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A comparative review and analysis of tentative ecological quality objectives (EcoQOs) for protection of marine environments in Korea and China

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A B S T R A C T

Ecological quality objectives (EcoQOs), as tools for implementing ecosystem approach, have long been acknowledged to protect the marine ecosystems and fisheries in regional seas through joint efforts by surrounding countries over the past decade. The present review analyzed the best available meta-data relating to the five ecosystem elements that were recently proposed by the Northwest Pacific Action Plan to evaluate the current status of coastal ecosystem health in marine environment of the Yellow Sea. We suggested the six tentative EcoQOs among five ecological quality elements including: 1) biological and habitat diversity; 2) invasive species; 3) eutrophication; 4) pollutants; and 5) marine litters. Environmental status was assessed, depending on the EcoQOs targets, by comparison to the world average values, existing environmental standards, or reported values of other regional seas. Results of analysis revealed that among the six tentative EcoQOs, two target objectives to marine biodiversity and concentrations of nutrients (viz., DIN and DIP) were met towards good environmental status. Whilst, three EcoQOs relating to hypoxia and red-tide, pollutants (persistent toxic substances and metals), and marine litters (including microplastics) did not meet and one relating to invasive species could not be judged due to insufficient data sets. The biggest weak point for developing suitable EcoQOs and assessing status of ecosystem health could be insufficient meta-data sets available and/or discrepancy in methodological details cross the data-sets or between the two targeted countries. Thus, the cooperation of neighboring countries, viz., Korea and China for the Yellow Sea, is necessary for the ecosystem based management of our regional sea in the future. Overall, this first time review for the assessment of target tentative EcoQOs in the Yellow Sea region encompassing coasts of Korea and China would provide a better understanding of the current status of environmental pollution and ecosystem health.

1. Introduction

Coastal environments have long been deteriorating due to (in) direct anthropogenic pollution, thus marine pollution has become a significant and common problem worldwide. For the management and sustainable use of coastal and marine ecosystem services, particularly for the regional seas neighboring multiple countries, intergovernmental efforts are deemed important. For example, ecological quality objectives (EcoQOs) have been developed to protect the marine ecosystems and fisheries in the regional seas over the past decade through the many international programs or societies (Rogers and Greenaway, 2005). The EcoQOs are tools in implementing ecosystem approach which represent the desired qualities of specific ecosystem elements, being proposed as several operational objectives of elements and/or indicators previously worldwide (OSPAR Commission, 2010a).

The EcoQOs system consists of elements (viz., indicators;

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specific issues of the ecosystem) and objectives (viz., targets; against which to measure progress). Meeting the EcoQO refers to a good state for the corresponding ecosystem element, while not meeting the EcoQO would indicate an immediate action plan being required (OSPAR Commission, 2010b). The EcoQOs were set up appropriately for evaluation of ecological status and protection of regional marine environment. Each EcoQO has its own target criteria and is a system that evaluates if it has achieved the corresponding criteria through a desired ecosystem monitoring program. OSPAR has been developing the EcoQOs system for protecting and conserving the region of North Sea and its resources, with 15 neighboring countries participated since 1992. The EcoQOs of the North Sea cover varying elements of ecosystem including phytoplankton, benthic species, fish, seabirds, and marine mammals (OSPAR Commission, 2010a). In addition, the aspect of anthropogenic activities and their effects is considered as one component of EcoQOs, such as chemical pollution, eutrophication, shipping (oil at sea), litter, and fishing. Integrated assessment of North Sea ecosystem adopting the EcoQOs has been well practiced being a successful example case of the management of regional sea.

The Northwest Pacific Action Plan (NOWPAP) region includes Yellow Sea, where two rapidly developing Asian countries of Korea and China have long experienced ecosystem threats linked to environmental deterioration during the past half century. These pollution-mediated marine ecosystem problems include: 1) a loss of habitat and biological diversity; 2) introduction of invasive species; 3) coastal eutrophication; 4) chemical pollution; and 5) marine litter (NOWPAP POMRAC, 2017). In fact, the individual scientific efforts to assess ecological conditions of polluted coastal environments of the NOWPAP region have significantly increased during the past several decades (Jeppesen et al., 2011; Ryu et al., 2016). However, the systematic monitoring of pollution and control have not been well practiced at intergovernmental level (Daler, 2005; Van Lavieren et al., 2011; Davis et al., 2015). Accordingly, it was quite difficult to select proper and comparable ecosystem elements to adopt and develop the consensus EcoQOs in the Northwest Pacific region.

Marine mammals, waterbirds, benthic and pelagic communities are all important components of marine ecosystem and the population and/or species diversity would support the overall ecological health quantitatively or functionally (NSCs, 2010; OSPAR, 2017). However, populations of some important coastal marine species have declined recently worldwide due to mainly human activities such as by over-exploitation or pollution into waterways (Trites et al., 1999; Schipper et al., 2008). Meanwhile, invasive species are becoming rapidly introduced in new areas and are proliferating in ways that are harming original ecosystems. It is well known that invasive species, mostly introduced through ballast water, are one of the significant threats to marine coastal environments (Mito and Uesugi, 2004).

In addition, eutrophication often adversely affects coastal ecosystems, leading to harmful algal blooms (HAB) and/or anaerobic waterborne conditions, namely hypoxia. Persistent toxic substances (PTSs) and metals and metalloids are major contaminants in aquatic ecosystems because they are toxic to marine life, persistent for long periods of time, are often not easily biodegradable, and could accumulate in marine organisms (Lotufo and Fleeger, 1997; Jones and De Voogt, 1999; Todd et al., 2010). In general, PTSs and metals released into the aquatic environment primarily originate in industrial areas, domestic areas, and also eventually from chemical accidents such as oil spills. Some PTSs have been repeatedly documented as widespread contaminants in coastal environments of the Yellow Sea, but their long-term ecological impacts remain in question (Zhang et al., 2009; Hong et al., 2012a, 2012b).

Marine litter commonly observed everywhere; at the sea surface, on coastal beaches, and on the seafloor, is of increasing concern in the NOWPAP region (NOWPAP, 2008, 2011). They can travel for extended distance and time before becoming stranded, thus the ecological impacts could not be limited in specific region and/or temporal period. It impairs scenery along the shoreline and is detrimental to marine biota, fisheries, safe vessel operation, navigational safety, and ecosystems, in general (Bergmann et al., 2015). Moreover, marine litter can be physically degraded into meso-particles (5–2.5 cm) and microparticles (<5 mm) that potentially impact aquatic ecosystems and ultimately, human health. Therefore, marine litter and micro-particles are a serious, global environmental problem.

The Yellow Sea Large Marine Ecosystem (YSLME) should be protected by joint efforts of Korea and China. It is desirable to establish common EcoQOs, similar to the case of the North Sea and to be evaluated and managed through systematic monitoring efforts. Considering the availability of monitoring data of ecosystem elements that were recently proposed by the NOWPAP experts group (NOWPAP POMRAC, 2017), we suggested six tentative EcoQOs to assess the ecosystem health and to protect the marine environments of the Yellow Sea (Table 1). The objectives of the present review are to provide a preliminary evaluation of the suitability of the tentative EcoQOs encompassing the key elements of biodiversity and pollution, particularly targeting the coastal areas of South Korea and China. We intensively examined and analyzed the available meta-data for the two selected countries within the NOWPAP region, focusing on the aspect of long-term perspectives under the six target EcoQOs (Table 1). Depending on the subject, we set a couple of operational criteria and indicators to systematically describe the current status of proposed EcoQOs and discussed long-term trends. The thoroughness of our review is limited to some extent, due to limited published data and literature across the target countries in time and space.

2. Data collection and analyses

2.1. Study area: the Yellow Sea

Geographically, the study area belongs to the NOWPAP region, where four neighboring countries of Korea, China, Japan, and Russia are cooperating to protect marine environments through the NOWPAP program, as a part of the Regional Seas Programme of the UNEP (United Nations Environment Programme) since 1994.

The Yellow Sea region, which is known to be one of the most productive area in ecological and socio-economic aspects worldwide, say with world top levels in marine biodiversity and fisheries products. The YSLME spans about 440,000 km^2 and averages 44 m in depth, providing well developed tidal flats (~18,000 km^2) that are situated along the coasts of Korea and China (Koh and de Jonge, 2014), which is far extended compared to the world best known tidal flats in the Wadden Sea area (~4700 km^2) (Fig. 1). The Ocean Health Index that evaluated the status of overall ecosystem health for the world's ocean indicated that South Korea ranked 41st and China ranked 160 th (Halpern et al., 2012; Ocean Health Index, 2018) (Fig. 1). Of note, the total score of Korea was 74 points that is higher than the global score (viz., world average of 221 countries EEZs in 2017; 70 points) and the total score of China was 62 points that is lower than the global score. Korea has obtained high scores (>95) in 'artisanal fishing opportunities', 'natural products', 'biodiversity', and 'coastal livelihood and economics', while China has only obtained high score in 'coastal livelihood and economics'. The Ocean Health Index project predicted that the overall score of Korea will likely increase at + 4%, but that of China will likely decrease at −7% in the future.

Table 1
Five ecological quality elements and six tentative objectives for protection of marine environments in Korea and China. The degree of monitoring efforts and metadata availability were given by country for a comparative purpose.

Ecological Quality Elements /Operational criteria or targets	Korea						China						Tentative Ecological Quality Objectives (EcoQOs)
	Monitoring efforts		Data availability*				Monitoring efforts		Data availability				
	nation-wide	project-based	0	1	2	3	nation-wide	project-based	0	1	2	3	
1. Biological and habitat diversity													
Species diversity of marine mammals and waterbirds	✓	✓			✓			✓	✓				
Species, age, and size structure of fish stocks	✓	✓				✓	✓	✓		✓			
Distribution of benthic and pelagic communities and their status (invertebrate, plants & algae, and fish)	✓	✓				✓	✓	✓				✓	1. Number of species and density of marine organisms should be maintained above the mean values of world ocean.
2. Invasive species													
Abundance and state characterization of invasive species		✓			✓			✓		✓			2. Invasive species should not be newly introduced.
Environmental impact of invasive species		✓		✓				✓		✓			
3. Eutrophication													
Nutrients concentration	✓	✓				✓	✓	✓				✓	3. Eutrophication should not occur.
Direct effects of nutrient enrichment	✓	✓				✓	✓	✓			✓		4. Coastal hypoxia and red tide should not be found at all sites.
Indirect effects of nutrient enrichment	✓	✓			✓		✓	✓		✓			
4. Pollutants													
Concentration of pollutants	✓	✓				✓	✓	✓				✓	5. Concentrations of organic pollutants and metals in sediments should not be exceeded the sediment quality guidelines.
Effects of pollutants		✓				✓		✓			✓		
5. Marine litter													
Characteristics of litter in the marine and coastal environment	✓	✓				✓	✓	✓			✓		6. Density of marine litter and microplastics in coastal waters should be maintained below the values of other regional seas.
Impacts of litter on marine life		✓		✓				✓		✓			

*Metadata availability given as degree of 0–3 based on literature survey; ‘0’ indicates no data available, ‘1’ for seldom and limited data available, ‘2’ for moderately accumulated data available, and ‘3’ for fairly well documented data available.

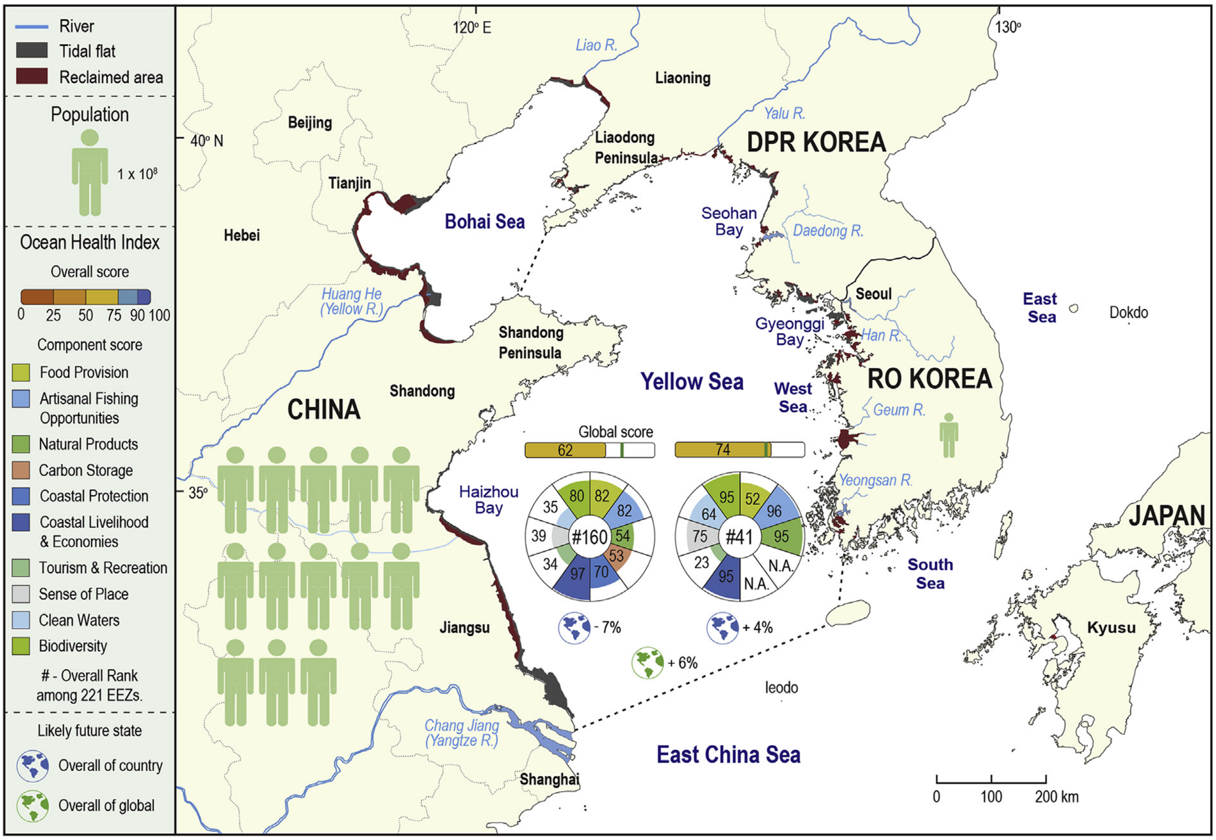

Fig. 1. Map showing the study area containing only in the Northwest Pacific Action Plan (NOWPAP) region and Ocean Health Index (OHI) of Korea and China. The dotted lines indicate the boundary of each coastal area.

2.2. Data collection

The NOWPAP initiated the development of EcoQOs in 2014 and agreed to prepare regional overview on possible EcoQOs in the 2016 meeting. The five proposed elements of the EcoQOs include 1) biological/habitat diversity, 2) invasive species, 3) eutrophication, 4) pollutants, and 5) marine litter (NOWPAP POMRAC, 2017). These elements primarily concern the anthropogenic pressure which cause adverse impacts on coastal and marine ecosystems. We collected all the available data in the coastal and open ocean of the marine environments of Korea and China from the peer-reviewed publications (total of 110 documents) since 1970s and analyzed the meta-data following the operational criteria or indicators suggested by the NOWPAP. The detailed description of data collection and literature lists for the 6 EcoQOs proposed in this review were given in the Supplementary Materials. Of note, the meta-data from North Korea could not be collected due to limited access and availability. It should be also mentioned that the data for some objectives were not available in time series, thus most comprehensive or recently reviewed data were utilized to describe the current status of pollution.

2.3. Operational criteria or targets

Considering the current monitoring system in the marine environments from Korean and Chinese governments, 2–3 operational criteria or targets were selected under the five elements of EcoQOs suggested by the NOWPAP (NOWPAP POMRAC, 2017) (Table 1). First, the ecological quality element, ***'biological and habitat diversity'*** included four major groups of taxa, namely marine mammals, waterbirds, fishes, and marine invertebrates. Operational criteria were considered as species diversity of marine mammals and waterbirds, species, age, and size structure of fish stocks, and distribution of benthic and pelagic communities and their status (invertebrate, plants and algae, and fish). Second, the element, ***'invasive species'*** designated by the governments of South Korea and China were compiled and described in a comparative manner; operational criteria were abundance and state characterization of invasive species and their environmental impacts. Third, the element, ***'eutrophication'*** indicating the status of water quality were evaluated; nutrients concentration (e.g., dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP)), direct effects of nutrient enrichment (coastal hypoxia and red-tide), and indirect effects of nutrient enrichment. Fourth, the element, ***'pollutants'*** indicates the potential adverse effects on marine organisms when the concentrations exceeded the existing environmental guidelines. The data of environmental contaminants including PTSs and metals have been fairly well documented in time and space, accordingly in-depth analysis was performed for various chemicals of concern. The PTSs of concern include polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDTs), hexachlorohexanes (HCHs), polycyclic aromatic hydrocarbons (PAHs), nonylphenols (NPs), polybrominated diphenyl ethers (PBDEs), and hexabromocyclododecanes (HBCDs). Other target metals and metalloids include As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn. Finally, the element, ***'marine litter'*** has been recently recognized as one serious emerging issue; operational criteria were characteristics of litter in the marine and coastal environments and their impacts on marine life. We collected meta-data for marine

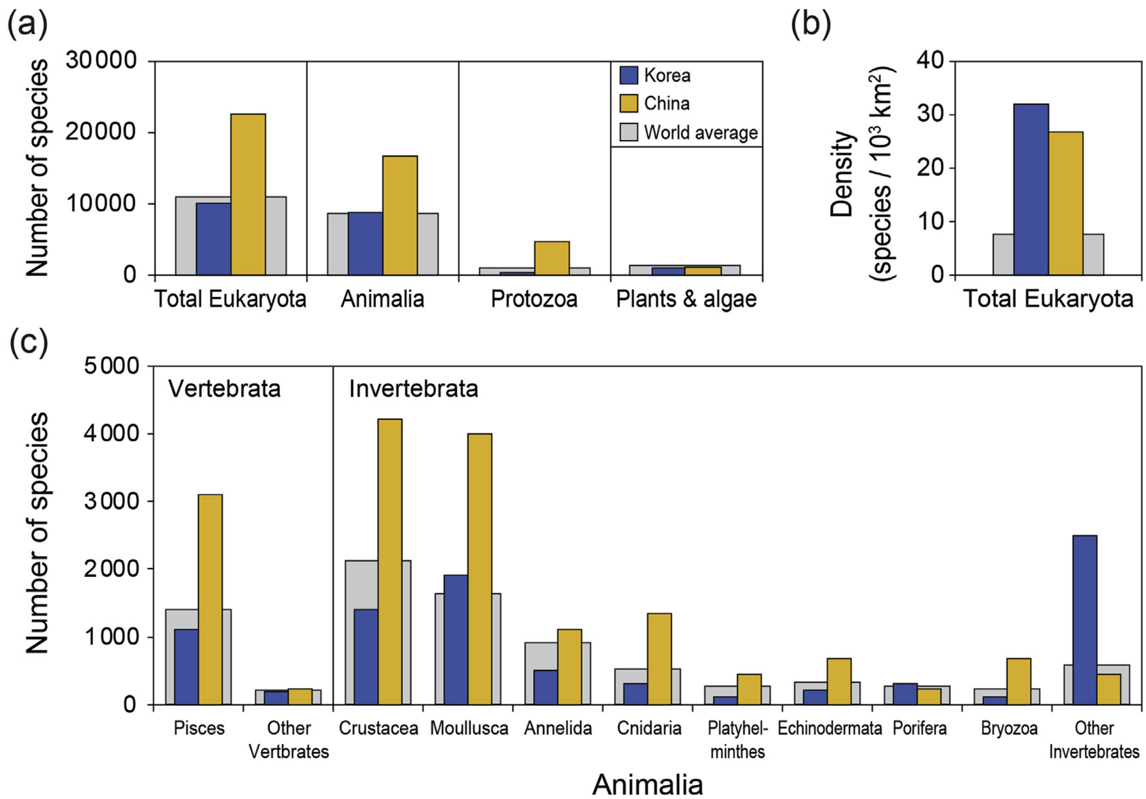

Fig. 2. Overview of marine biodiversity in Korea and China; (a) a number of marine eukaryotic species and (b) species per area values, and (c) a number of species in taxa of Animalia in coastal areas of Korea and China.

litter including microplastics in the beach and surface waters of the Yellow Sea and discussed the spatial characteristics and potential impacts on marine wildlife. Considering the availability of metadata, six tentative EcoQOs were proposed (Table 1). Environmental status of the Yellow Sea region was assessed by comparison to the world average values (biological and habitat diversities), existing environmental standards (eutrophication and pollutants), or reported values of other regional seas (marine litters and microplastics), respectively, in a quantitative manner.

3. Marine biodiversity

We suggest that EcoQO 1 is *"Number of species and density of marine organisms should be maintained above the mean values of world ocean."* A number of eukaryote species and density in coastal areas of South Korea and China were evaluated for biodiversity (Fig. 2). In Korea, total 9900 eukaryote species were recorded and composed high number of species in the order of Animalia, plants & algae, and Protozoa. Total species numbers of Eukaryota were similar or slightly lower than the average value of world ocean (10,759 species), while the species richness (species per area, spp. 10^3 km^{-2}) was about four times greater than the world average value (7.68 species 10^3 km^{-2}). The value of species per area in coastal areas of Korea was found to be highest (32.3 species 10^3 km^{-2}) compared to those of the world ocean (Costello et al., 2010). Despite its relatively small area, Korea, surrounded by sea on three sides, has various types of habitats including estuary, intertidal zone (mud flat, beach, rocky shore, and salt marsh), and island, which provides environments suitable for a variety of marine organisms (Park et al., 2014; Song et al., 2017).

In China, total 22,365 eukaryote species were reported and Animalia was found to be a main taxonomic group, followed by plants & algae, and Protozoa. The species number of Animalia and Protozoa were about 2–5 times greater than those of the world ocean due to the large area of Chinese coasts. The number of species per area of China was relatively smaller (26.9 species 10^3 km^{-2}) than that of Korea, but the value was about 3.5 times greater than the world average (Costello et al., 2010). These results indicated that China has not only large coastal area, but also suitable for inhabiting marine organisms with varying climate conditions in tropic, subtropic, and temperate regions. Among the Animalia, Invertebrata showed the great species diversity in both countries. In Invertebrata, Mollusca and Crustacea were the the most dominated taxa, followed by Annelida, Cnidaria, and others. Overall, the data has shown that Korean and Chinese coastal areas have greater number of species and species per area than those of other regional seas in the ocean.

Although number of species showed good state in Korea and China, however, the negative evidences for other elements of marine biodiversity and ecosystem health were also reported by some previous studies. For example, the number of minke whales was reduced from 1685 in 2001 to 733 in 2008 (McKinnell and Dagg, 2010). The populations of marine mammals in the Yellow Sea have been decreasing primarily due to heavy catch loads as well as habitat destruction owing to the coastal development. In case of fish stocks, Yellow Sea was known as one of the most exploited area in the world (Tang et al., 2003). Human activities such as overfishing, dam construction, and pollution in addition to climate change have been causing the long-term changes in fish population or species abundance. From 1980 to 2000, the number of catches of coastal fishes and demersal fishes decreased, while those of pelagic fishes increased in the Korean waters. In addition to the decrease in abundance, the size of demersal fish was continuously reduced (Zhang and Kim, 1999).

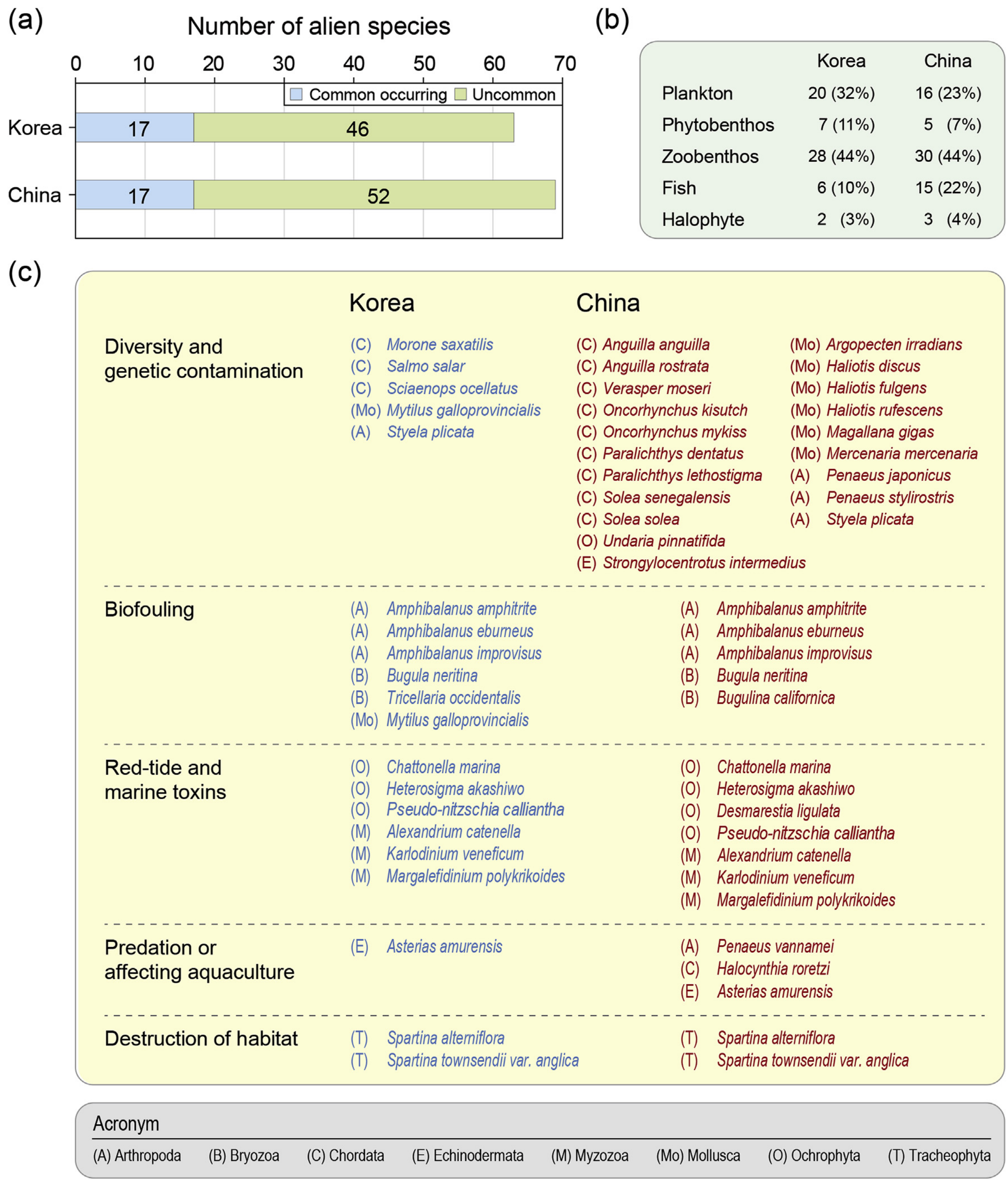

Fig. 3. Overview of invasive species in Korea and China; (a) a number of invasive species, (b) comparison of species composition, and (c) potential adverse impact(s) on ecosystems and corresponding species.

Overall, the results of present review suggested that the status of marine biodiversity in both Korea and China meets the tentative EcoQO 1. However, due to lack of data, comparative analysis for status of biological and habitat diversity concerning marine mammals, waterbirds, and fish stocks could not be conducted in the present review (Table 1). Several recent studies have reported that those elements were in a poor state apart from the species diversity around the world (Myers et al., 1997; Schipper et al., 2008). In order to protect and manage marine organisms and habitats, it is important to develop the appropriate EcoQO relating to the biodiversity through systematic monitoring efforts and collaborative studies by each country.

4. Invasive species

We suggest that EcoQO 2 is *"Invasive species should not be newly introduced."* Invasive species are known to cause diversity and genetic contamination, biofouling, red-tide (producing marine biotoxins), devastation of aquaculture, and destruction of habitats. Due to lack of available information and late monitoring (i.e., late recognition about harmful effects by invasive species), detailed information such as introducing time, pathways, and specific impacts on ecosystems in each country could not be timely provided (Xu et al., 2006; Chavanich et al., 2010; NOWPAP DINRAC, 2010, 2013; Xu et al., 2012; KOEM, 2015; Zhan et al., 2017). Thus, the evaluation for invasive species was limited to assess a total number of invasive species recognized in coastal areas of South Korea and China and their potential impacts on ecosystem in this review (Fig. 3). In Korea, total 63 invasive species were recorded with zoobenthos (28 species), plankton (20 species), phytobenthos (7 species), fish (6 species), and halophtyte (2 species). In China (NOWPAP region), total 69 species were reported with zoobenthos (30 species), plankton (16 species), fish (15 species), phytobenthos (5 species), and halophtyte (3 species). The compositions of invasive species in both countries were generally similar but the proportions of common species were rather small (17 species), viz., 27% in Korea and 25% in China (Fig. 3).

Both Korea and China have been suffering from devastation of coastal ecosystems and massive economic losses over the past decades by invasive species. Diversity and genetic contamination is the most well recognized negative impact by invasive species. Chordata was main taxa in this category, followed by Mollusca, Arthropoda, and others. Most of those invasive species were first utilized as commercial aquaculture organisms, but eventually caused adverse effects on native ecosystem (Savini et al., 2010). Unlike diversity and genetic contamination, invasive species causing other negative impacts on ecosystem could be introduced unintentionally by ships' ballast water, hull fouling of ships, and other routes (Hulme, 2009). Barnacles, sea moss, and mussel were well known invasive species causing biofouling both in the Korean and Chinese coastal waters.

Meantime, red-tides occur by numerous invasive species, such as dinoflagellates and diatoms, and produce marine toxins. For example, *Cochlodinium polykrikoides* caused large scale HAB in the southern coastal area of Korea and extremely serious damage to aquaculture species were evidenced (Jeong et al., 2004). *Pseudo-nitzschia calliantha* was known to produce a neurotoxin that causes amnesiac shellfish poison (Besiktepe et al., 2008) and *Desmarestia ligulata* was reported to have high sulfuric acid concentration in the body (Sasaki et al., 1999). Meanwhile, *Asterias amurensis* was a representative species affecting aquaculture and native benthic ecosystems in Korea and China. In addition, in China, economically negative effects were reported such as diffusion of pathogens by *Litopenaeus vannamei* (Briggs et al., 2004).

More recently, cordgrass (*Spartina* spp.) has been introduced unintentionally in several mudflat areas in the west coast of South Korea, and caused destruction and disturbance of the tidal flat ecosystems since 2012 (Kim et al., 2015). They have been increasingly and widely distributed along the west coast of Korea due to their rapid growth and reproduction habits. A variety of benthic animals and seabirds have lost their original habitats due to the invasion of cordgrass and negative impacts on fisheries and tourism became of significant concern in the local societies. In case of China, cordgrass had been planted intentionally to increase the stability of shoreline, mudflats, and beaches since the late 1970s (An et al., 2007). However, due to the various negative impacts, local biodiversity has been greatly affected, accordingly cordgrass is now recognized as one primary invasive species in China (Liu et al., 2016). Thus, on destructive aspect of habitat, both Korea and China have been severely damaged by cordgrass, although the introduction route and spatiotemporal extension of the *Spartina* spp. varied between the two countries.

In the present review, we could not judge whether the EcoQO 2 was met due to lack of available data on spatiotemporal distribution of invasive species and their ecological impacts on coastal ecosystems in Korea and China. In order to meet the EcoQO 2, monitoring efforts on community structure and functioning processes of invasive species are needed. The historical evaluations of such adverse impacts on original ecosystems should be fulfilled in the future.

5. Eutrophication

5.1. Nutrient concentrations

We suggest that EcoQO 3 is *"Eutrophication should not occur."*

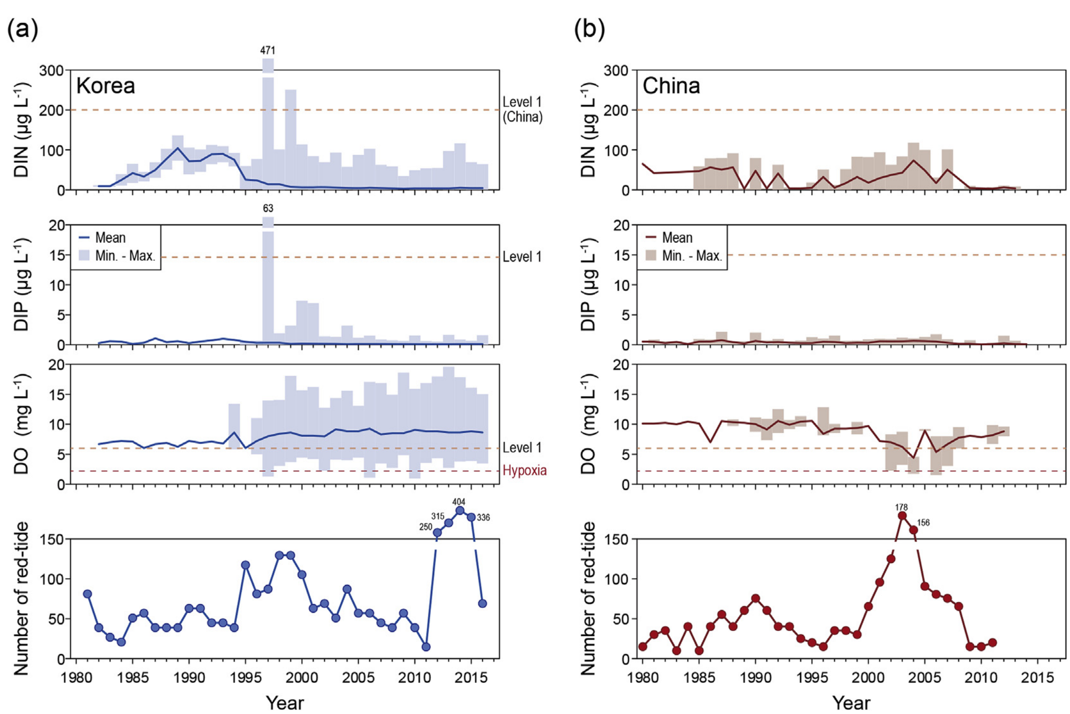

Fig. 4. Temporal concentrations of dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP), dissolved oxygen (DO), and occurrences of red-tide in the coastal areas of (a) Korea and (b) China from 1980 to 2015. Dotted lines indicate the water quality standard (WQS) of China (Level 1) for DIN, DIP, and DO. Hypoxia defined as DO concentration at < 2 mg L^{-1}. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Concentrations of DIN and DIP data of surface water in coastal areas of Korea and China over the past ~30 years were collected and used for the evaluation of eutrophication (Fig. 4). The nutrient concentrations were compared to the Level 1 (0.2 mg L^{-1} for DIN and 0.015 mg L^{-1} for DIP) of water quality standard (WQS) of China (maximum permissible concentration) (MEP, 1998). In Korea, Water Quality Index (WQI) including DIN and DIP as well as saturation (%) of DO in bottom water, chlorophyll a, and transparency are used for assessment of seawater quality (MLTM, 2011).

In Korea, since the 1980s, the concentrations of DIN and DIP showed an increasing tendency seemingly due to the rapid industrialization and insufficient sewage treatment facilities until the 1980s (Fig. 4). After the 1990s, the DIN and DIP concentrations showed a decreasing tendency, with exceptions of the elevated concentrations exceeding the WQS at some sites in the late 1990s, overall concentrations remained low levels since the 2000s. In China, DIN and DIP concentrations have gradually increased since the 1990s (Fig. 4). The concentrations were below the WQS at all stations of the Chinese coastal areas. Since the 2010s, the overall concentrations of DIN and DIP have maintained low levels. Overall, the nutrient concentrations in surface seawater both in Korea and China were generally found to satisfy the EcoQO 3.

Previous studies reported that the surface and bottom concentrations of DIN throughout the southern Yellow Sea were greater from 2006 to 2007 than those in previous years (Wei et al., 2015). Concentrations of PO_4-P and SiO_2-Si initially decreased from the 1950s to the 1990s, and then increased in the late 1990s (Wei et al., 2015). This trend somehow differed from the continual increase of NO_3-N during the same period. Meantime, N:P ratios from 1985 to 2006 increased annually, while the Si:N ratios declined. From 2001 to 2009 (with exceptions in 2003 and 2006), the average concentration of DIN in surface waters increased, while DIN concentrations in deep waters remained constant (Kim and Kim, 2013). The average concentrations of DIP in both surface and deep waters have remained constant during the past decade, while the concentration of DIN has varied (Kim and Kim, 2013). N:P ratios in surface layers of the eastern NOWPAP region have changed tremendously, while the ratio in the deep layer has remained relatively constant. Although N:P ratios have held more constant in the eastern NOWPAP region than in the Yellow Sea, previous studies predicted that the N:P ratio in the eastern NOWPAP region would be altered by an increase in atmospheric nitrogen deposition (Ohara et al., 2007; Kim and Kim, 2013).

Human activities have rapidly accelerated eutrophication in coastal waters and the concentration and composition of nutrients has detrimentally impacted the physiological development and reproduction of marine organisms. Increases in nutrient concentrations and composition changes have threatened the stability of marine ecosystem. Excess concentrations of nutrients could cause the eutrophication, hypoxia, and HAB, thus it needs to manage the sources (Hagy et al., 2004; Heisler et al., 2008). Since most nutrients enter the coastal ecosystem through point and non-point sources on lands, they can be solved by implementation of total pollution load management system (TPLMS) and/or upgrade of sewage treatment facilities (Chang et al., 2012).

5.2. Hypoxia and harmful algal blooms

We suggest that EcoQO 4 is *"Coastal hypoxia and red tide should not be found at all sites."* Concentrations of DO in the Korean coastal waters greatly varied depending on the locality and very low DO concentrations close to hypoxia were sometimes observed (Fig. 4) during the period of ~35 years. However, in terms of average, the DO concentrations in surface water have shown the above level of WQS of China (Level 1: 6 mg L^{-1}) (MEP, 1998). The DO concentration has shown relatively constant temporal trend from the 1990s until recently, without pronounced temporal variation. In the case of China, overall, DO concentration was greater than the WQS, but the concentrations were below the WQS in the mid-2000s, on average. During this period, great number of red-tide occurrence was recorded and relatively great DIN concentration was evidenced. Thus, deficient DO in surface water of the Chinese coastal waters in the mid-2000s appeared to be associated with eutrophication and red-tide occurrences. Since then, it has been showing a high DO concentration. According to the number of red-tides, approximately 100 red-tides per year occurred between 1995 and 2000 in Korea. Since then, there has been a tendency to decrease until 2010, but there has been drastic increase of >200 red-tides on annual basis from 2010 to 2015. In the case of China, great number of red-tides occurred from 2000 to 2002, then gradually decreased with only about 10 red tides per year from the year 2009.

SeaWiFS data spanning 1997–2006 indicated an increase in Chlorophyll a concentration in the Yellow Sea after 2002, but sea surface temperature (SST) did not change, nor did the concentration of suspended sediments (nLw555) (McKinnell and Dagg, 2010). However, the cause for this increase is not clear. Occurrences of HAB are extensive and frequent in coastal waters of the East China Sea. HAB frequency increased drastically after 2000, reaching frequencies almost 90-fold higher than in prior years. In the 1980s, *Noctiluca scintillans* (a dinoflagellate) was the main species involved in the reported algal blooms (Tang et al., 2006). Since the 2000s, *Prorocentrum dentatum* has become the dominant species in HAB, increasing in concert with an increase in N:Si and/or N:P ratios (Tang et al., 2006; Chai et al., 2009). The Chlorophyll a concentration at the ocean surface over the period of 1996–2002 did not change in the eastern NOWPAP area (Yamada et al., 2004). There were 304 red tide events along the Korean coast from 1999 to 2003, caused by 31 species of dinoflagellates (NFRDI, 2004). *Cochlodinium polykrikoides* dominated the southeastern NOWPAP region since 1996. The species has become more widespread recently and has begun to damage commercial fisheries. This was particularly true in 2003, when *C. polykrikoides* blooms reached 48,000 cells mL^{-1}, with the longest persistent bloom lasting for 62 days (Kim, 2010). The number of red tide blooms increased from 2010 to 2015, and the maximum cell concentration remained high (except for 2011) in the southeastern NOWPAP region (NIFS (National institute of Fisheries Science), 2017).

Overall, hypoxia and red-tide were still found in both Korea and China, indicating that they did not meet the tentative EcoQO 4. Continuous monitoring and management measures are needed to prevent damages caused by coastal eutrophication and red-tides in timely manner.

6. Pollutants

We suggest that EcoQO 5 is *"Concentrations of organic pollutants and metals in sediments should not be exceeded the sediment quality guidelines."* Concentrations of pollutants in water samples could reflect short-term contamination and varied among season, thus, we assessed the sediment contamination in this study. From the 1990s to present, available data on the PTSs and metals in sediments of the coastal areas of Korea and China were collected and analyzed (Fig. 5 and Fig. S1). The contamination status of sedimentary PTSs and metals in Korea and China were evaluated using the Canadian Sediment Quality Guidelines for protection of aquatic life, such as interim sediment quality guidelines (ISQGs), probable effect level (PEL), and federal environmental quality guidelines

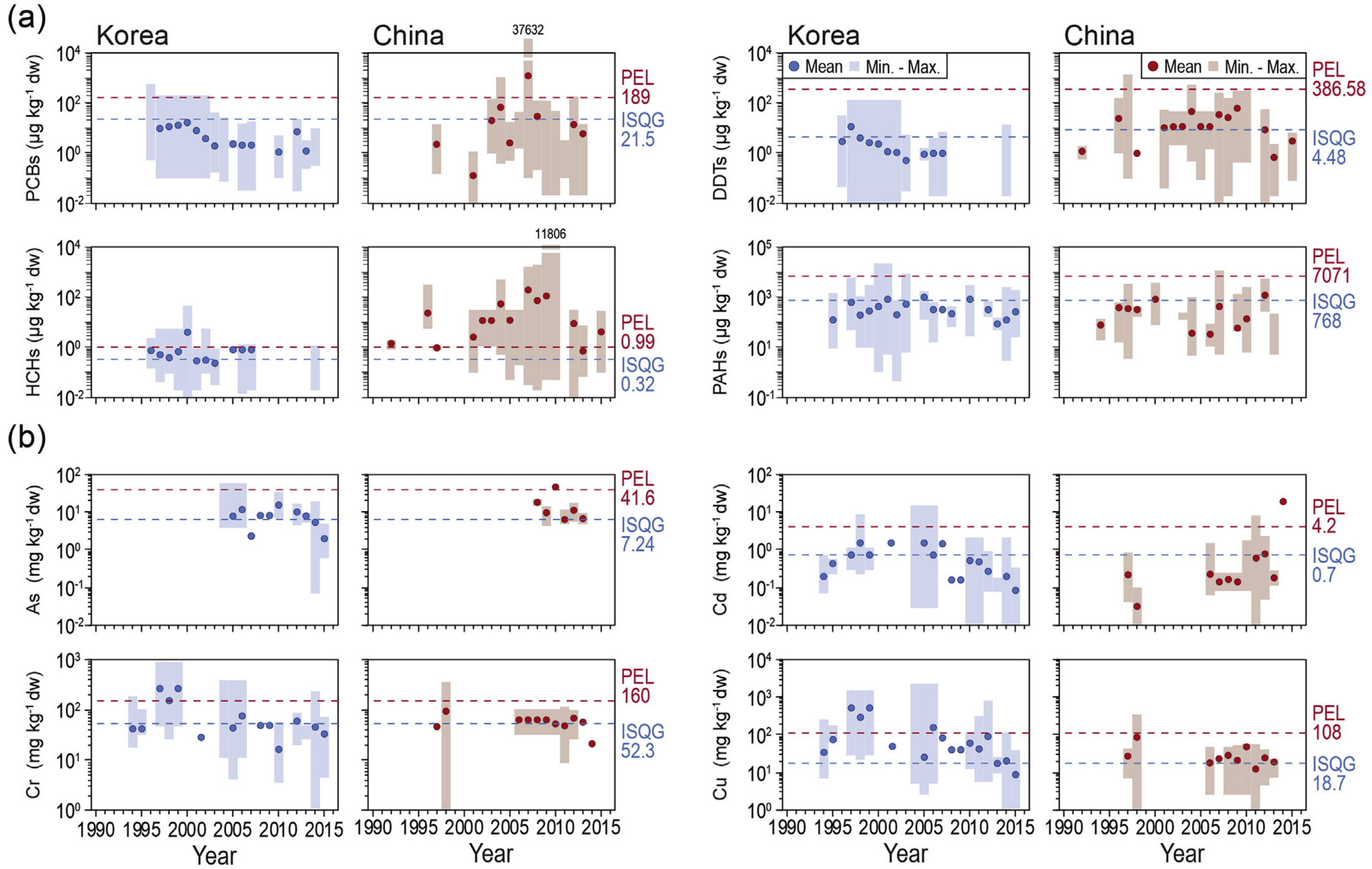

Fig. 5. Temporal concentrations of (a) persistent toxic substances (PTSs); PCBs, DDTs, HCHs, and PAHs and (b) metals and metalloid; As, Cd, Cr, and Cu in sediments of coastal areas of Korea and China from 1980 to 2015. Dotted lines indicate the sediment quality guidelines developed previously (ISQG: interim sediment quality guidelines; PEL: probable effect level).

(FEQG) and NOAA guidelines such as effect range low (ERL) and effect range median (ERM) (NOAA, 1999; CCME, 2001; ECCC, 2013, 2016).

During the past two decades, PCDD/Fs, HCHs, As, Cr, and Ni showed the exceeding concentrations of PEL in Korea and PCBs, DDTs, HCHs, As, and Cd exceeded guideline in China, on average. In addition, DDTs, NPs, PAHs, Hg, Pb, Zn, and Cu concentrations in Korean sediments exceeded the ISQGs, while PAHs, Cr, Hg, and Ni concentrations in Chinese sediments exceeded. The results of present review for PTSs revealed that the major pollutants in sediments differed each other between Korea and China. PBDEs and HBCDs were found to be lesser contaminated in both two countries, and none of them exceeded the FEQGs (Fig. S1). The most recently reported data of sedimentary concentrations of PTSs and metals and metalloid exceeding ISQGs were PCDD/Fs, HCHs, As, and Cr in Korea, and HCHs, As, and Cd in China. Overall, the results suggest that coastal sediments both in Korea and China are moderately polluted by PTSs and metals.

Study efforts on PTSs in coastal ecosystems of South Korea have been increasing given over the past two decades (Hong et al., 2012a; Khim and Hong, 2014; Lee et al., 2014, 2017; Jeon et al., 2017; Meng et al., 2017). Early PTSs research in Korea concentrated on a classic group of persistent organic pollutants, such as PCDD/Fs, PCBs, and organochlorine pesticides. Later research included new target chemicals, including PBDEs, HBCDs, and styrene oligomers (SOs). Twelve types of PTSs were detected at hotspot areas, such as Lake Sihwa, Gwangyang Bay, Masan Bay, Busan Harbor, and Ulsan Bay, with relatively greater concentrations than those reported in other coastal regions of Korea (Hong et al., 2016a). Most PTSs were detected at similar intensities in all research areas, except for some emerging PTSs, which include alkyl-PAHs (derived mainly from petroleum), HBCDs, and SOs (Ramu et al., 2010; Hong et al., 2016b; Yoon et al., 2017). In general, PTSs are well adsorbed on suspended particles due to their hydrophobic properties which are then settled down into the bottom and finally accumulated in coastal sediments (Wania and Mackay, 1996; Fu et al., 2003). In addition, PTSs and metals can be accumulated in marine organisms, such as suspension feeders and deposit feeders, and biomagnified through the food chain. Thus, sedimentary contaminants are of primarily concern in assessment of benthic ecological quality.

China has been subject to rapid development during the past 20 years and consequently, severe contaminations of PTSs and metals have been increasingly reported in the Bohai Sea, Yellow Sea, and East China Sea (Da et al., 2013). Hotspot areas were identified along the Bohai Sea and the Yellow Sea. Some regions were highly polluted by PBDEs, HBCDs, and perfluoroalkyl acids (PFAAs), and great concentrations of DDTs, butyltins, and HBCDs in shellfish were detected in the Yellow Sea and the East China Sea (Yang et al., 2008; Li et al., 2014; Yin et al., 2015). Temporal trends of PTSs and metals concentrations have mostly shown to decrease (Yang et al., 2012; Zhu et al., 2012), but monitoring data in multimedia samples are still limited.

Overall, sedimentary contaminations by PTSs and metals seem to be common environmental problems between Korea and China, with many classes of chemicals exceeding the guidelines. Of note, the major environmental pollutants of interest between two

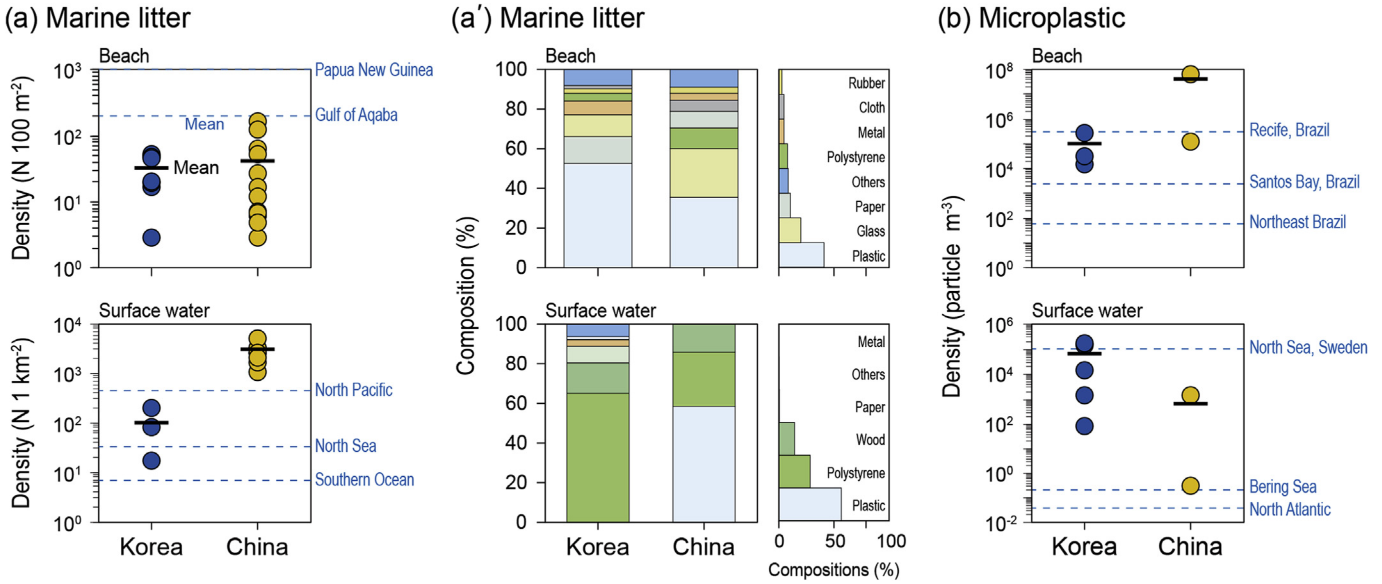

Fig. 6. Overview of pollution by the marine litters in Korea and China; (a) density of marine litter, (a') relative compositions of marine litter, and (b) density of microplastics in beach and surface water of Korea and China. Dotted lines indicate the values of the other regional seas reported previously.

countries would be different. Thus, contamination status of pollutants did not meet the tentative EcoQO 5. Continuous efforts for reducing contaminations of PTSs and metals in coastal waters are needed to protect ecosystem and human health. In addition, site-specific environmental quality guidelines of PTSs and metals to protect the corresponding regional sea, for example in China and Korea for the Yellow Sea region are needed, that will be essential to develop and assess the more suitable and reliable EcoQO for pollutants in the future.

7. Marine litter

We suggest that EcoQO 6 is *"Density of marine litter and microplastics in coastal waters should be maintained below the values of other regional seas."* The occurrences (viz., density) of litter in beach regions of Korea and China were comparable, while those in surface water were significantly different (Fig. 6). The most numerous type of litter in beach both in Korea and China was found to be plastic items, followed by glass and paper. The contamination status of marine litter on beach regions of Korea and China were generally less than those of other areas such as Papua New Guinea (120–7830 items 100 m^{-2}) and Gulf of Aqaba (200 items 100 m^{-2}) reported previously (Al-Najjar and Al-Shiyab, 2011; Smith, 2012). Meanwhile, density of marine litter in surface water in China was found to be about 30 times greater than that in Korea, on average. The greatest number of pieces of marine litter was polystyrene in Korea, while plastic was the most dominant litter in surface water in China. The density of marine litter in surface water both in Korea and China was greater than those reported in North Sea (38 items km^{-2}) and Southern Ocean (6 items km^{-2}) (Thiel et al., 2013; Ryan et al., 2014), particularly the values in China were greater than that of North Pacific region (459 items km^{-2}) (Titmus and Hyrenbach, 2011).

In the study investigated in beaches of Korea from March 2008 to November 2009 (Hong et al., 2014), the most abundant type of marine litter was found to be plastic; 49.8% in number (58.1% when included the foreign plastic bottles, lids, food wrappers buoys, and lighters). The second highest number of pieces of marine litter was found to be styrofoam. Wood was third most numerous, but constituted the greatest weight among the litter categories, followed by plastic and styrofoam. Total volume of litter, in decreasing order, was of styrofoam, plastic, and wood. The most common item was styrofoam (12.8%), followed by fishing rope, beverage bottles (glass), plastic bags, plastic food wrappers, plastic caps, and others. The highest source of litter was identified to be from ocean/waterway activities (49.2%), due to the high composition of fishing rope, buoys, and strapping bands. Shoreline/recreational sources accounted for 45.1% of marine litter. Overall, the major source of marine litter was related to fishing activities, which, if reduced, could greatly reduce the volume of marine litter along the Korean shoreline.

In China, litter on beaches, seafloor, and water column were surveyed during 2007–2014 (Zhou et al., 2016). Based on abundance and density, much more litter was collected from beaches than from the seafloor or water column because tidal currents and wind waves transport floating debris to shores. The high amount litter collected in the North China Sea may be due to the large number of people who use beaches there. Plastic dominated most of the litter, followed by styrofoam, wood, rubber, glass, fabric/fiber, and metal. The source of marine litter on beaches and the seafloor primarily originated from coastal/recreational activities. Navigation and fishing constituted a secondary source of litter, while the source of the litter on seafloor could not be clearly identified. In urban estuaries, an abundance of microplastics was reported. However, an apparent correlation between microplastics and the surrounding activities (population density, development intensity, and typhoon activity) could not be explained.

Marine microplastics have been of great concern in recent years, due to their ubiquitous and persistent nature in the aquatic environment. Plastic in the marine environment that degrade into smaller pieces, such as microplastics, might pose problems to marine organisms because the particles can be ingested and accumulated in digestive tracts (Wright et al., 2013). Density of microplastics in beach and surface water between Korea and China showed a different trend, with greater density in beaches of China and greater density in surface waters in Korea (Fig. 6). Contamination status of microplastics in beach and surface water in Korea and China was generally greater than those of other regional seas such as Santos Bay (Brazil) (Turra et al., 2014), Bering Sea (Doyle et al., 2011), and North Atlantic regions (Thompson et al., 2004).

In the study conducted in South Korea, plastic marine debris were collected at 12 sites in 2013–2014 (Lee et al., 2015). The particles were classified into three types: large microplastics (1–5 mm), mesoplastics (5–25 mm), and macroplastics (>25 mm). The mean abundances of each size category of plastic were 880.4 (large micro), 37.7 (meso), and 1.0 (macro) particles m^{-2}. The mean weight of each type was 0.58 (large micro), 0.65 (meso), and 18 (macro) g m^{-2}. Styrofoam overwhelmingly dominated the large microplastic (99.1%) and mesoplastic (90.9%) categories. A similar composition was reported in a previous study (Lee et al., 2013). Fiber was the most abundant macroplastic (54.7%). Based on weight, styrofoam dominated the large microplastic (74.6%) and mesoplastic (41.2%) categories, while fiber dominated the macroplastic (38.0%) category. A high correlation was observed between large microplastics and macroplastics.

In China, samples of microplastics in surface water were collected from 7 sites in the Yangtze River Estuary and 15 sites in the East China Sea (Zhao et al., 2014; Zhang et al., 2017). The microplastics were categorized into four size groups, >5 mm, >2.5–5 mm, >1–2.5 mm, and >0.5–1 mm. The compositions of each size were 0.2%, 4.4%, 28.4, and 67.0% in the Yangtze River Estuary, and 8.8%, 25.9%, 29.9%, and 35.4% in the East China Sea, respectively (Zhao et al., 2014; Zhang et al., 2017). The composition of microplastics indicated that polyethylene is the most dominant (51%), followed by polypropylene (29%), polystyrene (16%), polyethylene terephthalate (3%), and polymer plastics (<1%) including polyvinyl chloride, polyurethane, and acrylonitrile (Zhang et al., 2017).

Overall, marine litter and microplastics in beach and surface water showed distinct distribution and characteristics between Korea and China. Although the limited data sets are available, both Korea and China did not meet the tentative EcoQO 6. Thus, in order to protect the regional sea including the Yellow Sea in the future, joint efforts will be needed to reduce the pollution of marine litters and microplastics in coastal waters of Korea and China.

8. Future directions towards coastal management and policy

Rapid coastal development, coupled with dynamic environmental changes (due to human activities and climate change), might be expected to drive the wide-scale ecological deterioration observed in the NOWPAP region, including the Yellow Sea ecosystem. In the present review, we proposed six tentative EcoQOs out of five ecological quality elements to protect and manage the coastal ecosystems of Korea and China, particularly the Yellow Sea region based on the available data, and diagnosed the current status of marine ecosystem health. Results of review suggested that among the six EcoQOs, two EcoQOs such as marine biodiversity (EcoQO 1) and nutrient concentrations (EcoQO 3) were met, three EcoQOs such as hypoxia and red-tide (EcoQO 4), pollutants (EcoQO 5), and marine litters (EcoQO 6) did not meet, and one EcoQO such as invasive species (EcoQO 2) could not be judged. Overall, the most difficult point for developing suitable EcoQOs and assessment of ecosystem health status was insufficient meta-data sets available and/or differences in chemical analyses and biological identification methods between the countries.

As mentioned several times above, the cooperation of neighboring countries (Korea and China) is necessary for the management of regional sea such as the Yellow Sea. First, it is necessary to make an accurate diagnosis of current status of ecosystem and to draw out the threatening factors. Second, the suitable EcoQOs should be developed by an agreement between two countries, which are appropriate for management and protection of regional sea. Third, it is important to conduct systematic and continuous monitoring for evaluation of EcoQOs. Fourth, it is necessary to evaluate whether the EcoQOs are met, and if not, to establish and implement environmental policies accordingly. Meantime, the follow-up studies for the evaluation of appropriateness for the tentative EcoQOs suggested in this review and/or the development/modification of proposed EcoQOs (i.e., in response to the underestimated or possibly new threats) would be highly acknowledged. Finally, we suggest that further researches on the topics under insufficient understanding evidenced in this review, i.e., i) species diversity of marine mammals and waterbirds; ii) environmental impact of invasive species; iii) indirect effects of nutrient enrichment; and iv) impact of litter (microplastics) on marine life, are urgently needed. Apart from all the suggestions, it would be most important to produce and share the consistent and systematic database between the two countries or elsewhere. Despite the limited data (due to lack of comparable metadata), this study reviewed the current status of coastal ecosystems in Korea and China and will provide useful information for the development of appropriate EcoQOs for protection and management of the YSLME.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2018.06.094.

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<Supplementary Materials>

A comparative review and analysis of tentative ecological quality objectives (EcoQOs) for protection of marine environments in Korea and China

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Fig. S1. Temporal concentrations of (a) persistent toxic substances; PCDD/Fs, NPs, PBDEs, and HBCDs and (b) metals; Hg, Ni, Pb, and Zn in sediments of coastal areas of Korea and China from 1990 to 2015. Dotted lines indicate the sediment quality guidelines developed previously (ERL: effect range low; ERM: effect range median; FEQG: federal environmental quality guidelines; ISQG: interim sediment quality guidelines; PEL: probable effect level). ··· S14

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Data collections of ecological quality elements.

The data of marine biodiversity in Korea and China used in the present review were from Costello et al. (2010).

The invasive species data of Korea and China were based on the reports performed in NOWPAP regions (Chavanich et al., 2010; NOWPAP DINRAC, 2010; NOWPAP DINRAC, 2013; KOEM, 2015).

Concentrations of nutrients such as DIN and DIP, DO concentrations, and occurrences of red-tides in coastal environments of Korea and China were used based on national wide monitoring data in Korea and a total of 26 researches performed in NOWPAP regions (Zhu et al., 1997; Cha et al., 1998; Choo and Kim, 1998; Park and park, 2000; Taylor and Trainer, 2002; Gong et al., 2003; Li, 2003; Wang et al., 2003; Zhengyan et al., 2003; Zhao et al., 2004; Chai et al., 2006; Tang et al., 2006; Chen et al., 2007; Zhou et al.,2008; CASIO, 2011; NOWPAP CEARAC, 2011a; NOWPAP CEARAC, 2011b; Wang et al., 2011; Zhai et al., 2012; Li et al., 2014; Li et al., 2015; Wei et al., 2015; Yoon et al., 2015; Kodama et al., 2016; KOEM, 2017; Qiao et al., 2017; NIFS, 2017).

As for pollutants, concentrations of PTSs in sediments of Korea and China were reviewed using a total of 27 research articles and 2 review papers (Liu et al., 2000; Ma et al., 2001; Liu et al., 2001; Xu et al., 2001; Chen et al., 2002; Wu et al., 2003; Hu et al., 2005; Hu et al., 2006; Fu et al., 2007; Guo et al., 2007; Liu et al., 2007; Liu et al., 2008; Yuan et al., 2008; Zhang et al., 2009; Hu et al., 2010; Wang et al., 2010; Yuan et al., 2011; Zhao et al., 2011; Li et al., 2012; Lu et al., 2012; An et al., 2013; Li et al., 2013; Zhang et al., 2013; Duan et al., 2014; Zhang et al., 2014; Hong et al., 2016a; Hong et al., 2016b; Wang et al., 2016; Meng et al., 2017).

The metal and metalloids concentrations of sediments were reviewed with a total of 36 researches (Lee and Cha, 1997; Ahn and Choi, 1998; Kong et al., 1998; Jin et al., 2000; Chen et al., 2001; Kim et al., 2003; Hyun et al., 2007; Lee et al., 2008; Kim et al., 2009; Fang et al., 2009; Zhan et al., 2010; Oh et al., 2011; Choi et al., 2012; Na and Park, 2012; Yuan et al., 2012; Lim et al., 2013; Ra et al., 2013; Zhao et al., 2013; Chae et al., 2014; Fu et al., 2014; Hong et al., 2014; Jiang et al., 2014; Miao et al., 2014; Song et al., 2014; Ra et al., 2014; Xu et al., 2014; Zhuang and Gao, 2014; Kang et al., 2015; Rao et al., 2015; Xu et al., 2015; Song et al., 2015; Wang et al., 2015; Zhang et al., 2015; Gao et al., 2016; Lin et al., 2016; Feng et al., 2016).

Finally, marine litters and microplastics in beaches and seawater of Korea and China were reviewed with a total of 14 papers (Kim et al., 2005; Jo et al., 2005; NOWPAP, 2008; NOWPAP, 2011; Lee et al., 2013; Zhao et al., 2014; Kim et al., 2015; Chae et al., 2015; Lee et al., 2015; Yu et al., 2016; Zhou et al., 2016; Lee et al., 2017; Peng et al., 2017; Zhang et al., 2017).

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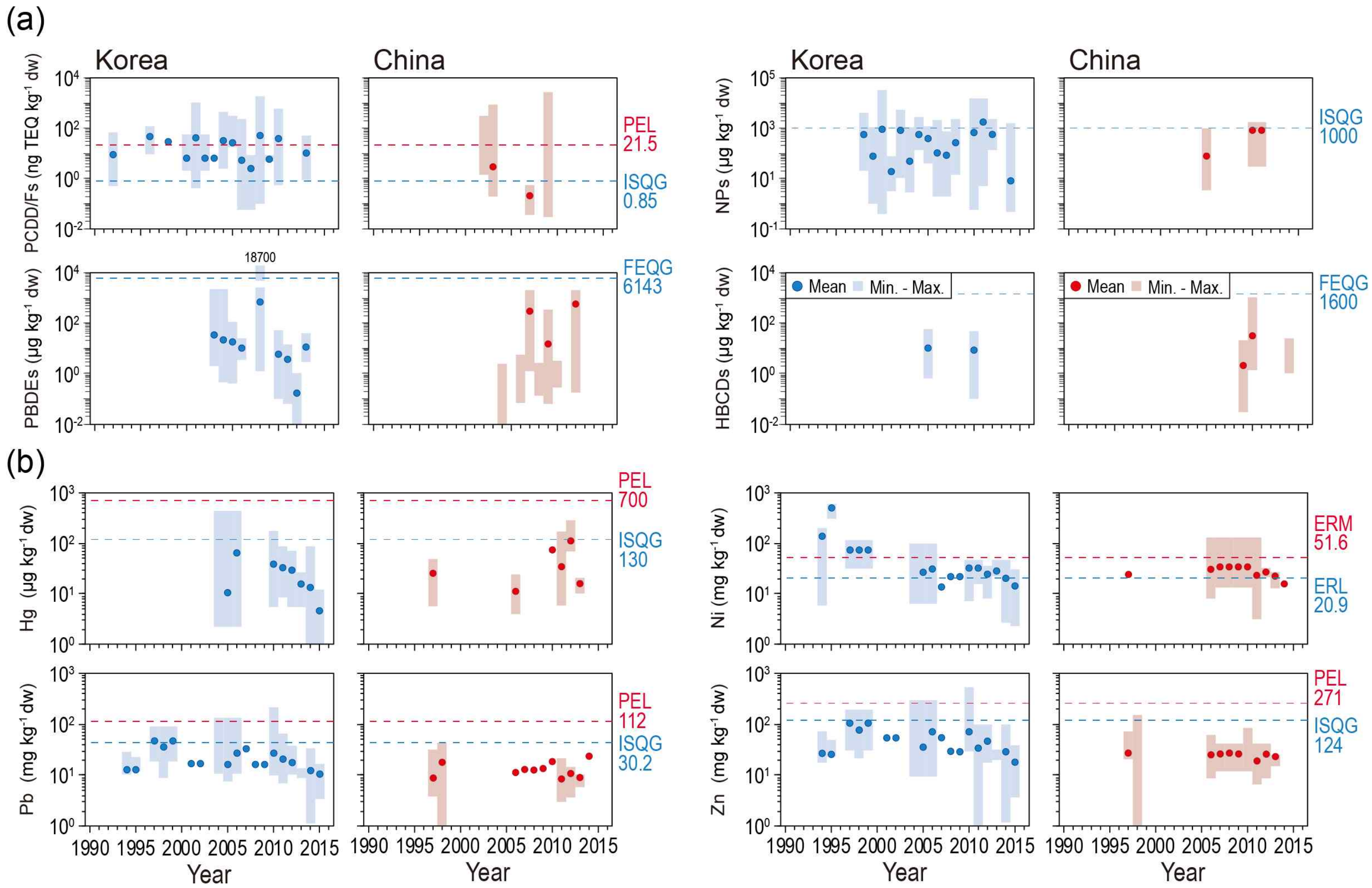

Fig. S1. Temporal concentrations of (a) persistent toxic substances; PCDD/Fs, NPs, PBDEs, and HBCDs and (b) metals; Hg, Ni, Pb, and Zn in sediments of coastal areas of Korea and China from 1990 to 2015. Dotted lines indicate the sediment quality guidelines developed previously (ERL: effect range low; ERM: effect range median; FEQG: federal environmental quality guidelines; ISQG: interim sediment quality guidelines; PEL: probable effect level).