Human-mediated introduction of marine organisms in Japan: a review

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Abstract The present status of human-mediated introductions of marine organisms in Japan is reviewed, based largely on the results of a questionnaire survey conducted in 2002–2003 by the Committee for the Preservation of the Natural Environment of the Japanese Association of Benthology. Taxa were classified according to criteria of known or unknown geographic origin, established invasion history, and presumed dispersal mechanisms associated with human activities. According to these criteria, 42 taxa were designated as introduced alien species, 26 taxa as species introduced from abroad (for fisheries, fishbait, or unintentionally) but where populations that are native to Japan also exist, 20 taxa as cryptogenic species, and 14 taxa as native species that were introduced domestically from an area where they were native in Japan to another area within Japan where they were not native. About half (22 spp.) of the alien species were introduced via shipping, and another half (19 spp.) for fisheries or by unintentional release with imported clams. The introduction rate of the 42 alien species has increased over the past century, with seven or eight species being introduced per decade after 1960. Several alien species have recently become widespread, from the Pacific coasts of central Japan to the Japan Sea coasts or northward, at a rate of 10–26 km per year^{-1}. The sites of the first records of alien species introduced via shipping were concentrated in Tokyo Bay and the eastern part of the Seto Inland Sea, and these were considered to have been the starting points for their dispersal within Japan. Impacts of several introduced species on native ecosystems, fisheries and other industries are also reviewed.

Keywords: alien species; human-mediated introduction; marine organisms; range expansion; rate of spread

INTRODUCTION

Human-mediated introduction of marine organisms beyond their native range has long been of great interest for ecologists and evolutionary biologists. Much information on many invasive marine organisms has been steadily accumulated for the development of risk assessments and management of marine invasions. Since the 1980s, introduced marine animals and plants have been reported in several countries, sea areas or continents (Pacific Ocean: Carlton 1987, Williamson *et al.* 2002, Hong Kong: Morton 1987, Hawaii: Coles *et al.* 1999, Australia: Hutchings *et al.* 1983, New Zealand: Cranfield *et al.* 1998, North America: Ruiz *et al.* 2000, Cohen and Carlton 1995, Europe: Leppäkoski *et al.* 2002).

In Japan, several authors have reported on regional fauna of introduced marine animal species (Tokyo Bay: Asakura 1992, Kajihara 1996, Furota 1997, 2001, 2002, Osaka Bay: Nabeshima 2002), their invasion history and distribution of introduced sessile animals (Arakawa 1980, Otani 2002), and the presumed vectors of 25 introduced marine organisms (Otani 2004). However, all these studies have not applied criteria to judge whether the species were introduced or not. Recent taxonomic rearrangements or confusion over some species reported in these papers have suggested that some of the species reported in the past as introduced might not be so. Such taxonomic problems, and insufficient survey records in the past for introduced marine organisms, have made it difficult to decide if the species are native or introduced (Carlton 1996). The application of standard criteria is essential to judge demonstrably human-mediated introduction of marine organisms. However, there have been no such systematic studies on a nationwide scale in Japan, and very few throughout the world (Chapman and Carlton 1991, 1994, Ruiz *et al.* 2000).

In 2002 and 2003, the Committee for the Preservation of the Natural Environment of the Japanese Association of Benthology (CPNE), carried out a questionnaire survey on the occurrence of introduced marine organisms in the field, including both published and unpublished records (Iwasaki *et al.* 2004a). The results obtained from the survey have been analysed by the committee, and the invasion history, geographic distribution and rate of range extension of introduced species in Japan have been published by Iwasaki *et al.* (2004a, 2004b) and Kimura *et al.* (2004). The present paper reviews these studies and provides an overview of human-mediated introduction of marine organisms in Japan.

Pages 104-112. In Koike, F., Clout, M.N., Kawamichi, M., De Poorter, M. and Iwatsuki, K. (eds), *Assessment and Control of Biological Invasion Risks*. Shoukadoh Book Sellers, Kyoto, Japan and IUCN, Gland, Switzerland, 2006.

METHODS OF THE QUESTIONNAIRE SURVEY

In 2002 and 2003, the CPNE sent a questionnaire, by e-mail or post to about 150 members of the Japanese Society of Benthology, the Sessile Organisms Society of Japan, the Malacological Society of Japan, and the Plankton Society of Japan, asking for the date and site of records for marine organisms considered to be introduced by human activities. Additionally, we asked the members to detail any documents or publications which have reported the occurrence of an introduced species in Japan. As a result of this survey, 94 respondents reported a total of 102 taxa.

Criteria for assessing the invasion and population status

Iwasaki *et al.* (2004a) assigned the 102 taxa to one of three categories of invasion status: introduced species, cryptogenic species (*sensu* Carlton 1996), and native species, with a set of criteria described below. Additionally, the report further classified the introduced species as one of the following (see Fig. 1):

a) Alien species introduced to Japan from abroad. The species does not have native populations in Japan.
b) Species introduced from abroad, but which also has populations that are native to Japan. The species hence has native populations both in Japan and abroad. The introductions took place for fisheries, fishbait or unintentional.
c) Domestically introduced: a species that is native in Japan but that has been introduced (= human induced movement) to another area in Japan where it is not native.

The criteria used to assign one of the three categories of invasion status were:

(1) Introduced species
  1) The species is not recognised as native in an area, and
  2) The distinction between the native and introduced range is known or inferred, and
  3) Vectors for the species to the area can be confirmed or inferred.
  4) For species that also have native populations in Japan, we assigned the invasion categories "introduced from abroad" or "introduced domestically" when their vectors for introduction to the new area from their native region were confirmed or inferred.

(2) Cryptogenic species (possible introductions: *sensu* Carlton 1996)
  1) The species is not recognised as native in an area, but
  2) The above criteria of (1)-2) and (1)-3) do not apply to the species, or
  3) The species scientific identity cannot be established due to taxonomic problems or confusion.

(3) Native species
  1) The species whose native range is well established and where clear evidence of native status is available.

Iwasaki *et al.* (2004a) classified the population status of each non-indigenous species as either established

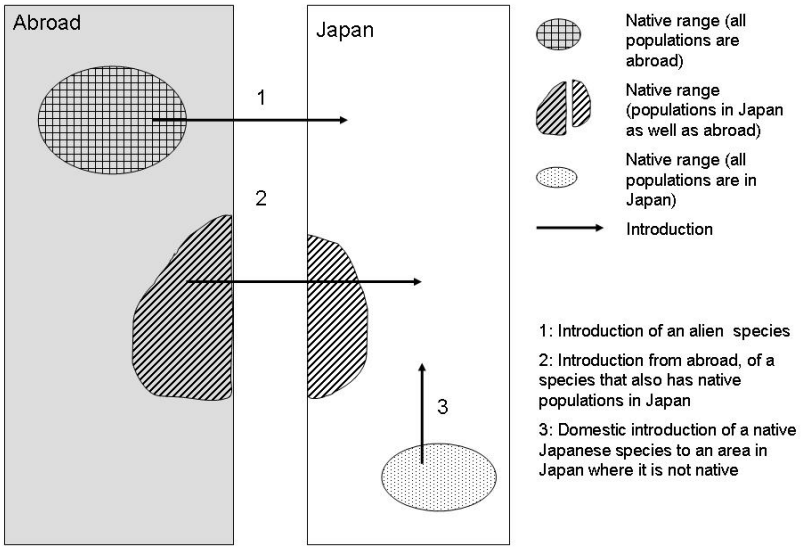

Figure 1 Further classification of introduced species (see text).

or unknown, according to the following criteria:

(1) Established
    1) The species' occurrence has been confirmed for two or more years in at least one prefecture since 1990, and
    2) Occurrence of breeding individuals has been confirmed in the field since 1970, or the occurrence of two or more cohorts, with very different size classes, has been confirmed for two or more successive years in one area since 1970.

(2) Unknown
    1) Species other than (1) above.

RESULTS FROM QUESTIONNAIRE SURVEY

Alien species introduced into Japan

A total of 42 species were designated as alien species by Iwasaki *et al.* (2004a) (Tab. 1 and 2). Twenty-two species were presumably transferred through shipping (Tab. 1), and Otani (2004, 2006) considers that the most plausible vector for most of the species was fouling on ship hulls. Establishment of populations of four species, the nudibranch *Cuthona perca*, the barnacles *Balanus variegatus cirratus* and *Balanus venustus*, and the crab *Callinectes sapidus*, could not be confirmed by Iwasaki *et al.* (2004a) (Tab. 1).

Nineteen taxa were introduced intentionally for fisheries (16 species), or unintentionally with the imported aquatic products (3 spp.) (Tab. 2). The snail *Nassarius* (*Zeuxis*) *sinarus*, which is considered to have been introduced unintentionally with bivalves imported from the Korean Peninsula, established its population in the Ariake Inlet, the largest inlet in Japan. The bivalves, *Corbicula* spp., have been imported abundantly from China and Korea, established their populations in many estuaries and rivers, and now expand their range rapidly in many prefectures. The population status of 16 other species is unknown due to the scarcity of information (Iwasaki *et al.* 2004a) (Tab. 2).

The green alga *Caulerpa taxifolia* is native to subtropical regions of Japan. However, the Mediterranean-adapted clones probably escaped from aquaria were found in temperate regions in 1992,

Table 1 Alien marine organisms introduced probably via shipping, modified from Iwasaki *et al.* (2004a). Population status; E: established, U: unknown. First record; HO: Hokkaido island, JS: Japan Sea, PO: Pacific Ocean, SIS: Seto Inland Sea, ECS: East China Sea including Ariake Inlet, SWI: South West Islands (For locations, see Fig. 3). **F**: year of first record in Japan, +: year unknown. Source region and presumed vector for each species are listed in Otani (2004, 2006).

Species	Population status	First record					
		HO	JS	PO	SIS	ECS	SWI
Gastropoda							
Crepidula onyx	E	2001	2000	**F1968**	1978	1988	
Cuthona perca	U			**F1992**			
Bivalvia							
Mytilus galloprovincialis	E	1995	1941	1935	**F1932**	1950	
Perna viridis	E		1992	1980	**F1967**	2000	1983
Xenostrobus securis	E		1986	1979	**F1972**	2003	
Mytilopsis sallei	E		1984	**F1974**	1990		
Petricola sp. cf. *lithophaga*	E			1989	**F1985**		
Mercenaria mercenaria	U			**F1998**			
Polychaeta							
Ficopomatus enigmaticus	E		1990s	1969	**F1966**		1980
Hydroides elegans	E		1983	**F1936**	1962	1950	1970s
Crustacea							
Balanus amphitrite	E	1963	1963	**F1935**	1938	1937	
Balanus variegates cirratus	U		1937		1963	**F1936**	
Balanus venustus	U		**F1967**				
Balanus eburneus	E		1963	**F1950**	1963	1963	
Balanus improvisus	E		1967	**F1952**	1962	1963	
Balanus glandula	E	2000		**F2000**			
Pyromaia tuberculata	E		1982	**F1970**	1970s		
Carcinus aestuarii	E		1996	**F1984**	1996		
Callinectes sapidus	U			**F1975**	1984		
Ascidiacea							
Polyandrocarpa zorritensis	E			**F1991**	1999	**F1991**	
Molgula manhattensis	E		1992	1975	**F1972**		
Phaeophyta							
Cutleria multifida	E			+	+		F1957

Table 2 Alien marine organisms introduced intentionally for fisheries (Fisheries) or aquarium industry (Aquarium), or unintentionally with the aquatic products (Unintentional), modified from Iwasaki *et al.* (2004a).

Species	Vector	First record	Population status
Gastropoda			
Haliotis rufescens	Fisheries	1966	Unknown
Haliotis kamtschatkana	Fisheries	1980s	Unknown
Haliotis tuberculata	Fisheries	1980s	Unknown
Stenothyra sp.	Unintentional	2000	Unknown
Nassarius sinarus	Unintentional	2000	Established
Bivalvia			
Ostrea edulis	Fisheries	1952	Unknown
Ostrea lurida	Fisheries	1948	Unknown
Crassostrea virginica	Fisheries	1956	Unknown
Corbicula sp.	Fisheries	1987?	Established
Phacosoma gibba	Unintentional	2002	Unknown
Meretrix petechialis	Fisheries	1969	Unknown
Crustacea			
Penaeus chinensis	Fisheries	1965	Unknown
Homarus americanus	Fisheries	1914	Unknown
Homarus gammarus	Fisheries	1978	Unknown
Eriocheir sinensis	Fisheries	1999?	Unknown
Osteichthyes			
Acipenser sinensi	Fisheries	1965	Unknown
Acipenser sturio	Fisheries	1975	Unknown
Salmo gairdneri	Fisheries	1929	Unknown
Salmo salar	Fisheries	1980	Unknown
Chlorophyta			
*Caulerpa taxifolia**	Aquarium	1992	Unknown

*: Mediterranean-adapted clones

1993 and 1994 (Iwasaki *et al.* 2004a). The population status of these is unknown (Tab. 2). We assigned this Mediterranean-adapted clones as "introduced species" because their ecology, physiology, morphology and potential impacts on native ecosystems are quite different from those of native populations.

Rate of introduction and site of first record for alien species

Analysis of the years of the first record for 42 alien species suggests that the rate of introduction has increased over the past century, with seven or eight species being introduced per decade after 1960 (Fig. 2) (Iwasaki *et al.* 2004a).

The sites of the first records for 42 alien species, which were reported by Iwasaki *et al.* 2004a, are shown in Fig. 3. Most species were recorded first along the coast of the Pacific Ocean or the Seto Inland Sea, reflecting the quantity and concentration of foreign trade goods in the regions. More than half of the 22 species introduced via shipping were first found in Tokyo Bay (6 spp.) or in the eastern part of the Seto Inland Sea including Osaka Bay (6 spp.), where the large ports are concentrated. Accordingly,

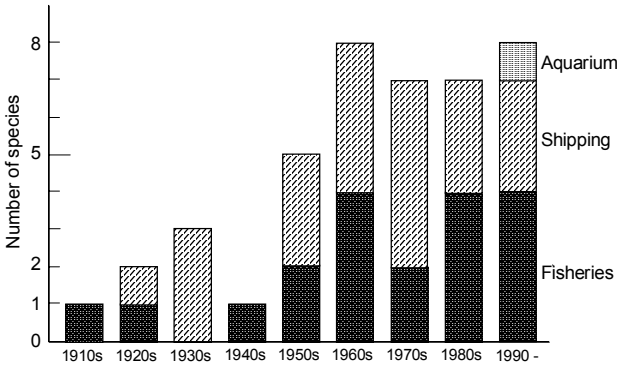

Figure 2 Years of the first records for 42 alien species introduced into Japan, modified from Iwasaki *et al.* (2004a). Probable vectors via which the species were introduced ("fisheries" for release or aquaculture, "shipping" in hull fouling or ballast water transport, and "aquarium" industry) are shown in different shadings.

the establishment of monitoring systems at the large ports in these regions is essential to detect new alien species at the early stage of their introduction via shipping.

The sites of first records for species introduced for fisheries are distributed widely in Japan. However, most intentional introductions were conducted by national or prefectural institutes for fisheries science and the sites of first records are concentrated around these institutes.

Rate of spread of several alien species

Data on temporal change in geographic distributions revealed that many alien species have become widespread recently, from the Pacific coasts of central Japan to the coasts of the Japan Sea or northward (Tab. 1) (Iwasaki *et al.* 2004a). The rate of spread for 8 alien species which had over 50 records for their occurrence in the field was calculated through regression analyses of the farthest distances of the recorded sites from the sites of first records against the time after the year of first record (Iwasaki *et al.* 2004b). All 8 species are considered to have been introduced via shipping. Five of the 8 showed a significant correlation between the greatest distance of spread in each year and time after the first record. Their average rate of spread ranged from 10 to 26km year^{-1} (Tab. 3), 26.4km year^{-1} for the slipper snail *Crepidula onyx*, 10.9km year^{-1} for the Mediterranean mussel *Mytilus galloprovincialis*, 23.9 km year^{-1} for the mytilid mussel *Xenostrobus securis*, 13.9km year^{-1} for the European barnacle *Balanus improvisus*, and 24.7km year^{-1} for the Mediterranean green crab *Carcinus aestuarii*. The distance-versus-time curves for the five species showed no saturation phase during which no

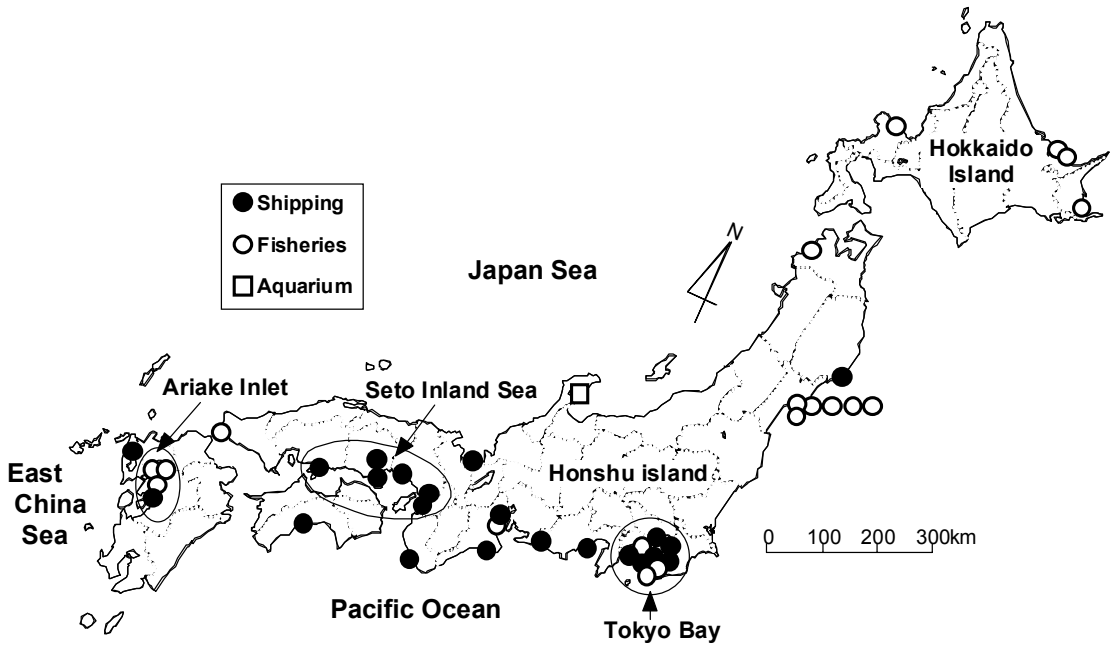

Figure 3 Sites of first records for 42 alien species introduced into Japan through fisheries for release or aquaculture (open circle), shipping (either hull fouling or ballast water) (closed circle), or aquarium industry (open rectangle).

range expansion takes place in the final stage of invasion. Thus their geographic ranges were considered to be expanding still. For the other three species, range expansion for the two barnacles, *Balanus amphitrite* and *B. eburneus,* was considered to have occurred only in the early stage of invasion and to have ceased by 10–15 years after the date of the first record. Information on the geographic distribution for the remaining species, the serpulid polychaete *Hydroides elegans,* was not sufficient to examine the pattern of its range expansion.

The sites of the first records for unintentionally introduced species were considered to have been the starting points for their spread in Japan (Iwasaki *et al.* 2004b). We suggest that eradication or control of the initially established populations as soon as they are discovered is essential to prevent the spread of introduced marine organisms in Japan.

Table 3 Long term trend of the range expansion of 8 non-indigenous species was examined by linear regression ($y = a + bx$) of the farthest distance from the site of first record (y) against the year (x) after first record (the year of first record = 0). The rate of spread is estimated by the slope (b) of the regression. n: number of samples (If there are multiple records in a year, only the record with the farthest distance from the site of first record was used. So the number of samples is smaller than 50 in several species.), R^2: coefficient of determination, a: Y-intercept, b: slope of regression, P: probability. After Iwasaki *et al.* (2004b).

Species	n	R^2	a	b	P
Gastropoda					
Crepidula onyx Sowerby	35	0.730	125.3	26.4	<0.001
Bivalvia					
Mytilus galloprovincialis Lamarck	58	0.215	497.1	10.9	<0.001
Xenostrobus securis (Lamarck)	32	0.677	14.2	23.9	<0.001
Polychaeta					
Hydroides elegans (Haswel)	31	0.068	271.1	3.9	0.158
Crustacea					
Balanus amphitrite Darwin	53	0.046	835.1	-5.2	0.121
Balanus eburneus Gould	38	0.032	924.5	7.3	0.279
Balanus improvisus Darwin	44	0.295	223.1	13.9	<0.001
Carcinus aestuarii Nardo	14	0.329	-54.7	24.7	0.032

Species introduced from abroad, but for which native Japanese populations also exist

Iwasaki *et al.* (2004a) designated twenty six taxa as species which have been introduced from abroad to Japan for fisheries or as fishbait (Gastropoda: 9 spp., Bivalvia: 10 spp., Brachiopoda: 1sp., Polychaeta: 3spp., Crustacea: 1sp., Osteichthyes: 2 spp.). All introductions were from China or Korea, intentionally for fisheries, or unintentionally with imported aquatic products (Tab. 4).

Yokogawa (1997) reported morphological and genetic differences between the introduced Chinese populations of the red arch shell *Scapharca broughtonii* and the Japanese ones. Introduction into Japan of different populations may disturb the genetic diversity of native populations through inbreeding. Before such introduction from abroad is considered, special caution and scientific research is needed to ensure the

Table 4 Introduced species from abroad but where native Japanese populations also exist: introductions for potential release as human food (Release) or fish bait (Fish bait), and unintentionally with imported aquatic products (Unintentional), modified from Iwasaki *et al.* (2004a).

Species name	Vector
Gastropoda	
Umbonium moniliferum	Unintentional
Batillaria cumingii	Unintentional
Euspira fortunei	Unintentional
Glossaulax didyma	Unintentional
Glossaulax reiniana	Unintentional
Rapana venosa	Unintentional
Reticunassa festiva	Unintentional
Varicinassa varicifera	Unintentional
Bivalvia	
Scapharca broughtonii	Release
Scapharca kagoshimensis	Unintentional
Crassostrea gigas	Unintentional
Mactra chinensis	Unintentional
Mactra veneriformis	Unintentional
Macoma contaculata	Unintentional
Sinonovacula constricta	Release
Ruditapes philippinarum	Release
Cyclina sinensis	Unintentional
Brachiopoda	
Lingula unguis	Unintentional
Polychaeta	
Perinereis nuntia	Fish bait
Perinereis aibuhitensis	Fish bait
Marphysa sanguinea	Fish bait
Crustacea	
Philya pisum	Unintentional
Osteichthyes	
Oncorhynchus kisutch	Release
Oncorhynchus tshawytscha	Release

conservation of native genetic resources (ICES 1995), however, no such measures have ever been taken in Japan.

"Domestic introduction" of Japanese native species

Fourteen taxa were designated as species native to Japan but introduced (= human induced movement) within Japan to regions where they are not native (Gastropoda: 3 spp., Bivalvia: 5 spp., Polychaeta: 1 sp., Crustacea: 3 spp., Echinoidea: 1 sp., Rhodophyta: 1 sp.) (Iwasaki *et al.* 2004a). The vector for about 80% of them is considered to be intentional and unintentional releases for fisheries. However, the list of such species introduced to areas where they are not native through fisheries (Iwasaki *et al.* 2004a) is not exhaustive. It is likely that many such species were introduced to non-native areas in Japan since the late 19th century (Murakami 1999).

Cryptogenic species

Twenty taxa were considered to be cryptogenic species which can not be recognised as either native or introduced (Gastropoda: 3 spp., Bivalvia: 3 spp., Bryozoa: 2 spp., Polychaeta: 2 spp., Crustacea: 3 spp., Ascidiacea: 1 sp., Osteichthyes: 2 spp., Dinophyceae: 2 spp., Rhodophyta: 1 sp., Chlorophyta: 1 sp.) (Iwasaki *et al.* 2004a). This is largely due to taxonomic problems in which current species names are invalid or to the scarcity of information on geographic distribution, invasion history or presumed invasion vectors.

IMPACTS OF INTRODUCED SPECIES

Genetic disturbance through hybridisation

Inoue *et al.* (1997) and Rawson *et al.* (1999) reported that genetic mixing between the Mediterranean mussel *M. galloprovincialis* and the native mussel *M. trossulus* was occurring on Hokkaido Island, the most northern part of Japan, suggesting hybridisation between the two species. The possibility of genetic disturbance through hybridisation or introgression has been pointed out in the case of the Chinese mitten crab *Eriocheir sinensis* and the native mitten crab *E. japonica* (Kobayashi 2003), the Chinese hard clam *Meretrix petechialis* and the native hard clam *M. rusoria* endemic to Japan (Kosuge 2002), alien and native Colbiculid bivalves (Komaru 2002), and the introduced (from abroad) and native populations of species native to Japan (Yokogawa 1997), although there has been no research so far to confirm this.

Exclusion and predation of native species

In the Tohoku District, northern part of Honshu Island, the Mediterranean mussel *M. galloprovincialis* has covered and out-competed native species, such as the barnacle *Chthamalus challengeri*, the oyster *Crassostrea gigas*, the mytilid bivalve *Septifer virgatus,* and the brown alga *Hizikia fusiforme* in the lower intertidal zones (Hoshiai 1958, 1960, 1961, 1964, 1965). It is believed that rocky intertidal communities of sheltered shores in Honshu, Shikoku and Kyusyu Islands have changed drastically after the invasion of this species.

The striped barnacle *Balanus amphitrite,* which was introduced probably in the 1930s, extended its geographical range in 1960s and 1970s over almost all of Honshu Island. Its predominance on the estuarine hard substrata is suggested to have drastically decreased the density of the native barnacle *Balanus reticulatus* (Yamaguchi 1989).

Until the mid-1990s, the native moon snail *Euspira fortunei* occurred only in the Ariake Inlet with very low density and it has been considered endangered in Japan. Since the mid-1990s, however, populations of this species have been introduced from abroad to regions in Japan where the species is not native. These introductions were unintentional, with the edible clam *Ruditapes phillipinarum* imported from China and Korea. Outbreaks of the populations introduced from abroad occurred on several locations on the shores of Honshu Island, and the carnivorous snails predated clam and other native bivalves, presumably causing drastic changes in the species composition of native sand-mud flat communities (Okoshi 2004).

Economic damage to fisheries

An outbreak of the serpulid polychaete *Hydroides elegans* in Hiroshima Bay has caused the heavy economic loss to cultured oyster crops through fouling on their shells, estimated at ¥3 billion in 1969 (equivalent to ca ¥10 billion today) (Arakawa 1971). Removal of the calcareous tubes from the shells of cultured oysters and pearl oysters is recognised as a great nuisance to oyster farmers.

The economic damage caused by *M. galloprovincialis* to the aquaculture of oysters, pearl oysters and scallops has been reported many times. For instance, an outbreak of this species near Hiroshima Bay in 1973 caused serious economic damage to cultured oyster crops, with a loss estimated at ¥500 million (equivalent to ca ¥1.5 billion today) (Arakawa 1974).

The carnivorous snail *Nassarius sinarus,* which was presumably introduced from Korea with imported bivalves, had an outbreak in the Ariake Inlet and predated gobies in the fishing nets (Fukuda 2004).

The above-mentioned introduced moon snail *Euspira fortunei* caused collapse of local clam fisheries in several shores from 2000 to 2004 (Okoshi 2004). Local fisheries cooperative associations tried to exterminate the populations that were introduced from abroad, but failed.

Economic damage to power plants and other factories

Mytilus galloprovincialis and the green mussel *Perna viridis* are considered to be the first and second worst fouling organisms of intakes of power stations and other factories on the Pacific coasts, causing the greatest amounts of serious damage to equipment and resulting in enormous costs of removing the mussel beds (Anon. 2003). Although no economic losses attributable to fouling mussels have been estimated, it is believed that the costs would have been reduced by more than half without the invasion of the mussels (Kajihara 1983). Other alien species such as the Serpulid polychaete *H. elegans,* the striped barnacle *B. amphitrite,* the European barnacle *B. improvisus*, and the ivory barnacle *B. eburneus* are also known to cause fouling damage to power stations (Anon. 2003).

Management and policy against marine invasion in Japan

To date, no Japanese official agencies or private sectors have taken effective measures to control or manage the introduction of marine organisms, or to promote public awareness (Williamson *et al.* 2002). The Invasive Alien Species Act, which was enforced in June 2005 in Japan, designates Invasive Alien Species and prohibits them from being raised, imported or otherwise handled. Surprisingly, however, no marine organisms are designated as Invasive Alien Species in this Act. Scientists should collect the information on ecological impacts of invasive marine species and keep appealing to the authorities to prevent their introduction.

Far East Asia, including Japan, is well known as one of the major donor regions of introduced marine organisms (Carlton 1987). Immediate official initiatives in cooperation with other countries are essential to prevent or reduce human-mediated introductions to Japan as well as from Japan to other countries.

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