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

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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 meiograss 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 NO₂⁻, NO₃⁻, NH₄⁺, PO₄³⁻ 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 NO₂⁻ at Wonpori from June to November was somewhat lower than that at the other locations; that of NH₄⁺ at Jangsuri 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 NO₂⁻ were 0.726, 0.692, 0.862, and 0.693, respectively. The coefficients between shoot height and NO₂⁻, total shoot weight and NO₂⁻, water temperature and Si(OH)₄-Si, water temperature and salinity, and water temperature and NO₂⁻ 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 Jangsuri, followed by the Wonpori population, and Si(OH)₄-Si and NO₂⁻ 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 NO₂⁻ and PO₄³⁻. 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 meiograss (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).

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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 meiograsses 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 meiograss populations provide a substantial amount of organic material via the food web, and also provide the habitats or shelters for a wide

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 Gyeongginsangnamdo (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 ml bottles in midlayer water depth and these waters were used for determining the contents of nitrite-nitrogen (NO₂⁻-N) by the N-(1-Naphthyl)-ethylenedimine dihydrochloride method (Bendschneider and Robinson 1952), nitrate-nitrogen (NO₃⁻-N) by cadmium-copper reduction (Wood et al. 1967), ammonium-nitrogen (NH₄⁻-N) by phenol-hypochlorite (Solórzano 1969), and phosphate-phosphorus (PO₄⁻-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
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 NO₂⁻N, NO₃⁻N, NH₄⁺-N, PO₄⁻P and Si(OH)₄-Si at the three sites from December 1999 to November 2000. The value of NO₂⁻N was 0.9-1.3 μM. The amount of NO₃⁻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 NH₄⁺-N was 7.8-9.0 μM; the concentration at Jangsuri was somewhat lower than those at the other locations. The concentration of PO₄⁻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
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 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

<table>
<thead>
<tr>
<th></th>
<th>Shoot height</th>
<th>Leaf width</th>
<th>Leaf no.</th>
<th>Branch no.</th>
<th>Total weight</th>
<th>Temperature</th>
<th>Salinity</th>
<th>pH</th>
<th>NH₄-N</th>
<th>Si(OH)₄-Si</th>
<th>NO₃-N</th>
<th>PO₄-P</th>
<th>NO₂-N</th>
<th>Site</th>
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</tr>
<tr>
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<td>1.000</td>
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</tr>
<tr>
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<td>0.249</td>
<td>1.000</td>
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<tr>
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<td>0.212</td>
<td>0.862</td>
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<tr>
<td>Total weight</td>
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<td>0.692</td>
<td>0.190</td>
<td>0.011</td>
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<tr>
<td>Temperature</td>
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<td>Salinity</td>
<td>-0.466</td>
<td>0.113</td>
<td>0.183</td>
<td>0.170</td>
<td>-0.045</td>
<td>-0.685</td>
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<tr>
<td>pH</td>
<td>0.202</td>
<td>-0.248</td>
<td>-0.257</td>
<td>-0.244</td>
<td>-0.286</td>
<td>0.330</td>
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<td>NH₄-N</td>
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<td>0.120</td>
<td>0.293</td>
<td>-0.072</td>
<td>-0.168</td>
<td>0.046</td>
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<tr>
<td>Si(OH)₄-Si</td>
<td>-0.637</td>
<td>-0.262</td>
<td>0.333</td>
<td>0.333</td>
<td>-0.370</td>
<td>-0.775</td>
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<td>NO₃-N</td>
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<td>-0.419</td>
<td>0.201</td>
<td>0.293</td>
<td>-0.536</td>
<td>-0.685</td>
<td>0.244</td>
<td>-0.148</td>
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<td>PO₄-P</td>
<td>0.247</td>
<td>-0.028</td>
<td>-0.253</td>
<td>-0.434</td>
<td>0.231</td>
<td>0.200</td>
<td>0.012</td>
<td>-0.038</td>
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<td>0.260</td>
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<td>NO₂-N</td>
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<td>0.014</td>
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<td>0.062</td>
<td>0.070</td>
<td>-0.071</td>
<td>-0.119</td>
<td>0.165</td>
<td>-0.257</td>
<td>0.002</td>
<td>0.408</td>
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<td>Site</td>
<td>0.258</td>
<td>0.179</td>
<td>-0.225</td>
<td>-0.127</td>
<td>0.218</td>
<td>0.151</td>
<td>-0.074</td>
<td>-0.144</td>
<td>-0.078</td>
<td>-0.060</td>
<td>-0.383</td>
<td>-0.110</td>
<td>-0.248</td>
<td>1.000</td>
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</table>

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

<table>
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<th>Characters</th>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 3</th>
<th>Component 4</th>
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<td>Shoot height</td>
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<td>0.090</td>
<td>-0.101</td>
<td>-0.036</td>
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<td>Leaf width</td>
<td>0.152</td>
<td>0.496</td>
<td>0.029</td>
<td>0.115</td>
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<tr>
<td>Leaf no.</td>
<td>-0.196</td>
<td>0.445</td>
<td>0.033</td>
<td>-0.278</td>
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<td>Branch no.</td>
<td>-0.250</td>
<td>0.417</td>
<td>-0.085</td>
<td>-0.324</td>
</tr>
<tr>
<td>Total weight</td>
<td>0.263</td>
<td>0.427</td>
<td>0.101</td>
<td>0.190</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.412</td>
<td>-0.001</td>
<td>-0.120</td>
<td>-0.291</td>
</tr>
<tr>
<td>Salinity</td>
<td>-0.245</td>
<td>0.114</td>
<td>0.187</td>
<td>0.415</td>
</tr>
<tr>
<td>pH</td>
<td>0.109</td>
<td>-0.315</td>
<td>-0.228</td>
<td>-0.334</td>
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<tr>
<td>NH₄-N</td>
<td>-0.082</td>
<td>0.177</td>
<td>0.060</td>
<td>-0.321</td>
</tr>
<tr>
<td>Si(OH)₄-Si</td>
<td>-0.402</td>
<td>0.000</td>
<td>-0.152</td>
<td>0.173</td>
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<td>NO₃-N</td>
<td>-0.400</td>
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<td>-0.064</td>
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<td>PO₄-P</td>
<td>0.204</td>
<td>-0.133</td>
<td>0.545</td>
<td>0.200</td>
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<td>NO₂-N</td>
<td>0.060</td>
<td>-0.012</td>
<td>0.625</td>
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<td>Site</td>
<td>0.140</td>
<td>0.101</td>
<td>-0.385</td>
<td>0.423</td>
</tr>
</tbody>
</table>

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 NO₃-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. NO₂-N (+ve) correlated with component 3, as did PO₄-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).

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 NH₄-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 NO₃-N are located in the third quadrant mainly including January and December and three sites.
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 Jangfsuri 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 classified 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 Yulirmi 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.

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