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The Korean tidal flat of the Yellow Sea: Physical setting, ecosystem and management

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A R T I C L E I N F O

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A B S T R A C T

The present article provides a regional overview of the Korean tidal flat extensively developed along the West Sea of Korea, encompassing oceanographic features, geology, and biology. In particular, the Korean tidal flat was fully described in the aspects of spatial scale (viz. size), geographical distribution, biodiversity, and local culture. A particular emphasis was given to explain the framework of the coastal management in Korea, in terms of a legal aspect, by highlighting reclamation versus protection issues. First, we described the Yellow Sea by sketching the boundary, ocean and tidal currents, discharges from the major rivers, sedimentology, and the cooperative surveys between Korea and China. Next, the West Sea of Korea, where the offshore boundary often neighbored rather close to coastal zone because of the associating traditional livelihoods, was described to point out certain characteristics of hydrography, coastal landscape, tidal channels, tide, and sedimentary process. Then the Korean tidal flat which is the main topic of this article was introduced by highlighting the geographical distribution, biodiversity of benthic diatoms and macrozoobenthos, artisanal fisheries, and local culture in aspect of ecosystem services in tidal flats. Meantime, the issue of reclamation was mini-reviewed by tracking the chronicle development, aerial coverage, and deteriorated environmental impacts on the coastal ecosystem. Herein, the untiring efforts towards protection of the Korean tidal flat are also included in viewpoints of legal framework and the designation of protected areas. Overall, the present collective description aims an introductory guidance for the individual papers of the special issue on the Korean tidal flat, with provisioning several key maps to be cross-utilized or referred.

1. Introduction

The "*Getbol*" is mentioned several places throughout the special issue including the present article, though not much exposed to the international society (Koh, 1999, 2011). Getbol is one of the several Korean words that represent the scientific term of "tidal flat", but the reason we choose "Getbol" herein was its sociological impact that comes from its origin, i.e., it encompasses the relationship between coastal communities and ecological services of the tidal flat. In particular, the term reflects the culture of communities that depend on artisanal fisheries conducted in and around the given area. The artisanal fisheries that commonly adopted in many tidal flats of Korea involve mostly a manual labor, accordingly the activities are usually limited to the walking distance down to the low water line (viz. within an intertidal zone). Thus, the spatial coverage of Getbol is about the same of intertidal flat, but the two terms differ in that the former refers to "human culture" inclusive, while the latter simply indicates "scientific spectrum." By syllables, "Get" means coastal area, and "bol" represents wide-open or plain field, thus together, "Getbol" can be defined as open field at the coastal area.

Policy report of the Wadden Sea clearly tells that the management of 'tidal area' includes not only intertidal zone but also subtidal zone, as a habitat unit (CWSS, 2010). Because tidal flats and its surrounding waters interact with each other, theoretically or practically, the tidal area should be recognized as a coherent habitat unit. However, Getbol commonly considers the walkable space for local fishermen and beach hikers, thus its boundary has been limited to a space unit for human use only. Such perspective-driven discrepancy seemed to be closely linked to tidal flat related policy between the Korean and the European Wadden Sea. For example, the boundary of tidal wetlands protected areas in Korea is strictly limited to the area falling into the low tide line. Accordingly, the

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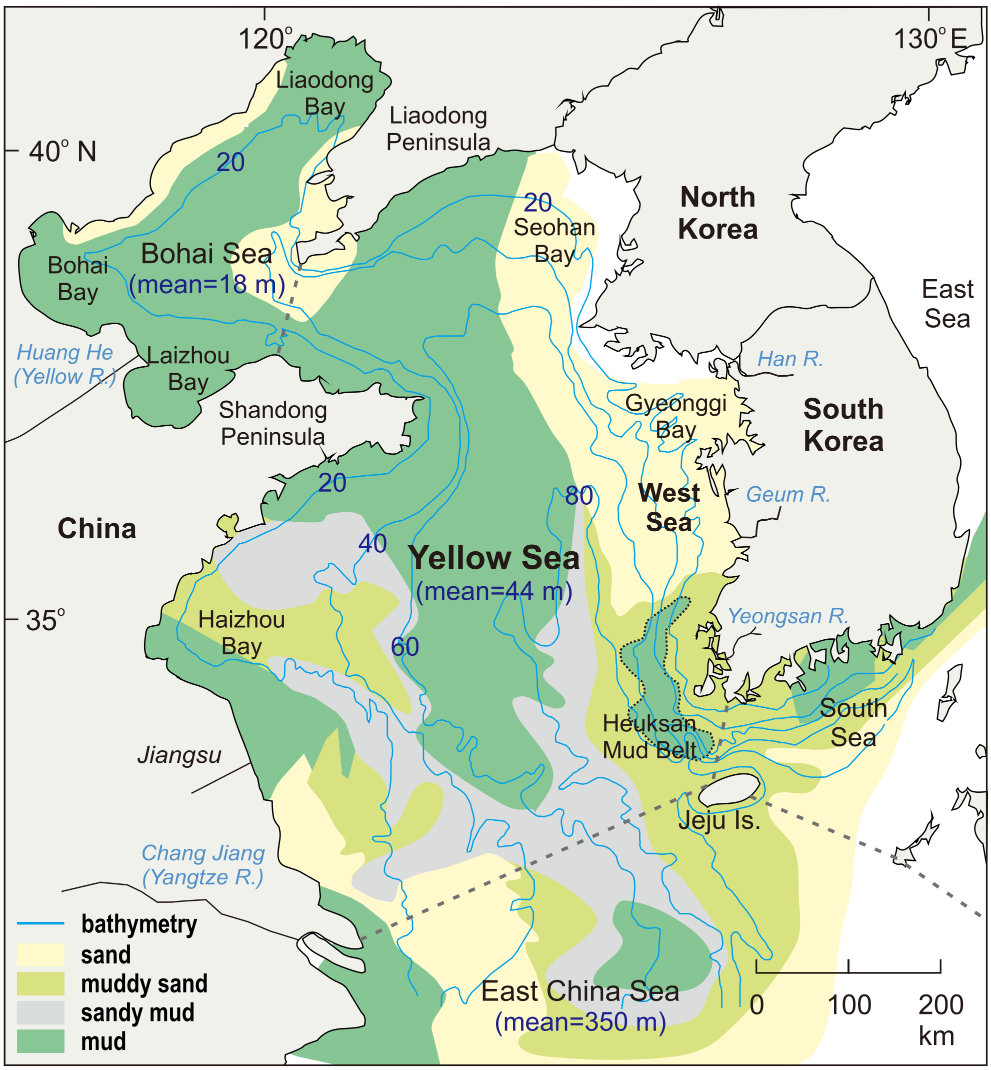

Fig. 1. Map of the Yellow Sea (Section 2) including the West Sea of Korea (Section 3), where tidal flats (Section 4) well developed along the coastline, with the information of the bottom topography.

coastal protection could not cover entire ecosystem of tidal area, rather limited to the sole space being exposed during the ebb tide. In Korea, to expand the boundary of protected area of tidal wetlands from intertidal zone to "tidal area", including subtidal zone, a legal adopting of tidal area for tidal flat would be highly encouraged. For instance, the expansion of tidal flat to cover a water depth of 6 m, which is the definition of the Ramsar "wetland", would be one example.

In the present study, we briefly analyzed the past scientific results in relation to the "Getbol", scientifically tidal flat, by period and subject to find out common or specific interests over the past decades, in quantitative manner. Only the peer reviewed articles published in the international journals are included in this analysis. We could find a total of 209 research papers relating to the tidal flat studies in Korea, since the first report in 1984 (scopus keywords: tidal flat and Korea). The number of papers increased from 10, 37, and to 107 in the periods of before 1990s, in 1990s, and in 2000s, respectively. Only for the last three years, the number of papers reached 55, showing a drastic increase of scientific outcome in more recent years, and it should be noteworthy that 5 papers are related to the issue of the Saemangeum reclamation project, which is also one of our key topics throughout the special issue. In anyhow, among those, the frequently studied subjects were found to be biological (85 papers, 41%), geological (80 papers, 38%), physical (9%), and chemical characteristics (7%). Other minor subjects (6%) relating to the engineering, sociology and policy aspects have been included later since the middle of 1990s. The subject of remote sensing seems to be emerging scientific concern as its scientific application gets more attention in the fields of tidal flat geology and ecology in recent years. One paper in the special issue introduced a case study of thematic mapping as potential use of remote sensing in management of the Korean tidal flats (Ryu et al., 2014a).

The scientific data from the Korean tidal flats were first introduced internationally in the middle of 1980s, with a subject of sediment transport (Wells et al., 1984). The first report relating to the tidal flat biology was also introduced by a foreign scientist, Frey et al. (1987), where macrofaunal zonation on the Songdo tidal flat close to Incheon was studied. Thus, such earlier studies at the beginning stage of tidal flat science in Korea would show certain weakness of scientific independence. It was first in late 1980s that few though, our own scientific results came out, for example Park et al. (1986) reported sediment transport in the Geum River estuary and Koh and Shin (1988) introduced the macrofauna community and zonation in the representative tidal flat of Banwol in Gyeonggi Bay.

Looking for the regional interests among the 24 geographical regions along the west coast of Korea (later defined as "West Sea", refer to Fig. 1), the most extensively studied region was found to be the Gyeonggi Bay (about 40%) off Incheon. This area is notorious as one of the worst environmental disasters during the industrialization of Korea, say well known reclamation project of the Sihwa, accordingly the given area has been much targeted to the scientific societies. Couple of regions with a great performance in scientific publication includes Saemangeum and Taean as those areas have been highlighted in the issues of Saemangeum reclamation and *Hebei Spirit* Oil Spill (*HSOS*) accident, respectively. In the present volume of special issue, those big issues relating to the environmental deterioration and ecosystem damages, i.e., the details of the Lake Sihwa (Lee et al., 2014), Saemangem (Park et al., 2014; Ryu et al., 2014b; Song et al., 2014), and *HSOS* issues (Hong et al., 2014; Kim et al., 2014) are all carefully addressed as review and/or case study.

A comprehensive review on the Korean Getbol (in Korean), having over a thousand pages of volume, was already bounded in the early 2000s (Koh, 2001), where every aspect from ecology to institutions are compiled. The volume tried not only to overview the sciences of the Korean tidal flat but also the policy-making process to scrutinize the embedded reasons for large-scale reclamations and dared to suggest a way of transition to protection of the Korean tidal flat. In this regard, the Wadden Sea management was shortly demonstrated as a classic example, the National Park of Schleswig–Holstein was sketched, and its National Park Law was translated into Korean. The present review would be an international miniature version of such knowledge collection and experiences relating to the Korean tidal flat.

A comparison between the Korean Getbol and the European Wadden Sea would be of great significance in this special issue. Earlier, Kellermann and Koh (1999) emphasized the Korean tidal flat as a pacific mirror of the European Wadden Sea, but still the current understanding of ecosystem of the Korean tidal flat is extremely shallow compared to that of the European Wadden Sea. Such scientific limitation in Korea could be explained by the short history in scientific community and/or lack of manpower through institutional supports on environmental science dimension. In fact, five governmental institutes are in operation including the Korea Institute of Ocean Science and Technology (KIOST), the National Fisheries Research and Development Institute (NFRDI), the Korea Hydrographic and Oceanographic Administration (KHOA), and the Korean Maritime Institute (KMI), and Korea Marine Environment Corporation (KOREM), but tidal flat specialists are very few over those institutes. Meantime, academia in universities is a part of personnel, but the tidal flat studies are not common even in the coast-neighboring schools. While, the rich knowledge accumulated in large number of specialized institutes in the Wadden Sea seems to support the management of the Wadden Sea in an ecosystem approach (Schwemmer and Colijn, 2009). Tidal flat research seems to be still an unfamiliar science in the Korean academic society and a process oriented ecosystem approach would be a challenge for its management at present. The delineation and recall of commons and differences in ecosystem, management, and sustainable development in the Korean and the European Wadden Sea (The Common Wadden Sea Secretariat, 2010) were the main theme of this article and throughout the special issue.

2. The Yellow Sea: oceanographic settings

2.1. Locality

Korean tidal flats and the West Sea of Korea are located along the eastern part of the Yellow Sea, forming important part of a larger regional ecosystem in the East Asia. The Yellow Sea is situated at longitudes 120–127°E and latitudes 32–40°N, bordering China to the west, Bohai Sea to the north, the Korean Peninsula to the east, and the East China Sea to the south (Fig. 1). The southern boundary is a line drawn from the northern part of the Chang Jiang (Yangtze River) Estuary eastwards to the Jeju Island, and then northwards to the south west coast of South Korea (UNDP, 2000). The East China Sea occurs beyond this boundary. The Yellow Sea is about 1 000 km from north to south, and 700 km from east to west, and is characterized as a semi-enclosed shallow sea. The northern part of the Yellow Sea is Bohai Sea which includes three surrounding bays, called Liaodong, Bohai, and Laizhou Bay. The boundary between the Yellow Sea and the Bohai Sea is the line connecting the Shandong Peninsula and the Liadong Peninsula.

The eastern part of the Yellow Sea is called the "West Sea" in Korea (Fig. 1). The widely developed tidal flats, viz., Getbol, in the West Sea occur along the coast and riverine estuaries in the western part of Korea. The total area of the tidal flats in the Yellow Sea, including the Chang Jiang Estuary and the west coast of South Korea, covers about 20,000 km^2, which also includes 1,350 km^2 of numerous bays and estuaries around the Shandong Peninsula (Barter, 2002). The Yellow Sea is a shallow basin with a mean and maximum water depth of 44 m and 103 m, respectively. Its total area is about 487,000 km^2, and it holds a volume of about 19,000 km^3 seawater.

2.2. Physiography

During the last glacial period, the Yellow Sea was sub aerially exposed when the sea level dropped by ca. 120 m below the present-day level (Chough et al., 2004). Subsequent high amplitude sea-level rise had a particularly strong influence on sedimentation during the erosional retreat of shorefaces and river mouths when pre-Holocene deposits were intensively eroded to form transgressive sheets and sediment ridges. As the rate of sea-level rise decreased, depositional processes were accelerated by sediment supply together with combined effect of topography and prevailing sea currents. The seafloor continues to slowly rise toward China, with this process being much more rapid along the Korean Peninsula. Accordingly, the sea bed gradually deepens from the west to the east, and an NW–SE trough, which is defined by an 80 m isobath, has developed along the southern part of the Yellow Sea (Kong et al., 2006).

Along the north to the south, the seafloor deepens trending axis that lies in the eastern part of the sea, reaching more than 100 m water depth around Jeju Island. The western part of the sea includes the deltas of the Huang He (Yellow River), where the isobaths occurring parallel to the coastline. In comparison, the eastern part of the sea is fringed by numerous islands, estuaries, and tidal flats. Tidal sand ridges are ubiquitous at a water depth of about 70 m. Off the Jiangsu coast, a shallow and flat seafloor forms at a water depth of 50 m, and slopes gently eastward to the central part of the sea (Fig. 1). The details of physiographic settings of the West Sea, Korea have been intensively reviewed in the separate chapter (Choi, 2014) of this special issue.

2.3. Currents

The ocean currents in the Yellow Sea were first observed and reported by Uda (1934). The schematic of the current system given by Uda is similar to more recent drawing by Tomczak and Godfrey (1994). Altogether, the Yellow Sea Warm Current (YSWC) flows into the Yellow Sea from the south of Jeju Island, and then into the China Coastal Current (CCC). The YSWC was shown to originate from the Kuroshio Current, from which the Taiwan Warm Current (TWC) also diverged to the east of Taiwan. Likewise, Tsushima Current originated from the TWC with a northward flow, while the CCC originated from the Tsushima current with a northward flow.

The Yellow Sea water body shows characteristic seasonal patterns (Hwang et al., 2014). For example, in winter, the Yellow Sea water primarily consists of the YSWC (12 °C, salinity 34.4), the CCC (8 °C, salinity 34), and the Korean Coastal Current (KCC) which flows northward along the West Sea of Korea (6 °C, salinity 32.5). During summer season, the salinity of the CCC and the KCC drops to 23.5 and 32.5, respectively, as a result of fresh discharge from rivers feeding into the Yellow Sea. In the middle part of the Yellow Sea, the Yellow Sea basin is occupied by the Yellow Sea Cold Water (YSCW), which has a low temperature and high salinity, forming the stratification as well as weakening of the YSWC. Such intermittent currents followed by seasonal differences in circulation (i.e., mixing and stratification etc.) through water column might influence community changes and its dynamics in the pelagic and benthic environments of the Yellow Sea. The details of currents in the Yellow Sea and adjacent seas and their seasonal circulations are presented in the special issue (Hwang et al., 2014), which will aid the understanding of the physical process in this region.

2.4. Sedimentology and sedimentation process

Over 60 major and small rivers flowing into the Yellow Sea supply nutrients, pollutants, and suspended sediments to the sea. In particular, the supply of suspended sediments is directly related to the formation of the tidal flat system, thus freshwater discharges into the sea would be of important characteristics. The major sources of sediments are the Huang He in the northern part of the Yellow Sea followed by the Yalu River in the northern part of Korean Peninsula and the Han River and the Geum River from South Korea. For example, a total of ca. 1,200 $\times$ 10^9 m^3 yr^{-1} of freshwater is discharged into the Yellow Sea, and about 40% comes from the Huang He in China (ca. 49 $\times$ 10^9 m^3 yr^{-1}). Next, the Yalu River (25–35 $\times$ 10^9 m^3 yr^{-1}), Han River (19–25 $\times$ 10^9 m^3 yr^{-1}), and Geum River (5–7 $\times$ 10^9 m^3 yr^{-1}) collectively account for about half of the total freshwater input to the Yellow Sea (Lim et al., 2007).

Accordingly, the Huang He is the major source for the sediment supply reaching about 1,080 $\times$ 10^6 tons yr^{-1} of sediment, but it should be noted that its contribution (>90%) is much greater than that of freshwater input (ca. 40%) in the Yellow Sea. While, relatively small amounts of sediment are supplied from the Yalu River (1.13–4.8 $\times$ 10^6 tons yr^{-1}), the Han River (4–12.4 $\times$ 10^6 tons yr^{-1}), and the Geum River (1.3–11 $\times$ 10^6 tons yr^{-1}), collectively accounting for only 2% of the total sediment supply from the Huang He (Lim et al., 2007). This could be simply explained by the size of these rivers, for example, the lotic length of the Huang He is 5 500 km, and its drainage area is 75.2 $\times$ 10^4 km^2, while the length and drainage area of the Han River is 500 km and 2.6 $\times$ 10^4 km^2, and even smaller for the Geum River.

The tremendous sediment loads from the Huang He are indeed associated with the high density of suspended sediments. The average density of suspended materials in the Huang He is 23.5 kg m^{-3}, whereas that of the Yalu River, the Han River, and the Geum River is below 0.3 kg m^{-3}. About 85–90% of discharged sediments from the Huang He are deposited within the Bohai Bay, while only 1.0–1.5 $\times$ 10^8 tons of Huang He-derived suspended sediments accumulate in the central part of the Yellow Sea (Schubel et al., 1986). These suspended sediments are transported to the southern part of the Yellow Sea via the Yellow Sea Coastal Current (YSCC), and influence the middle part of the Yellow Sea and the south coast of Jeju Island sedimentologically.

Suspended sediments derived from the Korean Peninsula accumulate in the coastal area of the West Sea of Korea and also the northern part of Jeju Island. Interestingly, the Chang Jiang discharges more than 20 times than the Huang He, but its low suspended sediment density was relatively low, say comparable to 50% of total discharged suspended sediments derived from the Huang He. About 70% of the sediment from the Chang Jiang accumulates immediately in the estuary and the remaining proportion could be transported to the southern part of the sea, weakening its influence on the Yellow Sea.

Looking for the sediment transport, suspended sediments from the Huang He are carried southward by the YSCC, bypassing the Shandong Peninsula (Lee and Chough, 1989). Off the eastern and southern coasts of the Shandong Peninsula, these turbid water plumes enter the central Yellow Sea, where considerable amounts of suspended particulates are deposited. When the Huang He was diverted into the Yellow Sea during the period between AD 1128 and 1855, the preceding Huang He Delta was formed by massive volumes of sediment accumulating in the coastal area of northern Jiangsu Province. The resuspended sediments are advected eastward and south-eastward by the Jiangsu Coastal Current, forming a large mud patch about 150 km southwest of Jeju Island. Meantime, the sediment behavior in the Chang Jiang Estuary is largely controlled by both tidal (mesotidal) and river runoff (Milliman et al., 1984). Although low river runoff and neap tides allow the estuary to act as a sink for riverine sediment, most sediment escapes the estuary resulting in submerged delta in the given area. DeMaster et al. (1985) estimated that more than half of the sediment escaping the Chang Jiang Estuary is deposited on the inner shelf north of 30 °N. Much of this mud is resuspended during subsequent winter storms and transported further south.

In the southeastern Yellow Sea, say the West Sea herein, sediments are primarily delivered by the Geum River. The resuspension of shallow bottom sediment is caused by the northerly winter monsoon, resulting in a high concentration of suspended sediment in both surface and bottom waters. The high turbidity of the coastal water maintains until the subsequent early spring. Thus, the sediments derived from the Korean Peninsula, especially those from the Geum River, appear to remain in suspension along the southwestern coast of Korea throughout the year.

2.5. Cooperative survey in the Yellow Sea between Korea and China

The Korea-China Joint Ocean Research Center was established in 1995 by the MOU between the Ministry of Ocean and Fisheries of Korea (MOF) and the State Oceanic Administration of China. A partnership between the Korea Institute of Ocean Science & Technology (Korea side) and the First Institute of Oceanography (China side) includes joint surveys in the Yellow Sea. Also, the cooperative survey between the NFRDI of Korea and the Offshore Environment Monitoring Center Station of China has been conducted since 1997 (about 10 surveys). Such surveys primarily monitor physicochemical parameters and collect seawater and sediment sample for analysis of nutrient, plankton, and heavy metals etc.

The UNDP/GEF Yellow Sea Large Marine Ecosystem Project (YSLME) also supported the joint Korea-China surveys. The most recent YSLME project was conducted during 2005–2010, with 30 million USD. About half of the total budget for the entire project came from the GEF and last half was supported from the Korean and Chinese governments. In the winter and summer of 2008, two cooperative cruises were carried out, where systematic monitoring encompassing a range of oceanographic studies (i.e., physical, geochemical, and biological observation and analyses) was performed. Analyzed parameters included nutrients, organic material, trace metals, sediment profile, pigments, bacteria, taxonomic

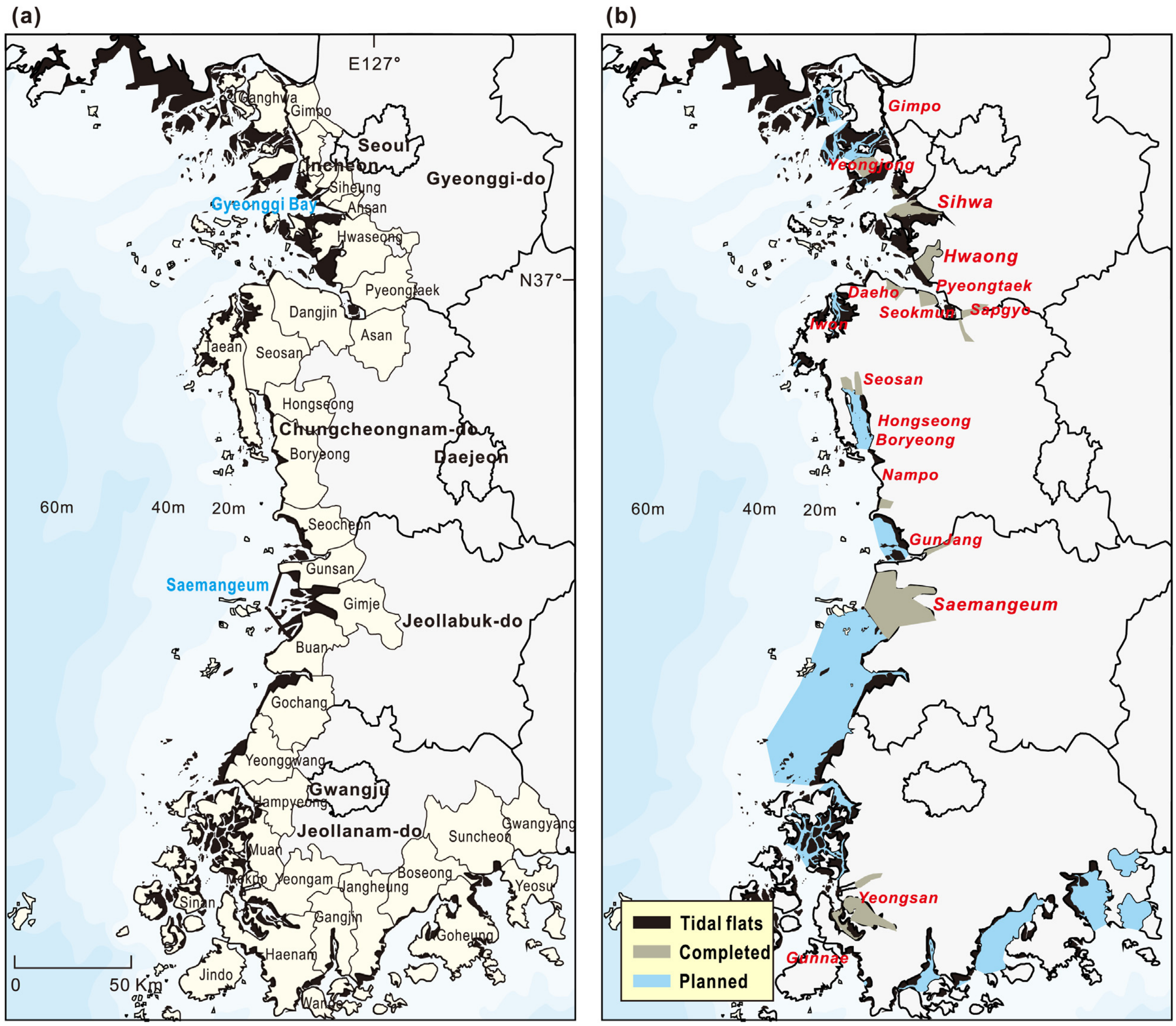

Fig. 2. Map showing the tidal flats in the West Sea of Korea and neighboring cites (or counties) and the reclamation plan established by the Korean government in 1996, with the information of the former reclamation projects (red ink). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

composition of phytoplankton, zooplankton and benthic fauna. The surveys were carried out at 37 stations between a latitude of 36.5 °N (connecting the Taean in Korea and Shandong Peninsula in China) and 32 °N (connecting the south of Jeju Island in Korea and the north of the Chang Jiang in China) and a longitude of 121.5 °E and 125.5 °E. The results were presented in a final report published in 2011. The main objective of this joint monitoring program was a quality evaluation of the ecosystem and habitat in the Yellow Sea. It was found that the organic carbon, nitrogen, and phosphorus in the sediments show trophic enrichment.

3. The West Sea, Korea: coastal landscape and bottom topography

The seas surrounding the Korean Peninsula are called the West Sea, the South Sea, and the East Sea by Koreans, and the "West Sea" is a part of the Yellow Sea, as mentioned above. In this section, coastal characteristics targeting the West Sea of Korea are described, including coastal geomorphology, coastal landscape, and sediment distribution to develop our understanding of the Korean tidal flat in the next section. The longitudinal boundary of the West Sea in this section extends from the Han River Estuary at the border between North and South Korea to the south of the Wando, Jeollanam-do (province) (Fig. 1).

3.1. Inland to coast

A detailed description of the relationship between coastal landform and territory topography in Korea is provided by Kwon (2006). In brief, the topography of the Korean peninsula consists of 70% mountainous area and 30% land plains developed adjacent rivers flowing into the seas. The main axis of mountain range runs from the north to south in the eastern part of the Korean peninsula, the Baek-du Mountains ranging from 1 000 to 2 000 m above sea level. This mountain chain formed about 25 million years ago during the Miocene epoch of the Cenozoic Era as a consequence of asymmetrical uplift in the process of warping, resulting in high topography in the east and low in the western part of the Korean peninsula. Accordingly, the rivers and their plains also run to the west, with flat river basins, while the surrounding area is formed of low-lying 200–300 m high mountains. Such topographical features of land to river and estuaries clearly influenced the coastal topography of the present forms. For example, the West Sea is characterized by indented, ria-type coastlines and long stretches of tidal

Fig. 3. Map showing the widely developed tidal flats in the West Sea of Korea, with detailed geographical information (Section 4.2), with the information of the locality of dikes (bold black line) associated with the given reclamation projects (red ink) in each province. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

flats in many places and the South Sea has also numerous ria-type bays but frequent rocky shores and a number of offshore islands. Meanwhile, the coastal area of the East Sea consists of straight coastlines owing to the strong wave, mostly composed of sandy beaches and rocky shores due to rapid sloping eastward from the Baek-du Mountain range (MOE, 2012).

3.2. Coastal landscape

The landscape of the West Sea is formed of typical indented coasts with sinuous coastlines (Fig. 2), which are surrounded by adjoining many rocky-mountains (mainly granite) of about 200–300 m in height. These features become increasingly distinctive toward to the south coast of Korea. In comparison, the East Sea has straight coastline, as a consequence of the uplift of the East Sea basin and the east mountain chains. The West Sea has numerous islands toward the south, with the southernmost Sinan-gun (county) encompassing about 1,000 islands. The inland landscape of the coastline consists of low mountain topography and pine tree vegetation. Satellite observations indicate that coniferous forests represent 52% of mountain, with *Pinus densiflora* being the dominant species. Broadleaf mixed forests, such as *Quercus* spp., represent 23% of the mountain vegetation, while the remainder is mixed forest (MOE, 2012).

3.3. Tidal channels

The coastal areas of the West Sea may be assigned into tidal flats and subtidal areas including tidal channels (Fig. 3). The submarine topography of Gyeonggi Bay, in front of Incheon, is characterized by 20–30 m deep tidal channels, the orientation of which corresponds to the southwest-northeast tidal currents. The landmass of the Taean-gun extends far westwards, and is located in the lowest part of the Gyeonggi Bay. The coastline of the Taean-gun along Chungcheongnam-do (province) has a waterway that flows from south to north. The coastline of the Geum River, Saemangeum, Gomso, and Yeonggwang of Jeollabuk-do (province) has tidal channels of southwest-northeast orientation. The Saemangeum, including numerous islands in the Gogunsan area, is an estuarine area of the Mangyeong and Dongjin rivers, and has offshore tidal channels connecting the two rivers. The Sinan County of Jeollanam-do is located to the west of Mokpo. Because of tidal channels flowing through the islands in the Sinan County, the landscape is shaped like a bunch of grapes.

3.4. Sediment distribution

Two distinctive sediment bodies have formed in the West Sea of Korea; (1) a sand deposit to the north of about 36 °N, and (2) a muddy-sand deposit composed of sand, sandy mud, and mud sediments to the south of about 36 °N (Fig. 1). The former extends northward near-shore off the Yalu River, and is composed of well-sorted sand grains of 2–3 ø in mean size (Lee and Chough, 1989). Lee et al. (1988) suggested that the sand in the latter deposit is composed of a transgressive basal layer that was formed during the Holocene sea-level rise. However, the coastal area also receives muddy sediments from major rivers such as the Han River and the Geum River flowing into the West Sea, which results in deposition of mixed sediment facies of mud and sand.

The fine-grained sediments derived from the Geum River (discharge, 5.6×10^6 tons yr^{-1}) are transported southward, forming an elongated mud belt (maximum thickness, 60 m) called the Heuksan Mud Belt along the southwestern coast of the Korean Peninsula (Fig. 1) (Chough et al., 2004). The northern half of the mud belt consists of unconsolidated Holocene mud, whereas the southern half is covered by older, semi-consolidated mud.

4. Tidal flats of the West Sea

The characteristics of the Korean tidal flats are addressed by highlighting tidal environments (tide, wave, and estuary), spatial distribution, sediment facies, and sediment dynamics in this section. The introductory description for the major tidal flats including location, shoreline topography, tidal conditions, and size of existing Getbol or claimed areas are collectively given. Fig. 2a shows the distribution of tidal flats along the west coast of Korea, with providing information of the adjacent provinces, counties, and major neighboring cities. The past reclamation plan (Fig. 2b) contrasting the presently existing tidal flats would reflect our former understanding in tidal flat management towards nation's developmental policy in Korea (Rural Development Corporation, 1996).

The well-developed tidal flats (widths of 4–5 km) exist in many places along the ria-type coast of the West Sea (Fig. 3). The tidal flats of the West Sea belong to the macro tidal regime due to the great tidal range and strong currents. The wind, tidal waves, and storms in the West Sea of Korea have relatively lesser impacts on the (de)formation of tidal flats, compared to those in the European environments (de Jonge, 1995). Tidal flats can be classified as sheltered and exposed depending on the topographic settings of coastline. Another classification would be possible, say embayed, semi-enclosed, estuarine, and open-coastal in geographical manner. Finally, the categorizing into the groups of open coast, embayment, and channel margin tidal flats would also be based on the geomorphological classification (Choi, 2014).

Because of the indented coastline, it has an embayed-type topography containing sheltered tidal flats. In 2004, nine major tidal flats of the West Sea were selected by the Ministry of Maritime Affairs and Fisheries (MOMAF, renamed the MOF after 2013). Six were classified as sheltered or semi-sheltered tidal flats, while three as exposed ones. We describe here the connection and distribution of the curved coastal topography, sheltered tidal flats, and exposed tidal flats along the north to south coast of Korea. The semi-exposed Han River Estuary tidal flat is situated at the northernmost part of the South Korean West Sea. The Asan Bay tidal flat is sheltered, the Seosan tidal flat is exposed, and the Mangyeong-Dongjin Estuary tidal flat in the Saemangeum area is semi-exposed. The Gomso Bay tidal flat is also semi-exposed, the Hampyeong tidal flat is sheltered, and the Sinan tidal flat is partially sheltered and partially exposed. Fully exposed tidal flats are also present in Gochang and other regions, but such type of tidal flats mostly belongs to narrow beach. In general, the estuarine tidal flats dominate the coast adjoining the West Sea, with the Han River tidal flat and the Saemangeum tidal flat being the largest. The Sinan tidal flat could be classified as an island tidal flat, because it is surrounded and anchored by hundreds of islands. Choi (2014) drew the open coast tidal flat as dominant, but the representative tidal flats by the MOF include many sheltered tidal flats.

4.1. Aerial dimension of the tidal flats

In South Korea, tidal flats cover a total area of about 2,500 km^2. About 2,100 km^2 of tidal flats are located on the west coast, while only remaining 400 km^2 of tidal flats are situated on the south coast. The tidal flat area could be calculated from the satellite images, based on the traditional Korean conception that Getbol (viz. tidal flats) are sedimentary shores with the seaward boundaries representing the mean lowest low level (MLLL). An alternative calculation is based on the nautical chart, rather than satellite imagery, using MLLL as the seaward boundary for tidal flats. The total mudflat area calculated by this method is estimated to be ca. 2 500 km^2 at present.

4.2. Geographical distribution of the tidal flats

The distribution of the Korean tidal flats, from north to south was described below by the name, location, size (area), and status (existing, planned for landfilling, and landfilled) of the tidal flats since the 1980s (Fig. 3). Table 1 summarizes information about the Korean tidal flat areas (total of 2,489 km^2), in terms of administrative districts, which consist of 5 provinces and over 20 counties adjacent to the existing tidal flats, with additional information for the reclamation projects in the given area (MLTM, 2008). At this time, the detailed description was only given to the tidal flats in the West Sea of Korea as those accounts for the majority (ca. 84% to the total areas) of the tidal flats in Korea (Table 1). Overall, the most extensive tidal flat areas adjoining the West Sea are located in Gyeonggi Bay, Saemangeum, and Jeollanam-do, with respective areas of 873 km^2, 400 km^2, and 1,037 km^2. However, it should be noted that the Saemangeum tidal flat was barraged in 2006, by the construction of a 33.9 km world longest dike. Most of the West Sea in Korea was embanked during the past several decades in order to promote land earning by the continuing reclamation projects of the tidal flats (Table 1), which would have resulted in great loss of the natural tidal flat areas. The below is the description of the tidal flats including the chronology of reclamation, if any, area by area (see Fig. 3 for corresponding locality).

The Gyeonggi Bay tidal flats are located between the Han River, which is the largest river in South Korea, and the Asan Bay. The Han River discharges about 19–25 $\times$ 10^9 m^3 yr^{-1}, and flows through the center of Seoul. The Han River estuary is located on the border between South Korea and North Korea, accordingly a barrage has not been built in the entire estuary because of political reasons. Thus, the natural mixing of seawater and freshwater along with the discharge of suspended sediment particles remains possible in the given area. At this natural site, the extensive tidal flats have formed in the lower reach of Han River that is split into several distributaries by bedrock islands.

The northernmost tidal flats occur in the Gyeonggi Bay and Haeju (North Korea). Satellite imagery shows that the Haeju tidal flat is shaped like a pitchfork, with several flats protruding in the direction of the tidal currents. The maximum distance from the shoreline to the boundary of the intertidal flat (i.e., the width of the tidal flat) is about 20 km. Thus, the Haeju tidal flat is the largest tidal flat along the Korean Peninsula. Of note, this tidal flat belongs to North Korea, and so is not included in the statistics of the Gyeonggi Bay tidal flat.

The second group of well-developed tidal flats occurs in the southern part of the Han River estuary. These flats include the southern Ganghwa Island (241 km^2), Yeongjong Island (area: 100 km^2, landfilled, now Incheon International Airport), and Sihwa (area: 180 km^2, landfilled, now industrial and municipal areas) tidal flats. The Gimpo tidal flat, which was located on the east of the Ganghwa Strait, but landfilled after 1987 for the purpose of landfill disposal of metropolitan waste. There was no reference stating the exact aerial range of the Han River estuary; thus, here we define the Han River estuary tidal flat including the Haeju, Gimpo, Ganghwa Island, Yeongjong Island, and Sihwa tidal flats.

The third tidal flat in the Gyeonggi Bay lies in the Asan Bay, which is located in the southern part of the Sihwa tidal flat. The north part of Asan Bay is called Namyang Bay and the Sapgyo, Seokmun, Daeho, and Garolim tidal flats are also included in the Asan Bay. The Namyang Bay tidal flat was diked in 2004, leading to the destruction of about 100 km^2 of the tidal flat. About 26, 37, and 22 km^2 of tidal flats in the Sapgyo, Seokmun, and Daeho were landfilled to make rice fields in 1979, 1998, and 1985, respectively. The tidal flat in the Garolim Bay covers an area of about 90 km^2, and represents the sole remaining tidal flat in the Gyeonggi Bay. However, the electricity company submitted an application to construct a tidal power plant; thus, this remaining natural tidal flat will be eventually barraged once the government approves the plan.

The most extensive reclamation was carried out in the Gyeonggi Bay, resulting only 2% of the natural coastline remained (Koh, 1999). Fortunately, the tidal flats adjacent to several offshore islands, such as the Seokmo Island, Ganghwa Island, and Janbong Island, remain pristine. The governmental statistics for these tidal flats was based on the administrative districts; thus, the tidal flats in the Gyeonggi Bay could be divided into some in the Gyeonggi-do (province) and others in Chungcheongnam-do in the government report. The boundary between the Gyeonggi-do and the Chungcheongnam-do is the main channel of the Asan Bay. The bays of Sapgyo, Seokmun, and Garolim, which are located to the south of the main channel, belong to the Chungcheongnam-do tidal flat area. The tidal flat covers an area of 359 km^2 in the Chungcheongnam-do, including the south part of the Taean, which encompasses the Cheonsu Bay (Seosan A and B), and the Hongseong, Boryeong, and Seocheon tidal flats.

The tidal flat in the Cheonsu Bay once covers an area of about 200 km^2; however, ca. 160 km^2 of tidal flat disappeared due to the reclamation into the rice fields in 1995. Tidal flats of ca. 20 km^2 in area were also present along the land-enclosed bays of the Hongseong and Boryeong in the southern part of the Cheonsu Bay; however, these tidal flats were also destroyed by the dike construction from the Hongbo reclamation project.

Moving southwards, the tidal flat of the Seocheon has the largest area, spanning about 30 km coastline, and is wide-open to the sea. The construction of a dike that ran parallel to the coastline was planned, but the project was canceled in 2008. As the political compensation for the reclamation project, the government made alternative plans and/or financial support to establish the Marine Biodiversity Institute and the National Biodiversity Museum in this county. Of note, this reclamation project was canceled by the veto of the President, which is the only case in the extensive tidal flat reclamation history in Korea.

The Geum River flows to the south of the Seocheon tidal flat, with a water discharge rate of about 7.0 $\times$ 10^9 m^3 yr^{-1}. Its estuarine

Table 1
Areas of the Korean tidal flats belonging to the neighboring county (or city) and province in the West Sea, total areas in the South Sea also given for a comparison, but not by the county basis, to those in the West Sea (MLTM, 2008).

Province County	Tidal flat area km^2	(%)	Major reclamation projects in the given areas
West Sea	2,080	(84)	
Gyeonggi-do	873	(35)	
Gimpo	32	(1)	Gimpo[a]
Incheon-Ganghwa	704	(28)	Yeongjong[a]
Siheung	6	(0.2)	
Ansan	49	(2)	Sihwa[a]
Hwaseong	73	(3)	Sihwa[a] and Hwaong
Pyeongtaek	8	(0.3)	Pyeongtaek
Chungcheongnam-do	359	(14)	
Asan	7	(0.3)	Sapgyo, Seokmun, and Daeho
Dangjin	28	(1)	Seokmun
Seosan	67	(3)	Iwon and Seosan[a]
Taean	138	(6)	
Hongseong	14	(1)	Hongseong
Boryeong	33	(1)	Nampo, Boryeong
Seocheon	71	(3)	Gunjang[a]
Jeollanam-do	118	(5)	
Gunsan	28	(1)	Gunjang[a] and Saemangeum[a]
Gimje	–	(–)	Saemangeum[a]
Buan	27	(1)	Saemangeum[a]
Gochang	64	(3)	
Jeollabuk-do	731	(29)	
Yeonggwang	145	(6)	
Hampyeong	19	(1)	
Muan	149	(6)	Yeongsan R. II[a]
Mokpo	7	(0.3)	Yeongsan R. II[a]
Yeongam	–	(–)	Yeongsan R. II & III-1[a]
Sinan	343	(14)	
Jindo	26	(1)	Gunnae
Haenam	43	(1.7)	Yeongsan R. III-1 & III-2[a]
South Sea	409	(16)	
Total	2,489		

[a] Details refer to Table 2 (for other statistics) and Fig. 2b (for geographical location).

system has been subject to severe human impact following dike construction in 1990. The Geum River is also the boundary between the Chungcheongnam-do and the Jeollabuk-do. Due to the dike at the mouth of the river estuary and the connecting tidal flats to the north, the Geum River estuary would be more linked to the Seocheon tidal flat.

The Saemangeum tidal flat is located to the south of the Geum River, but enclosed by the longest seawall of 33.9 km as certified by the World Guinness Record in 2010. The Saemangeum tidal flat once covered an area of about 400 km^2, including the estuarine areas of the Mangyeong River and Dongjin River.

The Gomso Bay lies to the south of Saemangeum area, which covers an area of about 100 km^2, with the main channel flowing along the north coast in the bay; hence, the 4 km wide tidal flat formed along the south coast of the bay. The Manila clam fishery is the primary work of fishermen in this Getbol area. This area was partly designated as a Getbol Protected Area (GPA; same as Coastal Wetland Protected Area (CWPA) in this review, see Section 6.2.4) in 2004, while the entire tidal flat area was recently designated as a UNESCO biosphere reservoir in 2013.

There are many tidal flats and beaches along the Gochang and Yeonggwang coastline; however, the coast is fully exposed and narrow in width. To the more south, tidal flats have formed along the ragged coastline around numerous islands. The Hampyeong Bay is surrounded by the Hampyeong County and the Muan County. About 42 km^2 of the Muan tidal flat has been designated as a GPA, with the thin-legged octopus being the main fishery resource of the given area.

The Sinan County encompasses a number of islands, with widely developed tidal flats around the most of islands, thus they could be termed island tidal flats, covering an area of about 1,000 km^2 in total. However, only a small area of tidal flats around the Jeung Island has been designated as a GPA. The Jeung Island tidal flat has multiple designations, including a provincial park and a UNESCO biosphere reservoir. While the Haenam tidal flat has been landfilled to disappear, unfortunately, it possessed the unique characteristics and ecological values though. This tidal flat was placed in the southern part of the Yeongsan River estuary. It was not estuarine but a bay-type tidal flat shaped like a bunch of grapes. Two tidal flats had been landfilled under the Yeongsan II and III project in 1980s and 1990s, respectively. Narrow mouth of the bay and extensive tidal flats developed in the inner bay happened to make it easier for diking, warranting a low cost but high land gains.

The border line of the West Sea and the South Sea starts from the southernmost of the Haenam County (Fig. 1). The area of tidal flats in the South Sea reaches only 16% of the total areas of the Korean tidal flat (Table 1), which are not fully described at this time. In brief, the Gangjin, Beolgyo, and Suncheon Bay tidal flats are located in the South Sea and the Nakdong Estuary tidal flat is located to the far east of the South Sea. Most of the South Sea tidal flats are bay type and caved deeply with far round shaped wedge compared to those of the West Sea. Such physiographic characteristics provided sheltered places for the aquaculture ground widely, which seemingly resulted in lesser exposure for the reclamation targets compared to the West Sea of Korea.

The reason to explain the tidal flat areas based on its municipality is that jurisdictional and administrative boundary is allocated along the main tidal channels of the tidal flats. The current management of the marine space in Korea is also based on the jurisdictional boundaries, thus, the coastal management would not consider ecosystem rather prefers administrative guideline. Of note, some tidal flats have been named after counties (e.g. Ganghwa tidal flat), while others have common names (e.g., Jangbong Island tidal flat). In the present article, both the county and/or common names of the tidal flats have been appropriately used. We have inserted the name of places as many districts as possible in Fig. 2 for easy follow through the text and elsewhere, particularly for the international audiences.

4.3. Biodiversity of tidal flat organisms

To date, about 30 Korean studies relating to the microalgal organisms (viz., microphytobenthos: MPB) have been introduced internationally, of which topics encompassed mainly floral assemblages and primary production of MPB. Majorities were found to be the studies on benthic diatom assemblages followed by primary production, with MPB dynamics being the least studied subject. Oh and Koh (1995) first reported diatom assemblages and distribution in the Korean tidal flats, which was also the first exposure of ecological features on Korean benthic diatoms to the international readers. The very study reported several dominant diatom taxa including *Navicula*, *Nitzschia*, and *Amphora*, with report of total 371 taxa in the Saemangeum tidal flat. A recent floristic study reporting 23 *Amphora* species with new records of 3 species in the Saemangeum supported the continuing great biodiversity of benthic diatoms in the given area (Park and Koh, 2012). Meantime, Park et al. (2012, 2013) established a new diatom genus, *Moreneis*, together with description of four new *Fogedia* species indicating a hidden floral diversity of the Korean tidal flat. Further there are still many more of prospective new diatom species from the Korean tidal flats being described as new to science (personal data, unpublished).

The primary productivities of the Korean tidal flats would not be smaller than those in other comparable tidal areas such as the European Wadden Sea. Recent studies reported that a daily productivity of ca. 1 000 mg Cm^{-2} d^{-1} from a mudflat in the Gyeonggi Bay (Kwon et al., 2014), and annual production of 546.15 g Cm^{-2} yr^{-1} from a sand flat in Nakdong estuary (Du and Chung, 2009), of which productivities seems to be within the top levels of MPBs primary production in the world. Such benthic driven production is particularly important in a tide-dominant area because the tide-induced resuspension of sediment particles associated with MPBs could be a significant food sources to pelagic ecosystem (Koh et al., 2006).

Meantime, the set of ecological studies on benthic organisms along the Korean tidal flats successfully supported the great faunal biodiversity, for example a total of >500 species for macrozoobenthos species in the West Sea (Park et al., 2014). To date, about 60 papers relating to the macrozoobenthos have been published in either international (20%) or local journals (80%), in Korea. Altogether the results indicated widespread distribution with varying species composition cross the estuaries and tidal areas. Our review on the 60 papers revealed that the most abundant species was found to be Annelida (44%) group followed by Mollusca (29%), Arthropoda (21%), and Echinodermata (2%) in the order.

Looking for the geographical distribution and species association of macrozoobenthos, two estuarine areas of Gyeonggi Bay and Saemangeum showed distinctive high species-diversity compared to other areas. For example, the Gyeonggi Bay including Incheon area showed the highest in the number of macrobenthic animals (n = 261) followed by the Saemangeum area (n = 173). The compositional association and diversity of macrozoobenthos would be closely related to the bottom sediment characteristics (Fig. 4, modified from Koh, 1997). For example, a localized distribution of sediment types along the West Sea of Korea, exampled in the Gyeonggi Bay and the Saemangeum areas, were clearly associated with dominant macrozoobenthos assemblages (Koh, 1997). The results generally indicated that ecological association of macrozoobenthos in the Korean tidal flats was primarily governed by the sediment facies, indicating a habitat-dependent separation of benthic assemblages. Meantime, it should be noted that all of the studied areas introduced in Fig. 4, ironically and unfortunately, have been disappeared by the reclamation projects (Table 1), which should be irrevocable loss of a valuable benthic biodiversity in terms of tidal flat ecosystem services.

4.4. Artisanal fisheries and community culture

The coastal residents harvest clams and other animals during the low tide with hand-held equipment such as rakes and hooks. The behaviors are clearly indicative of target organisms, thus it is important to know such characteristic in artisanal fisheries compared to commercial, mechanical fisheries which do not consider animal behaviors much. For example, clams and octopi are dug out of the mud, while finfish are collected in nets cast during the flood tide. Clams harvested include venus clam (*Cyclina sinensis*), razor clam (*Sinonovacula constricta*), duck clam (*Mactra veneriformis*), Manila clam (*Venerupis philippinarum*)) and Asian hard clam (*Meretrix lusoria*). Two types of octopus are harvested, such as the webfoot (short-legged) octopus and the whip-arm (thin-legged) octopus. Harvesting of clams and octopi represents traditional fisheries, and these fisheries are termed barehanded fisheries in Korea. The barehanded fisheries are compensated when the area is diked for the reclamation, but the sum reaches just the monetary compensation of three year harvests.

The classification of barehanded fisheries in the fishery industry is worthy of note herein, the details are provided in the separate chapter in this special issue (Zhang et al., 2014). Types of fisheries are clearly defined in the Fisheries Act, including licensed, permit-required, and reported fishery. The licensed fishery includes community fishery and cultivation, while permit-required fishery includes inshore and coastal fishery, and finally reported fishery includes barehanded fishery, skin diving fishery, and cast net fishery. The harvesting of clams and octopi represent both barehanded fishery and reported fishery. Clams and lavers are also cultivated in tidal flats, with this activity being classified as licensed fishery. The barehanded fishery belongs to the category of reported fishery, however, the local residents conventionally do not report their catches to the fishery authority. Consequently, the barehanded fishery could not be compensated at actual amounts by reclamation projects or by oil spill accidents (Kim et al., 2014).

A village cooperative is a traditional self-regulating organization with a long history tracking back to hundreds years ago regarding the management, harvest, and cultivation of the tidal flat living resources. Fishing village cooperatives may own and manage aqua farms. The main purpose of the cooperative is the sustainable management of tidal flat harvests. Other coastal villages without tidal flats also have such organizations, and the harvest of fishery resources based on the fishing village cooperative has been termed as community fishery in administrative manner since the 2000s. The fishing vessel fishery conducted in the nearshore and coastal waters also has a self-regulating organization for the coordination of fishery resources, but there is lesser autonomy compared to the cooperative organized in the tidal flat area, and thus the fishery authority has a limited role assisting coordination against fishing regulation among villages.

The shellfish-farming belongs to the licensed fisheries. The farming method involves sowing the spats on the rented tidal flat, without installing the pillars as in laver and oyster farming. A rent of 10 ha (0.1 km^2) per household from the authority is valid for 10 years but can be extended when the fishermen continued the business. The rent is considered to be a type of property right and trade can be permitted.

Fig. 5 shows the distribution of farming in the Gomso Bay, for example. The licensed farming based on spat sowing methods has been intensively developed on the Korean tidal flats (Kim et al., 2014). This indicates the economic importance of tidal flats for nearby local communities. The Gomso Bay has about 100 Manila clam farms with 8.5 km^2 areas and about 50 venus clam farms with 4.4 km^2 areas (Gochang Country, 2014). In total, 9 400 tons of manila clams are harvested per year, with the total income of about 20 million USD per year.

4.5. Threating tidal flat ecosystems: the large-scale reclamation

While a number of reclamation projects have been conducted during the last century in Korea, two of them viz. Sihwa and Saemangeum reclamation projects should be recognized as the worst

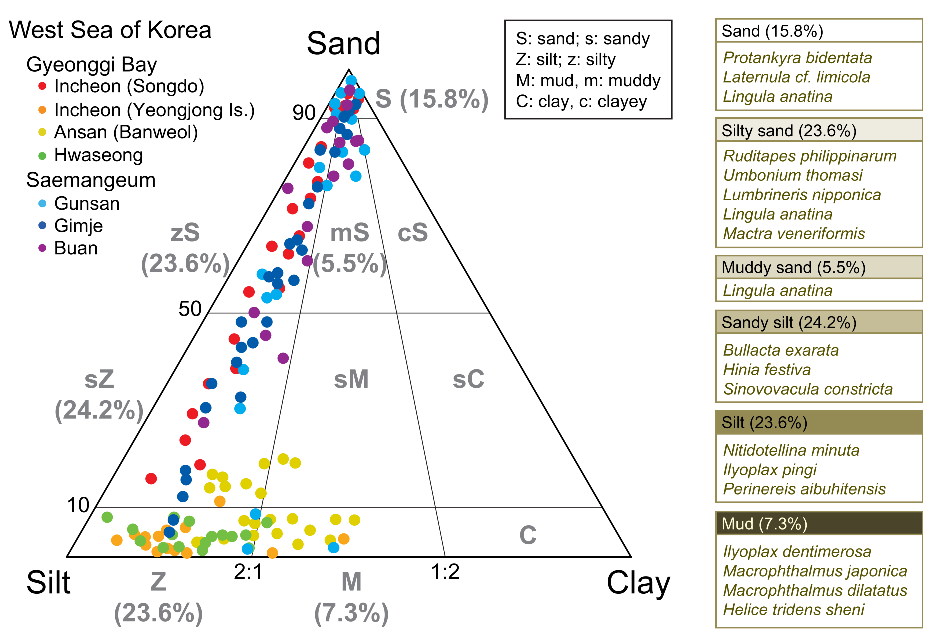

Fig. 4. Sediment facies in the representative tidal flats of the West Sea of Korea (say Gyeonggi Bay and Saemangeum area, see Figs. 2 and 3), with showing the association of the dominant macrozoobenthos species.

cases (Figs. 2 and 6a). The Sihwa reclamation project had been planned and initialized in 1987 to convert Sihwa tidal flats into agricultural lands along with provisioning a freshwater reservoir. Accordingly, a sea-dike was constructed in 1994, but the resultant reservoir had never been fully filled with freshwater due to a severe degradation of water quality and consecutive seawater circulation, simply the initial purpose has not been achieved.

In the meantime the vast tidal flats once developed in the Sihwa area have been devastated. Accordingly the fauna in Sihwa tidal flat has also vanished. In particular, it would be notable that the area had been famous for the production of commercial razor clams (*S. constricta*) representing over 90% of the whole catchment in Korea, however, presently none is being harvested. After seawater circulation in 1998 though, the ecosystem tended to recover inhabiting several species of gastropods. In fact, the recent set up of the tidal turbine on the dike to produce the tidal electricity increased the volume of seawater circulation. However the water quality has improved within the limits of water circulations close to the turbines, thus remains pollution problem. The environmental and ecological effects relating to the Sihwa reclamation project are extensively described in this special issue as a separate effort to deliver one of clear examples regarding incorrect coastal management policy in the West Sea (Lee et al., 2014).

Another big controversy was on the Saemangeum reclamation project which had been developed and implemented since the early 1990s, even after Sihwa reclamation project (Fig. 6b). About 400 km^2 of tidal areas had been converted into dry lands following the completion of 33.9 km long dike in 2006. Again, the benthic ecosystem has been destroyed, and so were the local fisheries on tidal flats, particular for artisanal fisheries.

5. The legal framework of the coastal area

5.1. Authority

The geographical range of the West Sea in terms of management extends from the border between South Korea–North Korea in the north to Jeollanam-do in the south. The offshore boundary extends from the coastline of the mainland to the territorial sea and EEZ. In Coastal Management Act (CMA), the coastal zone is defined as the coastal sea area and coastal land area. The coastal sea area includes the territorial sea while coastal land area includes the 0.5 or 1.0 km (for industrial area only) landward boundary, except for river, from the coastline. Tidal flat belongs to the coastal sea area by the CMA.

The MOF is responsible for the coastal management, and is established at the cabinet level in 1996. The MOF, once called the MOMAF at the inauguration, and later merged into the Ministry of Land, Transport, and Maritime Affairs (MLTM) in 2008, then recently revived in 2013. The tasks are threefold; the marine environment, fisheries, and ports and shipping (including safety). The MOF currently oversees a total of 92 laws for the management of the sea, 17 laws for the marine and coastal environment, 40 laws for fisheries, and 33 laws for the port and shipping. Two more laws are categorized into “Remark”, which includes act related with marine accident and special act on the issue of *HSOS*, all of which both now a legal basis supporting the compensation and restoration for damaged residents and marine ecosystem (Kim et al., 2014). The structure of implementation of such laws follows the act, enforcement decree, enforcement rules and long term plans, and annual plans, in general.

5.2. Acts related to the coastal management

Under the MOF, 17 laws for the marine and coastal environment are in operation in 2014 and only four laws among those directly relate to the coastal management toward the protection: CMA, Marine Environment Management Act (MEMA), Conservation and Management of Marine Ecosystems Act (CMMEA), and Wetlands Conservation Act (WCA). The name of the acts and the legal terms used in the present article were referenced from the Statutes of the Republic of Korea operated by the Korea Legislation Research Institute (Statutes of the Republic of Korea, 2014).

The MEMA was enacted in 2007 as a revision of the original Marine Pollution Control Act. The original law managed pollutants from ships and oil spills, but the concern for the management of land-based pollutants was reflected in the 2007 version. The objective of the MEMA now concerns rather the management of sea water quality.

The CMMEA enacted in 2006 is purposed to protect the coastal ecosystem and the designation of protected areas is the measure of implementation (Fig. 7). For example, 9 areas distributed sporadically along the entire coast of South Korea (totaling ca. 213 km^2)

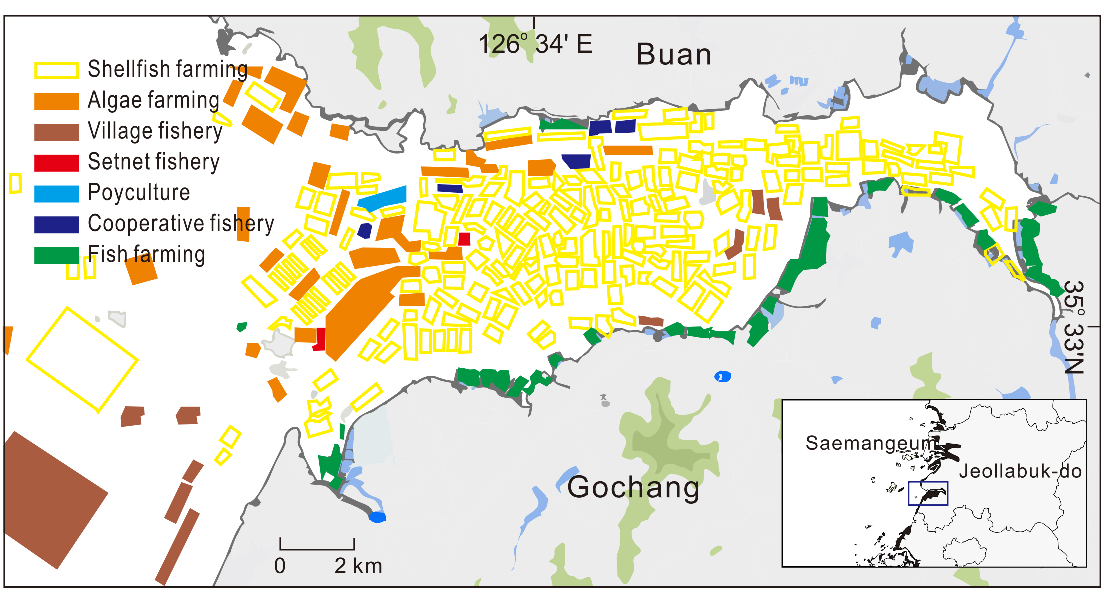

Fig. 5. Map showing the heavy aquaculture grounds on the tidal flats of the Gomso Bay (Gochang County) located behind the Saemangeum area.

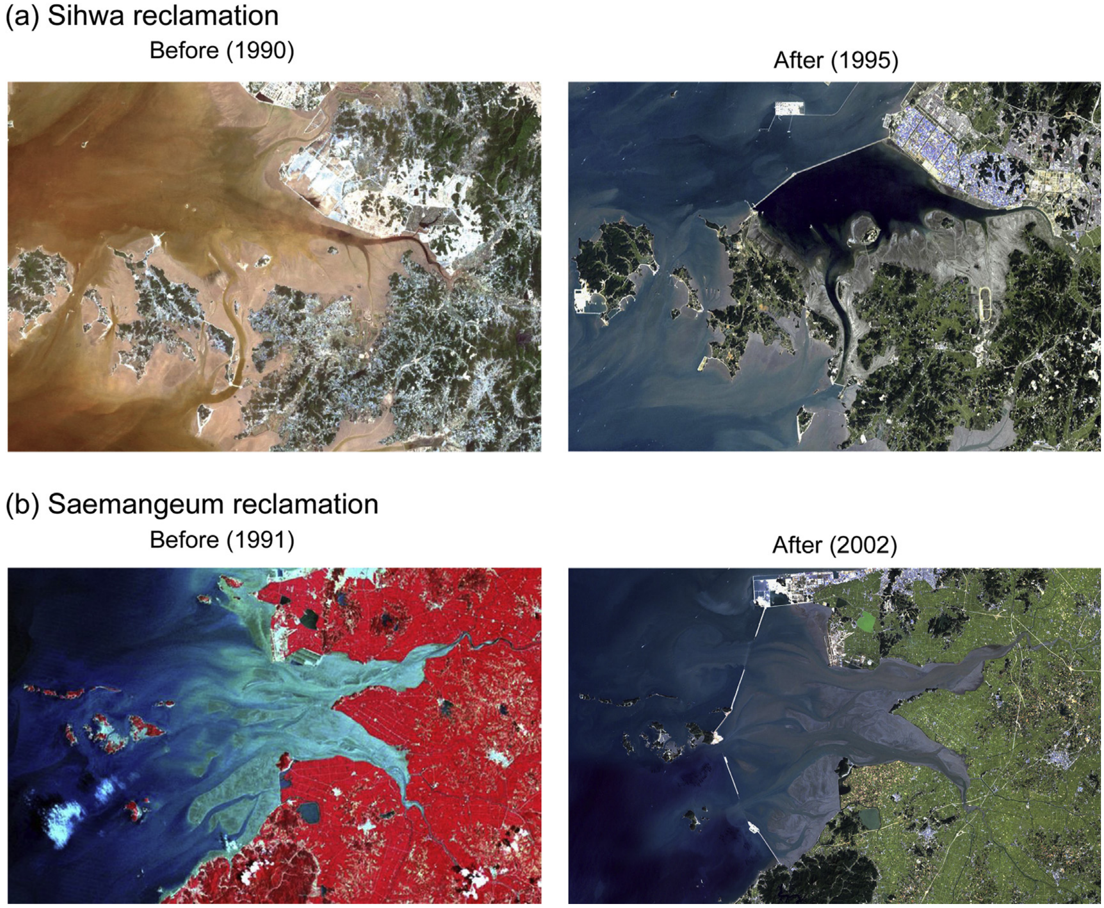

Fig. 6. Satellite images of the representative claimed areas in Korea, (a) Sihwa and (b) Saemangeum, before and after (or during) the dike construction owing to the corresponding reclamation projects.

have been designated as Protected Marine Area (PMA) by the CMMEA (KOEM, 2014). The protection of seascape, underwater scape, sand dune and sand bar would be primary concern for those CMMEA designated areas but the actual implementation seemed to completely underestimate the ideal goal of the act seen by its title.

The WCA was cooperatively overseen by the Ministry of Environments (MOE) and the MOF. The term "coastal wetlands" was defined as areas between the water line at spring tide and the water line at ebb tide (Article 2 of the WCA); in other words, the intertidal zone. Tidal flat protection areas are named as GPA or CWPA, as mentioned earlier, in the governmental reports and statistics. A total of 12 sites (11 designated by the MOF and one by the Incheon local government; Songdo site) totaling about 220 km^2 coverage belong to the GPAs.

Out of 40 fisheries acts only two acts are directly related to the marine space, namely the Fishery Resources Management Act (FRMA) and the Fishing Ground Management Act (FGMA). Before getting into the details of these acts, the Fisheries Act would be worthy to brief as a basic act in fisheries section. The Fisheries Act addresses fishery businesses, fishery catch transportation, and fisheries product processing businesses, in general. The term "fishery business" is defined as the business of catching, gathering, or cultivating marine animals or marine algae and the act also deals the issues of licensing, permission, and regulations, thus its role should be associated with others acts including FRMA and FGMA.

The FRMA regulates the protection, recovery, and formation of fishery resources. The term "fishery resources" is defined as valuable aquatic animals and plants in the sea, i.e., primarily considers the useful resources for the national economy and people's living. The act promotes and regulates fishery resources, marine ranches, and catch quota. The FRMA has four main components. First, this act controls the capture and gathering of fisheries, and sets the fishing prohibited zones for the protection of resources. Second, the act sets the limits on the number of fishing vessels, fishing methods and equipment, and total catchable quota. Third, the act includes plans to foster the fishery resources, such as the installation of artificial fisheries banks, the composition of marine ranches and undersea forests, aquatic seedlings, and improvements of marine environments. Finally, it designates the fishery resources protection zone, which has been requisitely acknowledged in allowing the healthy fishery conditions such as the spawning of fishery resources, development of aquatic seedlings, and growth of juveniles. The implementation of this act is considered to represent a type of spatial management for the protection of marine resources. Fishery resource protection zones have been designated in many bays in the South Sea and only two places in the West Sea (Cheonsu Bay and Yeonggwang) (Fig. 7).

The FGMA regulates the fishing ground environment, particularly where dense aqua farms are developed. This act has a similar function to the MEMA; however, the management areas are specialized to the fishing grounds. The act aims to prevent fishing ground pollution, specifically the organic pollutants produced by aquaculture. The major practices are surveys on environment, the designation of the coastal areas and special areas subject to management, and improvement of environment. Actual projects include the dredging of bottom sediment beneath the culture cages, the regulation of buoys, and the development and supply of

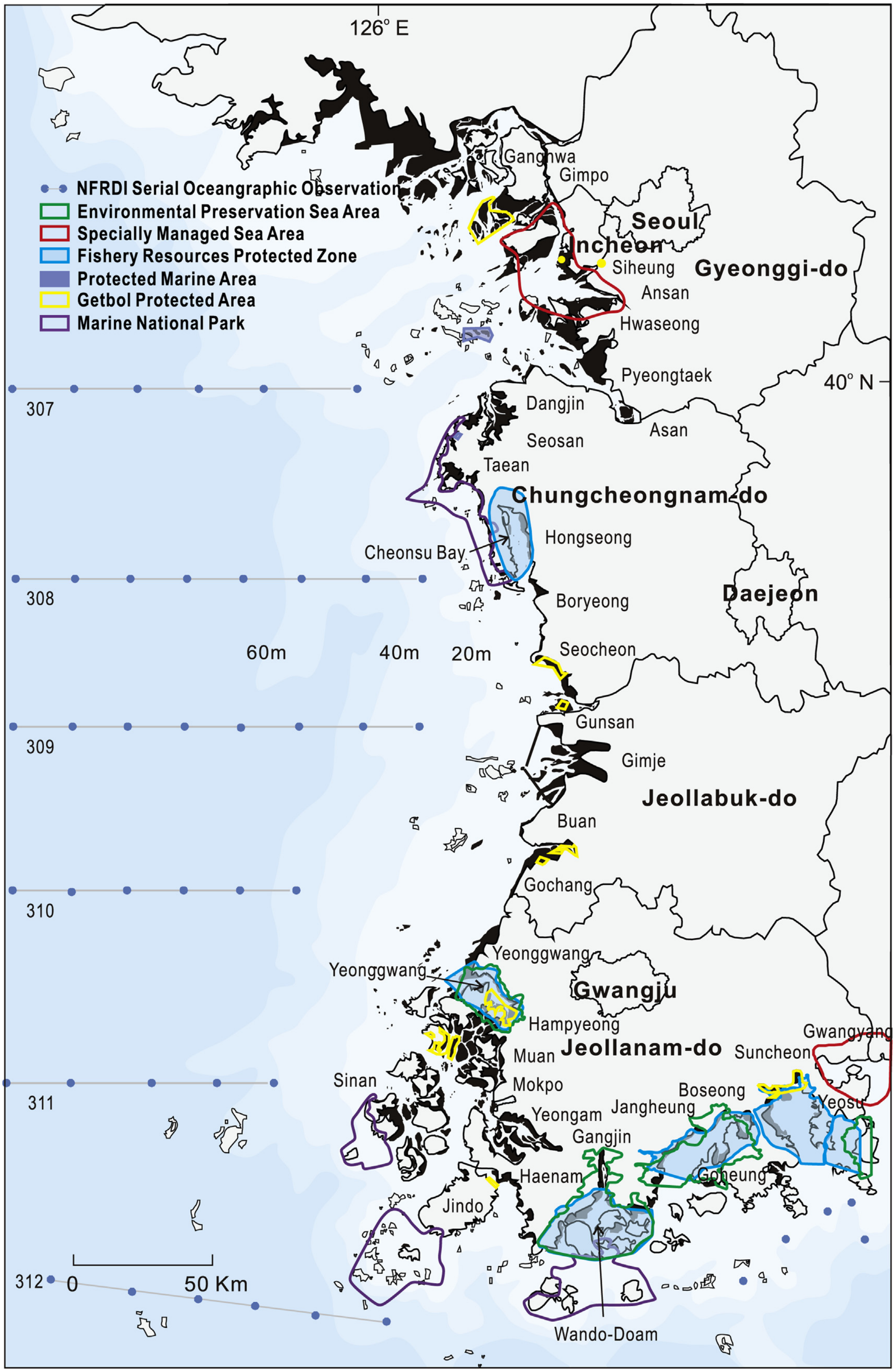

Fig. 7. Map showing the six categories of marine protected areas (refer to Section 6.2), designated by the acts related to the coastal management (refer to Section 5.2), along the West Sea of Korea.

environmentally sound feeding pellets. In conclusion, the FGMA manages the aquaculture, rather than marine space for the protection of fishery resources.

5.3. Acts associated with the tidal flat reclamation

The Public Waters Management and Reclamation Act (PWMRA) disregards the protection related acts introduced above and strongly supports the improper coastal development. This act was revised and renamed from the Public Waters Reclamation Act enacted in 1961, reflecting somehow a long history of our developmental policy in coastal management. The original version was first established in 1918 during the period of Japanese occupation. The aim was to promote welfare by preserving and managing public waters by reclamations and the act prescribes the procedures of holding the reclamation licenses.

The term "public water" includes those sea areas defined by the CMA. The tidal flat is termed tideland, and defined as any space occurring from the high-water to the low-water line. To get the license of the reclamation, the Environmental Impact Assessment (EIA) and costs-benefits analysis are needed. A target sea area should be included in the basic plan of reclamation prior to the application of project permission. The basic plan is reviewed by the National Coastal Management Council established by the CMA. The least areal coverage is 10 ha (0.1 km^2) requires the license for reclamation. The large-scale reclamations depicted in Table 2 have been permitted by the PWMRA. About 1,000 km^2 of tidal flats have been reclaimed since the 1980s. Theoretically, the CMA could allocate the utilization, reclamation and protection of coastal spaces, but little is coordinated by the act.

6. Management of the West Sea

6.1. Overview of monitoring in the West Sea

Tides are currently observed at 55 stations along the entire coast by the Korea Hydrographic and Oceanographic Administration (KHOA, 2014), where the nautical chart for navigation is produced. In the West Sea, 25 tide stations are in operation. In particular, 10 tide stations are located in the Gyeonggi Bay where the ship traffic is heavy and tides are with maximum tidal amplitude of about 10 m. Tide stations record the tidal height, water temperature, and salinity and some stations additionally measure the air pressure, air temperature, wind direction, and wind speed.

The water qualities are currently monitored by the KOEM under the MEMA (KOEM, 2014). The environmental monitoring and management are practiced by establishing administrative boundaries in the coastal zone on the basis of county boundary. The boundary system produces a total of 66 management areas containing 417 monitoring stations for the whole coast, among them 17 areas with ca. 90 monitoring stations belong to the West Sea. Target parameters include general water quality including water temperature, salinity, pH, and nutrients. The heavy metals and hazardous chemicals are also monitored in the media of seawater (198 stations), sediment (198 stations), and marine organisms (50 stations). It should be also noted that such monitoring has been carried out in a seasonal basis since 1996, but the automatic mooring system has been first adopted since 2011 and now in operation at 14 stations (5 stations in the West Sea). The environmental quality given as I to V is suggested from the set of periodic data for the purpose of management in the sea and coastal areas. In addition to water quality monitoring, the ecological monitoring for the range of plankton, benthos, and nekton has been carried out in coastal and offshore areas in a seasonal basis, which generally guide biodiversity of marine organisms and seasonal distribution in an administrative manner.

Monitoring for a fisheries management is performed separately by an extra agency called the NFRDI. The NFRDI or the former NFRDI Serial Oceanographic Observation (NSO) has been monitoring the oceanographic date since 1921 (NFRDI, 2014). At the start of the NSO, six transect lines were surveyed occasionally from two to six times a year. In 1935, 14 lines were covered, and extended up to 100 miles off the whole coast. In 1961, the NSO set up 22 transect lines with 175 stations. The present grid includes 25 transect line with 196 stations, among them six lines and 52 stations are in operation in the West Sea (Fig. 7). The measurement parameters are water temperature, salinity, dissolved oxygen, nutrients, zooplankton, and meteorological variables at 14 water depths bi-monthly, which seemed to be more valuable for fisheries management, compared to similar monitoring results that produced by the KOEM above.

In addition, fishing grounds are monitored, particularly focusing on the bays and closer coastal areas where intensive fisheries activities such as aquacultures are concentrated. The monitoring is composed of two categories under the FGMA; an overview monitoring for fishing grounds along the entire west coast and an intensive monitoring at congested aquaculture sites. The former concentrates coastal fisheries, community fisheries, aquacultures of finfish and shellfish, and macroalgae with grids of 42 stations. The latter concerns the monitoring at three bays of Garolim, Cheonsu, and Gomso, which are considered as key aquaculture area by the FGMA. Monthly measurements on water temperature, salinity, dissolved oxygen, chemical oxygen demands, dissolved inorganic nitrogen and phosphorus, suspended solids, and chlorophyll-a have been included for the former, while bi-monthly measurements on the red tide, oxygen deficiency, and low salinity are targeted for the latter.

6.2. Marine protected area

The term of Marine Protected Area (MPA) here applies for protected areas designated by four laws relevant to the protection (see Section 5.2). In Korean legal framework, the designation of certain coastal areas for protection can be categorized into three groups; namely for environment, fisheries resources, and ecosystem. The legal terms of designated areas in these three categories are Environmental Management Sea Area, Fishery Resources Protected Zone, Protected Marine Area, and GPA (CWPA). Fig. 7 shows their locality together with a rough estimation of aerial coverage for various categories of the MPAs, with additional information including the NFRDI monitoring stations and one more management unit, Marine National Park (MNP) for a comparison. The major concern of the special issue would be the protection of the Korean tidal flat, thus the GPAs directly governing the past, present, and future management of our tidal flats and ecosystem should be emphasized. We display the GPAs herein with at the last and begin

Table 2
Major reclamation projects of the Korean tidal flats since the late 1970s.

Reclamation project	Claimed area (km^2)	Freshwater lake area (km^2)	Dike length (km)	Began-completed
Saemangeum	401	118	33.9	1991–2005
Sihwa	173	61	12.7	1987–1996
Seosan	156	40	7.7	1980–1995
Gunjang	150			
Yeongsan R. II	108	35	8.6	1978–1982
Yeongsan R. III-1	128	43	2.2	1988–1993
Yeongsan R. III-2	74	23	2.1	1989–2005
Yeongjong	46			1992–1995
Gimpo	38			1980–1989
20 other projects	400			
Total	1,700			

with spatial designation for environment, fisheries resources, and then ecosystem including the GPAs.

6.2.1. Environmental management sea area

Environment here refers to a legal terminology that primarily means the management of water quality and pollution from land, ships (especially the oil spills) and aquaculture ground origins. As mentioned above, the MEMA designates certain areas in the sea for the management purpose, thus the term of Environmental Management Sea Area (EMSA) can be used as legal terminology. The designation of EMSA are twofold; A designation to foster or preserve the well reserved resources named by the Environmental Preservation Sea Area (EPSA), and next to improve the low quality environment named by the Specially Managed Sea Area (SMSA). The first reaches an aerial dimension of about 1 880 km^2 and the second of about 2 890 km^2. The significant aerial proportion of the EMSA includes land (ca. 56% on average) and takes a measure of total pollution load management system. The SMSA of Sihwa-Incheon purposes to manage the pollution loadings not only from the metropolitan city of Incheon but also from the discharge of Sihwa Lake, as described in a separate review chapter (Lee et al., 2014).

6.2.2. Fishery resources protected zone

The Fishery Resources Protected Zone (FRPZ) encompasses both coastal land and the sea, similar to the EMSA, of which designation aims to protect and foster fishery resources under the National Land Planning and Utilization Act in combination with the FRMA, but particularly targeting bay areas. A total of 10 FRPZ have been established in Korea since 1976, covering a total area of 3,870 km^2, of which the marine area represents 2,625 km^2. The majority of the FRPZ ($n = 7$) have been established in the South Sea that has a ria type coast with a number of deep bays, encompassing important fish spawning and nursery grounds that being used for extensive aquaculture. In the West Sea, three FRPZ have been established in Cheonsu Bay, Yeonggwang, and Wando-Doam Bay. The Cheonsu Bay protection zone was designated in 1978, covering a total area of 213 km^2, of which the land represents 83 km^2; however, it should be noted that the protection zone was partially downgraded in 2009. The Yeonggwang protection zone was designated in 1981, covering a total area of 275 km^2, of which the marine area covers 159 km^2. The Wando-Doam Bay zone was designated in 1982, and has a total area of 660 km^2 with the marine area of 360 km^2, of which marine area is the largest among the 10 FRPZ in Korea.

In addition to the FRPZ, seven areas have been designated as shellfish production zones (not shown in Fig. 7), covering an area of 290.95 km^2 in the South Sea. These areas have been established in order to meet the health requirements of the United States, Japan, the European Union (EU), and other countries for the export of shellfish, including oysters, mussels, ark shells, and the Manila clams.

6.2.3. Protected marine area

The PMA is a legal term under the CMMEA and purposed to protect marine organisms, ecosystem, and landscape. Nine areas have been designated in Korea as mentioned above, covering a total area of 213 km^2. Daeijak Island and Sindu-ri sand dune are in the West Sea. The Daeijak Island was designated in 2003, covering a total area of 56 km^2 to protect the sand dunes exposed at low tide. The Sindu-ri was designated earlier in 2002 to protect the largest coastal sand dunes in Korea, but the designated coastal area by the CMMEA was not large (0.64 km^2). It should be noteworthy that many of the PMA are situated in the South Sea, encompassing a total of 157 km^2, thus lesser appreciated in terms of the management of the West Sea tidal flats compared to other MPAs.

6.2.4. Getbol protected area

The GPAs (viz. CWPA) were established according to the WCA enacted in 1999. The administrative term of inland wetlands is "wetland," while that of marine and brackish environments is "coastal wetland". The legal definition of coastal wetland is the area between the highest reach of the water at high tide and the lowest reach of the water at low tide, with the exclusion of the subtidal area. A total of 12 GPAs has been established since 2001, covering about 220 km^2 tidal flats. Nine GPAs have been established in the West Sea and three in the South Sea. Interestingly, two sites of the Nakdong River Estuary and the Han River Estuary, which also encompass the large areas of tidal flats at the mouth of estuaries, have been designated as protected areas by the ME (not by the MOF). However, those sites could not be currently counting as the GPA because the management of estuary does not belong to the legal authority of the MOF. In anyhow, practically 14 sites including above two estuaries along the Korean coasts are currently under the legal protection by the MPA related acts in Korea in a broad manner.

6.3. Marine national park

The MNP is purposed mostly to protect the coastal landscape, not the marine environment and/or ecosystem. Considering this original purpose, the MNP would not be in the legal category of the MPA which primarily targeting the ecosystem protection. The beauty of the coastlines and islands attract people and the designation of the coastal landscape as the national park has begun already in 1968.

Three MNPs have been designated and managed in the Korean seas and two of them are situated in the West Sea. A total of 21 terrestrial national park and two MNPs have been designated, covering a total area of ca. 6,600 km^2 in 2013, with half of the land area and another half of the marine area, on the legal basis of the Natural Park Act since 1967.

The MNPs in the West Sea are Taeanhaean (haean; coast), Byeonsanbando (bando; peninsula), and Dadohaesang (Dado; many islands, haesang; sea surface). The Taeanhaean MNP was designated in 1978, encompassing 26 beaches along 230 km of coastline, covering a total area of 327 km^2 (290 km^2 sea area and 374 km^2 land area). Most of the Taeanhaean MNP area is off the coast; however, the designation was purposed to protect the landscape only. The Byeonsanbando MNP was designated in 1988, but its areal coverage of marine area (9.2 km^2) to the total (155 km^2) is the smallest among the MNPs. The Dadohaesang MNP was designated in 1981, covering a total area of 2,322 km^2, of which 339 km^2 is terrestrial area and 1,987 km^2 is marine area. It is located in the south of the West Sea and the western South Sea. Even the park areas cover the sea surface largely to showcase the islands associated landscape, accordingly having the largest aerial coverage among the MNPs.

7. Conclusions

A comparative description of the Korean to the European Wadden Sea would elucidate the communalities and differences and should lighten the understanding of the Korean Wadden Sea (meaning "Getbol" herein) noticeably. As noted, Korean people's understanding of the Korean Wadden Sea has been limited to the aerial dimension being physically exposed tidal land during ebb tide. The Korean word of "Getbol" indicates the aerial limitations to the tidal flat as mentioned above, and the legal framework of protection has excluded the subtidal area. It simply means that the management is not constitutive of the tidal area as a unit system.

The Korean Wadden Sea represents uniqueness in landscape, tides, and ecosystem. The belt-like tidal wetlands of 1–3 km width is continued along the entire west coast, but narrowed occasionally where rocky shores protruded. The landscape of indented coastline is often associated with numerous islands stubbed among the flats, particularly in the southern part of the country.

The ecosystem is exposed to a macrotidal regime ranging from maximum of 10 to 4 m tidal heights from north to south of the South Korea. Sand nourishments are mainly from several major rivers and no barrier islands are developed. Sand beaches are not massive. A striking feature is the coastline of ponderous concrete dikes as seen at the newly constructed 33.9 km long seawall of the Saemangeum. The mountainous sloping to the indented coastline of the Korean Wadden Sea would be one discrete identity from the European Wadden Sea where the flats continue to fertile hinterlands. The historic developments of summer and winter dikes to protect the coastal population from the storm surges and floods are not seen in the Korean tidal flats.

The managed commercial fishery in the Wadden Sea is another feature of the differences (CWSS, 2010). The Korean fisheries are rather artisanal and associated with local community culture in the coastal region of the West Sea. The cultural landscape in terms of the human settlement is barely observed (The Wadden Academy and CWSS, 2010).

In the protection, the fundamental issue should concern the ecosystem unit (Moser and Brown, 2007). To set up the Korean tidal flat as a coherent system for the management as practiced in the European Wadden Sea, various aspects should be synthesized. The issue is difficult to approach and beyond the introductory chapter, but a sketch embraces the aspects of tradition, social understanding, science, policy, institution, and politics etc. The term of "Getbol" in Korean was a traditional aspect of Korean peoples' understanding of the tidal flat as a territory of economic earning for living in bare foot.

The shallow history of science and weak understanding of the Korean coastal seas should have impeded the treatment of the Korean tidal flat as an ecosystem unit. The protection related laws from environment to fisheries were sectorally, in other words independently, operated. Information and knowledge on the policy process and science accumulated in the Wadden Sea are transferring through the 2009 Memorandum of Understanding (Title: *Mutual cooperation for the purpose of conservation and management of tidal flat ecosystems*) at the governmental level between Wadden Sea countries and Korea (CWSS, 2014). The special issue was thought to be a baseline for the further understanding of human coupled, ecological and social system of the Korean versus the European Wadden Sea.

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