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Macrozoobenthos of Korean tidal flats: A review on species assemblages and distribution

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ABSTRACT

A comprehensive review of benthic macrofaunal studies conducted along the west coasts of Korea over the last 40 years has been made by providing the most updated checklist of the Korean marine benthic invertebrates. Tidal flats were the very habitat of interest with inclusion of subtidal areas. As part of review, a critical re-identification of taxa is provided together with the analysis of faunal assemblages and the regional distribution of the species. A total of 624 species belonging to ten phyla has been compiled from 72 references. The phylum Annelida was found to comprise most taxa ($n = 248$) followed by Mollusca ($n = 196$) and Arthropoda ($n = 135$). While annelids prevailed in the subtidal area compared into intertidal, mollusk and arthropod species prevailed in the intertidal. Among 17 regions across the west coast of Korea, the Incheon exhibited the largest number of macrobenthic animals ($n = 272$) followed by the Jeonjupo where 173 species have been reported over the past 30 years. More than half of all species compiled are reported from one region only while certain opportunistic polychaetes e.g. *Heteromastus filiformis* widely distributed across the coast. Overall, we suggest that future macrozoobenthos studies in Korea should focus on long-term changes by broadening target species and regions that fully covered along the entire coast of Korea.

1. Introduction

One of the key socio-ecological features of the dynamic tidal flat ecosystem would be the provisioning of massive secondary production supported by the high diversity of macrobenthic organisms (Heip et al., 1995). Such intertidal areas vastly developed along the western coast of Korean peninsula (the West Sea, eastern part of the Yellow Sea), with being extensively utilized as feeding and nursery grounds for numerous invertebrates and fish (Koh and Khim, 2014) and foraging grounds for migrant coastal birds (Van de Kam et al., 2010). The Korean tidal flats are characteristic firstly in their macrotidal regime with maximum of ca. 10 m tidal range and also in the long extension of the intertidal area up to ~10 km to the seaside in many places.

Internationally, the Korean tidal flats of the West Sea possessing total area of ~2 500 km^2 with >400 benthic flora (Park et al., 2014) and fauna (reviewed in the present study), has been comparatively recognized as a Pacific mirror of the world featured tidal wetlands of the European Wadden Sea (Kellermann and Koh, 1999). However, the full extent of the knowledge on tidal flat species composition and the distribution of marine benthic invertebrates on the Korean tidal flats that has accumulated over the past 40 years has not been documented in an integrated manner, in spite of great progress having been achieved during this period of time.

This review is an attempt to make our data on the species richness of the Korean tidal flats available to global comparisons. In the present study, we first aimed to update the list of marine benthic invertebrates found in the Korean tidal flats and adjacent subtidal areas of the West Sea, being supported by critical taxonomic re-identification of the previously reported taxa. Accordingly, the spatiotemporal distribution of tidal flat benthic organisms could be overviewed in terms of biogeography, by highlighting faunal assemblages that reflects a habitat classification. In particular, the habitat classification based on species occurrences toward regional distribution characteristics are carefully addressed in semi-quantitative manner. Finally, the outlook for future researches supporting the sound science toward ecosystem-

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based management of the Korean tidal flats was suggested, by emphasizing the socio-ecological value of marine benthic diversity.

2. Data collection and analysis of the macrozoobenthos in Korea with taxonomic remarks

To provide a list of marine macrobenthic invertebrate species reported in the Korean tidal flats, the occurrence and distribution were analyzed based on the meta-data collected from the previous works. A total of 72 peer-reviewed articles of which scientific interests, as stated by the authors, were on the macrofauna assemblages in tidal flats and adjacent subtidal areas of the West Sea, have been published since the 1970s (Fig. 1). The taxonomic contributions such as illustrated encyclopedia, description of new recorded species or new to science not supporting the ecological aspects are excluded. As for the purpose of regional comparison, 17 regions are allocated along the west coast of Korea (Koh and Khim, 2014). The northern limit of the boundary has been set as Han River (region A) because the Data from the North Korea was practically unavailable due to political situation in Korean Peninsula. Haenam (region Q) has been set as the southern limit of 17 regions because the area is considered as the southern end of the west sea in both terms of history and administration.

Two early studies were included, the works by Paik (1973) and Lee (1987), which are not directly related to tidal flats, but of important note to deliver the earlier efforts on ecology of marine invertebrate in Korea. Mostly, the studies have been conducted within the single region of tidal flat area, except for two studies where 4 regions of the Incheon (region B), Asan (region C), Daesan (region C), and Jeonjupo (region J) were all targeted (Koh, 1997, 1999).

As part of the analysis, we endeavored to provide the critical re-identification of the reported species by through comparisons with the database of the World Register of Marine Species (WoRMS) and appropriate literature sources or expert knowledge. The list of the recent valid (or appropriate) taxonomic name from the former identified species in question was carefully suggested for a total of 90 species; 1 Cnidaria, 49 Mollusca, 22 Annelida, 13 Arthropoda, and 5 Echinodermata (Table 1). The species identified to genus or species level including those re-identified ones are listed alphabetically in each phylum, to fully update the list of marine invertebrates with a total of 624 species in the Korean tidal flats

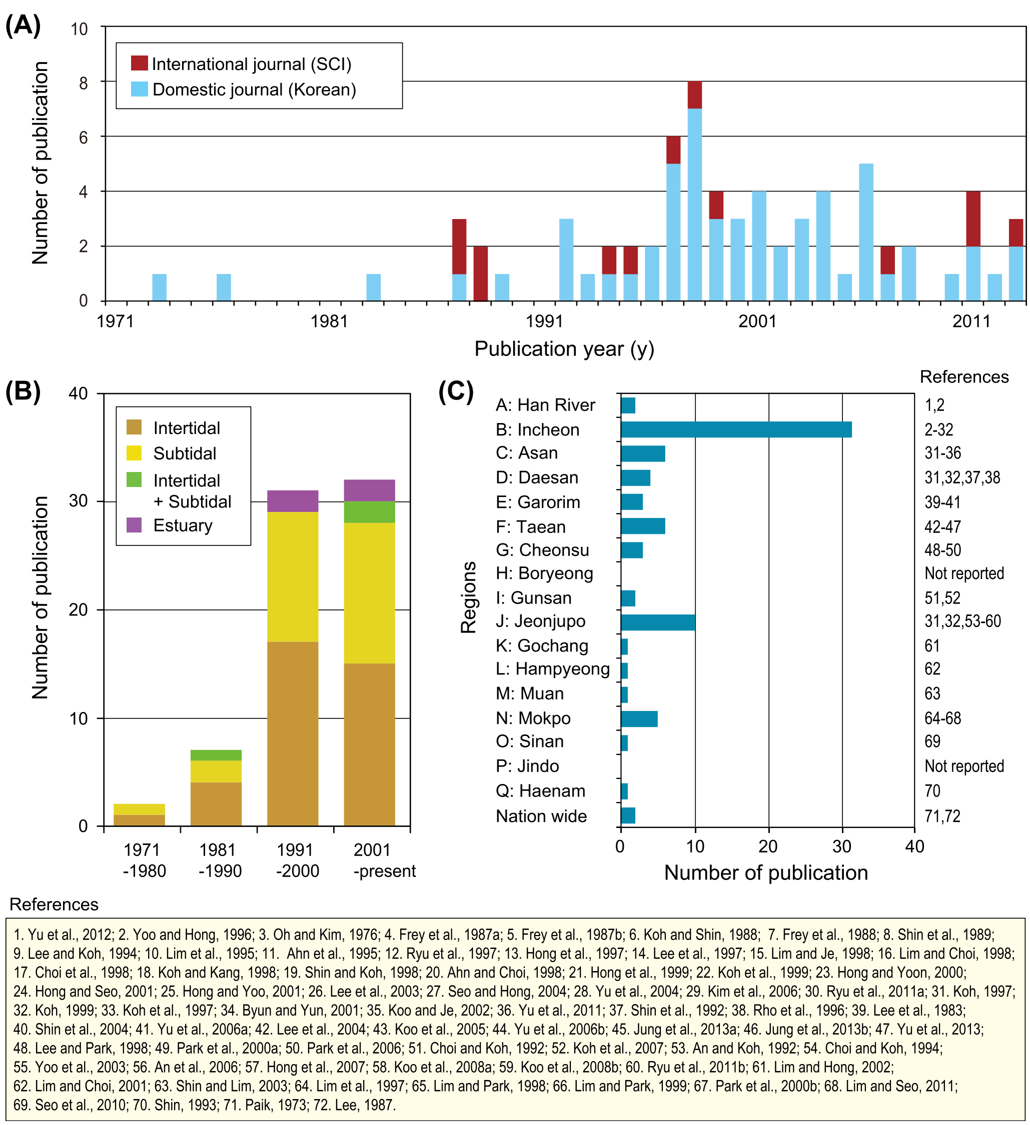

Fig. 1. The overview on macrozoobenthos studies conducted at the west coast of Korea; (A) yearly number of publications over the past 40 years, (B) decadal number of publications according to habitat, and (C) the number of publications referring to 17 regions along the west coast with corresponding references, a total of 72 reviewed articles.

Table 1
List of suggested identification for macrozoobenthos found in the Korean tidal flats, being updated based on the World Register of Marine Species and/or expert judge.

Phylum	Species in question, reported in original articles	Suggested identification (listed in Table S1)	Remark
Cnidaria	*Tubularia mesembryanthemum*	*Ectopleura crocea*	WoRMS
Mollusca	*Anisocorbula venusta*	*Corbula venusta*	Expert judge
	Balcis sp.	*Melanella* sp.	WoRMS
	Barleeia angustata	*Ansola angustata*	WoRMS
	Brevimyurella awajiensis	*Strioterebrum japonicum*	WoRMS
	Brevimyurella lischkeana	*Strioterebrum japonicum*	WoRMS
	Cirolana japonensis	*Natatolana japonensis*	WoRMS
	Coelomactra sp.	*Mactra* sp.	WoRMS
	Collisella langfordi	*Lottia langfordi*	Expert judge
	Dorvillea matsushimaensis	*Schistomeringos matsushimaensis*	WoRMS
	Dosinorbis japonicus	*Dosinia japonica*	Expert judge
	Euspira (or *Lunatia*) *fortunei*	*Laguncula pulchella*	WoRMS
	Fluviocingula sp.	*Iravadia* sp.	WoRMS
	Glauconomya sp.	*Glauconome* sp.	WoRMS
	Gomphina aequilatera	*Macridiscus aequilatera*	WoRMS
	Gomphina melanaegis	*Macridiscus melanaegis*	Expert judge
	Hinia (or *Reticunassa*) *festiva*	*Nassarius festivus*	WoRMS
	Kellia japonica	*Kellia suborbicularis*	WoRMS
	Laternula limicola	*Laternula rostrata*	WoRMS
	Mactra veneriformis	*Mactra quadrangularis*	WoRMS
	Monodonta labio labio	*Monodonta labio*	WoRMS
	Musculista senhousia	*Arcuatula senhousia*	WoRMS
	Neptunea arthritica cumingii	*Neptunea cumingii*	Expert judge
	Niotha livescens	*Nassarius livescens*	WoRMS
	Odostomia omaensis	*Brachystomia omaensis*	WoRMS
	Parthenope validus	*Enoplolambrus validus*	WoRMS
	Periploma otohimeae	*Pendaloma otohimeae*	WoRMS
	Philine argentata	*Philine orientalis*	WoRMS
	Pitar indescoroides	*Pitar indecorus*	Expert judge
	Pleurobranchaea novaezealandiae	*Pleurobranchaea maculata*	WoRMS
	Raetellops pulchella	*Raeta pulchella*	Expert judge
	Rhizorus radiolus	*Volvulella radiola*	WoRMS
	Ruditapes philippinarum	*Venerupis philippinarum*	WoRMS
	Scapharca satowi	*Anadara satowi*	WoRMS
	Striarca tenebrica	*Didimacar tenebrica*	WoRMS
	Striarea olivacea	*Estellacar olivacea*	Expert judge
	Tapes variegate	*Venerupis aspera*	WoRMS
	Tectonatica janthostomoides	*Cryptonatica janthostomoides*	WoRMS
	Tellina nitidula	*Nitidotellina hokkaidoensis*	WoRMS
	Thais clavigera	*Reishia clavigera*	Expert judge
	Tiberia pulchella	*Orinella pulchella*	WoRMS
	Trapezium liratum	*Neotrapezium liratum*	WoRMS
	Tristichotrochus unicus	*Calliostoma unicum*	WoRMS
	Tugonia sinensis	*Cryptomya sinensis*	WoRMS
	Turbo oronate coreensis	*Lunella coreensis*	WoRMS
	Varicorbula yokoyamai	*Corbula yokoyamai*	WoRMS
	Venus foveolata	*Venus cassinaeformis*	WoRMS
	Yokoyamaia ornatissima	*Philine ornatissima*	WoRMS
	Yoldia johanni	*Yoldia seminuda*	WoRMS
	Zeuxis sp.	*Nassarius* sp.	WoRMS
Annelida	*Aedicira pacifica*	*Aricidea pacifica*	WoRMS
	Anaitides koreana	*Phyllodoce koreana*	WoRMS
	Anaitides sp.	*Phyllodoce* sp.	WoRMS
	Ancistrosyllis hanaokai	*Sigambra hanaokai*	WoRMS
	Aricidea jeffreysii	*Aricidea cerrutii*	WoRMS
	Ceratonereis erythraeensis	*Simplisetia erythraeensis*	WoRMS
	Cirolana japonensis	*Natatolana japonensis*	WoRMS
	Cirrophorus armatus	*Paradoneis armata*	WoRMS
	Glycera chirori	*Glycera nicobarica*	Böggemann (2002)
	Glycera rouxii	*Glycera unicornis*	WoRMS
	Mellina cristata	*Melinna cristata*	WoRMS
	Neanthes japonica	*Hediste japonica*	WoRMS
	Nectoneanthes latipoda	*Nectoneanthes uchiwa*	Sato (2013)
	Nectoneanthes oxypoda	*Nectoneanthes uchiwa*	Sato (2013)
	Nereis succinea	*Neanthes succinea*	Sato (2013)
	Nothria iridescens	*Onuphis iridescens*	WoRMS
	Onuphis willemoesi	*Protodiopatra willemoesii*	WoRMS
	Perinereis aibuhitensis	*Perinereis linea*	Arias et al. (2013)
	Periserrula leucophryna	*Paraleonnates uschakovi*	WoRMS
	Prionospio krusadensis	*Prionospio aucklandica*	WoRMS
	Prionospio pinnata	*Prionospiocoora*	Expert judge
	Typosyllis	*Syllis*	WoRMS
Arthropoda	*Actaea orientalis*	*Gaillardiellus orientalis*	WoRMS
	Cancer japonicas	*Anatolikos japonicus*	WoRMS
	Cirolana japonica	*Metacirolana japonica*	WoRMS
	Helice tridens sheni	*Helicana wuana*	WoRMS
	Heteropanope makianus	*Phlumnopeus makianus*	WoRMS
	Penaeus orientalis	*Penaeus chinensis*	WoRMS
	Philyra heterograna	*Lyphira geterograna*	WoRMS
	Philyra pisum	*Pyrhila pisum*	WoRMS
	Phylyra pisum	*Pyrhila pisum*	WoRMS
	Pinnotheres sinensis	*Arcotheres sinensis*	WoRMS
	Pseudophotis sp.	*Photis* sp.	WoRMS
	Scopimera globosa longidactyla	*Scopimera longidactyla*	Sakai (1976)
	Synchelidium lenorostralum	*Eochelidium lenorostralum*	WoRMS
Echinodermata	*Amphioplus megapomus*	*Amphioplus laevis*	WoRMS
	Amphioplus squamata	*Amphipholis squamata*	WoRMS
	Asterina pectinifera	*Patiria pectinifera*	WoRMS
	Comanthus japonica	*Oxycomanthus japonicus*	WoRMS
	Ophiopeltis sinicola	*Amphiura sinicola*	WoRMS

(Table S1 of Supplemental Material). Meantime, it should be also noted that expert judges were made in re-identification of 9 mollusk species, when not listed in the WoRMS or absent in corresponding references.

A comprehensive checklist of the recorded macrozoobenthic species of the Korean tidal flats of the West Sea is provided with additional information on ecological features (Table S1). This ecological checklist of the Korean macrozoobenthos includes the species occurrence and distribution cross three types of habitats and also across 17 regions along the coast of the West Sea (Fig. 1). Some minor environmental parameters including bottom sediment facies or salinity, if available, are also utilized to better understand the faunal assemblages and zonal distribution during the analysis and discussion. In addition, available substratum information of the species was retrieved from the corresponding literature and provided herein (Table S2).

3. Scientific efforts on the macrofaunal studies in Korea

Three aspects in terms of scientific efforts, say the yearly number of publications, the study area of interest in habitats, and the area of interest in locality (viz., 17 regions along the coast) were

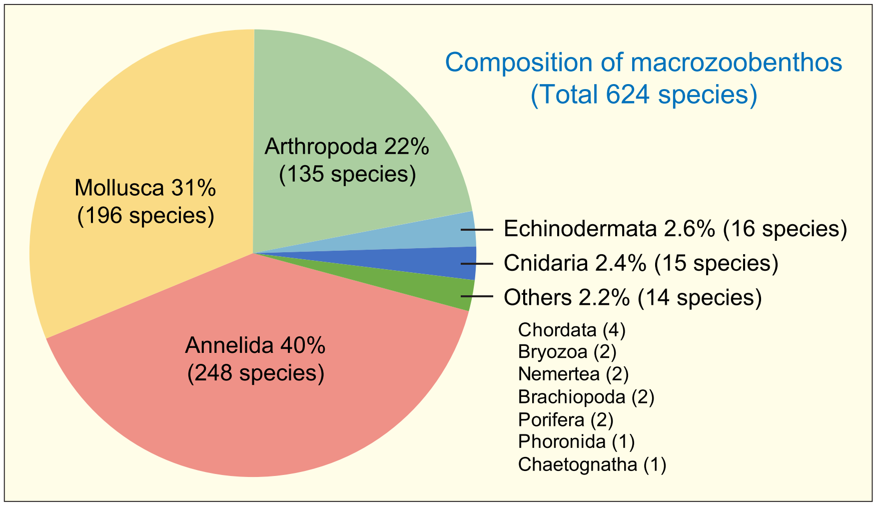

Fig. 2. Macrozoobenthos recorded in the west coast of Korea, showing the species composition at phylum level; a total of 10 phyla encompassing 624 species identified from the meta-data extracted from 72 articles listed in Fig. 1.

highlighted in this review. We believe such synthetic analysis will aid the understanding of the Korean marine invertebrates in terms of species diversity and biogeography in a historical manner.

With regard to the number of studies (Fig. 1A), only three articles had been published until the middle of the 1980s since the first report in 1973, then publications rapidly increased thereafter. Of note, the same trend was found for publications on the intertidal microphytobenthos (Park et al., 2014), indicating the increased scientific efforts given on the tidal flat ecology in the recent years. Indeed more than half of the studies were published in the mid-1990s to mid-2000s. During the corresponding period, the social controversies greatly increased upon the large-scale landfilling projects such as the “Lake Shihwa” project (Lee et al., 2014) and the “Saemangeum” project (Ryu et al., 2014). The majority of those studies have been documented in the local journals hence could not be available to the international audiences in practical manner, 12 published internationally though.

The analysis has shown that most of the studies have been conducted primarily in intertidal area (56%) followed by the subtidal (43%), with similar proportions over time (Fig. 1B). Studies encompassing both habitats (intertidal + subtidal) were only conducted by Shin et al. (1989), Lee et al. (2004), and Koo et al. (2005). Estuary was found to be the least studied habitat. Only recently the salinity effects on the spatial distribution of macrozoobenthos were investigated (Lim and Hong, 2002; Lim and Seo, 2011).

Finally looking at the study intensity cross the regional locality (Fig. 1C), the Incheon (region B) seemed to be most intensively targeted. The high degree of study efforts given to this locality

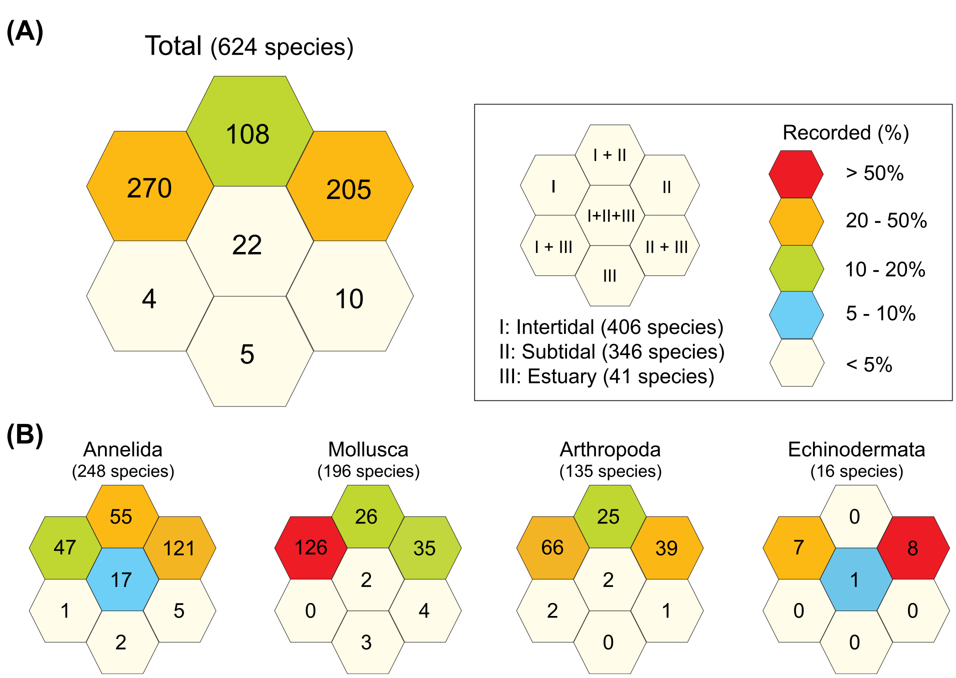

Fig. 3. The occurrence of macrozoobenthos species in and cross intertidal, subtidal, and estuarine habitats; (A) for all 624 species, (B) for by 4 major taxonomic groups of the Annelida, Mollusca, Arthropoda, and Echinodermata.

would be explained by the fact that it encompasses the largest tidal flats, occupying 35% of the total areas of the Korean tidal flat. Another reason would be the increasing and continuing concerns on the Lake Shihwa reclamation (allocated in region B), which has been a long standing issue of the environmental pollution. The Jeonjupo (Saemangeum tidal flat; region J) ranks second among the regions in terms of study effort with 10 publications. It was not possible to find a peer-reviewed article of macrobenthic community from two regions, viz., Boryeong and Jindo, although there are certain gray literature of benthic community in the given areas. Of note, the Han River district encompasses wide tidal flats but is adjacent to the North Korean territory, hence the access is extremely limited due to the political reason, resulting in lack of study efforts (only two publications).

4. Chronological description on the macrofaunal studies in Korea

The study of the macrobenthos from the Korean tidal flats would date back to the 1970s. Paik (1973) reported nine species of subtidal polychaetes from the Yellow Sea, followed by Oh and Kim (1976) who documented 27 polychaetes from the intertidal flats of the Incheon as *Magelona japonica* being the most dominant species (>50% of total abundance). Later in the 1980s, the scopes and scales of macrofaunal studies greatly expanded. For example, Lee et al. (1983) investigated subtidal macrobenthic community in the Garorim Bay with providing the list of 340 identified species and 15 dominant species. Later, Lee (1987) has further extended the sampling areas covering the most of the Korean side of the Yellow Sea by analyzing dredge samples, but limited to the report of polychaete species. He listed a total of 96 species categorizing their distribution relating to the characteristics of water masses, finally suggested six representative groups of benthic assemblages.

Of note, all the above studies were published in local journals, hence expected limited access to international audience. Furthermore, these early studies were mostly conducted in the subtidal or far offshore regions. In the 1980s, two independent investigations were made on the distribution of macrofauna on tidal flats in the Incheon region, and the results were published by Frey et al. (1987a, b) and Koh and Shin (1988). The latter study conducted in 1984–85 addressed the zonation of macrofauna along three transects from high to low tide level in Gyeonggi Bay. The former one performed in

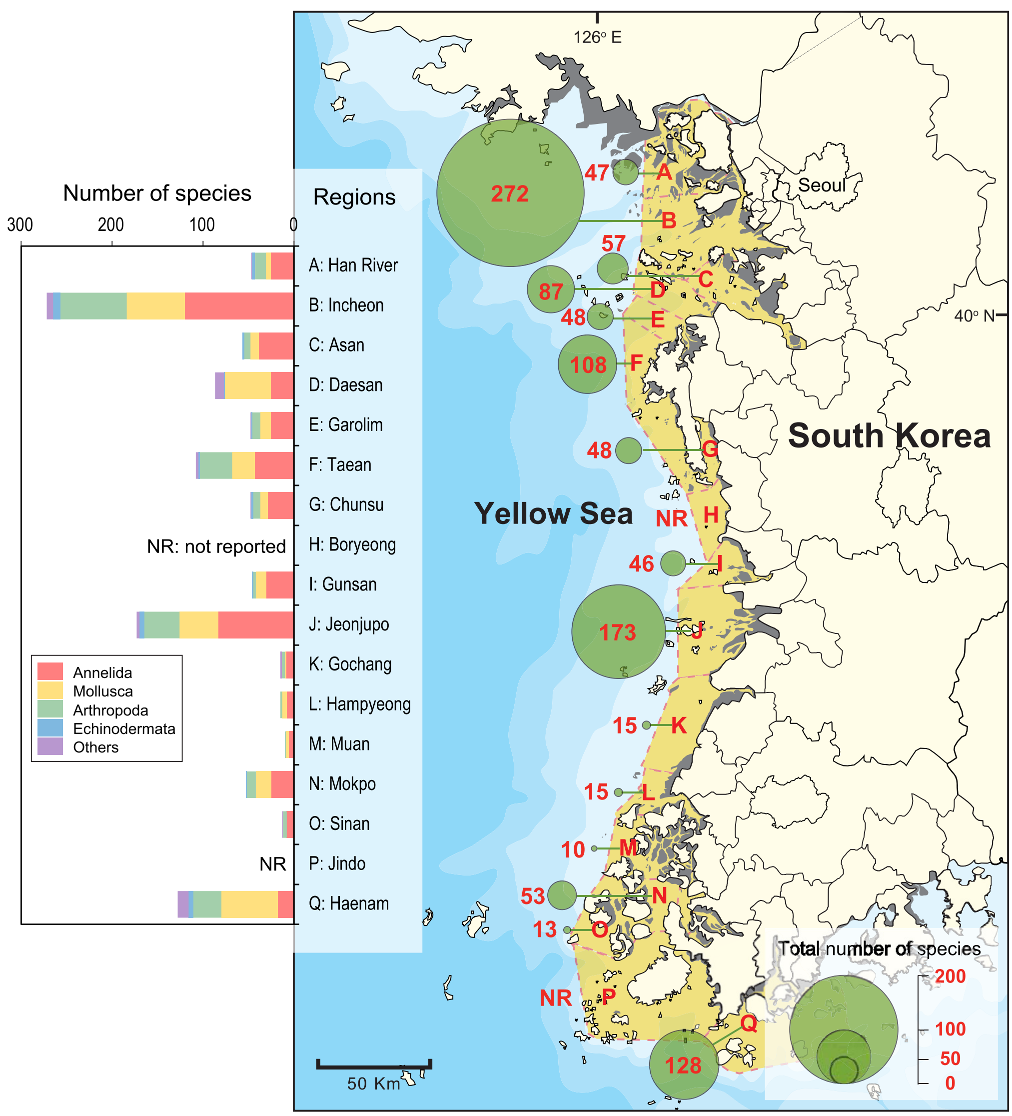

Fig. 4. Map of the west coast of Korea (West Sea, eastern part of the Yellow Sea), showing the total numbers of recorded species by 17 regions and the specie composition of the macrozoobenthos in each region.

1986 investigated a 4-km long transect near the Incheon, focusing on the zonation of conspicuous macrofaunal species. Both studies measured species abundances as end-point and tried to address the faunal distribution in relation to the given environmental condition, primarily bottom sedimentary facies. These pioneering studies would be regarded as the birth of macrozoobenthic research on the Korean tidal flats in tidal flat ecology history.

Since the 1990s, the tidal flat ecology study in Korea further included the anthropogenic influences, primarily pollution, as a response to environmental pressure by rapid industrialization, particularly in the coastal regions. The most controversial issue was the loss of tidal flats due to embankment and landfill projects being intensively conducted since the 1980s. In fact, the series of grand reclamation projects have resulted in a huge loss of former native tidal flats in timely manner, including many places around the Gyeonggi Bay, particularly the Lake Shihwa (Lee et al., 2014), and the Saemangeum area (Ryu et al., 2014). Correspondingly about half of the publications were dedicated to the Incheon area (region B) encompassing the Lake Shihwa and ~20% in the Jeonjupo area (region J) including the Saemangeum (Fig. 1).

As the reclamation aimed to facilitate industrial developments, a set of studies also endeavored to address pollution issue being potentially associated with the Lake Shihwa reclamation project (Ahn et al., 1995; Ryu et al., 1997). Such environmental studies looking for the benthic faunal responses against pollution loads and gradients in the Incheon area continued in the 2000s. For instance, Shin and Lim (2003) and Shin et al. (2004) reported the macrobenthic communities on tidal flats of the Tando Bay and the Garorim Bay, respectively. Later, the study of Ryu et al. (2011a) also reported the impact of heavy metal pollution gradients to the population and community structure of benthic macrofaunal species at Incheon North Harbor.

A set of the Saemangeum studies since the 1980s to the present also reflects the continuing scientific concerns over the region, particularly on landfilling area of the Saemangeum lake. A couple of studies at the time of planning the Saemangeum reclamation (viz., before the embankment), which now provides significant data, being used to estimate the loss of benthic faunal assemblages in the given area. For example, An and Koh (1992) investigated the Saemangeum in 1988, looking for the assemblages and distribution of the benthic invertebrates with intensive field works along the 8 transects in the Saemangeum tidal flat. At the same time, Choi and Koh (1994) also reported the macrobenthos community in the subtidal regions of the Geum-Mangyeong-Dongjin estuaries in the year of 1988. During or after the embankment, such ecological studies have been subsequently conducted specifically targeting the dike impact which would have inevitably influenced the direction and/or strength of the tidal currents, particularly in the inside of the dikes (Koo et al., 2008a, b; Ryu et al., 2011b).

5. Characteristics of the macrofaunal habitats in the Korean tidal flats

Included in the list of the macrozoobenthic species found on Korean tidal flats are species which have been previously documented to the genus or species level (Table S1). A total of 624 species is primarily composed of three major faunal groups: Annelida ($n = 248$ species), Mollusca ($n = 196$), and Arthropoda ($n = 135$) collectively accounting for ~95% of the total macrozoobenthos species (Fig. 2). The number species in the intertidal, subtidal, and estuarine habitats were counted and presented in honeycomb diagrams (Fig. 3). In general, 406 of 624 species were found in the intertidal favoring macrozoobenthos, with some of these species occurring also in the subtidal ($n = 108$) and estuary ($n = 4$). Of note, the co-occurrence cross all three habitats ($n = 22$) indicated the salinity tolerable species.

Annelid species were predominantly found in the subtidal area (ca. 50% of polychaetes, $n = 121$), while >60% of the mollusk species and ca. 50% of arthropods were exclusively reported in the intertidal area (Fig. 3B). It should be noted that the proportion of overlapping occurrence of macrozoobenthic species in more than one habitat decreased from phyla Annelida (31%, $n = 78$), Arthropoda (22%, $n = 30$), Mollusca (16%, $n = 32$), and to Echinodermata (6%, $n = 1$).

6. Characteristics of the macrofaunal distribution along the west coast of Korea

Along the west coast of Korea, the Incheon area (region B) exhibited the most diverse faunal assemblages with 272 species recorded, of which polychaetes (Annelida) showed predominance of 120 species followed by crustaceans (Arthropoda) and mollusks with 73 and 64 species, respectively (Fig. 4). It should be noted that the number of 272 species is approximately half of the total number of reported species ($n = 624$) from 17 regions along the west coast of Korea. The Incheon region seems to be a hotspot of biodiversity based on species diversity, otherwise the high number of species might simply reflect the greatest sampling intensity (over 30 studies) given in the corresponding region (Fig. 1C). Similarly the Jeonjupo (region J) was found to be next in diversity ($n = 173$) with also next in sampling intensity. Interestingly, a taxonomic composition in the Jeonjupo was similar to that found in the Incheon area, i.e., polychaetes accounted for about half of the total macrozoobenthos over the past 40 years. The Jeonjupo, which is called by Korean marine environmental monitoring network, is well known region encompassing the former Saemangeum tidal flat (Ryu et al., 2014), as mentioned above.

Next ecological hotspot being highlighted would be the areas of Haenam (region Q), Taean (region F), and Daesan (region D), showing the relatively great number of recorded species of 128, 108, and 87, respectively. Taean showed a predominance of polychaetes, while Haenam and Daesan regions were primarily

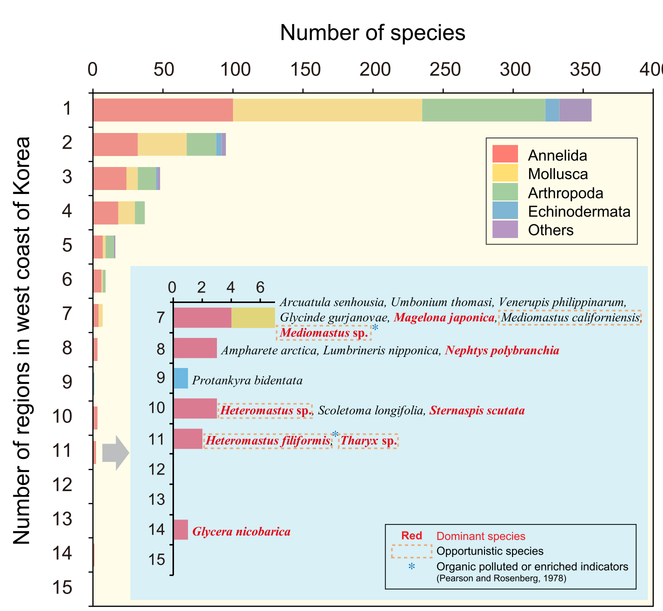

Fig. 5. Number of macrozoobenthos species which occurred in one or more regions simultaneously. The inset shows the most common species, some of which have been categorized with respect to dominance, opportunistic behavior, and indicator property for organic pollution or enrichment.

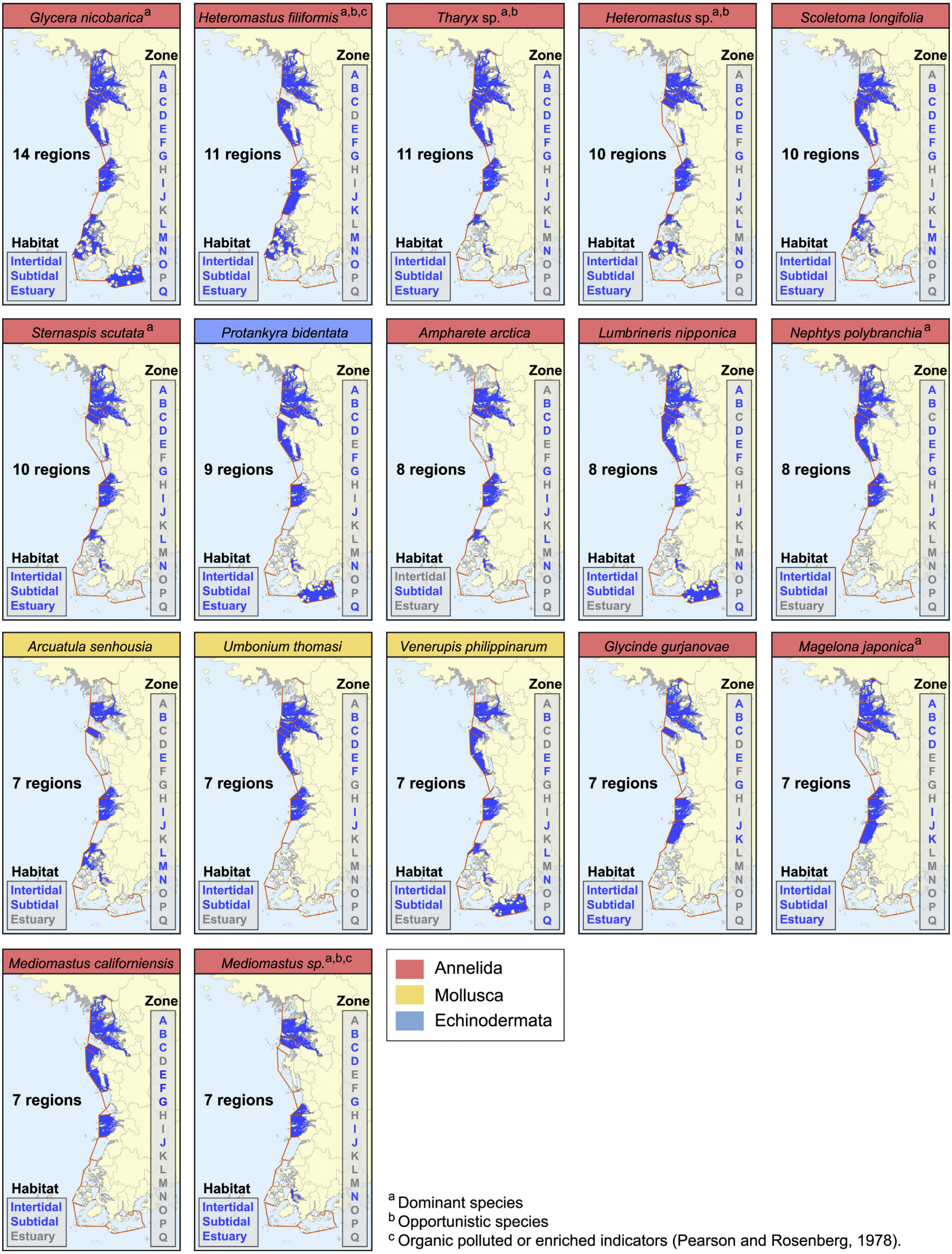

Fig. 6. Distribution of 15 selected macrozoobenthos species in 7 regions or more along the west coast of Korea; occurrences and habitats associated with corresponding species highlighted in blue.

occupied by mollusks (>50%). Interestingly, these top eco-regions except Haenam have been heavily threatened by various environmental pressures, such as landfilling (regions B, D, and J), industry (region B), oil spill pollution (regions F), and more recently tidal barrage for tidal power plant (region B).

Looking for the regional occurrence of macrozoobenthos compiled in the present review, over 350 species were found in single region only (Fig. 5), suggesting that a considerable amount of macrozoobenthos species in Korea would be geographically confined or such pattern could be from an biased regional sampling effort. Also, the indented and ria type coastlines could be one reason for such limited distribution ranges (Koh and Khim, 2014). Of note, polychaetes have a disproportionally high share of species occurring at >6 regions. Meantime, five of 13 polychaete species recorded in >6 regions could be regarded as opportunistic species (Inset in Fig. 5), in fact two (*Mediomastus* sp. and *Heteromastus filiformis*) of them were classified as indicators for organic enrichment or pollution (Pearson and Rosenberg, 1978). Widespread distribution of such dominant opportunistic species might indicate that the west coast of Korea is subject to frequent long-term physical (by macrotidal regime) and/or chemical (by pollution) disturbances. However, due to a lack of studies before the period of coastal development (say in the 1970s), it cannot be concluded whether the present pattern is natural or a response to anthropogenic disturbances.

We further described the distribution for the 17 species which occurred in more than seven regions to characterize the commonly occurring species cross the regions (Fig. 6). The polychaete species *Glycera nicobarica* was all found crossing the regions where corresponding taxa surveyed (14 regions, see Fig. 1), indicating its widest distribution, followed by two polychaete species *H. filiformis* and *Tharyx* sp. co-occurring in 11 regions. Next, three polychaete species co-occurred in ten regions, including *Heteromastus* sp., *Scoletoma longifolia* and *Sternaspis scutata*. Of note, five co-occurring species (*Glycera nicobarica*, *H. filiformis*, *Tharyx* sp., *S. longifolia*, and *S. scutata*) found in >9 regions inhabited cross the three types of intertidal, subtidal, and estuary areas. Certain mollusks and crustaceans also belonged to the widespread species, generally reflecting the common representative macrozoobenthos in the Korean tidal flat.

7. Conclusions

In the present review, a set of 72 macrobenthos studies conducted at the west coasts of Korea over the past 40 years has been revisited by an intensive meta-data analysis combined with a critical taxonomic re-identification. A provisioning of comprehensive Korean macrozoobenthos checklist with ecological information on habitat types (intertidal, subtidal, estuarine) and regional distributions were first provided as partial outcome of the present review (Table S1).

We list a total of 624 marine invertebrate species belonging to ten phyla. For 90 species, names or the identifications have been updated or corrected (Table 1). The phylum Annelida was found to be the richest taxonomic group with 248 species, followed by Mollusca, Arthropoda, and Echinodermata, collectively accounting for the majority (>95%) of the Korean macrozoobenthos. Of all species, 63% were recorded from the intertidal zone, including 17% reported in the near-shore subtidal zone as well. About half of all species are known from only one of 17 regions along the coast. The accelerating industrialization in the coastal zone as well as major embankments of tidal flats since the 1980s, facilitated macrobenthic research on possible impacts, and caused a particular focus on two regions (Incheon and Jeonjupo), resulting in a biased distribution of scientific efforts. Only the cosmopolitan, *H. filiformis*, was found all around the west coast of Korea with consistent occurrence since the 1980s. This species should be subjected to intensive research with regard to identity, genetic homogeneity, and population dynamics.

We recommend the following suggestions for future Korean tidal flat ecology study, (1) strong efforts to publish data from gray reports in peer-reviewed journals, (2) balancing efforts to investigate for a more even distribution of species and localities along the coast, and finally (3) technical efforts to develop a standardized macrobenthic monitoring system with appropriate quality control.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2014.07.019.

References

Ahn, I.-Y., Choi, J.-W., 1998. Macrobenthic communities impacted by anthropogenic activities in an intertidal sand flat. Mar. Pollut. Bull. 36, 808–817.
Ahn, I.-Y., Kang, Y.-C., Choi, J.-W., 1995. The influence of industrial effluents on intertidal benthic communities in Panweol, Kyeonggi Bay. Mar. Pollut. Bull. 30, 200–206.
An, S., Koh, C.-H., 1992. Environments and distribution of benthic animals on the Mangyung-Dongjin tidal flat, west coast of Korea. J. Ocean. Soc. Korea 27, 78–90 (in Korean).
An, S., Lee, J.-H., Woo, H.J., Koo, B.J., Lee, H.-G., Yoo, J.-W., Je, J.G., 2006. Benthic environment and macrofaunal community changes during the dike construction in Saemangeum subtidal area, Korea. Ocean Polar Res. 28, 369–383 (in Korean).
Arias, A., Richter, A., Anadon, N., Glasby, C.J., 2013. Revealing polychaetes invasion patterns: Identification, reproduction and potential risks of the Korean ragworm, *Perinereis linea* (Treadwell), in the Western Mediterranean. Estuar. Coast. Shelf Sci. 131, 117–128.
Böggemann, M., 2002. Revision of the Glyceridae Grube 1850 (Annelida: Polychaeta). Abh. Senckenb. Naturforsch. Ges. 555, 1–249.
Byun, S.H., Yun, S.G., 2001. Community structures of macrobenthos during summer 1996 in the Asan Bay, Korea. J. Nat. Sci. Taegu Univ. 18, 103–113 (in Korean).
Choi, J.W., Koh, C.-H., 1992. The distribution and feeding guilds of the polychaete community in the west coast off Kunsan, Korea. J. Ocean. Soc. Korea 27, 197–209 (in Korean).
Choi, J.W., Koh, C.-H., 1994. Macrobenthos community in Keum-Mankyung-Dongjin estuarine and its adjacent coastal region, Korea. J. Ocean. Soc. Korea 29, 304–318 (in Korean).
Choi, J.-W., Kim, D.-S., Shin, S.-H., Je, J.-G., 1998. Spatial distribution of macrobenthos in the sandflat of Taebudo, Kyonggi Bay, the west coast of Korea. Ocean Res. 20, 97–104 (in Korean).
Frey, R.W., Hong, J.-S., Howard, J.D., Park, B.-K., Han, S.-J., 1987a. Zonation of benthos on a macrotidal flat, Inchon, Korea. Senckenb. Marit. 19, 295–329.
Frey, R.W., Howard, J.D., Hong, J.-S., 1987b. Prevalent lebensspuren on a modern macrotidal flat, Inchon, Korea: ethological and environmental significance. Palaios 2, 517–593.
Frey, R.W., Hong, J.-S., Hayes, W.B., 1988. Physical and biological aspects of shell accumulation on a modern macrotidal flat, Inchon, Korea. Neth. J. Sea Res. 22, 267–278.
Heip, C.H.R., Goosen, N.K., Herman, P.M.J., Kromkamp, J., Middelburg, J.J., Soetaert, K., 1995. Production and consumption of biological particles in temperate tidal estuaries. Oceanogr. Mar. Biol. 33, 1–150.
Hong, J.-S., Jung, R.-H., Seo, I.-S., Yoon, K.-T., Choi, B.-M., Yoo, J.-W., 1997. How are the spatio-temporal distribution patterns of benthic macrofaunal communities affected by the construction of Shihwa Dike in the west coast of Korea? J. Korean Fish. Soc. 30, 882–895 (in Korean).
Hong, J.-S., Seo, I.-S., 2001. The community ecology of benthic macrofauna on the Cheokjeon tidal flat, Incheon, Korea 1. Community structure. J. Korean Soc. Oceanogr. 6, 190–200 (in Korean).

Hong, J.-S., Yamashita, H., Sato, S., 2007. The Saemangeum reclamation project in South Korea threatens to extinguish an unique mollusk, ectosymbiotic bivalve species attached to the shell of *Lingula anatine*. Plankton Benthos Res. 2, 70–75.
Hong, J.-S., Yoo, J.-W., 2001. A revisit on zonal macrobenthic communities in Chokchon tidal flat, Incheon, Korea, after the survey in 1986. J. Korean Soc. Oceanogr. 36, 83–92.
Hong, J.-S., Yoo, J.-W., Jung, R.-H., 1999. Macrobenthic communities on the tidal flats around Yongjong and Yongyu Islands, Inchon, Korea. J. Korean Soc. Oceanogr. 34, 220–230.
Hong, J.-S., Yoon, S.-P., 2000. Zonation of the exposed sandy beach macrofauna in Okjukpo, Taechongdo, Korea. J. Korean Soc. Oceanogr. 5, 146–156 (in Korean).
Jung, Y.-H., Park, H.-S., Yoon, K.-T., Lee, H.-G., Ma, C.-W., 2013a. Structure changes of macrobenthic community on rocky shores after the Hebei Spirit oil spill. Ocean Polar Res. 35, 219–228 (in Korean).
Jung, Y.-H., Yoon, K.-T., Park, H.-S., Ma, C.-W., 2013b. Spatial distribution and community structure of macrobenthos on the sandy shore of Anmyeondo, Korea. Ocean Polar Res. 35, 27–37 (in Korean).
Kellermann, A., Koh, C.H., 1999. Korean tidal flats: the West Pacific mirror of the European Wadden Sea. Wadden Sea Newsl. 1, 7–8. CWSS, Wilhelmshaven, Germany.
Kim, C.-S., Yoo, J.-W., Park, M.-R., Lee, C.-G., Hong, J.-S., 2006. Effects of predation on macrobenthic communities in Seonjae-do tidal flat. J. Korean Soc. Oceanogr. 39, 142–150 (in Korean).
Koh, B.-S., Choi, O.-I., Jo, Y.-J., Song, J.-H., Kwon, D.-H., Lee, C.-I., Lee, D.-Y., 2007. Spatial distribution patterns of common species of macrobenthos in Biin Bay of the Yellow Sea, Korea. J. Wetl. Res. 9, 13–24.
Koh, C.-H., 1997. Korean megatidal environments and tidal power projects: Korean tidal flats – biology, ecology and land uses by reclamation and other feasibilities. La Houille Blanche 3, 66–78.
Koh, C.-H., 1999. Sediment Fauna, Fisheries Catches and Land Earning from Korean Tidal Flat. Korea Ocean Res. Dev. Inst., PACON International.
Koh, C.-H., Kang, S.-G., 1998. Sample size determination for the estimation of population density of marine benthos on a tidal flat and a subtidal area, Korea. J. Korean Soc. Oceanogr. 33, 113–122.
Koh, C.-H., Kang, S.-G., Lee, C.-B., 1999. Determination of the optimum sampling area for the benthic community study of the Songdo tidal flat and Youngil Bay subtidal sediment. J. Korean Soc. Oceanogr. 4, 63–70.
Koh, C.H., Khim, J.S., 2014. The Korean tidal flat of the Yellow Sea: physical setting, ecosystem and management. Ocean Coast. Manage. 102, 398–414.
Koh, C.H., Shin, H.C., 1988. Environmental characteristics and distribution of macrobenthos in a mudflat of the west coast of Korea. Neth. J. Sea Res. 22, 279–290.
Koh, C.-H., Yang, M.-R., Chang, W.-K., 1997. Growth and production of *Sinonovacula constricta* (Bivalvia) from the Hwaseong tidal flat in the Namyang Bay, Korea. J. Korean Soc. Oceanogr. 2, 21–30 (in Korean).
Koo, B.J., Je, J.-G., 2002. A preliminary study on changes in macrobenthic assemblages in the fenced experimental plots for restoring tidal marsh, Hogok-ri tidal flat, west coast of Korea. Ocean Polar Res. 24, 63–71.
Koo, B.J., Shin, S.H., Woo, H.J., 2005. Distribution of benthic macrofauna in subtidal area and on sand flat of Sindu-ri coast, Korea. J. Wetl. Res. 7, 69–88 (in Korean).
Koo, B.J., Shin, S.-H., Lee, S., 2008a. Changes in benthic macrofauna of the Saemangeum tidal flat as result of a drastic tidal reduction. Ocean Polar Res. 30, 485–495 (in Korean).
Koo, B.J., Shin, S.-H., Woo, H.J., Kim, E.-S., Je, J.G., 2008b. Changes in macrobenthic community structure on Gunsan tidal flat after the closing of the Saemangeum 4th Dyke. Ocean Polar Res. 30, 497–507 (in Korean).
Lee, C.H., Lee, B.-Y., Chang, W.K., Hong, S., Song, S.J., Park, J., Kwon, B.-O., Khim, J.S., 2014. Environmental and ecological effects of Lake Shihwa reclamation project in South Korea: a review. Ocean Coast. Manage. 102, 545–558.
Lee, J.-H., 1987. Distributional pattern of polychaetes in the benthic community of the Yellow Sea. Bull. Korean Fish. Soc. 20, 224–229 (in Korean).
Lee, J.-H., Hong, J.-S., Yi, S.K., 1983. Studies on the benthic fauna in Garolim Bay, Korea subtidal soft-bottom community. J. Ocean. Soc. Korea 18, 111–116.
Lee, J.-H., Koh, B.-S., Park, H.-S., 1997. Marine environmental assessment based on the benthic macroinfaunal compositions in the coastal area of Incheon, Korea. J. Korean Fish. Soc. 30, 771–781 (in Korean).
Lee, J.-H., Park, H.-S., 1998. Community structures of macrobenthos in Chonsu Bay, Korea. J. Korean Soc. Oceanogr. 33, 18–27.
Lee, J.-H., Park, J.-Y., Lee, H.-G., Park, H.-S., Kim, D., 2003. Environmental assessment of the Shihwa Lake by using the benthic pollution index. Ocean Polar Res. 25, 183–200 (in Korean).
Lee, J.-H., Yu, O.H., Lee, H.-G., Park, J.-Y., 2004. Effect of environmental variables on the inter- and subtidal macrobenthic communities in the Iwon Dike area. J. Korean Fish. Soc. 37, 295–306 (in Korean).
Lee, Y.-H., Koh, C.-H., 1994. Biogenic sedimentary structures on a Korean mud flat: Spring-neap variations. Neth. J. Sea Res. 32, 81–90.
Lim, H.-S., Choi, J.-W., 1998. Macrobenthic community at the subtidal area around Taebudo in Kyeonggi Bay, Korea. J. Korean Fish. Soc. 31, 453–462 (in Korean).
Lim, H.-S., Choi, J.-W., 2001. Community structure of subtidal macrobenthos in Hampyung Bay during autumn in 1997, southwest coast of Korea. J. Korean Fish. Soc. 34, 327–339 (in Korean).
Lim, H.-S., Hong, J.-S., 2002. Spatial distribution of macrozoobenthos along the salinity gradient and sedimentary environment in the Watancheon Estuary, Beobseongpo, southwest coast of Korea. J. Korean Soc. Oceanogr. 7, 8–19 (in Korean).
Lim, H.-S., Je, J.-G., 1998. Macrobenthic communities on the macro-tidal flats of Taebudo and Tando in the west coast of Korea. Ocean Res. 20, 121–130 (in Korean).
Lim, H.-S., Lee, J.-H., Choi, J.-W., Jong-Geel, J., 1995. Macrobenthic community on the soft-bottom around the Youngjong Island, Korea. J. Korean Fish. Soc. 28, 635–648 (in Korean).
Lim, H.-S., Park, K.-Y., 1998. Community structure of the macrobenthos in the soft bottom of Yongsan River Estuary, Korea. J. Korean Fish. Soc. 31, 343–352 (in Korean).
Lim, H.-S., Park, K.-Y., 1999. Community structure of macrobenthos in the subtidal soft bottom in semi-enclosed Yongsan River Estuarine Bay, southwest coast of Korea. J. Korean Fish. Soc. 32, 320–332 (in Korean).
Lim, H.-S., Park, K.-Y., Ihm, B.-S., Lee, J.-S., Chu, S.-D., 1997. Macrozoobenthic community on the mud-tidalflat around Mokpo coastal area, Korea. Korean J. Ecol. 20, 355–365 (in Korean).
Lim, H.-S., Seo, C.-H., 2011. Structure change of macrozoobenthic community after 10 years in Youngsan River estuarine bay, southwest coast of Korea. J. Korean Soc. Oceanogr. 16, 254–267 (in Korean).
Oh, I.S., Kim, W.S., 1976. The polychaetous annelid and environment in the intertidal flat, Inchon, Korea. J. Ocean. Soc. Korea 11, 71–76.
Paik, E.-I., 1973. Some benthic polychaetous annelids from the Yellow Sea. Bull. Korean Fish. Soc. 6, 123–131.
Park, H.-S., Kang, R.-S., Lee, J.-H., 2006. Distribution patterns of the dominant macrobenthosand the benthic environments on subtidal soft-bottom in Chonsu Bay, Korea. J. Korean Fish. Soc. 39, 214–222 (in Korean).
Park, H.-S., Lee, J.-H., Choi, J.-W., 2000b. Spatio-temporal distributions of macrobenthic community on subtidal area around Mokpo, Korea. J. Korean Soc. Oceanogr. 5, 169–176 (in Korean).
Park, H.-S., Lim, H.-S., Hong, J.-S., 2000a. Spatio- and temporal patterns of benthic environment and macrobenthos community on subtidal soft-bottom in Chonsu Bay, Korea. J. Korean Fish. Soc. 33, 262–271 (in Korean).
Park, J., Kwon, B.-O., Kim, M., Hong, S., Ryu, J., Song, S.J., Khim, J.S., 2014. Microphytobenthos of Korean tidal flats: a review and analysis on floral distribution and tidal dynamics. Ocean Coast. Manage. 102, 471–482.
Pearson, T.H., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. 16, 229–311.
Rho, B.J., Park, K.S., Lee, J.W., 1996. An ecological study on the macrozoobenthos around Daesan Industrial Complex. Korean J. Environ. Biol. 14, 69–80 (in Korean).
Ryu, J.-S., Choi, J.-W., Kang, S.-G., Koh, C.-H., Huh, S.-H., 1997. Temporal and spatial changes in the species composition and abundance of benthic polychaetes after the construction of Shihwa Dike (West Coast of Korea). J. Korean Soc. Oceanogr. 2, 101–109 (in Korean).
Ryu, J., Khim, J.S., Kang, S.-G., Kang, D., Lee, C.-H., Koh, C.-H., 2011a. The impact of heavy metal pollution gradients in sediments on benthic macrofauna at population and community levels. Environ. Pollut. 159, 2622–2629.
Ryu, J., Khim, J.S., Choi, J.-W., Shin, H.C., An, S., Park, J., Kang, D., Lee, C.-H., Koh, C.-H., 2011b. Environmentally associated spatial changes of a macrozoobenthic community in the Saemangeum tidal flat, Korea. J. Sea Res. 65, 390–400.
Ryu, J., Nam, J., Park, J., Kwon, B.-O., Lee, J.-H., Song, S.J., Hong, S., Chang, W.K., Khim, J.S., 2014. The Saemangeum tidal flat: long-term environmental and ecological changes in marine benthic flora and fauna in relation to the embankment. Ocean Coast. Manage. 102, 559–571.
Sakai, T., 1976. Crabs of Japan and the adjacent Seas. Kodansha Ltd, Tokyo, p. 774.
Sato, M., 2013. Resurrection of the genus *Nectoneanthes* Imajima, 1972 (Nereididae: Polychaeta), with redescription of *Nectoneanthes oxypoda* (Marenzeller, 1879) and description of a new species, comparing them to *Neanthes succinea* (Leuckart, 1847). J. Nat. Hist. 47, 1–50.
Seo, I.-S., Choi, B.-M., Yun, J.S., Kim, D.I., Lee, J.U., Hwang, C.-H., Kang, Y.S., Kang, Y.S., Son, M.H., 2010. Community structure of macrobenthic invertebrates during spring and autumn around Ui Island, Sinan-gun, Jeollanam-do. Korean J. Environ. Biol. 28, 133–142 (in Korean).
Seo, I.-S., Hong, J.-S., 2004. The community ecology of benthic macrofauna on the Cheokjeon tidal flat, Incheon, Korea 2. Spatio-temporal distribution patterns of the major dominant species. J. Korean Soc. Oceanogr. 9, 93–105 (in Korean).
Shin, H.C., Choi, J.W., Koh, C.H., 1989. Faunal assemblages of benthic macrofauna in the inter- and subtidal region of the inner Kyeonggi Bay, west coast of Korea. J. Ocean. Soc. Korea 24, 184–193 (in Korean).
Shin, H.C., Kang, S.-G., Koh, C.-H., 1992. Benthic polychaete community in the southern area of Kyeonggi Bay, Korea. J. Ocean. Soc. Korea 27, 164–172 (in Korean).
Shin, H.C., Koh, C.-H., 1998. Benthic polychaete community in northern Kyeonggi Bay in December 1995. J. Korean Soc. Oceanogr. 3, 261–270 (in Korean).
Shin, H.C., Lim, K.H., 2003. Macrobenthic communities on the tidal flats in Tando Bay on the west coast of Korea. Bull. Inst. Fish. Sci. 12, 65–73 (in Korean).
Shin, S., 1993. Study on the environment and benthos in the intertidal zone of Haenam peninsula, Korea. Bull. Korean Fish. Soc. 26, 63–75 (in Korean).
Shin, S.H., Gu, B.J., Je, J.G., 2004. Spatial distribution of benthic macrofauna on the tidal flat of Garolim Bay, west coast of Korea. Korean Wetl. Soc. 6, 57–72 (in Korean).
Van de Kam, J., Battley, P.F., McCaffery, B.J., Rogers, D.I., Hong, J.-S., Moores, N., Ki, J.-Y., Lewis, J., Piersma, T., 2010. Invisible Connections: Why Migrating Shorebirds Need the Yellow Sea. CSIRO Publishing, Melbourne.

Yoo, J.-W., Kim, C.-S., Park, M.-R., Lee, H.-G., Lee, J.-H., Hong, J.-S., 2003. The selection of appropriate sampler for the assessment of macrobenthos community in Saemangeum, the west coast of Korea. J. Korean Soc. Oceanogr. 8, 285–294 (in Korean).

Yoo, J.-W., Hong, J.-S., 1996. Community structures of the benthic macrofaunal assemblages in Kyonggi Bay and Han Estuary, Korea. J. Korean Soc. Oceanogr. 31, 7–17.

Yu, O.H., Koh, B.-S., Lee, H.-G., Lee, J.-H., 2004. Effect of environmental variables on changes in macrobenthic communities in the coastal area of Inchon, Korea. J. Korean Fish. Soc. 37, 423–432 (in Korean).

Yu, O.H., Lee, H.-G., Lee, J.-H., 2012. Influence of environmental variables on the distribution of macrobenthos in the Han River Estuary, Korea. Ocean Sci. J. 47, 519–528.

Yu, O.H., Lee, H.-G., Lee, J.-H., 2011. The influence of environmental variables on macrobenthic communities after dike construction in Asan Bay, Korea. Korean J. Environ. Biol. 29, 326–344 (in Korean).

Yu, O.H., Lee, H.-G., Lee, J.-H., 2006a. The intertidal macrobenthic community along an artificial structure. J. Korean Fish. Soc. 39, 132–141 (in Korean).

Yu, O.H., Lee, H.-G., Lee, J.-H., Kim, D.-S., 2006b. Impacts of sand mining on the macrobenthic community in Gyeonggi Bay, Korea. Ocean Polar Res. 28, 129–144 (in Korean).

Yu, O.H., Lee, H.-G., Shim, W.J., Kim, M., Park, H.S., 2013. Initial impacts of the *Hebei Spirit* oil spill on the sandy beach macrobenthic community west coast of Korea. Mar. Pollut. Bull. 70, 189–196.