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Distribution of Eelgrass, *Zostera marina* L. on Coasts of the Korean Peninsula: Preliminary Study for Eelgrass Restoration

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Abstract : Eelgrass, *Zostera marina* L. widely spreads throughout all the coastal areas of the Korean Peninsula. However, some previously reported eelgrass populations disappeared. The disappearance was probably caused by anthropogenic disturbance such as reclamation and pollutant or exceeded nutrient release. Eelgrass beds occurred from the intertidal to the subtidal zone, mainly in lagoon, estuaries, ports, barrier reef and bays. Eelgrass beds were also found at the intertidal mud and sand flats, subtidal mud and sandbank in more exposed areas. Habitat characteristics of eelgrass beds distributed on the coasts of the Korean Peninsula varied among coast areas. Eelgrass distributed constantly throughout the southern coast of Korea, while the distribution was limited at lagoon, bay, port, or barrier reef on the eastern coast, because of steep water depth and high wave energy in that coast. On the western coast, eelgrass mainly appeared at the intertidal and subtidal zones in islands. Sediment characteristics of the *Z. marina* beds varied with locality, tidal current and water motion. Sediments of *Z. marina* beds were composed of sand, muddy sand, sandy mud and mud. Mean grain size ranged from 1.5 to 4.1 phi.

Key words : distribution, eelgrass, *Zostera marina* L., Korean coast, restoration.

1. Introduction

Seagrass beds are one of the most productive of plant communities (McRoy and McMillan 1977), providing habitat and food for a wide variety of flora and fauna (Heck and Westone 1977; Orth *et al.* 1984; Huh and Kitting 1985). Since seagrass beds provide essential habitat and organic carbon sources for economically important animals, status of seagrass meadows are closely related with coastal fish and shell fish production (Orth *et al.* 1984; Huh and Kitting 1985). They also influence the abiotic environment by enhancing sedimentation, reducing current and wave velocities (Fonseca and Cahalan 1992). Because seagrass can take up inorganic nutrients through both leaf and root tissues from water column and sediments (Iizumi and Hattori 1982; Terrados and Williams 1997; Lee and Dunton 1999), seagrass can remove over-enriched water column nutrients, which cause the coastal eutrophication. Therefore, seagrass meadows provide a wide array of ecological functions that are important for production and health of estuarine and coastal ecosystems.

There have been significant declines in seagrass coverage in many parts of the world (Orth and Moore 1983; Dennison *et al.* 1993; Short and Wyllie-Echeverria 1996; Aioi 1998). Habitat loss is often related to reduced water quality and increased turbidity caused by anthropogenic activities. Estuarine and coastal ecosystems are receiving extraordinary amounts of nutrients as a consequence of anthropogenic loading in watersheds (Valiela *et al.* 1992; Short and Burdick 1996). Increased nutrient inputs into the water column can adversely affect seagrass survival and production through stimulated phytoplankton, epiphytic and macroalgal growth (Short 1987; Short *et al.* 1995). Stimulation of competing primary producers caused by water column nutrient enrichment leads to light reduction and declines of seagrasses.

Because of critical role seagrass habitat plays in estuarine and coastal ecosystem, efforts are underway to restore seagrass habitats. Once seagrass cover is lost, physical, chemical and biological characteristics of the site may change (Duarte 1995). Such changes can prevent natural restoration at historic seagrass sites even when water quality is adequate. Seagrass transplantation has been used for habitat restoration and mitigation for seagrass loss or damage (Fonseca *et al.* 1998). The leading factor of seagrass transplant success is adequate transplanting site selection (Fonseca *et al.* 1998). Historical seagrass distribution is an important consideration in selecting transplanting sites. Restoration at sites of historical seagrass distribution may result in higher transplant success than in previously unvegetated sites. Therefore, monitoring seagrass distribution is essential for management and future restora-tion of seagrass habitats.

Eelgrass, *Zostera marina* L. (Zosteraceae), is one of the most abundant seagrass species in the world. This species widely distribute in temperate and arctic seas of northern hemisphere (den Hartog 1970), and is common in Korea and Japan (Miki 1932, 1933). Eelgrass is marine flowering plant primarily occurring in the subtidal zone with occasional extension into the lower intertidal region in tide pools (Fig. 1). Eelgrass often grows in dense, extensive beds or meadows, creating a highly productive components of estuary and coastal ecosystem.

Since Nakai (1911) reported *Zostera marina* L. from Korea, five species of *Zostera* have been recorded in Korea (Choi *et al.* 2001; Miki 1932, 1933; Shin and Choi 1998; Lee 1998, 2001; Lee *et al.* 2000a, 2000b, 2000c, 2000d, 2001). However, these reports only partially described the distribution and ecological consideration of eelgrass. Despite their importance in coastal ecosystem, the study of seagrass in Korea has been neglected. Most seagrass beds in the coasts of Korea have rapidly disappeared for the recent two or three decades due to reclamation, dike making, urbanization and industrialization. In particular, all of eelgrass beds disappeared in the locality such as Hansilpo Bay in Gyeongsangnam-do during this period (Kong 1981). In southern coast, eelgrass beds have been lost since 1970s, which affected serious loss of coastal fisheries (Huh *et al.* 1998). The basic information on distribution and ecology of *Zostera* species are urgently required for promoting effective and efficient conservation of these species. In the present study, distribution of *Zostera marina* in the Korean Peninsula was investigated to provide valuable information for conservation and future restoration of eelgrass habitat.

2. General properties of oceanographical conditions

The Yellow Sea

The Yellow Sea (western sea of Korea) is semi-enclosed by the Korean Peninsula in the east and the main land China in the west, connected with the Pohai Bay in the northwest and the East China Sea in the south. The surface area of Yellow Sea is 48.7×10^4 km^2 with average depth of 44 m. The coastlines of the Yellow Sea are variously represented by rias type coast, and ramified by many islands, estuaries and bays. The hydrographic properties and circulation characteristics of the Yellow Sea are critically influenced by climatic conditions. Winter cooling and summer heating, fresh water discharges from the rivers, southerly inflow of warm saline waters of a branch of the Kuroshio and sweeps of cold and dry northerly winter monsoon and warm humid southerly summer monsoon are the major determinants of the water properties and circulation characteristics. The tide in the Yellow Sea is predominantly semidiurnal and the tidal range is rather wide, especially in the eastern part of the Yellow Sea. The maximum tidal range is about 9.0 m at Incheon.

The South Sea

The South Sea (southern sea of Korea) is a shallow sea with an average depth of 101 m, and the surface area of 7.54 $\times 10^4$ km^2. The boundary of South Sea is connected to the East China Sea and northern part is to the southwestern coastal zone of the Korean Peninsula. Jeju Island is located nearly at the margin of the South Sea and the Tsushima Current, a branch of Kuroshio, flows toward the East Sea of Korea through the southeastern part of the area. The coastlines of the South Sea are very complex rias type coast, include many islands, estuaries and bays. The tide of the South Sea is generally dominated by typical semidiurnal tide. The spring tidal range is 1.2 m at Busan and increases to the west 3.0 m at Yeosu and 3.1 m at Wando.

The East Sea

The East Sea is a marginal sea adjoining the North Pacific through the Korean Strait in the south, and through the Tsugaru, Soya and Tartar Straits in the north of the sea. Shaped in rectangular pattern with the total area of 130 × 10^4 km^2 and mean depth of 1,543 m which is wider and deeper than the Yellow Sea and the South Sea of Korea. The coastlines of the East Sea are very simple and linear, and include ports and lagoons. The spring tidal range of the East Sea is 20 cm at Pohang and increases to the south 60 cm at Ulsan and 120 cm at Busan.

3. Materials and methods

Experimental plants, seawater and sediments were collected by SCUBA from meadows of *Zostera marina* on the coasts of the Korean Peninsula from March 1998 to December 2000 to investigate biological distribution and environmental characteristics of eelgrass habitat. Sediment samples were collected using a PVC hand core sampler (10 cm in diameter) at each site to measure sediment grain size and organic contents. Mean grain size was expressed in phi unit and particle size distribution by coefficients of sorting, and sediment properties were determined by sand, muddy sand, sandy mud and mud. Abundance of *Zostera marina* was expressed in common (>1,000 m^2), uncommon (100-1,000 m^2) and scarce (<100 m^2) by the area of occupancy.

Community and habitat description of *Zostera marina* beds were based on a number of major physical categories and the frequency of plant stands. The geographical distribution of the *Z. marina* in coasts of the Korean Peninsula was summarized in the map. We plotted locations of *Zostera marina* beds on 1:30,000 scale map, using intertidal features as reference points and recorded in the tidal range. Water temperature and salinity were measured with a salinometer (YSI Model 33) and tidal range information could be found in the NORI (www. nori.go.kr).

Habitats of *Zostera marina* L. were defined according to parameters of physical environment such as substratum type or degree of wave exposure. Community and habitat descriptions of *Z. marina* L. were characterized by salinity, wave exposure, substratum, zone, height band and frequency of occurrence. Wave exposure classification was defined sheltered, very sheltered and extremely sheltered. Vegetation zones of beds were separated into intertidal and subtidal zones. Height bands of habitats were characterized as upper, mid and lower shore. Habitat types of *Z. marina* beds were classified into bay, port, lagoon, estuary, and barrier reef.

4. Results and discussion

Geographical distribution of *Zostera marina* L. in the Korean Peninsula

Eelgrass, *Zostera marina* L. occurred in numerous localities along the coast of the Korean Peninsula. The northmost population of the eelgrass on the eastern coast of South Korea was in Hwajinpo Lake (lagoon), while the northmost population in the western coast was in Baengnyeong Island. We found several eelgrass beds from Jeju Island that were the southmost eelgrass population in Korea (Fig. 2). We found that the eelgrass population at Hansilpo on the southern coast reported by Kong (1981) disappeared due to reclamation. Miki (1932) reported eelgrass popula-tions from a few areas in the Korean Peninsula. In the present study, we observed that eelgrass, *Z. marina* widely spreaded throughout all the coastal areas of the Korean Peninsula (Fig. 2). However, some eelgrass populations reported previously disappeared. The disappearance was probably caused by anthropogenic disturbance such as reclamation and pollutant or exceeding nutrient release.

Habitat type of eelgrass distributed in the coast of the Korean Peninsula varied among coast areas (Fig. 3). Eelgrass distributed constantly throughout the southern coast of Korea, while distribution was limited at lagoon, bay, port, or barrier reef on the eastern coast, because of steep water depth and high wave energy in that coast. In the western coast, eelgrass mainly appeared at the intertidal and subtidal zones of islands.

Eelgrass habitat characteristics

In the eastern coast, salinity in Hwajinpo Lake (lagoon) varied from 8.0 ‰ to 24.5 ‰ due to changes in fresh water inflow during sampling periods, while salinity at other eelgrass habitat was affected by ocean water. Eelgrass beds on the eastern coast mainly occurred in subtidal zone (0.8 to 6.0 m depth) with sandy sediment, and sediment grain size ranged from 2.0 ϕ to 3.8 ϕ (Tables 1, 2). A tidal movement in the eastern coast was very weak with tidal range of about 40 cm, and did not affect eelgrass habitat characteristics. Shoot density of eelgrass was relatively higher than that of other *Zostera* species such as *Z. asiatica,* but was usually sparse or moderately dense in the eastern coast.

In contrast to the eastern and southern coast, distribution of eelgrass populations was limited at islands in the western coast of the Korean Peninsula (Fig. 3). Eelgrass beds occurred at both intertidal and subtidal zones (Table 1). Salinity at intertidal zone reflected changes in rainfall and fleshwater inflow. The maximum depth limit for eelgrass distribution was about 4 m in the western coast of the Korean Peninsula. Tidal range in the western coast was extremely high: the maximum tidal range was 9 to 10 m in Incheon. Since the high tidal range produced strong tidal current (5-6 knot), eelgrass distribution was affected more by the tidal current than wave in the western coast of the Korean Peninsula. Sediment type was diverse from mud to sand, and sediment grain size ranged from 2.5 ϕ to 4.1 ϕ in the west coast (Table 2).

Eelgrass distributed in intertidal and subtidal zones of the southern coast of the Korean Peninsula. Depth distribution of eelgrass in subtidal zone of the southern coast was 0.6 to 7.0 m (Table 1). The maximum tidal range was 1.4 m to 3.9 m, and produced 1 to 1.5 knot tidal current in the southern coast. Sediment type in the eelgrass habitat was sand or muddy sand, and sediment grain size ranged from 1.5 ϕ to 4.3 ϕ in the southern coast (Table 2). Eelgrass distribution was affected by both tidal current and wave energy in the southern coast.

Eelgrass habitat restoration

Over the last decade, eelgrass habitats have declined mainly due to human induced disturbances (Valiela *et al.* 1992; Short and Burdick 1996). Because seagrass habitats play an important role in estuarine and coastal ecosystem, the habitats are protected under the law, and numerous projects have attempted to restore seagrass habitat (Davis and Short 1997; Fonseca *et al.* 1998). Several seagrass transplanting methods have been developed, and transplan-tations have been conducted for seagrass habitat restoration (Davis and Short 1997; Fonseca *et al.* 1998), Since a success of seagrass transplantation depends on physical and chemical characteristics in transplanting sites and seagrass physiology, researches in seagrass physiology and ecology, and habitat characteristics are critical for seagrass ecosystem restoration. The present study about eelgrass distribution and habitat characteristics will provide valuable informations on selections of transplanting site, the proper season and method for eelgrass habitat restoration in estuarine and coastal ecosystems in the Korean Peninsula.

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Table 1. Biological, physical and chemical characteristics of eelgrass, *Zostera marina* beds on the eastern, western and southern coast of the Korean Peninsula.

Sites / Characteristics	Eastern coast	Western coast	Southern coast
Salinity	full-variable	full-variable	full-variable
Wave expose	open, sheltered, very sheltered	sheltered, very sheltered	sheltered, moderately open
Substrata	sand	sand, mud, muddy sand, sandy mud	sand, muddy sand
Tidal stress	very weak	weak to strong	weak to strong
Zone	subtidal	intertidal, subtidal	intertidal, subtidal
Height band	mid and lower shore	upper, mid and lower shore	mid and lower shore
Depth band	0.8-6.0	intertidal-4.0	0.6-7.8
Frequency occurrence	moderately common	common	common
Habitat type	lagoon, bay, port, barrier reef	island bay and port	bay, port, barrier reef
Community description	sparse to moderately dense	moderately dense	sparse to dense

Table 2. Characteristics of surface sediment in *Zostera marina* L. beds on the eastern, western and southern coast of the Korean Peninsula.

Coast	Site	Composition (%)		Type	Mz (ϕ)	O.C (%)	Sort (ϕ)
		Sand	Mud				
Eastern coast	Hwajinpo	95.1	4.9	S	3.1	2.1	0.7
	Namae	99.0	1.0	S	2.9	3.7	0.8
	Duksan	97.4	2.6	S	2.2	1.7	0.9
	Jangho	99.2	0.8	S	2.1	2.7	0.9
	Yungdong	98.0	2.0	S	3.0	4.5	0.8
	Hoopo	99.5	0.5	S	2.0	1.6	0.8
	Yungduk	99.5	0.5	S	2.5	2.4	0.8
	Chilpo	98.7	1.3	S	3.5	1.9	0.7
	Kampo	96.5	3.5	S	3.5	3.6	0.8
	Ilsan	90.2	9.8	S	3.8	2.8	0.8
	Daebyun	96.8	3.2	S	2.2	5.7	1.5

	Baengnyeongdo	91.5	8.5	S	3.5	3.0	0.8
	Soejakdo	95.2	4.8	S	2.5	2.4	1.0
	Sungbong(IT)	94.3	5.7	S	2.7	1.0	0.6
Western coast	Sunbong(ST)	91.6	8.4	S	2.9	0.9	0.7
	Sunyudo	42.3	57.7	sM	4.0	1.5	0.6
	Woido	57.7	42.1	mS	3.5	1.1	1.0
	Anchado	10.5	89.5	M	4.1	6.5	2.0
	Shinmyung	85.9	14.1	mS	3.2	4.0	1.0
	Angolpo	77.1	22.9	mS	3.1	6.9	1.2
	Dagu	94.9	5.1	S	2.9	1.7	0.7
	Myungju	95.2	4.8	S	2.5	2.8	1.0
	Ukgok	88.2	11.8	mS	2.2	5.2	1.7
	Gokryong	83.4	16.6	mS	2.8	6.0	1.3
	Shinwol	91.2	8.8	S	2.2	4.6	1.4
	Dadae(IT)	95.1	4.9	S	2.1	3.2	1.4
	Daede(ST)	96.0	4.0	S	2.4	3.6	0.7
	Susan	86.5	13.5	mS	1.5	8.4	1.1
Southern coast	Kwangyang	97.0	3.0	S	2.1	1.7	0.8
	Yulrim	90.9	9.1	S	3.3	5.1	0.5
	Hangdae	75.4	24.6	mS	2.7	7.7	1.5
	Seipo(deep)	78.9	21.1	mS	3.0	2.3	1.1
	Seipo(swallow)	92.7	7.3	S	3.5	0.9	0.4
	Narodo	86.7	13.3	mS	3.1	4.6	0.8
	Kwansan	26.7	73.3	sM	4.0	2.6	0.9
	Chunghaejin	49.7	50.3	sM	4.3	7.1	-
	Jukrim	78.1	21.9	mS	4.4	4.7	1.6
	Sungsan	99.1	0.9	S	2.1	3.5	0.7
	Hamduk	98.3	1.7	S	1.6	4.3	1.0

S = sand, M = mud, mS = muddy sand, sM = sandy mud, Mz(ϕ) = mean grain size, O.C = organic contents, W.C = water contents, IT = intertidal and ST = subtidal.