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A Preliminary Study on Growth and Habitat Characteristics of *Zostera marina* (Zosteraceae) in Gamak Bay, Yeosu

Do-Hoon Kim*, Jin-Hyung Park[1] and Jong-Ahm Shin

Division of Aqualife Science, Yosu National University, Yeosu 550-749 and
[1]Department of Civil Engineering, Chonnam National University, Gwangju 500-757, Korea

This study was performed to obtain basic information on the ecology of *Zostera marina* and to promote efficient conservation of this species which has been decline in Gamak Bay, Yeosu, Korea. Water column characteristics and eelgrass morphology at Anpori, Jangsuri and Wonpori were investigated every month from December 1999 to November 2000. The water temperature, salinity and pH at the three sites were 10.0-27.0°C, 29.4-34.7‰ and 8.1-8.5, respectively. The water temperature at Anpori tended to be slightly lower than that at the other locations; the salinity at Wonpori from July to November was a little lower than that of the other locations. The concentrations of NO_2-N, NO_3-N, NH_4-N, PO_4-P and $Si(OH)_4$-Si at the three sites were 0.9-1.3, 2.0-6.2, 7.8-9.0, 3.0-3.6 and 22.2-30.2 μM, respectively. The concentration of NO_3-N at Wonpori from June to November was somewhat lower than that at the other locations; that of NH4-N at Jansuri was somewhat lower than the others. The mean shoot height and leaf width of the Anpori, Jangsuri and Wonpori populations were 80.6 cm and 0.9 mm, 90.0 cm and 1.0 mm, and 95.3 cm and 1.0 mm, respectively. The mean total shoot weight of the Anpori, Jangsuri and Wonpori ones was 24.5, 31.0 and 29.7 g, respectively. The mean leaf and branch numbers of the Anpori, Jangsuri and Wonpori populations were 16.5 and 2.6, 16.1 and 2.4 and 15.4 and 2.6 individuals, respectively. The correlation coefficients between shoot height and water temperature, leaf width and total shoot weight, leaf number and branch number, and $Si(OH)_4$-Si and NO_3-N were 0.726, 0.692, 0.862, and 0.693, respectively. The coefficients between shoot height and NO_3-N, total shoot weight and NO_3-N, water temperature and $Si(OH)_4$-Si, water temperature and salinity, and water temperature and NO_3-N were -0.716, -0.536, -0.775, -0.685 and -0.685, respectively. The first four principal components explain 71.1% of the total sample variance. For axis 1, shoot height and water temperature tended to correlate with the population of Jansuri, followed by the Wonpori population, and $Si(OH)_4$-Si and NO_3-N tended to correlate strongly with the Anpori population. For axis 2, total weight, leaf width, leaf number and branch number showed a tendency to correlate with the Anpori and Jangsuri populations. For axis 3, the Anpori population tended to be influenced by NO_2-N and PO_4-P. For axis 4, the Wonpori and Jangsuri populations tended to be affected by salinity. The tendency, however, differed according to season.

Key Words: Gamak Bay, growth, habitat, principal components analysis, Yeosu, *Zostera marina*

INTRODUCTION

The well-known catastrophic effect of the "wasting disease" of the eelgrass (*Zostera*) beds along the coasts of the North Atlantic in the early 1930's attests to the fundamental ecological importance of seagrass communities. With the demise of these seagrass beds, the structure and composition of the associated flora and fauna were altered. Fishery production declined and a reorientation in fisheries strategies had to be affected. It was primarily this ecological catastrophe which triggered renewed research interest in seagrasses in most parts of the world (Fortes 1998).

The genus *Zostera* can be divided into two subgenera, *Zostera* and *Zosterella*, based on the closed or open sheath in leaf bases and the presence or absence of retinaculum in spadix. Since Nakai (1911) reported *Zostera marina* L. in Korea, five species of the *Zostera* and one of *Zosterella* have become known in Korea (Miki 1932, 1933; Chung 1957; Lee 1979; Kong 1981, 1982, 1984; Choi 1984; Cho and Boo 1998; Shin 1998; Shin and Choi 1998; Lee 2001; Shin *et al.* 2002).

The importance of eelgrasses to coastal productivity was emphasized in the classic studies on *Z. marina* in Danish waters (Petersen and Boysen-Jensen 1911; Boysen-Jensen 1914). Subsequent work in Korea has shown that the eelgrass populations provide a substantial amount of organic material via the food web, and also provide the habitats or shelters for a wide

*Corresponding author (kdh5060@hanmail.net)

variety of flora and fauna (Huh 1986; Go and Cho 1997; Huh and An 1997, 1998; Huh and Kwak 1997a, 1997b, 1997c, 1997d, 1998a, 1998b, 1998c, 1998d, 1998e, 1998f, 1998g; Yun *et al.* 1997; Huh *et al.* 1998). Also ecological studies on *Z. marina* in Korea have been reported by Kong (1981), Huh *et al.* (1998), Lee *et al.* (1999, 2000a, 2000b, 2000c, 2000d, 2001, 2002), Lee (2001) and Lee and Lee (2001).

Despite its importance in the coastal ecosystem, the study of eelgrass in Korea has been relatively neglected. Most eelgrass beds on the coasts of Korea have rapidly disappeared over the past two or three decades due to reclamation, dike construction, urbanization, industrialization and environmental pollution. In particular, all of the eelgrass beds disappeared in localities such as Hansilpo Bay in Gyeongsangnamdo (Kong 1981). On southern coast of Korea, eelgrass beds have been lost since the 1970s, which has resulted in a serious loss of coastal fisheries (Huh *et al.* 1998). Basic information on the ecology of *Z. marina* is urgently required in order to promote efficient conservation of the species.

The last thirty or forty years has been a rapid increase in pressure on the eelgrass and the other shallow coastal resources of the Yeosu region. It is highly possible for *Z. marina* to fall into an "extinction vortex" (Gilpin and Soulé 1986) in this region. In the present study, the growth performances of *Z. marina* and some environmental factors were investigated in the eelgrass bed at three sites in Gamak Bay, Yeosu, Korea as a part of study on conservation biology.

MATERIALS AND METHODS

Shoots of *Zostera marina* were collected in the coastal waters of Anpori, Jangsuri and Wonpori in Gamak Bay, Yeosu, Jeollanamdo, Korea (Fig. 1) from December 1999 to November 2000.

Five morphological characteristics of the eelgrass such as shoot height, total shoot weight, leaf width, leaf number, branch number were measured every month.

Water temperature, pH and salinity were measured using DO meter (YSI, Model 33, S-C-T Meter). The waters were sampled using 500 m*l* bottles in midlayer water depth and these waters were used for determining the contents of nitrite-nitrogen (NO_2-N) by the N-(1-Naphthyl)-ethylenedimine dihydochloride method (Bendschneider and Robinson 1952), nitrate-nitrogen (NO_3-N) by cadmium-copper reduction (Wood *et al.*

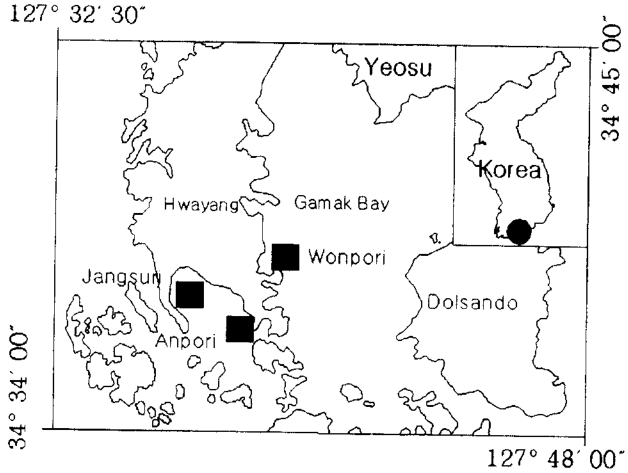

Fig. 1. Map showing the collection site of *Zostera marina*.

1967), ammonium-nitrogen (NH_4-N) by phenolhypochlorite (Solórzano 1969), and phosphate-phosphorus (PO_4-P) by ascorbic acid (Murphy and Riley 1962) and silicate-silicon ($Si(OH)_4$-Si) by APAH, AWWA and WEF(1995) in the laboratory.

To examine the relationships between the growth performances of *Z. marina* and the habitat characteristics, a principal components analysis (PCA) was performed using standardized data. From the PCA biplot drawn by projecting the variable points onto the respective plot vector, an simulation of the variable performances in each field plot was obtained. The relative length of a loading vector indicates the rate of increase – long vectors are more gradual increases, short vectors are faster increases. This means that the length of vector shows the contribution of growth features to habitat characteristics along each of the axes – long vectors are slower growth, short vectors are faster growth. The direction of a vector indicates the values of the variable increase in that direction, that is, how well the growth performance is correlated with the axes. The cosine of the angle between two vectors reveals the degree of correlation of the variables. For example, a small angle between vectors indicates a high correlation and a large angle indicates a low correlation between growth performances. Also, different axes separate different groups of the variables (Digby and Kempton 1987; Palmer 1993; Stuart *et al.* 1999; Quinn and Keough 2002).

RESULTS AND DISCUSSION

Figure 2 shows the monthly variations of water temperature, salinity and pH at the three sites from December 1999 to November 2000. The water

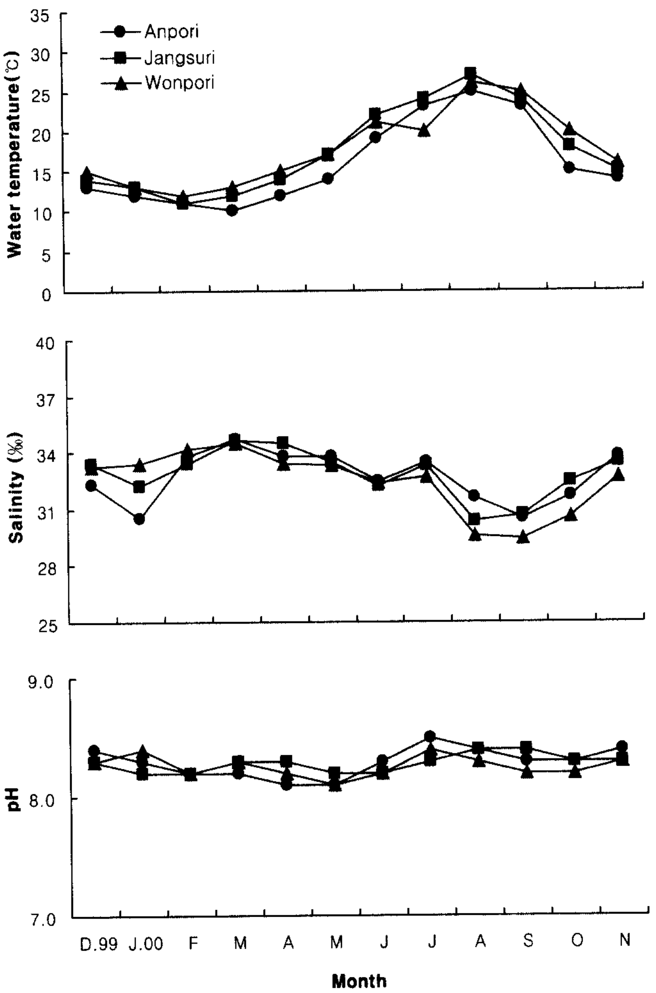

Fig. 2. Monthly variations of water temperature, salinity, pH at three sites from December 1999 to November 2000.

temperature at the three sites ranged from 10.0°C to 25.0°C; that at Anpori tended to be slightly lower than the others. The salinity at the three sites fluctuated between 29.4‰ and 34.7‰; that at Wonpori from July to November was a little lower than the others. The pH fluctuated from 8.1 to 8.5.

Figure 3 shows the monthly variations of concentrations of NO_2-N, NO_3-N, NH_4-N, PO_4-P and $Si(OH)_4$-Si at the three sites from December 1999 to November 2000. The value of NO_2-N was 0.9-1.3 μM. The amount of NO_3-N was 2.0-6.2 μM; the amount at Wonpori from June to November was somewhat lower than the other locations. The concentration of NH_4-N was 7.8-9.0 μM; the concentration at Jangsuri was somewhat lower than those at the other locations. The concentration of PO_4-P was 3.0-3.6 μM. The amount of $Si(OH)_4$-Si was 22.2-30.2 μM; the amount at Wonpori from April to August was somewhat lower than those at the other locations.

Figure 4 shows the comparisons of shoot height, total shoot weight, leaf width, leaf number and branch number of *Z. marina* among the three sites from December 1999 to November 2000. The shoot height of *Z. marina* at Anpori ranged from 45.4 to 106.8 cm (mean 80.6 ± 25.3 cm) ; that at Jangsuri was 55.7-124.1 cm (mean 90.0 ± 27.9 cm); and that at Wonpori was 63.4-142.1 cm

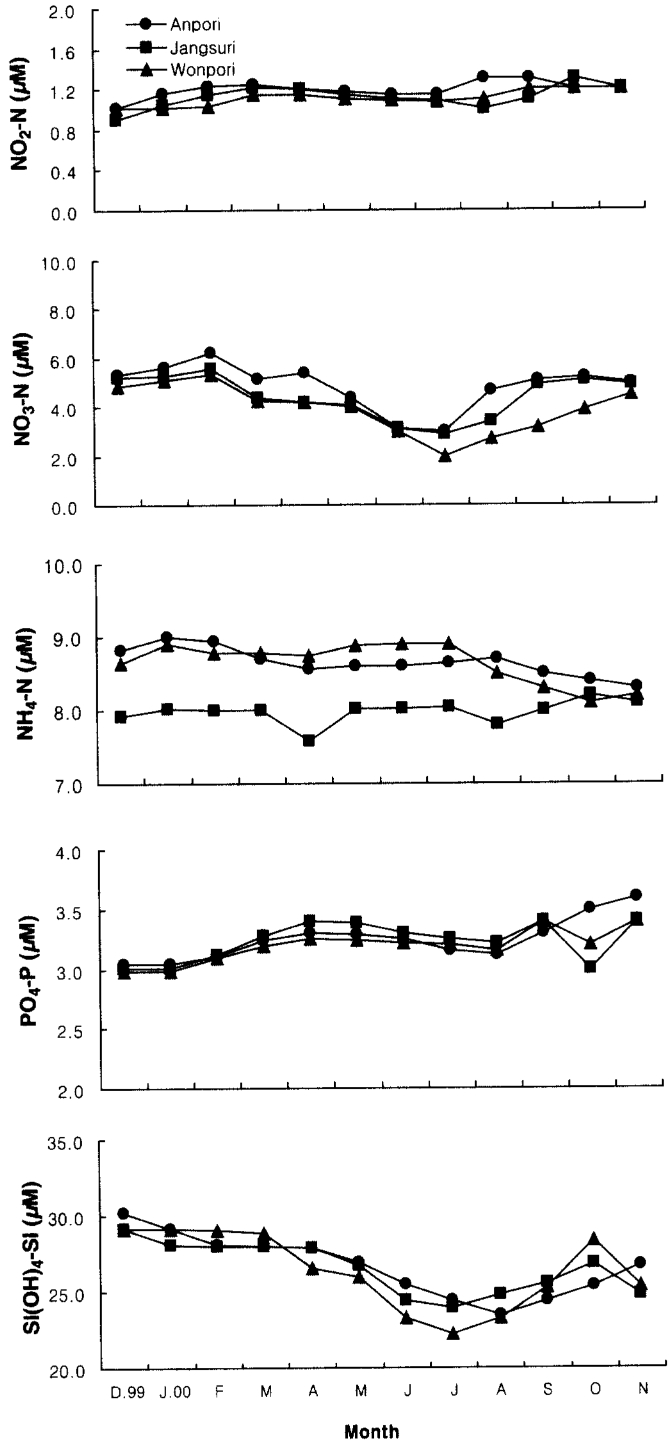

Fig. 3. Monthly variations of NO_2-N, NO_3-N, NH_4-N, PO_4-P, $Si(OH)_4$-Si at three sites from December 1999 to November 2000.

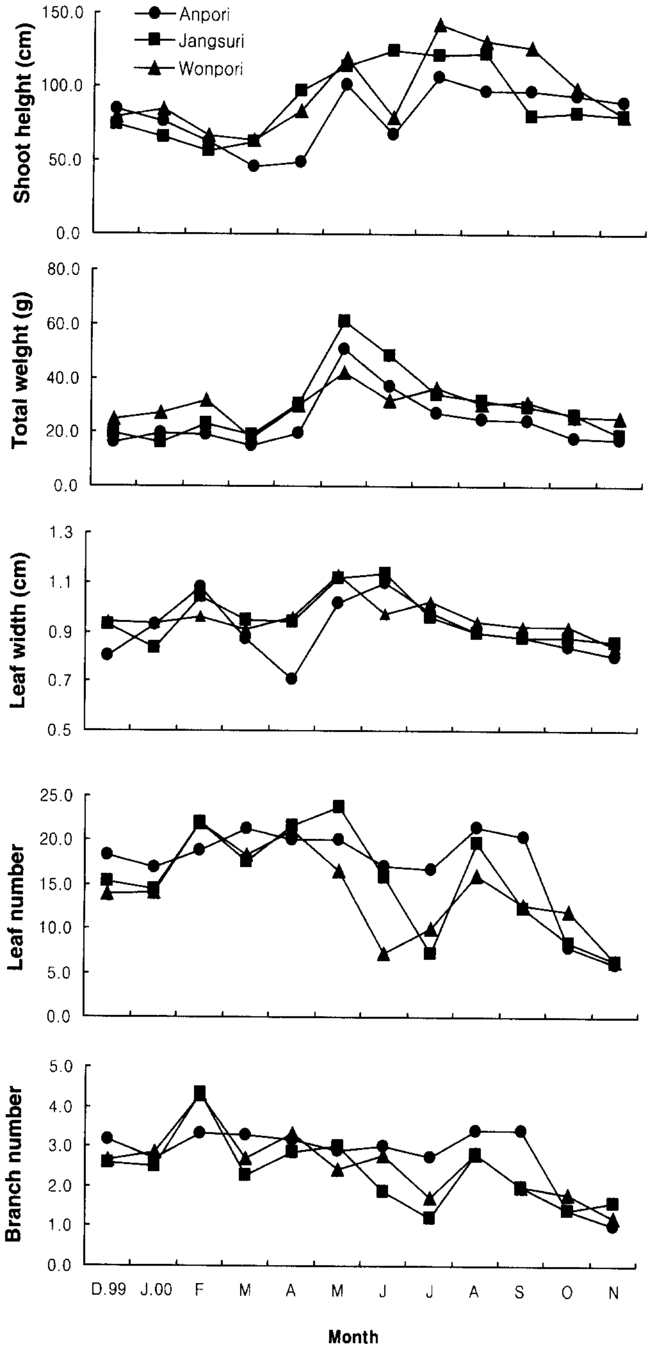

Fig. 4. Comparisons of shoot height, total shoot weight, leaf width, leaf number and branch number of *Z. marina* at three sites from December 1999 to November 2000.

(mean 95.3 ± 28.3 cm). In February, the shoot height at Jangsuri and Wonpori showed the minimum, and in March that at Anpori showed the minimum. Generally, the Anpori population showed the shortest shoot height. The total shoot weight of the Anpori, Jangsuri and Wonpori populations was 15.2-22.0 g (24.5 ± 17.1 g), 16.0-60.8 g (31.0 ± 19.0 g) and 17.9-42.2 g (29.7 ± 17.0 g); the total shoot weight of the three populations showed the minimum in March. The weight of the Anpori population was the lowest. The leaf width of the Anpori, Jangsuri and Wonpori populations was 0.5-1.1 mm (0.9 ± 0.2 mm), 0.8-1.1 mm (1.0 ± 0.2 mm) and 0.9-1.1 mm (1.0 ± 0.2 mm). Generally, the Anpori population was narrow in leaf width. The leaf number of the Anpori, Jangsuri and Wonpori populations was 6-21 (16.5 ± 8.1), 6-22 (16.1 ± 8.9) and 6-13 (15.4 ± 8.5). The total leaf number of the three populations was the minimum in June. In general, the Wonpori population showed smallest leaf number. The branch number of the Anpori, Jangsuri and Wonpori populations was 1-3 (2.6 ± 1.1), 1-4 (2.4 ± 1.2) and 2-4 (2.6 ± 1.6). The total branch number of the three populations was the minimum in November. The mean branch number was the smallest in the Jangsuri population among the three populations.

Table 1. Basic statistical data

Characters	Mean	SD
Shoot height	89.04	24.48
Leaf width	0.93	0.09
Leaf no.	15.36	5.73
Branch no.	2.57	0.81
Total weight	27.81	10.38
Temperature	17.08	5.01
Salinity	32.67	1.44
pH	8.28	0.9
NH_4-N	8.39	0.39
$Si(OH)_4$-Si	26.52	2.08
NO_3-N	4.39	1.00
PO_4-P	3.23	0.16
NO_2-N	1.13	0.14
Site	2.0	0.83

Table 1 shows basis statistical data, including the arithmetic mean and standard deviation, related to the environmental and growth data (Figs 2, 3 and 4)

Table 2 shows a pairwise simple correlation matrix among 14 variables. In a positive simple correlation matrix, the correlation coefficients between shoot height and water temperature, between shoot height and total shoot weight, between leaf width and total shoot weight, between leaf number and branch number, and between $Si(OH)_4$-Si and NO_3-N ranged from 0.595 to 0.862. In the negative correlation matrix, the correlation coefficients between shoot height and NO_3-N, between shoot height and $Si(OH)_4$-Si, between total shoot weight and NO_3-N, between water temperature and $Si(OH)_4$-Si, between water temperature and salinity, and between water temperature and NO_3-N ranged from -0.536 to -0.775. The correlation values demonstrate how most variables

Table 2. Correlation matrix among 14 variables

	Shoot height	Leaf width	Leaf no.	Branch no.	Total weight	Temperature	Salinity	pH	NH_4-N	$Si(OH)_4$-Si	NO_3-N	PO_4-P	NO_2-N	Site
Shoot Height	1.000													
Leaf width	0.325	1.000												
Leaf no.	-0.193	0.249	1.000											
Branch no.	-0.379	0.212	0.862	1.000										
Total weight	0.595	0.692	0.190	0.011	1.000									
Temperature	0.726	0.187	-0.198	-0.260	0.376	1.000								
Salinity	-0.466	0.113	0.183	0.170	-0.045	-0.685	1.000							
pH	0.202	-0.248	-0.257	-0.244	-0.286	0.330	-0.172	1.000						
NH_4-N	-0.105	0.164	0.120	0.293	-0.072	-0.168	0.046	-0.065	1.000					
Si(OH)4-Si	-0.637	-0.262	0.333	0.333	-0.370	-0.775	0.385	-0.204	-0.018	1.000				
NO_3-N	-0.716	-0.419	0.201	0.293	-0.536	-0.685	0.244	-0.148	0.036	0.693	1.000			
PO_4-P	0.247	-0.028	-0.253	-0.434	0.231	0.200	0.012	-0.038	-0.243	-0.420	-0.260	1.000		
NO_2-N	-0.003	0.010	0.014	-0.080	0.062	0.070	-0.071	-0.119	0.165	-0.257	0.002	0.408	1.000	
Site	0.258	0.179	-0.225	-0.127	0.218	0.151	-0.074	-0.144	-0.078	-0.060	-0.383	-0.110	-0.248	1.000

predominantly vary in the same direction, as shown, for example, by the high positive values between branch number and leaf number, and the water temperature and the shoot height. The negative value between the amount of NO_3-N and the shoot height illustrates how some variables vary in the opposite direction. In addition, some variables vary independently of one another, as shown by the values close to zero seen between the amount of NO_2-N and the shoot height, and the amount of NO_2-N and NO_3-N.

Table 3 shows the eigenvalues and loading factors according to the PCA. The eigenvalue of the first principal component was 4.406; the first principal component explains 31.5% of the total sample variance; the first four principal components, collectively, explain 71.1% of the total sample variance. Consequently, the sample variation is summarized very well by the four principal components, and a reduction in the data from 36 observations on 14 variables to 36 observations on 4 principal components is reasonable. Component 1 was defined by shoot height (+ve), water temperature (+ve), $Si(OH)_4$-Si (-ve) and NO_3-N (-ve). Component 2 was defined by the leaf width (+ve), leaf number (+ve), branch number (+ve) and total shoot weight (+ve), and was characterized by the positive values of morphological traits. NO_2-N (+ve) correlated with component 3, as did PO_4-P (+ve) slightly less. Salinity (+ve) and site (+ve) correlated with component 4. The foregoing variables, however, had moderate correlations (0.4 to 0.6).

Table 3. Eigenvalue and loading factor by the principal components analysis

Characters	Component			
	1	2	3	4
Shoot height	0.414	0.090	-0.101	-0.036
Leaf width	0.152	0.496	0.029	0.115
Leaf no.	-0.196	0.445	0.033	-0.278
Branch no.	-0.250	0.417	-0.085	-0.324
Total weight	0.263	0.427	0.101	0.190
Temperature	0.412	-0.001	-0.120	-0.291
Salinity	-0.245	0.114	0.187	0.415
pH	0.109	-0.315	-0.228	-0.334
NH4-N	-0.082	0.177	0.060	-0.321
$Si(OH)_4$-Si	-0.402	0.000	-0.152	0.173
NO_3-N	-0.400	-0.145	0.086	-0.064
PO_4-P	0.204	-0.133	0.545	0.200
NO_2-N	0.060	-0.012	0.625	-0.205
Site	0.140	0.101	-0.385	0.423
Eigenvalues	4.406	2.465	1.619	1.468
Percentage	31.470	17.606	11.561	10.483
Cum. Percentage	31.470	49.076	60.637	71.120

Figure 5 shows the plots of the scores for the morphological and habitat characteristics of *Zostera marina* in Gamak Bay, Yeosu. Water temperature and three morphological traits including shoot height, total shoot weight and leaf width are located in the first quadrant (the right upper space of the coordinate plane), mainly including four months (May, June, July and August) and three sites. Salinity and NH_4-N and two morphological traits (leaf and branch number) are situated in the second quadrant mainly including three months (February, March and April) and three sites. $Si(OH)_4$-Si and NO_3-N are located in the third quadrant mainly including January and December and three sites.

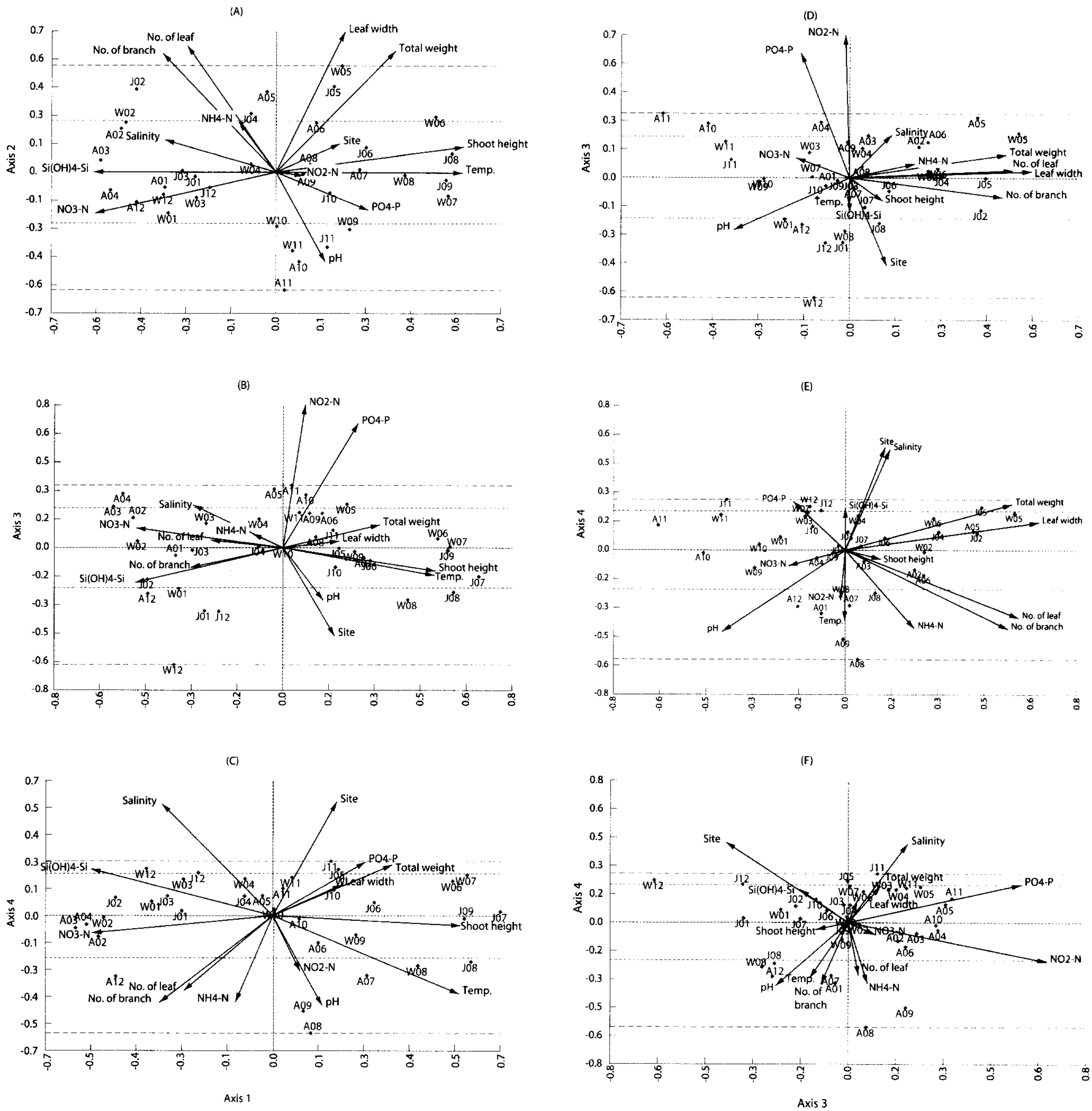

Fig. 5. Plots of scores for morphological and habitat characteristics of *Zostera marina* on the principal components axes. A; Plot of scores on the axis 1 and 2: B; Plot of scores on the axis 1 and 3: C; Plot of scores on the axis 1 and 4: D; Plot of scores on the axis 2 and 3: E; Plot of scores on the axis 2 and 4: F; Plot of scores on the axis 3 and 4.

pH, PO_4-P and NO_2-N are situated in the fourth quadrant mainly including September, October and November, and three sites. Two groups can be identified along axis 1: the warm season (from May to November) and the cold season (from December to April). Also, two groups can be identified along axis 2: morphological trait-relevant and morphological trait–free, according to seasons. For axis 1, shoot height and water temperature tended to correlate with the population of Jansuri, followed by the Wonpori population, and also $Si(OH)_4$-Si and NO_3-N tended to correlate strongly with the Anpori population. For axis 2, total weight, leaf width, leaf number and branch number showed a tendency to correlate with the Anpori and Jangsuri populations. The tendency differed according to season (Fig. 5A).

Shoot height and water temperature indicated the highest positive correlations because of very nearly parallel vectors in the same direction. This biplot can be divided into two groups along axis 1 according to season. One group included NO_2-N, PO_4-P, water temperature, pH, shoot height, total weight and leaf width, and the other group included salinity, NO_3-N, $Si(OH)_4$-Si, NH_4-N, leaf number and branch number. For axis 3, the Anpori population tended to be influenced by NO_2-N and PO_4-P (Fig. 5B). In the biplot for axis 1 and axis 4, the correlations between total shoot weight and leaf weight, and between leaf number and branch number were very strongly negative because of their opposite direction vectors. For axis 4, the Wonpori and Jangsuri populations tended to be affected by salinity (Fig. 5C). Figures 5D and E show that two groups can be identified along axis 2; morphological trait-relevant and morphological trait-free, regardless of season. Figure 5F shows that Anpori groups were dominant for axis 3. Also, they could be classifed according to the Anpori-included and Anpori-excluded groups for axis 4. These tendencies have been highly affected by seasons.

In a typical community study, the first three eigenvalues may account for 40 to 90% of the total variance. In some cases, however, particularly with large and noisy data sets, the first two PCA axes may account for as little as 5% of the total variance and yet be quite informative ecologically. However, in other cases, 90% of the variance may be accounted for, yet the result may be ecologically meaningless or severely distorted. In the end, the assessment of PCA results must be conducted on the basis of ecological utility; a mere percentage of variance accounted for has not been found to be a reliable indicator of the quality of results (Gauch 1982).

Detailed studies on the distribution and habitat characteristics of *Z. marina* in Korea were reported by Lee *et al.* (2000a, 2001, 2002) and Lee (2001). Especially, Lee *et al.* (2001) described the habitat type, estimated area, bed type, water depth, sediment characteristics and some morphological characteristics of the *Z. marina* populations of Wonpori, Sepori, Hangdaeri and Yulrimri in Gamak Bay, Yeosu, Jeollanamdo. However, plants and sediment samples were collected during June and August 2000 from Busan, Gyeongsangnamdo to Jindo, Jeollanamdo along the southern coast of Korea; moreover, the concentration of inorganic nutrients was not measured. Therefore, the result of Lee *et al.* (2001) cannot be directly compared to that of this study.

The distribution of seagrass meadows is considered to be limited by environmental factors such as light availability (Dennison and Alberte 1982, 1985, 1986; Duarte 1991; Zimmerman *et al.* 1991; Izumi 1996), nutrient availability (Kenworthy and Fonseca 1992; Murray *et al.* 1992; Pérez *et al.* 1994), temperature (Pérez and Romero 1992), or sediment turbulence and water transparency (Kawasaki *et al.* 1988; Izumi 1996), and other factors. A computer model of the growth of *Z. marina* suggested that irradiance and temperature are the principal environmental factors controlling seagrass growth (Wetzel and Neckles 1986).

Eelgrasses are one of the key coastal ecosystem-supporting factors. The ecological and economic roles of eelgrasses are useful in the development of marine-ranch systems. Due to the dense beds they form, covering large areas in shallow coastal waters, eelgrasses perform various biological and physical functions in the marine environment. These functions include the stabilization of substrata; sediment production; the supply of a habitat, nursery-ground and primary food source for fish and many other invertebrates among others. Therefore, deeper and continuous study is needed to manage the populations and habitats of eelgrasses before they fall into the "extinction vortex" in Gamak Bay.

REFERENCES

APHA, AWWA, WEF. 1995. 4500-Si E. Heteropoly blue method. In: Eaton A.D., Clesceri L.S. and Greenberg A.E. (eds), *Standard methods for the examination of water and waste water 19th ed.* APHA, Washington. pp.4-12-4-121.

Bendschneider K. and Robinson R.J. 1952. A new spectrophotometric method for the determination of nitrite in sea water. *J. Mar. Res.* **11:** 87-96.

Boysen-Jensen P. 1914. Studies concerning the organic matter of the sea bottom. *Rep. Dan. Biol. Stn.* **22:** 1-39.

Choi H.-K. 1984. *A monograph of vascular hydrophytes in Korea.* PhD Thesis, Seoul Nat. Univ., Seoul. 272 pp.

Choi T.O. and Boo S.M. 1998. Marine flora of Oeyondo Islands on the Yellow Sea, Korea: I. Green algae and seagrasses. *Algae* **13:** 1-11.

Chung T.H. 1957. *Korean Flora : Part II. Herbaceous Plants.* Sinjisa, Seoul. 1025 pp.

Dennison W.C. and Alberte R.S. 1982. Photosynthetic responses of *Zostera marina* L. (eelgrass) to *in situ* manipulations of light intensity. *Oecologia.* **55:** 137-144.

Dennison W.C. and Alberte R.S. 1985 Role of daily light period in the depth distribution of *Zostera marina* (eelgrass). *Mar. Ecol. Prog. Ser.* **25:** 51-61.

Dennison W.C. and Alberte R.S. 1986. Photoadaptation and growth of *Zostera marina* L. (eelgrass) transplants along a depth gradient. *J. exp. mar. Biol. Ecol.* **98:** 265-282.

Digby P.G.N. and Kempton R.A. 1987. *Multivariate analysis of ecological communities.* Chapman and Hall, London. 206 pp.

Duarte C.M. 1991. Seagrass depth limits. *Aquat. Bot.* **40:** 363-378.

Fortes M.D. 1998. Seagrasses : Their role in marine ranching. In:

Ohno M. and Critchley A.T. (eds), *Seaweed cultivation and* marine ranching. JICA Yokosuka, Japan. pp. 131-151.

Gauch H.G. Jr. 1982. *Multivariate analysis in community ecology.* Cambridge University Press. 298 pp.

Gilpin M.E. and Soulé M.E. 1986. Minimum variable populations: Processes of species extinction. In: Soulé M.E. (ed.), *Conservation biology: The science of scarcity and diversity.* Sinauer Associaties, Sunderland, MA. pp. 19-34.

Go Y.B. and Cho S.H. 1997 Study on the fish community in the seagrass belt around Cheju Island. I. Species composition and seasonal variations of fish community. *Korean J. Ichthyol.* **9**: 48-60 (in Korean with English abstract).

Huh S.H. 1986. Species composition and seasonal variations in abundance of fishes in eelgrass meadows. *Bull. Korean Fish. Soc.* **19:** 507-519 (in Korean with English abstract).

Huh S.H. and An Y.R. 1997. Seasonal variation of Shrimp (Crustacea: Decapoda) community in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *J. Korean Fish. Soc.* **30:** 532-542 (in Korean with English abstract).

Huh S.H. and An Y.R. 1998. Seasonal variation of crab (Crustacea: Decapoda) community in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *J. Korean Fish. Soc.* **31:** 535-544 (in Korean with English abstract)

Huh S.H. and Kwak S.N. 1997a. Feeding habits of *Pholis nebulosa. Korean J. Ichthyol.* **9:** 22-29 (in Korean with English abstract)

Huh S.H. and Kwak S.N. 1997b. Feeding habits of Syngnathus schlegeli in eelgrass (*Zostera marina*) bed in Kwangyang Bay. *J. Korean Fish. Soc.* **30:** 896-902 (in Korean with English abstract).

Huh S.H. and Kwak S.N. 1997c. Species composition and seasonal variations of fishes in eelgrass (*Zostera marina*) bed in Kwangyang Bay. *Korean J. Ichthyol.* **9:** 202-220 (in Korean withe English abstract)

Huh S.H. and Kwak S.N. 1997d. Feeding habits of Leiognathus nuchalis in eelgrass (*Zostera marina*) bed in Kwangyang Bay. *Korean J. Ichthyol.* **9:** 221-227 (in Korean withe English abstract).

Huh S.H. and Kwak S.N. 1998a. Feeding habits of *Pseudoblennius cottoides. J. Korean Fish. Soc.* **31:** 37-44 (in Korean with English abstract).

Huh S.H. and Kwak S.N. 1998b. Feeding habits of *Sebastes inermis* in the eelgrass (*Zostera marina*)bed in Kwangyang Bay. *J. Korean Fish. Soc.* **31:** 168-175 (in Korean with English abstract).

Huh S.H. and Kwak S.N. 1998c. Feeding habits of *Favonigobius gymnauchen* in the eelgrass (*Zostera marina*) bet in Kwangyang Bay. *J. Korean Fish. Soc.* **31:** 372-379 (in Korean with English abstract).

Huh S.H. and Kwak S.N. 1998d. Feeding habits of Conger myriaster in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *J. Korean Fish Soc.* **31:** 665-672 (in Korean with English abstract).

Huh S. H. and Kwak S. N. 1998e. Jeeding habits of juvenile *Takifugu niphobles* in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *J. Korean Fish. Soc.* **31:** 806-812 (in Korean withe English abstract).

Huh S.H. and Kwak S.N. 1998f. Feeding habits of *Acentrogobins pflaumii* in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *Kordan J. Ichthyol.* **10:** 24-31 (in Korean with English abstract).

Huh S.H. and Kwak S.N. 1998g. Feeding habits of *Lateolabrax japonicus* in the eelgrass (*Zostera marina*) bed in Kwangyang Bay. *Bull. Korean Soc. Fish. Tech.* **34:** 191-199 (in Korean with English abstract).

Huh S.H., Kwak S.N. and Nam K.W. 1998. Seasonal variations of eel grass, *Zostera marina* and epiphytic algae in *Zostera marina* bed in Kwangyang Bay. *J. Korean Fish. Soc.* **31:** 56-62 (in Korean with English abstract).

Iizumi H. 1996. Temporal and spatial variability of leaf production of *Zostera marina* L. at Otsuchi, northern Japan. In: Kuo J., Phillips R.C., Walker D.I. and Kirkman H. (eds), *Seagrass biology: Proceedings of an international workshop.* pp. 143-148.

Kawasaki Y., Yamada S. and Honda M. 1988. *Method for eelgrass (*Zostera marina *L.) bed creation by Seeding.* Abiko Res. Lab. Rep. No. 88030. Central Research Institute of Electric Power Industry, Tokyo. 21 pp.

Kenworthy W.J. and Fonseca M.S. 1992. The use of fertilizer to enhance growth of transplanted seagrasses *Zostera marina* L. and *Halodule wrightii* Aschers. *J. Exp. Mar. Biol. Ecol.* **163:** 141-161.

Kong Y.S. 1981. The ecological study of eelgrass, *Zostera marina* L. in Hansilpo, Chungmu. *Bull. Tong-yeong Fish. Jr. Coll.* **16:** 1-8 (in Korean with English abstract).

Kong Y.S. 1982. Development of spike and seed of *Zostera marina* L. *Bull. Tong-yeong Fish. Jr. Coll.* **17:** 37-42 (in Korean with English abstract).

Kong Y.S. 1984. On the growth pattern of *Zostera* nana. *Bull. Tong yeong Fish. Jr. Coll.* **19:** 13-15 (in Korean with English abstract).

Lee K.S. and Lee S.Y. 2001. Status and restoration of seagrass habitat on the south coast of the Korean peninsula. *Nature Conservation* **116:** 15-20 (in Korean).

Lee S.Y. 2001. *A Study on the ecological and taxonomical characteristics of Zostera (Zosteraceae) in Korea.* Ph. D. Thesis. Hanyang Univ., Seoul. 167 pp. (in Korean withe English abstract).

Lee S.Y., Lee S.M., Jee H.G. and Choi C.I. 2001. The distribution and habitation characteristics of *Zostera marina* L. along the southern coast of Korea. *Korean J. Environ. Biol.* **19:** 313-320 (in Korean with English abstract).

Lee S.Y., Kwon C.J. and Choi C.I. 2000a. Distribution of *Zostera* (Zosteraceae) and habitat characteristics in the eastern coastal waters of Korea. *J. Korean Fish. Soc.* **33:** 501-507 (in Korean with English abstract).

Lee S.Y., Kwon C.J. and Choi C.I. 2000b. Sediment characteristics from the beds of *Zostera marina* and *Z. asiatica. J. Nat. Sci. & Technol. Hanyang Univ.* **2:** 25-29.

Lee S.Y., Kwon C.J., Heo S. and Choi C.I. 2000c. Seagrass (*Zostera marina* L., Zosteraceae) bed in the brackish lake Hwahinpo, Korea. *Korean J. Limnol.* **33:** 336-341.

Lee S.Y., Kwon C.J., Heo S. and Choi C.I. 2000d. The habitat characteristics and distribution of seagrass, *Zostera marina* L. (Zosteraceae) in the Hwajinpo Lake, Korea. *Proceedings of international symposium on the river and lake environments. 10th ISRLE, Busan Meeting.* pp. 71-74.

Lee S.Y., Kwon C.J., Kim T.J., Suh Y. and Choi C.I. 1999. Morphological examination of *Zostera asiatica Miki* (Zosteraceae) from various habitats. *Korean J. Environ. Biol.* **17:** 503-512.

Lee S.Y., Kwon C.J., Lee K.S. and Choi C.I. 2002. Distribution of eelgrass, *Zostera marina* L. on coasts of the Korean Peninsula: preliminary study for eelgrass restoration. *Ocean Polar Res.* **24:** 55-61.

Lee S.Y., Lee S.M., Jee H.G. and Choi C.I. 2001. The distribution and habitation characteristics of *Zostera marina* L. along the southern coast of Korea. *Korean J. Environ. Biol.* **19:** 313-320 (in Korean with English abstract).

Lee T.B. 1979. *Illustrated Flora of Korea.* Hyangmunsa, Seoul. 990 pp.

Miki S. 1932. On the sea-grasses new to Japan. *Bot. Mag. Tokyo* **46:** 774-788.

Miki S. 1933. On the sea-grasses in Japan (I), *Zostera* and *Phyllospadix,* with reference to morphological characters. *Bot. Mag. Tokyo* **47:** 842-862.

Murphy J. and Riley J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **27:** 31-36.

Murray L., Dennison W.C. and Kemp W.M. 1992. Nitrogen versus phosphorus limitation for growth of an estuarine populations of eelgrass (*Zostera marina* L.). *Aquat. Bot.* **44:** 83-100.

Nakai T. 1911. Flora Koreana II. *J. Coll. Sci. Imp. Univ. Tokyo* **26:** 1-573.

Palmer M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. *Ecology* **74:** 2215-2230.

Petersen C. G. and Boysen-Jensen P. 1911. Valuation of the sea. I. Animal life of the sea bottom, its food and quantity. *Rep. Dan. Biol. Stn.* **20:** 3-81.

P rez M. and Romero J. 1992. Photosynthesis response to light and temperature of the seagrass *Cymodocea nodosa* and the prediction of its seasonality. *Aquat. Bot.* **43:** 51-62.

Pérez M., Duarte C. M., Tomero J., Sand-Jensen K. and Alcoverro T. 1994. Growth plasticity in *Cymodocea nodosa* stands: the importance of nutrient supply. *Aquat. Bot.* **47:** 249-264.

Quinn G. P. and Keough M. J. 2002. *Experimental design and data analysis for biologists.* Cambridge University Press, Cambridge. 537 pp.

Shin H. 1998. Taxonomy and distribution of seagrasses, with special emphasis of family Zosteraceal in Korea. *Kor. J. Plant Tax.* **28:** 99-109.

Shin H. and Choi H. K. 1998. Taxonomy and distribution of *Zostera* (Zosteraceae) in eastern Asia, with special reference to Korea. *Aquat. Bot.* **60:** 49-66.

Shin H., Cho K. H. and Oh Y. S. 2002. *Zostera* geojeensis, a new species of seagrass from Korea. *Algae* **17:** 71-74.

Solórzano L. 1969. Determination of ammonia in natural waters by phenolhypochlorite method. *Limnol. Oceanogr.* **14:** 799-801.

Stuart M.D., Hurd C.L. and Brown M.T. 1999. Effects of seasonal growth rate on morphological variation of *Undaria pinnatifida* (Alariaceae, Phaeophyceae). *Hydrobiologia* **398/399:** 191-199.

Wetzel R.L. and Neckles H. 1986. A model of *Zostera marina* L. photosynthesis and growth : simulated effects of selected physical-chemical variables and biological interactions. *Aquat. Bot.* **26:** 307-323.

Wood E.D., Armstrong F.A.J. and Richards F.A. 1967. Determination of nitrate. *J. Mar. Bio. Ass. UK.* 47: 23-31.

Yun S.G., Huh S.H. and Kwak S.N. 1997. Species composition and seasonal variations of benthic macrofauna in eelgrass, *Zostera marina,* bed. *J. Korean Fish. Soc.* **30:** 744-752 (in Korean with English abstract).

Zimmerman R.C., Reguzzoni J.L., Wyllie-Echeverria S., Josselyn M. and Alberte R.S. 1991. Assessment of environmental suitability for growth of *Zostera marina* L. (eelgrass) in San Francisco Bay. *Aquat. Bot.* **39:** 353-366.

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