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A Rapid Assessment Survey of Invasive Species of Macrobenthic Invertebrates in Korean Waters

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Abstract – Introduced species are a growing and imminent threat to living marine resources in parts of the world's oceans. The present study is a rapid assessment survey of invasive macrobenthic invertebrate species in Korean ports. We surveyed over 40 ports around Korea during the period of May 2010~March 2013. Among the sampling sites were concrete walls, docks and associated floats, bumpers, tires, and ropes which might harbor non-native species. We found 15 invasive species as follows: one Sponge, two Bryozoans, three Mollusks, one Polychaete, four Cirripedes, and four Ascidians. Three morphologically similar species, namely *X. atrata*, *M. galloprovincialis*, and *X. securis* were further examined for distinctions in their morphology. Although they could be reasonably distinguished based on shell shapes, significant overlap was noted so that additional analysis may be required to correctly distinguish them. Although many of the introduced species have already spread to all three coastal areas, newly arrived invasive species showed a relatively restricted range, with a serpulid polychaete *Ficopomatus enigmaticus* and a mytilid bivalve *Xenostrobus securis* found only at a few sites on the East Coast. An exception is for *Balanus perforatus,* which has rapidly colonized the East coast of Korea following its introduction into the region. Successful management of invasive macrobenthic invertebrates should be established in order to contain the spread of these newly arrived species.

Keywords – marcobenthos, invasive species, Korean waters, distribution

1. Introduction

Many inland and coastal water environments around the world are heavily invaded by non-native species. These invasive species can have a great impact on local native populations and ecosystems. They may also alter the structure and ecological functioning of critical habitats and affect aquaculture and fishery, with consequent significant pressures being placed on natural resource management and conservation of coastal habitats.

The Korean coastal waters and adjacent areas are generally known to be less invaded ecosystems, probably due to the relatively low volume of foreign waters being discharged (e.g., via ships ballast water (Ohtsuka et al. 2004). Nonetheless, surveys conducted in these waters show that some non-indigenous species (NIS) have invaded some regions (Chavanich et al. 2010).

There are, so far, a total of 18 non-native fouling species officially designated as invasive by the Korean government (MOMAF 2011), although other numerous species may also be considered cryptic. Voiding of ballast water and hull fouling have been implicated in many of the introductions of these species.

Regardless of its source of introduction, it is important to know the current status of the distribution of an invasive species, from which efforts can be initiated to manage those species that have already invaded. Some of the macrobenthic organisms are of commercial importance, with many being cultured. There have been infrequent surveys and reports about invasive marine macrobenthic organisms in Korean waters. However, no comprehensive study has so far been conducted to monitor their presence in major harbors and adjacent waters.

In this study we aimed to identify the distribution of those invasive fouling macrofauna from which we could set up a

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plan to manage those species (for example, limit their spread around coastal waters). We also aimed to detect any further invasive organisms in the major harbors that have not been previously reported.

2. Materials and Method

The field sampling was carried out for about three years from May 2010 through March 2013, encompassing 153 sampling sites of 42 major Korean ports. The 1st year survey was focused on the East Coast and Jeju Island, the 2nd year on the South Coast, and the 3rd year on the West Coast (Fig. 1).

Sampling sites included structures around the ports such as concrete walls, docks and associated floats, bumpers, tires, and ropes where fouling organisms could mostly be found. For submerged areas in the docks, picturing and sampling were carried out by diving. The collected sample specimens were preserved in 3.7% buffered formaldehyde or 70% alcohol. Scraping was conducted on a surface of 50 cm × 50 cm and the coverage of each surface by each species was examined, categorizing each site as rare (if coverage of a species is < 10% of the surface), common (10–70%), and abundant (> 70%).

Morphological comparisons were made for the three species *Xenostrobus atrata*, *Mytilus galloprovincialis*, and the newly invaded *X. securis,* as they are similar in looks. Thirty randomly selected individuals of each species were measured for shell length on different parts (see Results) with an image analysis system (Lumion Inc., Warmond, The Netherlands). The measurement was made down to 0.01 mm unit. Principal component analysis was conducted to extract the orthogonal components to discriminate the three species based on morphological characteristics.

3. Results and Discussion

A total of 15 invasive species were found during the survey (Table 1), including one sponge, two bryozoans, three mollusks, one polychaete, four cirripedes, and four ascidians. Many of the species complex detected were found on all three coasts of Korea (Fig. 1). The most widely spread species was *Mytilus galloprovincialis,* with a high coverage at many of the sampling sites (Fig. 1a). The individual invasive species distribution showed some distinctive patterns. *Balanus perforatus* was restricted in its distribution only to the east and south-east coast (Fig. 1b). *Ciona intestinalis* was widespread, but was missing along the south-western part of the coast. (Fig. 1c). *Crepidula onyx* was found on the south and east coast, but was not detected on the west coast (Fig. 1d). Two newly invaded species were recorded during the survey, including a serpulid polychaete *Ficopomatus enigmaticus* and a mytilid bivalve *Xenostrobus securis* (Fig. 1e, f). *X. securis* were found only at three sites, and *Ficopomatus enigmaticus* at

Table 1. Non-native species found during the survey and their historic record of invasion

Species	Native Range	First Report in Korea	References
Halichondria bowerbanki Burton, 1930	the British Isles	Tongyoung, Korea in 2008	Jeon and Sim 2009
Bugula neritina Linnaeus, 1758	Cosmopolitan in temperate, subtropical and tropical waters	Gogunsan Island and Bian Island.	Rho and Lee 1980
Schizoporella unicornis Johnston in Wood, 1844	Cosmopolitan	1980s?	Song 1985
Crepidula onyx Sowerby, 1824	Eastern Pacific Ocean coast of the Americas	Guryongpo in 1992	Choe 1992
Mytilus galloprovincialis Lamarck, 1819	the Mediterranean, Black, and Adriatic Seas	Busan Port in 1936	Lee et al. 2010
Xenostrobus securis Lamarck, 1819	New Zealand and Australia		This study
Ficopomatus enigmaticus Fauvel, 1923	Australia		This study
Balanus amphitrite Darwin, 1854	Cosmopolitan	Jeju in 1970's	Kim and Kim 1980
Balanus eburneus Gould, 1841	Nova Scotia to the Caribbean Sea and Gulf of Mexico	Guryongpo in 1981	Kim 1992
Balanus perforatus Bruguière, 1789		Guryongpo in 2006	Kim and Hong 2012
Balanus improvisus Darwin, 1854	Cosmopolitan	East Coast in 1980's	Kim 1992
Ciona intestinalis Linnaeus, 1767	Cosmopolitan	Tongyoung in 1970's	Kim et al. 1980
Styela plicata Lesueur, 1823	Cosmopolitan in tropical to temperate waters	In 1960's	Rho 1968
Ascidiella aspersa Müller, 1776	Norway to the Mediterranean	Southern coastal area in 2009	Pyo et al. 2012

two sites on the east coast only.

Principal component analysis revealed that the three principal components accounted for 82% of the morphological variation among the three morphologically similar species *X. securis, X. atratus* and *M. galloprovincialis* (Table 2). The length ratio of some morphological features was significantly

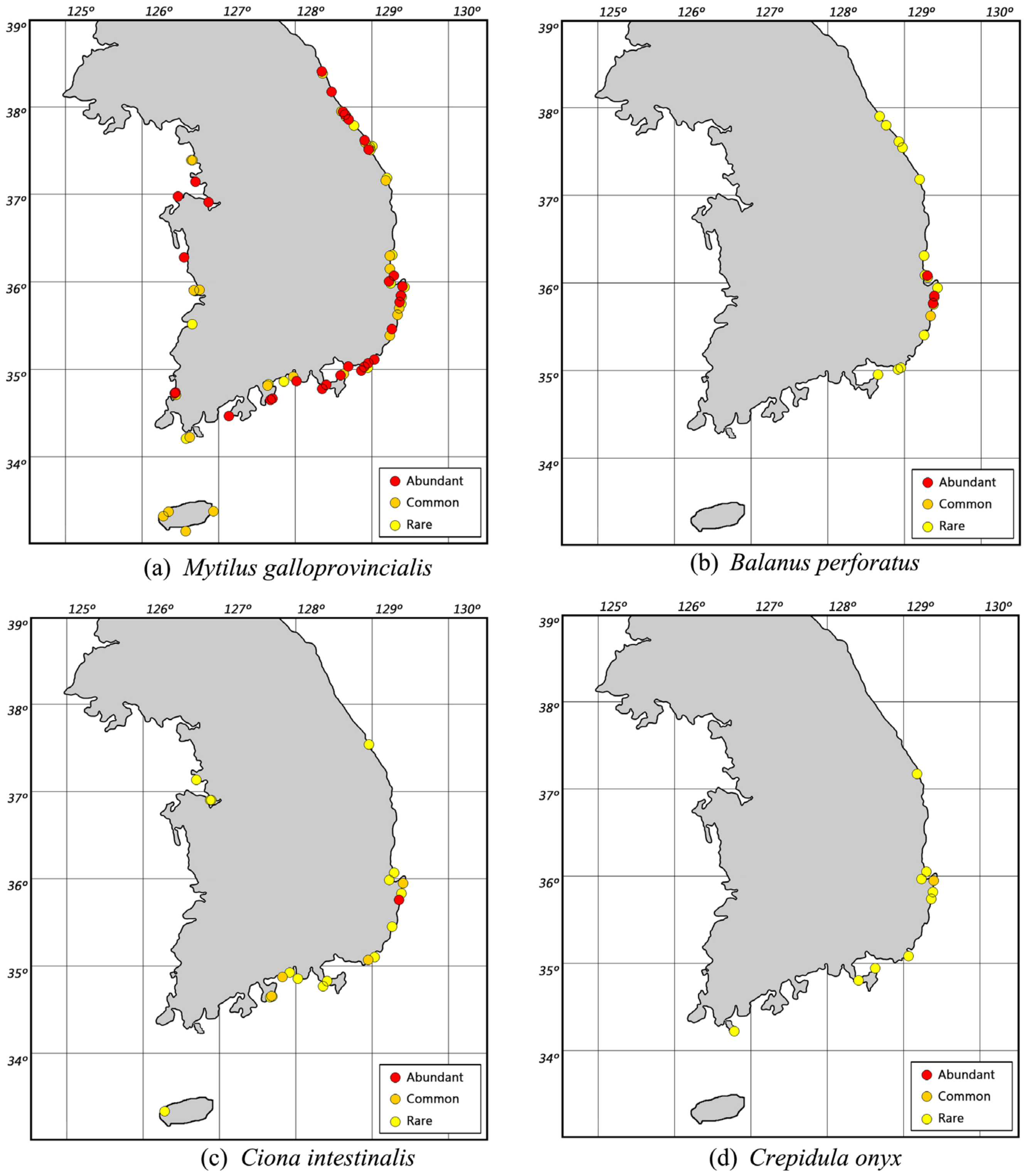


Fig. 1. Distribution of the invasive species on the three coastal areas of Korea

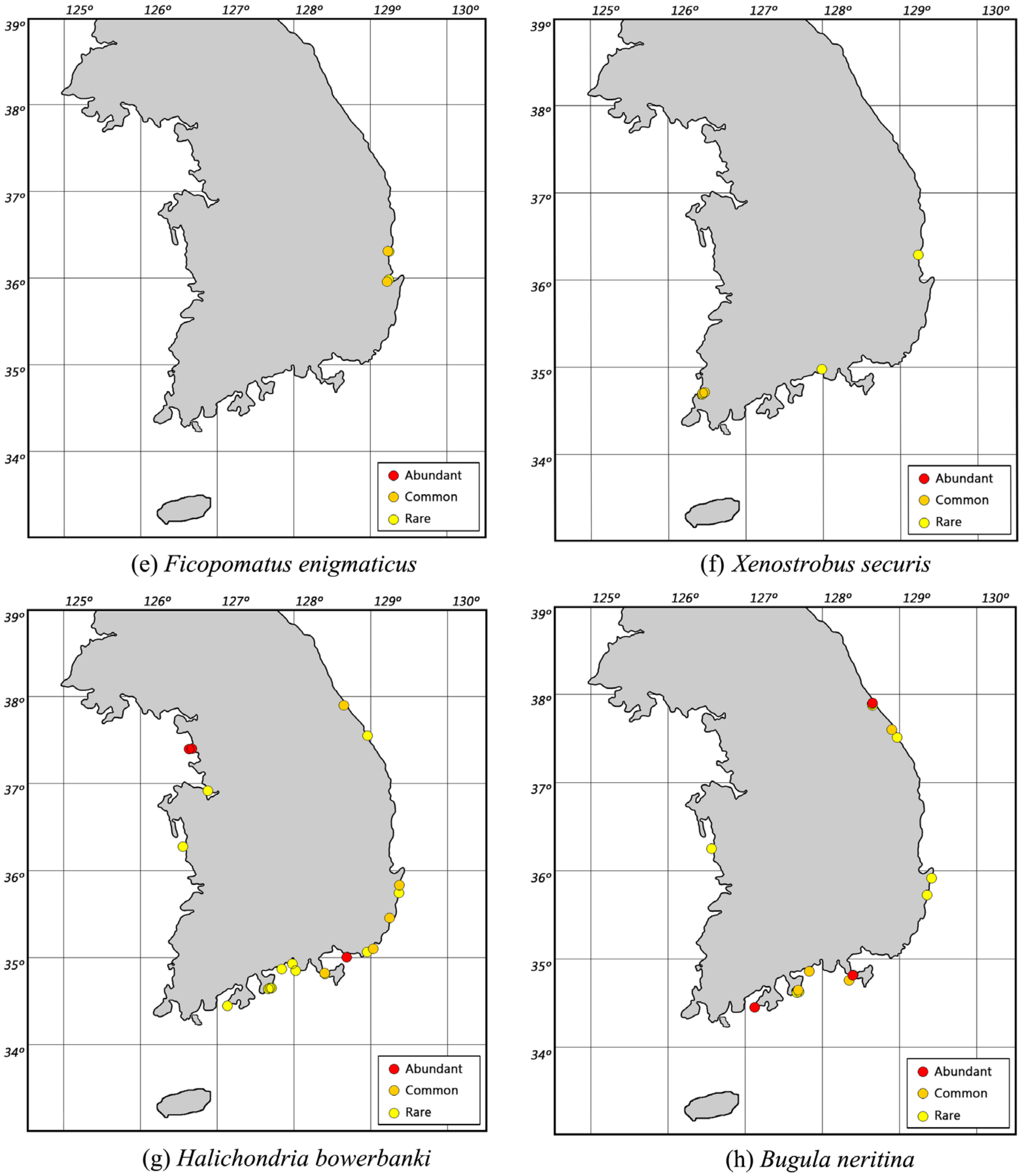
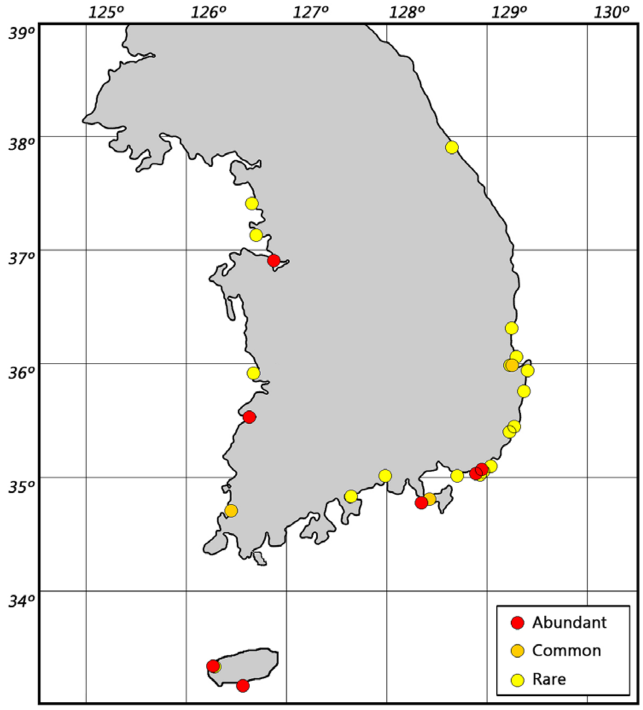


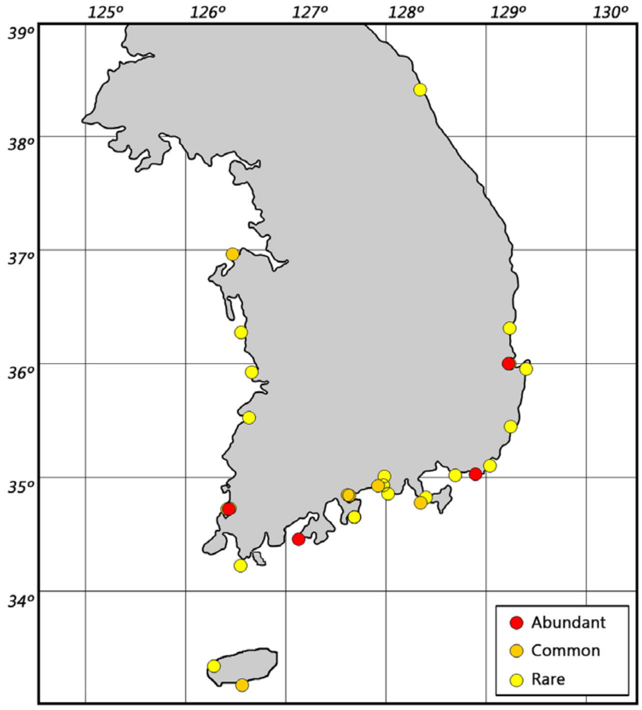
Fig. 1. Continued

different between species (Table 3). *M. galloprovincialis* (Table 2) was distinct from the other two species in many of the length ratio of morphological features except for c/SH and SH/SL (Fig. 2).

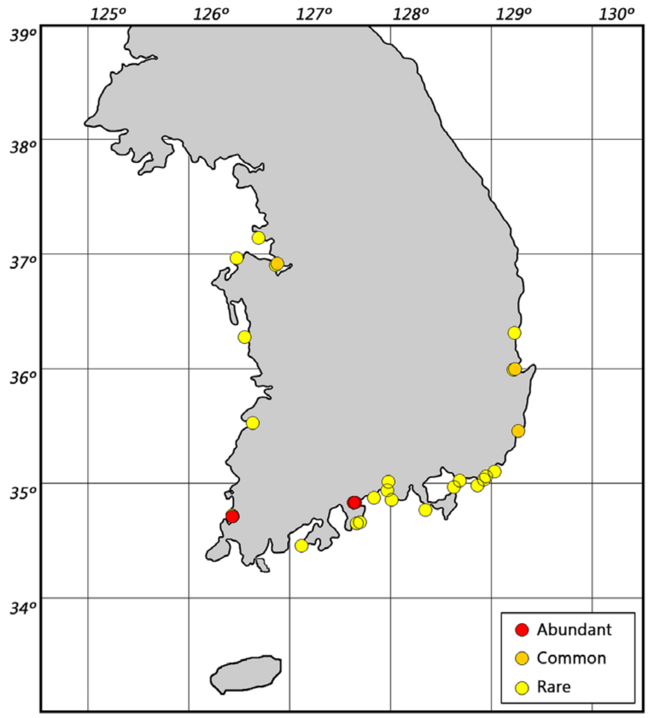
Mytilus galloprovincialis, native to the Mediterranean, Black, and Adriatic Seas, is a well known invader worldwide,



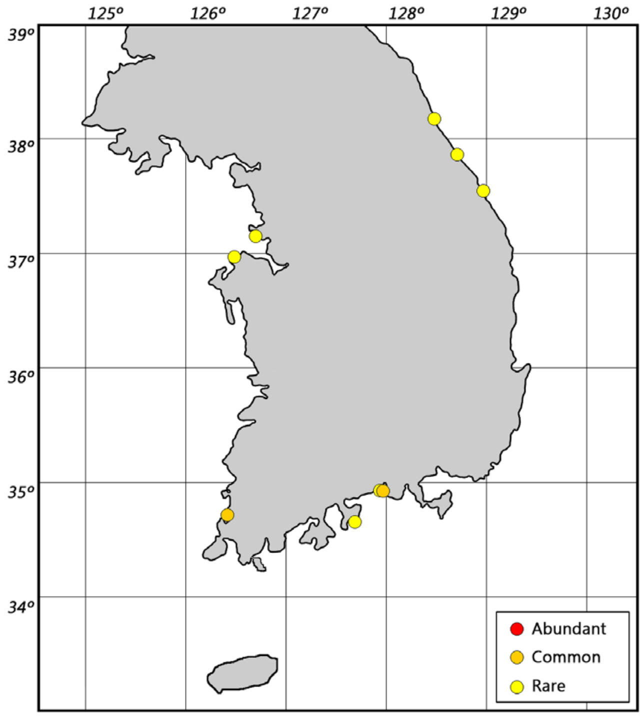
(i) *Balanus amphitrite*



(j) *Balanus eburneus*



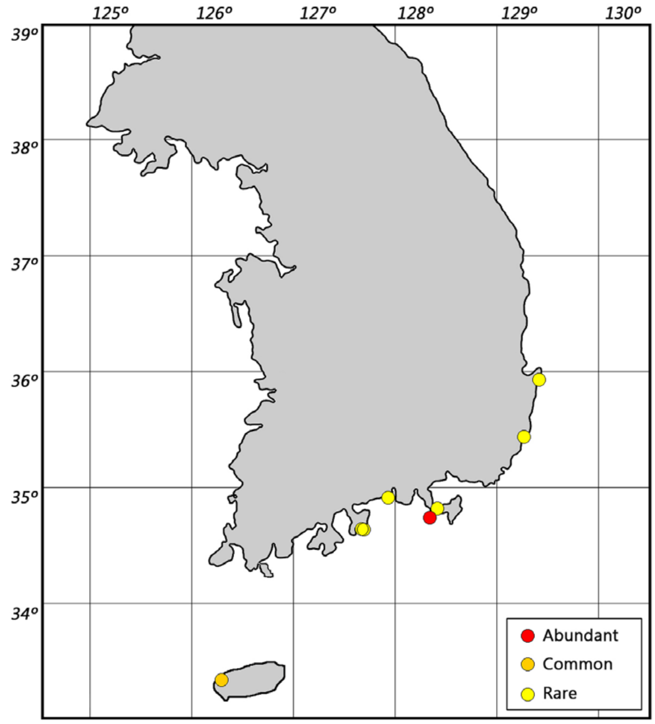
(k) *Balanus improvisus*



(l) *Ascidiella aspersa*

Fig. 1. Continued

and was first observed in Busan Port in 1936. It was misidentified as *Mytilus edulis* and now is found in all intertidal areas of the Korea coast except for Jeju Island (Fig. 1a). As in many countries around the world, it is one of the most successful invaders in Korean waters and has largely replaced the native mussel, *Mytilus coruscus,* since its invasion.



(m) *Styela plicata*

Fig. 1. Continued

Halichondria bowerbanki (Fig. 1g) is a polymorphic sponge that lives on rocky surfaces in the shallow subtidal zone. It is a common species in the British Isles, and has spread to Europe (van Soest 2016). It seems that this species has become established in Korea in recent years even though it was found in earlier years in adjacent countries. The specimens were first collected by hand from Tongyoung Bay, Korea in 2008 (Jeon and Sim 2009).

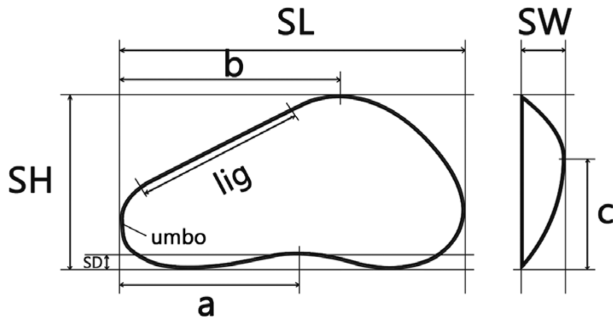


Fig. 2. The morphological characteristics used to differentiate three invasive species. SH-shell height, SW-shell width, SL-shell length, SD-depth of bent, a-shell height to the maximum bent, b-shell height to maximum shell length, c-shell length to maximum shell width

Bugula neritina (Fig. 1h) has a broad global distribution in temperate, subtropical and tropical waters. The species has frequently been collected from ships' hulls and is also known to attach to oyster shells (The Exotics Guide, http://www.exoticsguide.org/). It is also known to be highly

Table 2. The results of principal component analysis based morphological variation among three invasive species

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	2.39	0.92	0.76	0.52	0.40
%variation	47.9	18.4	15.2	10.5	8.0
Cumulative %	47.9	66.3	81.5	92.0	100.0

Table 3. Length ratio of various morphological features (Fig. 2) for each combination of two species (mean and standard deviation)

Ratio of shell features	*X. securis vs. X. atratus*	*X. atratus vs. M. galloprovincialis*	*M. galloprovincialis vs. X. securis*
SH/SL	0.496 (0.0306) 0.578 (0.0321)***	0.578 (0.0321) 0.588 (0.0236)	0.588 (0.0236) 0.496 (0.0306)***
SW/SL	0.209 (0.176) 0.224 (0.0131)***	0.224 (0.0131) 0.176 (0.0116)***	0.176 (0.0116) 0.209 (0.176)***
b/SL	0.612 (0.0333) 0.592 (0.0411)	0.592 (0.0411) 0.551 (0.0272)***	0.551 (0.0272) 0.612 (0.0333)***
c/SH	0.431 (0.0817) 0.413 (0.0746)	0.413 (0.0746) 0.352 (0.0651)**	0.352 (0.0651) 0.431 (0.0817)***
lig/SL	0.478 (0.0315) 0.465 (0.0447)	0.465 (0.0447) 0.411 (0.0197)***	0.411 (0.0197) 0.478 (0.0315)***
a/SL	0.482 (0.0484) 0.522 (0.0889)*	0.522 (0.0889) n/a	n/a 0.482 (0.0484)
SD/SH	0.043 (0.0266) 0.036 (0.0154)	0.036 (0.0154) n/a	n/a 0.043 (0.0266)

**: $p < 0.01$, ***: $p < 0.001$; n/a – data not available

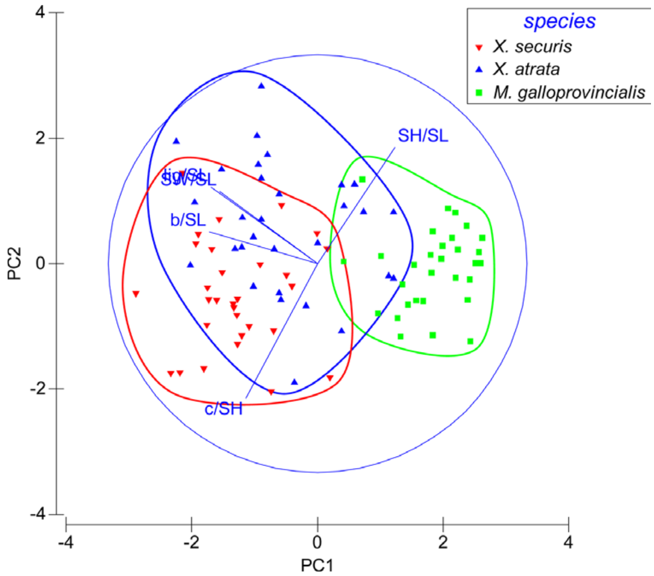


Fig. 3. Principal component analysis of The morphological characteristics used to differentiate three invasive species; SL-shell length, SH-shell height, SW-shell width, a-shell length to the maximum bent, b-shell length to maximum shell height, c-shell height to maximum shell width, lig-length of ligament

tolerant of mercury, such that anti-fouling compounds based on this would have little deterrent effect (The Exotics Guide, http://www.exoticsguide.org/). Transport to Korean waters and spread within the waters may have been accomplished primarily by means of hull fouling or through oyster transfers. This marine invertebrate fauna was first reported in the Gogunsan Island and Bian Island in Korean waters in 1980 (Rho and Lee 1980). It is peculiar though that this fauna has not yet been found in Jeju Island waters. *Bugula neritina* looks similar to *B. dentata* in the bushy shape of the colony; however the latter (which is dark green in color) clearly differs from the former, which is reddish brown. In Korea, it is now found in the East Sea, South Sea and Yellow Sea (Seo1 and Min 2009).

Three *Balanus* species, *Balanus amphitrite*, *B. eburneus*, and *B. improvises*, seem to have spread over all three coasts (Fig. 1i–k). This species in Korean waters was first described by Kim and Kim (1980). The occurrence of *B. improvisus* in Japan is most likely due to human introduction. It was first recorded in 1962, and it has since been spreading slowly (Iwasaki 2006). Another *Balanus* species, *B. improvises*, tolerates a wide range of water temperature and salinity, occurring from fully marine conditions to fresh water (Moore and Frue 1959). *Balanus amphitrite* is much less tolerant of low salinity, and does not normally occur under estuarine conditions. *B. eburneus* has a much more restricted distribution than either of the other species with regards to temperature, but it is highly tolerant of low salinities (Moore and Frue 1959).

Of the *Balanus* spp., *B. perforatus* (Fig. 1b) is a relatively new invader. This large barnacle, which grows up to 30 mm in both diameter and height, is a warm water species present between latitudes 36°N and 52°N, occurring commonly in the Mediterranean and along the eastern Atlantic coast from north Wales to West Africa. They form part of the fouling community on the hulls of ships (Marine Life Information, http://www.marlin.ac.uk/speciesinformation.php?speciesID=2719). *B. perforatus* was found for the first time in Guryongpo, Yangpo, and Gampo Ports, exclusively on the east coast on June 24, 2006 (Kim and Hong 2010). Two years later in 2008, thirteen more sites were found to have been invaded and they were mostly concentrated on the east coast, where some of the important international shipping traffic ports such as Busan and Ulsan are located. It seems that *B. perforatus* has rapidly colonized the East coast of Korea following its introduction in the region. Based on the northern limit of its distribution in Sacheon Port in 2008, this would be approximately equivalent to the movement of water with passive larvae of about 300 km to the north for two years, extending its distribution north by 150 km a year.

Crepidula onyx (Fig. 1d) is a hermaphroditic gastropod which develops from a juvenile to a male, and later to a female. The native range for this species is the Eastern Pacific Ocean coast of the Americas, from Southern California to Chile (Abbott and Haderlie 1980). The species was first reported in port Guryongpo in 1982 (Choe and Park 1992) and it has may have arrived in Japan in the 1970s (Iwasaki 2007). The species is mostly attached to the surface of a large gastropod and assumed to be introduced unintentionally by the trade in fishery products. The emergence on the south and the south-east coast of the species is assumed to be via redistribution of infected shellfish (Lee et al. 2010). Its distribution on the south coast seems in line with the tolerance temperature range of 10–22°C (Morton 1987; Iwasaki et al. 2004). Thee tunicates found in this study appear to be limited to the south and east coasts, which may be related to its relatively narrow range of water temperature tolerance for inhabitation between 11–27°C (Curran and Chan 2013). The west coast of Korea can be harsh during winter when the water temperature may go down below 4°C (Kang and Kim 1987).

Ciona intestinalis (Fig. 1c), the sea vase, is a tunicate that has such widespread distribution that its natural range is under debate. It was first reported in Korea at an ark shell farm in the southern coastal area in 1978 (Kim et al. 1980). *Ascidiella aspersa* (European sea squirt, Fig. 1l) is a solitary marine and estuarine tunicate that is native from Norway to the Mediterranean. It was first found during a survey from 2009 to 2011 around a coastal area in Korean waters (Pyo et al. 2012). *Styela plicata* (Fig. 1m) is a solitary ascidian found in shallow warm coastal waters. *S. plicata* has been historically classified as a cosmopolitan species, but has been considered in recent years as an introduced or invasive species in some regions of the world (de Barros et al. 2009). They were first found in oyster culture farms on the southern coast of Korea in the later 1960's (Rho and Lee 1989) and can reduce the growth of oysters (Kang et al. 1978).

The invasive pygmy mussel *Xenostrobus securis* (Fig. 1f) is native to southern Australia and New Zealand. It is an ecologically important species, heavily altering pre-existing benthic communities (Barbieri et al. 2011). The species invaded Japan in the 1970s (Iwasaki 2007) and the first report in Korea was from the east coast in 1995 (Lee et al. 2010). Although they could be reasonably distinguished based on shell shapes, significant overlap was noted so that additional analysis (e.g., DNA analysis) by researchers may be warranted to correctly discriminate among them.

Ficopomatus enigmaticus (Fig. 1e), commonly known as the Australian tubeworm, is a reef-building polychaete. They have been introduced to shallow waters worldwide, and alter habitats and cause biofouling. They may be also a bioengineering organism by altering the physical nature of the invaded environment and by providing refuge for other species (Schwindt et al. 2001).

The sampling could potentially have been biased as it is difficult to randomize sampling areas in ports. With broad coverage around the coastal ports including Jeju Island in the South Sea, however, the data represents the most comprehensive study conducted and the current status of invasive fouling organisms in Korea. The frequency distribution agrees with invasion history in that old invaders generally occupy more ports than newly arrived ones (Pyo et al. 2012). Although the data are incomplete for examining the pathways for introduction of the species found in this study, it is likely that many of the species may have been introduced via fouling on the hulls of ships, as they had been to other seawaters of the world (Global Invasive Species Database, http://www.iucngisd.org/gisd/). Of the provinces investigated, the seas around Jeju Island appear to be the least invaded ecosystem. The invasion of several species may be accidental and related to imports of other organisms and introduced together with other baits and live organisms, given that there is virtually no possibility that these invaders are transported by ocean currents or other natural mechanisms. The Jeju Island therefore may serve as a barometer of management practice for preventing the invasion of other organisms or further spreading in the region.

4. Conclusions

Although many of the introduced species already have spread to the three coastal areas, newly arrived invasive species showed a relatively restricted range, with a serpulid polychaete *Ficopomatus enigmaticus* and a mytilid bivalve *Xenostrobus securis* being examples of this. *X. securis* is found only at a few sites on the East Coast. An exception is for *Balanus perforatus*, which has rapidly colonized the east coast of Korea following its introduction in the region. Successful management of macrobenthic invasive invertebrates should be established in order to contain the spread of those newly arrived species.

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