H		Australia and New Zealand
Mytilopsis sallei	H, C		East Asian Sea
Petricola sp. cf. *lithophaga*	Unknown		Unknown
Mercenaria mercenaria	Unknown		North West and North East Atlantic, North East Pacific
******Phacosoma gibba*	*F		*North West Pacific
Arthropoda			
Amphibalanus amphitrite	B, H		East Asian Sea
Amphibalanus eburneus	H		North West Atlantic
Amphibalanus improvisus	H		Unknown
Amphibalanus variegatus	Unknown		Unknown
Amphibalanus venustus	Unknown		East Asian Sea
Amphibalanus glandula	H		North East Pacific
Pyromaia tuberculata	H	B	North East Pacific
Carcinus aestuarii	H	B	Mediterranean
Callinectes sapidus	H	B	North West and North East Atlantic
Chordata			
Polyandrocarpa zorritensis	H		Australia and New Zealand
Molgula manhattensis	H		North West Atlantic, Wider Caribbean, North East Pacific
Phaeophyceae			
Cutleria multifida	H		Unknown
Chlorophyceae			
Caulerpa taxifolia	A?		Unknown

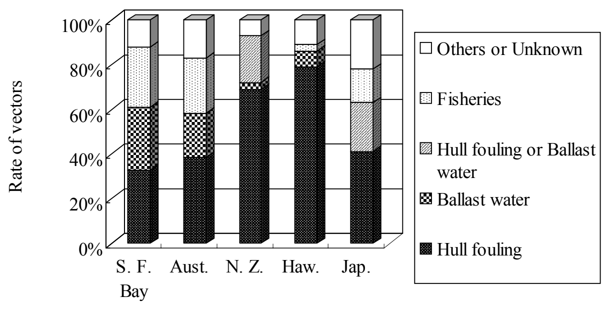

Figure 1 Relative importance of various vectors responsible for the introduction of marine organisms among different regions. (S. F. Bay: San Francisco Bay in 1995; Aust.: Australia in 1995; N. Z.: New Zealand in 1998; Haw.: Hawaii in 1999; Jap.: Japan in 2004) (based on data in Cohen and Carlton 1995, Hewitt and Martin 1996, Cranfield *et al.* 1998, Eldredge and Carlton 2002, Otani 2004)

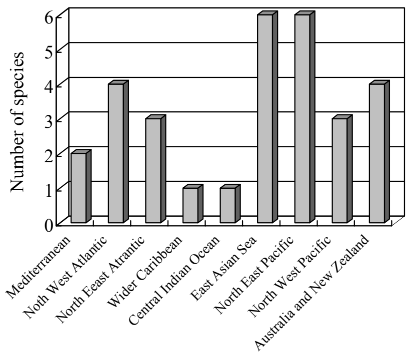

Figure 2 Presumed source bioregions for introduced species in Japanese waters. (In many cases more than one possible vector is considered for a species, so that the total for all bioregions exceeds 26.)

REGIONAL DIFFERENCES IN THE RELATIVE IMPORTANCE OF VECTORS

The number of unintentionally introduced species for each vector was determined to establish the importance of different vectors in Japan. To check whether or not these vectors are specific to Japan, the number of species per vector in some other regions was compared with that in Japan (Fig. 1). These regions are San Francisco Bay, Australia, New Zealand and Hawaii. After removing intentionally introduced species from the results, the number of introduced species per vector was recalculated, except for New Zealand. In the case of New Zealand, the result of Cranfield *et al.* (1998) was used because this rate was calculated based on 148 species unintentionally introduced into New Zealand. In the case of Australia, since Hewitt and Marchin (1996) showed all the possible vectors for the introduction of each species, the number of introduced species per vector was recalculated following the way of Hewitt *et al.* (2004), which gives equal weighting to every vector.

As expected, hull fouling is the most important vector for introduction in all regions, including Japan (Fig. 1). It is tempting to think of this as an inheritance from earlier days, before the use of ballast water was developed, because it is known that many slow-moving wooden sailing ships travelled the world with heavily-fouled hulls (e.g., Carlton 2001b). However, taking account of some recent indications about the importance of hull fouling (Cranfield *et al.* 1998, Lewis 2001, Gollasch 1999, 2002, Coutts *et al.* 2003, Godwin 2003, Minchin and Gollasch 2003, Hewitt *et al.* 2004, Otani 2004) and the fact that hull fouling is the most important vector in all regions, as shown in this study, it cannot be said that hull fouling is only an inheritance. Rather, it should be considered as the most important vector, not only in the past but also at present (see also Cranfield *et al.* 1998).

The importance of introduction by ballast water is different in different regions. For example, the percentage of species that have been introduced by ballast water to San Francisco Bay and Australia is at least 20%. In contrast, this rate is less than 10% in the other three regions. In Japan, notably, there are no species that have been introduced by ballast water alone. The relative importance of introduction by ballast water may be a result of differences in quantity and quality of ballast water discharged in each region.

To check this, I first examined the quantity of discharged ballast water by a single ship in the different regions (Fig. 3). The quantity of discharged ballast water is larger in San Francisco Bay, Australia, and New Zealand than in Japan and Hawaii.

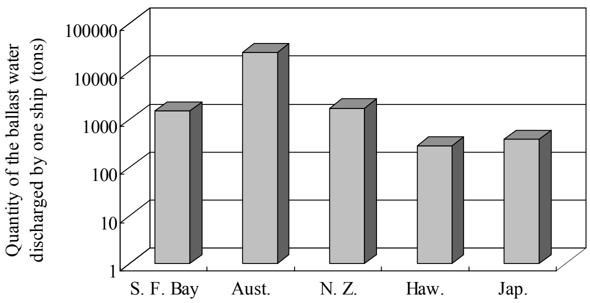

Figure 3 Quantity of ballast water discharged per ship in different regions. This includes all the ships that entered ports of the region, except for Australia. Australia's case includes only bulkers and tankers. (S. F. Bay: San Francisco Bay from 1999 to 2001; Aust.: Australia in 1991; N. Z.: New Zealand from 1996 to 1997; Haw.: Hawaii from 1999 to 2001; Jap.: Japan in 1997) (based on data of Kerr 1994, Hay *et al.* 1997, Ruiz *et al.* 2001, Raaymakers and Gregory 2002)

Comparing these values with the number of introduced species by vector, it is clear that regions with high levels of ballast water discharge correspond to regions that have many species introduced by ballast water (except for New Zealand). This implies that the number of species introduced by ballast water is related to the quantity of ballast water discharged. The quantity of discharged ballast water differs among regions due to differences in their trading patterns, types of ships, etc. Since it is considered that before the 1960s many merchant navies operated without discharging much ballast water, except for some older types of bulk carriers and tankers, it is possible that the difference in the quantity of discharged ballast water caused by trading patterns was smaller than it has been since. Since the 1960s, because of the rapid industry growth in Western Europe and Japan, demand for raw materials such as ore, coal, grain or crude oil increased (Ogawa 1997). In response to this, specialised carriers were developed, including for ore and coal carriers (bulkers), car carrier, and so on. In Japan, where shipbuilding was supported by the Japanese government and by long-term cargo freight guarantees, the number of specialised carriers and enlarged tankers increased in this period (Ogawa 1997). Unlike old merchant navy, bulkers and tankers take up a large quantity of ballast water on the way to the port of loading and discharge almost all of it at the loading port while loading dry bulk or liquid commodities. It is known that the quantity of ballast water taken up by one bulker accounts for 30% to 40% of its DWT (deadweight tons) (Kerr 1994). For example, a 150,000 DWT bulker loads 45,000 tons to 60,000 tons of ballast water (Kerr 1994) and

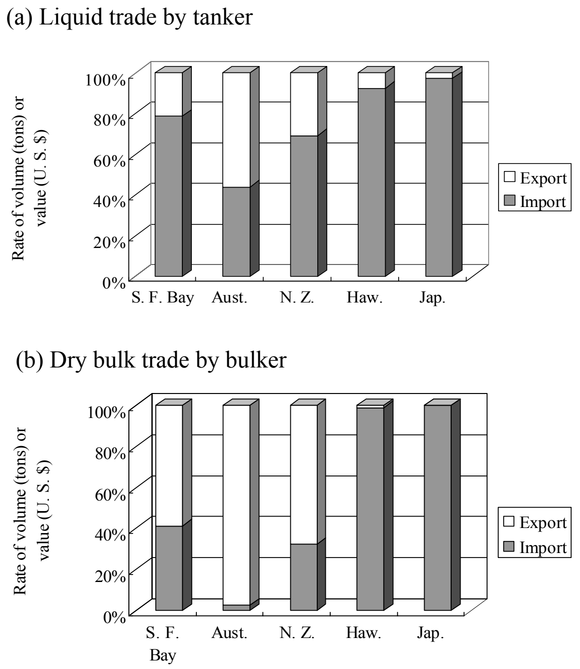

Figure 4 Rate of export and import in volume (tons) transported by dry bulk carrier by region except for New Zealand. For New Zealand import and export are by value (US$). (S. F. Bay: San Francisco Bay in 2000; Aust.: Australia from 2000 to 2001; N. Z.: New Zealand in 1997; Haw.: Hawaii in 2000; Jap.: Japan in 1997) (based on the data of United Nations 2000, U. S. Army Corps of Engineers 2001, The Japanese shipowners' Association 1999, Bureau of Transport and Regional Economics 2003)

discharges almost all of it to allow loading of commodities. Taking into consideration the fact that the sum total of bulkers and tankers accounts for 74.0% by DWT of all the fleets in the world in 2003 (Lloyd's Register Fairplay 2004) and that other parts of the merchant navy do not discharge a lot of ballast water at once (e.g., Kerr 1994, Hay *et al.* 1997), it can be easily recognised that almost all the discharged ballast water in the world is derived from bulkers and tankers. It is therefore assumed that the difference in quantity of discharged ballast between regions is associated with them. Bulkers or tankers call with full ballast water to the region from where dry bulk or liquid commodities are exported. Consequently, regions whose export rate of dry bulk commodities exceeds the import rate are defined as exporters and the reverse ones are defined as importers. The largest quantity of ballast water will be discharged at the exporters and only a small quantity will be discharged at the importers. For liquid trade, which depends on tanker transport, all regions are assigned importer status except for Australia. Meanwhile, for the dry bulk trade, San Francisco Bay, Australia and New Zealand are assigned exporter status and Hawaii and Japan are assigned importer status (Fig. 4). Among exporters, only Australia is an exporter for both. However, it can be considered that the ballast water discharge of Australia depends on bulkers because the volume of dry bulk commodities exported by bulker is more than 13 times that of liquid commodities exported by tanker (Bureau of Transport and Regional Economics 2003).

It is concluded that exporters have a high ballast water discharge by bulkers and that there is a high possibility that many introductions of marine species were caused by ballast water of bulkers. The fact that the rate of introduction via ballast water is higher in San Francisco Bay and Australia than in Hawaii and Japan supports this. New Zealand's case is different. Although this country is considered an exporter of dry bulk commodities (Fig. 4), only a few introduced species are by ballast water, as seen in the fact that the number of species introduced by ballast water itself is only 3% (Cranfield *et al.* 1998). Furthermore, "similar numbers of adventives that arrived in hull fouling have become established in New Zealand over the last 40 years as in the previous 50 years" (Cranfield *et al.* 1998) and so the importance of hull fouling has not changed for a long time. There is also no evidence that the rate of introductions via ballast water has increased. In view of the wide range of invertebrate larvae that were found in the wide variety of vessels and, in particular, in the ballast tanks of bulk carriers (Hay *et al.* 1997), and the fact that New Zealand is an exporter, it would be prudent for them to be prepared for a potential increase of introduction via ballast water in future. In spite of national regulatory measures in New Zealand to control introductions via ballast water, as long as there are living organisms in ballast tanks, the threat of introduction will continue.

In San Francisco Bay and Australia, although hull fouling is the most important vector, it is also thought that ballast water has become a major vector in the past 10 or 20 years (Fofonoff *et al.* 2003, Hewitt *et al.* 2004, Wonham and Carlton 2005). More than 20% of species introduced by ballast water were recorded in these regions. Although national regulatory measures to control introductions via ballast water have been implemented in these regions based on the voluntary guideline adopted at IMO in 1997, the increase of introductions via ballast water needs further attention. It is likely that the rapid increase of transport of dry commodities around the world in the past 20 years has led to a major increase in ballast water discharges in those regions which have been the world's dry commodities exporters (UNCTAD Secretariat 2003) (Fig. 5).

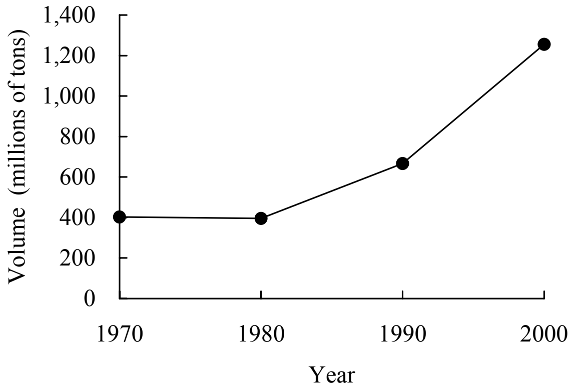

Figure 5 The transition of dry commodities carried by bulker of over 18,000 DWT (dead weight tons) worldwide. (Based on the data from UNCTAD Secretariat 2003)

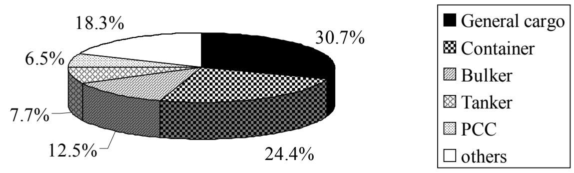

Figure 6 Relative number of ships calling at Japanese ports by ship's type in 1997. (Modified from The Japan Association of Marine Safety 1999)

Introductions via ballast water are lower in importers than in exporters, but importers do not necessarily have zero-discharge ballast water. The reason why introductions via ballast water are low for importers may be due to the "age" of the ballast water in the ballast tanks. As described above, the operation of ballast water is different among ship types or according to the way they are used. More than half of the ocean-going vessels calling at Japanese ports are general cargo ships and container ships (The Japan Association of Marine Safety 1999) (Fig. 6). Although bulkers and tankers still account for about 20% of vessels, they do not discharge a lot of ballast water in Japan because they call with a full load. They only discharge a little ballast water from their after-peak tanks depending on the necessity of adjusting their trim to ensure even keel conditions before entering port.

We estimated the rate of discharge of ballast water by three ship types, such as PCCs (Pure Car Carriers), general cargo ships and container ships in Japan, based on 2002 data from the National Ballast Water Information Clearinghouse (Tab. 3). Although these data are for US ports, considering that the ballast water operations of these three ship types is the same in the US and Japan, it is possible to apply them to Japan.

It is estimated that less than 10% of general cargo ships and PCCs and less than 15% of container ships calling at Japanese ports discharge ballast water. The volume of discharged ballast water into Japanese ports is only about 5% of all the ballast water brought into Japan with these three ship types. This means that the ballast water that is discharged is likely to have been held inboard for a long period. As a general rule, abundance and species diversity of plankton decrease with the length of the confinement of the organisms in the tanks (Gollasch *et al.* 2000). This tendency has been documented (Chu *et al.* 1997, Gollasch *et al.* 2000, Wonham *et al.* 2001), leading to a conclusion that when ballast water is discharged, most of the organisms in it have already died, with the exceptions of diatoms, protozoa and some of the copepoda (e.g., Cohen *et al.* 2000, Chu *et al.* 1997) including the harpacticoida, *Tisbe graciloides*, which are known to increase their number (Gollasch *et al.* 2000). This may suggest the reason why introduction via

Table 3. The number of ships that either discharged or did not discharge ballast water and the amount of ballast water carried and discharged for six US ports by ship type in 2002

		General cargo ship	Container-ship	PCC (Pure Car Carrier)
A	Number of ships that entered with ballast water	282	2 218	126
B	Number of ships that discharged ballast water	18	316	12
	B/A (%)	6.4	14.2	9.5
C	Amount of ballast water carried (metric ton)	908 090	16 933 567	67 505
D	Amount of ballast water discharged (metric ton)	56 327	864 355	25 757
	D/C (%)	6.2	5.1	3.8

1. Followed Packard 1984 to classify ships' type
2. Selected ports are Long beach, Los Angeles, New York, Oakland, San Francisco, and Seattle.
3. Ships for which the type was unknown, or which entered without ballast water were omitted

(Based on data of National Ballast Water Information Clearinghouse) ballast water is of little importance to importers such as Japan.

THE MECHANISM OF INTRODUCTION VIA HULL FOULING

Minchin and Gollasch (2003) described six mechanisms for introduction by hull fouling. They are: (1) spawning and brood release from hulls, (2) detachment of mobile specimens from hulls, (3) colonisation by detachment of organisms from hulls, (4) dropping of fouling organisms by cleaning of hulls, (5) disposition of untreated wastes by the cleaning of hulls at boatyards, and (6) colonisation from hulls of wrecks.

Among these, it is considered that spawning and brood releases from hulls are the most important mechanism for colonisation (Minchin and Gollasch 2003). Lewis (2001) also pointed out that, since a single fertile fouling organism has the potential to release many thousands of eggs, spores or larvae into the water, each with the capacity to found new populations, hull fouling could play an important role for introductions. For example, more than 20 of the Onuphidae (Polychaeta), more than 50 of the European clam *Corbula gibba*, and one male and two ovigerous (= egg bearing) females of the European green crab *Carcinus maenas* were found in a sea chest (Coutts *et al.* 2003) and if these species spawn, considerable numbers of larvae will be released into the water. For example, a 46mm female of *Carcinus maenas* produced 185,000 eggs and released larvae simultaneously into the sea (Yamada 2001). The number of larvae potentially released by the two females in the example above, would amount to 370,000. It is considered that such larvae or eggs can be released through the cooling system of the generator while it is operating during anchorage. When these eggs or larvae are released into the water they may be damaged by the rise in temperature of cooling water or by the intake pump. The temperature of water taken into the cooling system goes up by nearly 10 °C before being discharged into the sea. Research on damage caused by the rise of water temperature for species such as *Acartia tonsa* (Copepoda), zoea of *Sesarma cinereum* (Grapsidae), and the hard clam *Meretrix lusoria* in the cooling system of a power station, shows that the likelihood of death through water temperature increase is low, except during summer when the temperature of the water discharged rises close to 40°C (Suisei Seibutsu to On-Haisui Kenkyu Kyougikai 1973, Dotsu and Kinoshita 1988). This means that almost all the larvae in the cooling system are likely to be released alive. With regard to mechanical damage, it is said that when organisms pass through impellers of the ballast pump, they may get damaged and die within a few days (e.g., Gollasch *et al.* 2000). But given the importance that ballast water plays in introduction in some regions, the mechanical damage caused by the ballast water impeller seems not to be a serious impediment to dispersal. The structure of the pumps used in the cooling system and in the ballast tank is the same, so organisms are likely to live in the cooling system after passing through the pump and likely to be released live into the water.

As in the example of *Carcinus maenas*, the number of larvae discharged from a hull structure like the sea chest is likely to be large. In Japan's case, hull fouling is a much more significant vector, compared to ballast water.

Among the six mechanisms for introduction via hull fouling, there is no doubt of the importance of spawning and brood release as a mechanism for introduction. However, depending on circumstances, other mechanisms are also likely to be important. A survey to clarify the role of different mechanisms for introductions into Japan via hull fouling is needed.

RISK ASSESSMENT

It has been said that over 15,000 species are moved around the world every week in ballast water (Steneck and Carlton 2001). When we add to this the number of organisms that can be moved around the world attached to hulls, we reach a vast number. The situation would be very serious if all of them succeeded in establishing themselves in a new region. Fortunately, however, only a fraction of them survive in the new conditions (Steneck and Carlton 2001).

There are two important conditions that make introduction possible. The first is similarity of climate and marine conditions, such as salinity. Secondly, the volume of shipping traffic and geographical proximity are important (e.g., Gollasch 2002, Clarke *et al.* 2003). For example, in respect of climate, it is said that introductions tend to occur easily between both sides of the same ocean within the same hemisphere, such as between the Asian region and the west coast of North America facing each other across the Pacific Ocean, or between northern Europe and the east coast of North America facing each other across the Atlantic Ocean (e.g., Carlton 1987, Carlton and Geller 1993). Gollasch (2002) states that the risk of introduction from the same climate zone is the highest and that it reduces with the degree of difference of the climate between the donor and the receiver region. It can be seen also from the example of Japan that climate similarity must have facilitated introductions. Referring to the bioregions described by Hewitt *et al.* (eds.) (1999), there are many source bioregions where species introduced into Japanese waters originated. Among them, the North East Pacific and the East Asian Sea are the largest bioregions that are likely to be sources of introduced species in Japanese waters (Fig. 2). The North East Pacific and the North West Pacific are on nearly the same latitude and have a common climate zone with Japan from the subtropical zone to the boreal zone (Nishimura 1981). It is concluded that the commonality of climate between two regions facilitated success in Japanese waters of introductions resulting from the high frequency of shipping traffic (see Raaymakers & Gregory (eds.) 2002). The North Pacific route for introduction mentioned by Carlton (1987) reflects the climate similarity on both sides of the north Pacific Ocean as well as the high frequency of shipping traffic in this area.

The East Asian Sea, another important bioregion for introductions in Japan, overlaps the Indo-West Pacific Region (Nishimura 1981). Its characteristic climate is subtropical to tropical. There are few subtropical zone in Japan; the range from Inubo Saki in the south up to Kyushu belongs to the warm-temperate zone (Asakura 2003). In other words, the Japanese climate zone is largely to the north of this subtropical source region. Gollasch (2002) suggested that introductions can happen from outside the same climate zone, and this happened in the case of Japan. Probably, such introductions occurred because the climate conditions are still fairly similar, combined with the high frequency of shipping traffic between Japan and the East Asian Sea (see Raaymakers and Gregory (eds.) 2002).

Although there are only three reported introduced species from the North West Pacific (Fig. 2), the possibility of introductions from this zone must be consider as high, due to its proximity and to being in the same climate zone. The report of ballast water risk assessment carried out for Dalian in the Peoples Republic of China, (Clarke *et al.* 2003), considers that the risk of introduction from a nearby sea is the highest. Some Korean ports and Iwakuni port in Japan are ranked as "risky" ports with regards to introductions into Dalian port and other ports in China are considered to be "the most risky" ones for Dalian (Clarke *et al.* 2003). The risk depends on the high frequency of the shipping traffic, the climate similarity and the proximity between these ports and Dalian. The considerations for Dalian can also be applied to Japan. It can be said that the risk of introductions from Korea or China, including Dalian, to Japan is high. Although there are few introductions by shipping from these regions now, it would be best to accept that there will be more introductions from these regions with increased shipping traffic (see Raaymakers and Gregory (eds.) 2002). For Britain, it is known that most introduced species came from mainland Europe and that all of them are secondary introductions (Eno *et al.* 1997). It is hence possible that the introductions between regions that are close to each other, including Japan also include secondary introductions, and possibly such secondary introductions from nearby regions may outnumber introductions of species that are native in the nearby source-regions. Secondary introductions from nearby regions are likely to be a problem in Japan in the future.

MEASURES JAPAN SHOULD TAKE TO PREVENT OR REDUCE INTRODUCTIONS OF MARINE ORGANISMS

Japan is one of the biggest sources of ballast water to foreign countries. The volume of ballast water taken from Japan was about 318 million tons in 1997, accounting for more than 10% of all the ballast water discharged in the world in that year (Otani 2004). This means that Japan has to be concerned about the problem of introductions caused by ballast water and has to address, more than most other countries in the world, the management and control of ballast water. At the 1st East Asia Regional Workshop held in Beijing in 2002, Japan expressed a wish to consider measures, including legal aspects, to cope with the problem of ballast water following the convention adopted by the IMO in 2004 (Raaymakers and Gregory (eds.) 2002). However, considering that introduced species from Japan, like the starfish *Asterias amurensis,* have caused damage to the economy or ecosystems in other countries, such as Australia (e.g. Byrne 1996, Byrne *et al.* 1997), Japan should develop statutes and systems and develop treatment technology as fast as possible.

In this study, it was assumed that Japanese marine introductions were mainly caused by hull fouling, but this is not based on actual research data. So far, there have been no surveys of hull fouling carried out specifically focussed on introductions. Furthermore, there is no data about sea chest fouling. Actual surveys of hull fouling, including surveys of sea chests, are required. In particular, such surveys are urgently needed on ships that move back and forth between Japan and countries of the North East Pacific, the East Asian Sea, and nearby countries in the North West Pacific, because as known from the assessment in this study, countries in these bioregions are considered to be the main source regions for introduced marine species in Japan.

With respect to baseline surveys, there are only a few reports about the distribution of marine species in Japan. In particular, there is still insufficient information about the distribution of marine species in Tokyo Bay, Osaka Bay, and Ise Bay, where there are large ports (and where, hence, a large number of introduced species will be expected). This lack of data is a big obstacle to coping with the problem of marine introduction to Japan. It is therefore necessary to carry out, as soon as possible, a nationwide baseline survey, including these areas, to collect data about the presence and distribution of marine species in our waters. This information would enable us, in the future, to detect newly introduced species at an early stage and to take measures suitable for Japanese conditions to prevent or to reduce further marine introductions.

In addition to this, in order to prevent or reduce introductions by hull fouling, which is a major vector in Japan, it is necessary to: (1) develop effective and non-toxic antifouling paint technology and to recommend its use, (2) develop technology to minimise the translocation of organisms on ships' hulls in areas such as sea chests and other parts that are not painted with antifouling paint (these include DDSS (Dry Docking Support Strips), propeller and propeller shaft), (3) increase the frequency of ship dockings, to inspect and to clean hulls, and (4) regulate by statute or ban the underwater cleaning of ships' hulls. Because introductions are caused by international trade and exchange, it is impossible to address the problem in one country or region on its own. It is necessary to address this problem at an international level, just like problem of ballast water has already been addressed internationally.

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