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Coastal Plant and Soil Relationships along the Southwestern Coast of South Korea

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We studied how plant species distribution was regulated by the relationships between vegetation and soil factors on the southwestern coast of South Korea. Vegetation was classified using two-way indicator species analysis (TWINSPAN), thereby producing four vegetation groups that were linked to three habitat types. Two ordination techniques -- detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) -- were applied to examine the relationships between vegetation and 12 edaphic factors, including soil pH, water and osmotic potentials, moisture content, electrical conductivity, Cl^- and Na^+ contents, total Kjeldahl nitrogen, and contents of organic matter, sand, silt, and clay. Results were similar for both types of evaluations. According to DCA and CCA, the 23 communities tended to cluster into three types: salt swamp, salt marsh, and sand dune. The first two canonical axes accounted for 14.9% of the community–soil factor relationship among communities. As identified via CCA, the main gradients were soil–water relations and soil texture.

Keywords: CCA, coastal vegetation, DCA, soil factor, TWINSPAN

Because of their transitional situation between sea and terrestrial ecosystems, the southwestern coastal wetlands of South Korea include various habitats, such as salt marshes, salt swamps, and sand dunes. Their vegetation has been studied comprehensively by Kim (1971, 1975), Kim et al. (1982), Kim and Ihm (1988), Jung and Kim (1998), and Ihm et al. (2001a). All of these reports have described hierarchical syntaxonomic classifications for halophyte vegetation and halophyte–soil relationships. Furthermore, Min and Kim (1999a, b, 2000) have investigated coastal vegetation dynamics and succession on reclaimed lands while Ihm and Lee (1998) and Ihm et al. (2006) have examined the soil factors affecting those coastal plant communities. Kim (2005) has studied invasive plants on disturbed sand dunes, and Ihm (1989) has determined the ecophysiological characteristics of halophytic species.

Spatial boundaries for plant species on coastal wetlands appear to follow environmental gradients (Armstrong et al., 1985). In controlling the distribution and abundance of plants within and across habitat types, soil factors, sea levels, and saline water tables are believed to play major roles (Ustin et al., 1982; Brewer and Grace, 1990; Glenn et al., 1991; Ihm and Lee, 1998). Similar results have been reported by Kim and Ihm (1988), Ihm (1989), and Min and Kim (1999a, b). The objectives of the current study were to 1) investigate the plant communities within the southwestern coastal wetlands of South Korea, and 2) assess the relationships between these vegetation and the edaphic factors that are presumed to regulate species distribution.

MATERIALS AND METHODS

Study Areas

This research was conducted at sites along the southwestern coast of South Korea (32 to 36° N and 125 to 128° E), with all locales being within Cheollabuk-do and Cheollanam-do Provinces. Tables 1 and 2 provide a summary of conditions for three distinct habitat types -- salt marsh, salt swamp, and sand dune -- as described by their hydrology, soil texture, etc., (Ihm and Lee, 1998; Ihm et al., 2001a, b, 2006). This region is one of the temperate areas of East Asia. Between 1971 and 2000, the mean annual precipitation and temperatures at Kunsan and Mokpo were 1201 mm/12.6°C and 1125 mm/13.8°C, respectively (KMA, 2007).

Data Collection

To describe the halophyte vegetation, 485 phyto–sociological relevés were taken from September 1989 to August 2001, using the Braun–Blanquet (1964) method. We followed the botanical nomenclature published in *Coloured Flora of Korea* (Lee, 2003). To examine particular rooting environments, we removed soil from a depth of 10 cm. Air-dried samples were then used for physico-chemical analyses. Water potential and osmotic potential of these soils were measured by the method of Ihm (1989). Soil texture was characterized via Köhn's apparatus method, while its organic matter content was determined by ashing the samples at 550°C for 4h. Electrical conductivity and pH were measured in a 1:5 soil:water extract using an S-C-T meter (Model 33; YSI, USA) and an Ion-analyser (Model 407A; Orion, USA), respectively. Total Kjeldahl nitrogen content was determined by the micro-Kjeldahl method (Allen et al., 1986), while the respective amounts of chloride or calcium were measured via the argentometric method (Kalthoff and Stenger, 1947) or with a flame photometer (Coleman 51; Perkin Elmer, USA).

Multivariate Analysis

We employed both classification and ordination techniques for our effective analysis of vegetation and related

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Table 1. Habitat types, characteristics, and study sites along the southwestern coast of South Korea.

Habitat type	Characteristics and study site
Salt marshes	Higher salinity and clay content. Study sites: Iksan-gun Sinji-ri, Kimje-gun Sopo-ri, Puan-gun Taehang-ri, Kochang-gun Sinduk-ri, Yonggwang-gun Hasa-ri, Muan-gun Hyunhwa-ri, Shinan-gun Upnae-ri, Suncheon Sunhak-ri, Yeocheon Sorido
Salt swamps	Moderate salinity and clay content, but higher soil moisture content; occurring in areas either with high water tables or where fresh water flows down into salt marshes. Study sites: Kochang-gun Wolsan-ri and Duu-ri, Muan-gun Pokgil-ri and Dodae-ri, Posong-gun Jeonil-ri
Sand dunes	Lower salinity and soil moisture content. Study sites: Kochang-gun Tongho-ri, Yongjong-ri and Charyung-ri, Yonggwang-gun Paeksu-ri, Muan-gun Songhyun-ri, Shinan-gun Chido-up and Uido, Kohung-gun Deokjung-ri and Kahwa-ri

Table 2. Soil variables within coastal plant communities of salt marsh, salt swamp, and sand dune along the southwestern coast of South Korea. Data are presented as mean and standard error of 3~40 replications.

Soil variable	Salt marsh	Salt swamp	Sand dune
pH	6.7 (0.3)	6.7 (0.3)	7.0 (0.2)
Water potential (-MPa)	3.06 (1.22)	1.49 (0.35)	0.31 (0.08)
Moisture content (%)	21.4 (3.4)	23.8 (4.9)	6.8 (1.8)
Osmotic potential (-MPa)	2.45 (0.79)	0.98 (0.18)	0.20 (0.07)
Electrical conductivity (mS cm^{-1})	1.04 (0.38)	0.87 (0.14)	0.29 (0.04)
Cl^- content (mg g^{-1})	11.9 (5.3)	2.8 (1.0)	0.4 (0.1)
Na^+ content (mg g^{-1})	13.2 (5.5)	5.2 (1.3)	0.5 (0.1)
Total Kjeldahl nitrogen (mg g^{-1})	0.31 (0.15)	0.46 (0.16)	0.21 (0.10)
Organic matter (%)	3.7 (0.6)	3.6 (0.7)	1.4 (0.6)
Sand (%)	46 (28)	60 (6)	75 (7)
Silt (%)	35 (20)	26 (3)	15 (5)
Clay (%)	21 (9)	15 (4)	10 (3)

environmental factors. A floristic cover data matrix consisted of 23 sites (communities) and 56 species; these were classified according to two-way indicator species analysis (TWINSPAN), using the default settings for the computer program PC-ORD for Windows version 4.20 (McCune and Mefford, 1999). Our study sites were ordered first by divisive hierarchical clustering, and then the species were clustered based on the classification of sites (Gauch and Whittaker, 1981). We used the PC-ORD program to conduct both detrended correspondence analysis (DCA) (Hill and Gauch, 1980) and canonical correspondence analysis (CCA) (ter Braak, 1986) for ordinations on the vegetation and plant species–environmental variable matrices. DCA is an indirect gradient technique whereby environmental gradients are inferred from the species composition data. In contrast, CCA is a direct gradient technique applied in relating species composition to measured environmental variables. Although CCA provides a better spread of points than DCA, both ordination techniques are based on reciprocal averaging (Hill, 1973).

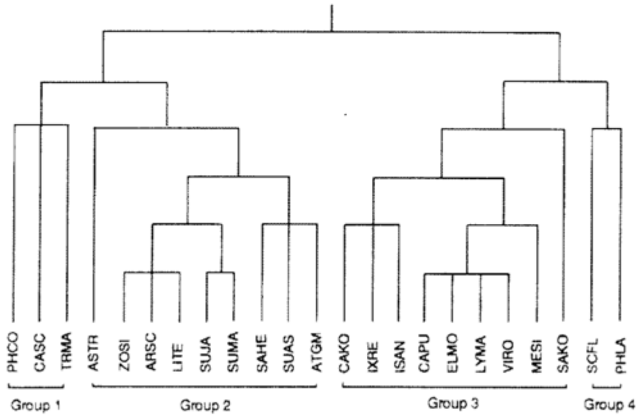

Figure 1. TWINSPAN classifications for 23 communities along southwestern coast of South Korea. PHCO, *Phragmites communis*; CASC, *Carex scabrifolia*; TRMA, *Triglochin maritimum*; ASTR, *Aster tripolium*; JOSI, *Zoysia sinica*; ARSC, *Artemisia scoparia*; LITE, *Limonium tetragonum*; SUJA, *Suaeda japonica*; SUMA, *Suaeda maritima*; SAHE, *Salicornia herbacea*; SUAS, *Suaeda asparagoides*; ATGM, *Atriplex gmelini*; CAKO, *Carex kobomugi*; IXRE, *Ixeris repens*; ISAN, *Ischaemum anthephoroides*; CAPU, *Carex pumila*; ELMO, *Elymus mollis*; LYMA, *Lysimachia mauritiana*; VIRO, *Vitex rotundifolia*; MESI, *Messerschmidia sibirica*; SAKO, *Salsola komarovi*; SCFL, *Scirpus fluviatilis*; PHLA, *Phacelurus latifolius*.

RESULTS

Soil Variables

Water and osmotic potential increased from salt marshes and salt swamps to sand dunes. Sand dunes showed the lowest mean electrical conductivity, 0.29 mS cm^{-1}, while the marshes had the highest value, 1.04 mS cm^{-1}. A gradient in soil texture occurred from marshes to sand dunes.

Vegetation Classification

The TWINSPAN classification hierarchy, based on species cover, gave a primary clustering of communities into two groups. The first was characterized by *Phragmites communis*, *Carex scabrifolia*, *Aster tripolium*, and *Zoysia sinica* in the swamps and marshes. The second group was represented by *Carex kobomugi*, *Ixeris repens*, *Scirpus fluviatilis*, and *Phacelurus latifolius* in the dunes and swamps. Four vegetation groups were recognized in this classification (Fig. 1), with Groups 1 and 4 being distinct from Group 2 or 3. These divisions were as follows: Group 1 included *P. communis*, *C. scabrifolia*, and *Triglochin maritimum*, and could be categorized as typical salt swamp vegetation; Group 2 contained *A. tripolium*, *Z. sinica*, *Artemisia scoparia*, and *Limonium tetragonum*, and various characteristics of typical salt marsh vegetation; Group 3 had *C. kobomugi*, *I. repens*, *Ischaemum anthephoroides*, and *C. pumila*, which are found on typical sand dunes; and Group 4 had *S. fluviatilis* and *P. latifolius*, which are usually common to salt swamps.

Ordination

Figure 2 presents the DCA ordination results of the coastal plant data set. The 23 community scores were plotted along Axes 1 and 2, and again tended to cluster into the three groups of salt swamp, salt marsh, and sand dune. Their respective communities were separated from right to left on Axis 1 with an eigenvalue of 0.866, which reflected the ecological relationships between edaphic factors and the distribution pattern for coastal wetland communities in this study area (Table 3). DCA Axis 1 illustrated a soil moisture–electrical conductivity–organic matter gradient, i.e., three factors that increased from left to right along the first axis. Axis 2 showed a sand–silt content gradient, with sand content gradually increasing from top to bottom along the second axis. Its eigenvalue of 0.699 was less important.

The CCA eigenvalues for the first two ordination axes were 0.848 and 0.722 (Table 3), which explained 14.9% of the variance in the community data. These results suggested a strong association between vegetation type and the measured soil factors presented in a biplot (Jongman et al., 1995). In the intra-set correlations of soil factors with the first CCA axis, we noted that Axis 1 was correlated with soil water and osmotic potential, soil moisture content, electrical conductivity, and organic matter. This fact became more apparent in the ordination biplot (Fig. 3). CCA Axis 2 was related to Cl^-, Na^+ and clay contents. An ordination diagram produced by CCA is shown in Figure 3. Here, the main gradients, identified by CCA, were soil–water relations and soil texture factors. This pattern of ordination was consistent with that of the DCA results obtained for coastal plants (Fig. 2).

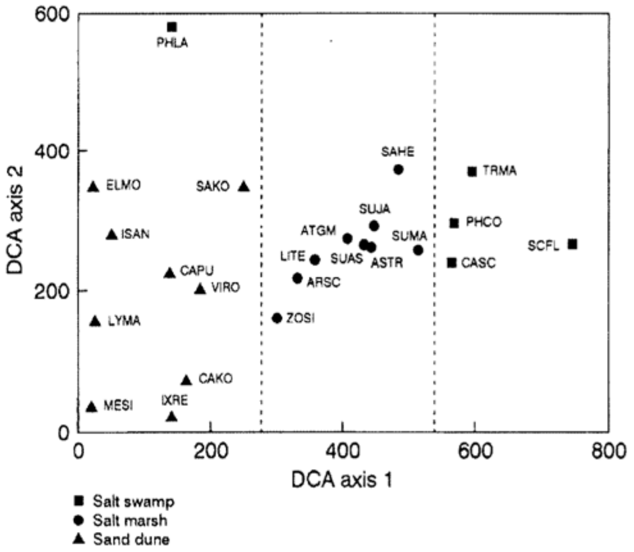

Figure 2. DCA ordination diagram for 23 coastal plant communities. Species labels are presented in Figure 1.

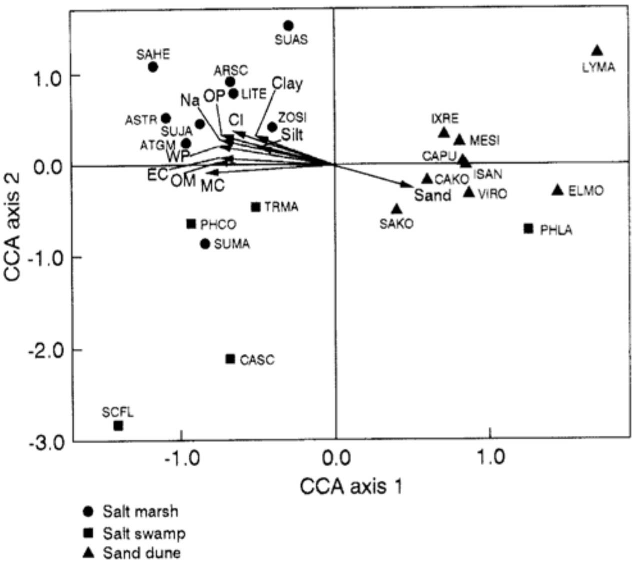

Figure 3. CCA ordination diagram for 23 coastal plant communities. Species labels are presented in Figure 1. WP, water potential; MC, soil moisture content; OP, osmotic potential; EC, electrical conductivity; Cl, Cl^- content; Na, Na^+ content; OM, organic matter.

Table 3. Summary statistics for CCA ordinations and comparisons with results from DCA.

	Axis 1	Axis 2	Axis 3
CCA			
Eigenvalues	0.848	0.722	0.634
Cumulative % explained	8.0	14.9	20.9
Pearson correlation	0.988	0.973	0.969
DCA			
Eigenvalues	0.866	0.699	0.492

DISCUSSION

Spatial distribution of plant species and communities in coastal wetlands is related to heterogeneous soil and aboveground environments. The heterogeneity of edaphic factors, sea levels, and microclimatic conditions leads to variations in the distributional behavior of coastal plant communities. Characteristic vegetation could be divided into three types (Table 2), with most group members having much in common with the species recorded by Kim and Ihm (1988), Ihm and Lee (1998), Jung and Kim (1998), and Kim (2005). Following the Braun–Blanquet methodology, we recognized these types as salt marsh, salt swamp, and sand dune (Ihm et al., 2001a). This finding is partially consistent with our TWINSPAN results. The salt-marsh species group (Group 2) included the association of *A. scoparia*, *A. tripolium*, *Atriplex gmelini*, *L. tetragonum*, *Salicornia herbacea*, *Suaeda asparagoides*, *S. japonica*, *S. maritima*, and *Z. sinica*. The salt-swamp species groups (Groups 1 and 4) contained *C. scabrifolia*, *P. communis*, *S. fluviatilis*, *T. maritimum*, and *P. latifolius*. The sand-dune species group (Group 3) had the association of *C. kobomugi*, *Messerschmidia sibirica*, *C. pumila*, *Elymus mollis*, *I. anthephoroides*, *I. repens*, *Lysimachia mauritiana*, *Salsola komarovi*, and *Vitex rotundifolia*.

We also examined the environmental correlates of species distribution within these three habitat types. Using the DCA ordination results of the coastal plant data set (Fig. 2), we could plot the 23 community scores along Axes 1 and 2; these tended to cluster into three groups along the first axis (eigenvalue=0.866). The ordination diagram displayed graphically that the composition of the salt-marsh species group was transitional between two other groups. Communities in the salt-swamp group were separated toward the positive end of Axis 1, while those within the sand-dune group were separated out at the other end.

In the diagram produced by CCA, the pattern of ordination was consistent with that of our DCA results (Fig. 2, 3). The communities were arranged into two groups of sand dune and other vegetation along Axis 1 as well as two groups of salt marsh plus salt swamp vegetation along Axis 2. The results of both DCA and CCA ordinations clearly showed the relative positions of communities along critical ecological gradients. Therefore, we were able to identify soil water and osmotic potential, soil moisture content, electrical conductivity, organic matter, and soil texture as more important factors for determining the distribution patterns of coastal vegetation on the southwestern coast of South Korea (DCA Axis 1: soil moisture – electrical conductivity–organic matter gradient; DCA Axis 2: sand–silt content gradient; CCA Axis 1: soil water and osmotic potential, soil moisture content, electrical conductivity, and organic matter gradient; CCA Axis 2: Cl^-, Na^+ and clay content gradient). The types of communities derived via TWINSPAN were corroborated by DCA and CCA, although there was a certain degree of overlap in the ordination space between the different groups. In all, 14.9% of the variance among species data could be explained by the two CCA axes. These low values could be attributed to high noise levels typical of species-abundance data (ter Braak, 1986). Although ecological data sets frequently have a large proportion of unexplained random variation (Gauch, 1982), they are still able to demonstrate the important underlying causes of community structure (Bocard et al., 1992). CCA is an explanatory technique designed to isolate a subset of environmental factors that leads to an ecologically meaningful interpretation of essential gradients in a few dimensions (Palmer, 1993). To test the meaningfulness of these environmental variables, we compared our CCA results with those obtained from DCA (Table 3). Here, the eigenvalues of CCA Axis 1 were lower than those of DCA Axis 1.

In the study of this region, a multiple regression model has shown that the abundances for 14 coastal plant communities in the salt marshes are determined by soil pH, osmotic potential, and sand content (Ihm and Lee, 1998; Ihm et al., 2006). When a principal component analysis is utilized in this region, PCA Axis 1 is designated as the gradient for soil texture and water potential as related to salinity (Ustin et al., 1982; Brewer and Grace, 1990; Ihm and Lee, 1998), whereas PCA Axis 2 is the gradient for soil moisture and total nitrogen (Boucaud and Billard, 1985). On PCA Axis 1, the coastal plant communities can be divided into three groups: 1) salt-marsh communities that are characterized by low water and osmotic potentials, high electrical conductivity, and elevated sodium and chloride contents; 2) salt-swamp communities, with more moderate properties; and 3) sand-dune communities, which have higher water and osmotic potentials, and low sodium and chloride contents. Those PCA results are, in fact, consistent with the conclusions drawn from our DCA and CCA. Besides various chemo–physical factors, the following biotic influences are important in determining the pattern of halophyte distribution (Bertness and Ellison, 1987; Kiehl et al., 1996; Pennings and Callaway, 1996; Piernik, 2003; Kim, 2005). They include competition, nutrient limitation, impact of parasites and herbivores, and cultural management by grazing and cutting.

In conclusion, following the Braun-Blanquet methodology, we were able to separate three community types of coastal habitat -- salt marsh, salt swamp, and sand dune (Kim and Ihm, 1988). Our DCA and CCA evaluations showed that the 23 community scores tended to cluster into three vegetation groups, and that soil–water relations and soil texture-related factors were more important determinants of species distribution patterns within a coastal vegetation.

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