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Soil Particle Sizes and Plant Communities on Coastal Dunes

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To identify and assess the distribution patterns of coastal dune vegetation along the eastern, southern, and western coasts of South Korea, we investigated the plant communities and soil factors at 30 sites. In all, 12 communities on CCA (canonical correspondence analysis) Axis 1 and 2 could be arranged into 3 groups: 1) 2 communities of *Elymus mollis* and *Ischaemum anthephoroides*, with medium sand contents; 2) 6 communities of *Carex pumila*, *Carex kobomugi*, *Ixeris repens, Zoysia macrostachya*, *Calystegia soldanella*, and *Vitex rotundifolia*, with coarse sand contents; and 3) 4 communities of *Lathyrus japonicus*, *Glehnia littoralis*, *Messerschmidia sibirica*, and *Rosa rugosa*, with very coarse sand contents. As identified via CCA ordination, the distribution of these groups was positively correlated with soil particle sizes.

Keywords: CCA ordination, coastal dune, plant community, soil particle size

Coastal dunes represent various habitats in South Korea. Along the eastern coast, they are developed by coastal currents and the prevailing winds whereas those on the western or southern sides result from very large or small tides, respectively (Lee et al., 1982; Lee and Chon, 1983, 1984; Pethick, 1984; Lee and Ignacjuk, 1985). The combination of dune height and shape with intact vegetation creates protection against winds, which first affect the mounding of sand by eroding particles from the windward side and then depositing them on the leeward side. Vegetation is an important factor in dune stability (Godfrey, 1977; Barbour, 1987; Costa et al., 1996; Kutiel et al., 2004), and has adapted to salt-laden winds.

Comprehensive studies on the coastal wetlands of South Korea have included investigations of halophyte distribution (Kim, 1971; Kim and Ihm, 1988); the dispersion structure of dune plants on the Sung San-po seashore in Jeju-do (Park, 1967); invasive plants on disturbed sand dunes (Kim, 2005); growth properties of *Carex kobomugi* (Min, 2004); vegetation distribution and standing biomass in the sand dunes of Kohung (Lee et al., 2000); plant distribution and succession in reclaimed lands along the west coast (Min and Kim, 1999a, b, 2000); and soil factors in the plant communities on the southwestern coast (Ihm and Lee, 1998; Ihm et al., 2006, 2007; Lee et al, 2007). Moreover, general surveys have been conducted of the sand dune vegetation on the eastern coast (Lee and Kim, 2000); the western, southern, and eastern coasts (Lee et al., 1982; Lee and Chon, 1983, 1984); and in Kyungpook Province (Jung and Kim, 1998).

Factors related to soil texture, sea levels, salinity, and saline water tables are believed to play major roles in controlling the distribution and abundance of plants within and across coastal wetland types (Kim and Ihm, 1988; Ihm and Lee, 1998; Ihm et al., 2006). Therefore, our objective was to clarify our understanding of some of those possible interactions and to assess the relationships between soil particle size and plant community distribution on coastal dunes.

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MATERIALS AND METHODS

Study Area

Three coastal areas of South Korea were monitored (Fig. 1):

1) The eastern coast at Gangwon-do Goseong-gun Chodo-ri Hwajinpo (S1), Gajin-ri (S2) and Gonghyeonjin-ri (S3), Yangyang-gun Dongho-ri (S4), Jangyo-ri (S5), Bukbun-ri (S6), Gwangjin-ri (S7) and Jigyeong-ri (S8), Gangneung-si Jumun-ri (S9), Donghae-si Nobong (S10), Samcheok-si Mae-

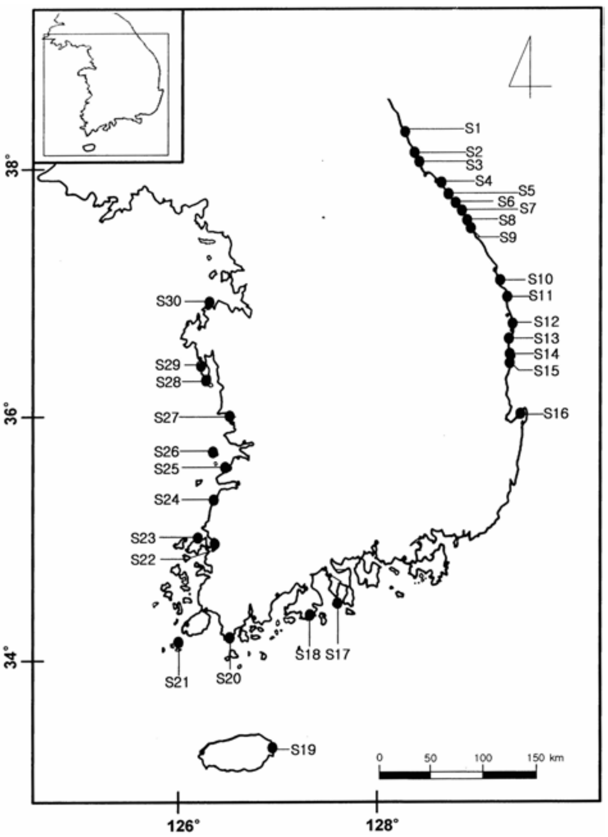

Figure 1. Map of study areas.

won-ri (S11), Gyeosangbuk-do Uljin-gun Mangyang-ri (S12) and Wolsong-ri (S13), Yeongduk-gun Baekseok-ri (S14) and Byeonggok-ri (S15), and Pohang-si Honghwan-ri (S16).

2) The southern coast at Jellanam-do Yeosu-si Nangdo-ri (S17), Goheung-gun Deokjung-ri (S18), Jeju-do Bukjeju-gun Sinyang-ri (S19), and Jellanam-do Haenam-gun Tongho-ri Sagumi (S20).

3) The western coast at Jellanam-do Jindo-gun Kwanmaedo-ri (S21), Muan-gun Songseok-ri (S22) and Haeun-ri (S23), Jellabuk-do Gochang-gun Yongjeong-ri (S24), Buan-gun Mapo-ri (S25), Gunsan-si Seonyudo-ri (S26), Chungcheongnam-do Seocheon-gun Dasa-ri (S27), Taean-gun Jungjang-ri (S28) and Gijipo (S29), and Banggal-ri Hakampo (S30).

These sites were investigated from April 2004 to September 2005, using the method of Braun-Blanquet (1964). Taxonomic nomenclature followed that of Lee (2003).

Data Collection

The soil environment near the roots was examined at a depth of 20 cm. Air-dried samples were used for physicochemical analysis. Moisture content was calculated as the difference in weight between fresh soil and the same sample oven-dried at 105. Organic matter content was determined by ashing the samples at 550 for 4 h. Electrical conductivity, pH, and salinity were evaluated from a 1:5 soil:water extract using a salinity meter (Model 63; YSI, USA). Soil A-P (available phosphorus) content was measured at a wavelength of 880 nm with a spectrophotometer (Bray, 1948), while TKN (Total Kjeldahl nitrogen) content was determined by the micro-Kjeldahl method. Soil particle sizes were determined with a dry sieve, according to standard analysis in the USDA soil classification system (SCS, 1994). Categories included clay (<2 μm), silt (2~50 μm), very fine sand (50~100 μm), fine sand (100~250 μm), medium sand (250~500 μm), coarse sand (500~1000 μm), very coarse sand (1000~2000 μm), and gravel (>2000 μm).

Canonical Correspondence Analysis of Distribution Patterns within Coastal Dune Plant Communities

The distribution patterns for coastal dune plant communities as a function of soil particle size were examined by CCA (ter Braak, 1986), using the program PC-ORD for Windows version 4.20 (McCune and Mefford, 1999).

RESULTS

Soils were analyzed from 12 coastal plant communities of *Elymus mollis*, *C. kobomugi*, *C. pumila*, *Ixeris repens*, *Lathyrus japonicus*, *Glehnia littoralis*, *Zoysia macrostachya*, *Messerschmidia sibirica*, *Calystegia soldanella*, *Vitex rotundifolia*, *Rosa rugosa*, and *Ischaemum anthephoroides* in South Korea (Table 1). Mean moisture contents ranged from 0.15 to 0.59%, while soil organic matter averaged 0.04 to 2.08%. Soil pH (6.49 to 6.99), electrical conductivity (108 to 189 μS cm^{-1}), and TKN contents (0.06 to 0.13 mg g^{-1}) did not differ among these communities. Average soil A-P contents ranged from 40 to 77 μg g^{-1}.

E. mollis communities occur between the high-water mark and shrubby communities in coastal dunes (Kim and Ihm, 1988; Ihm et al., 2007; Lee et al., 2007). For that predominant species, the soils in our study (Fig. 2) consisted prima-

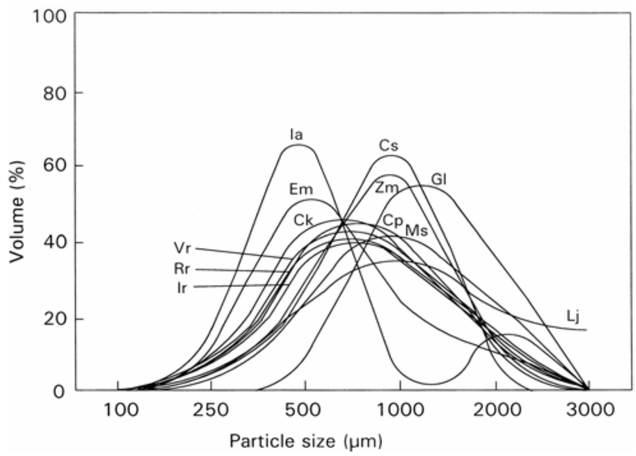

Figure 2. Distribution of soil particle sizes for each community on coastal dunes of South Korea. Em, *E. mollis*; Ck, *C. kobomugi*; Cp, *C. pumila*; Ir, *I. repens*; Lj, *L. japonicus*; Gl, *G. littoralis*; Zm, *Z. macrostachya*; Ms, *M. sibirica*; Cs, *C. soldanella*; Vr, *V. rotundifolia*; Rr, *R. rugosa*; Ia, *I. anthephoroides*.

Table 1. Soil properties for 11 plant communities in coastal dunes of South Korea (mean and standard deviation of above five replications).

Community	Moisture content (%)	Organic matter (%)	Electric conductivity (μS cm^{-1})	pH	A-P (μg g^{-1})	TKN (mg g^{-1})
Elymus mollis	0.43 (0.64)	0.34 (0.41)	138 (56)	6.99 (0.16)	77 (25)	0.13 (0.03)
Carex kobomugi	0.24 (0.24)	0.21 (0.16)	124 (43)	6.59 (0.06)	66 (10)	0.08 (0.02)
Carex pumila	0.48 (0.47)	0.81 (0.35)	168 (53)	6.67 (0.10)	55 (9)	0.06 (0.02)
Ixeris repens	0.17 (0.10)	0.12 (0.14)	108 (80)	6.88 (0.16)	42 (7)	0.09 (0.04)
Lathyrus japonicus	0.16 (0.12)	0.04 (0.04)	112 (43)	6.58 (0.16)	57 (8)	0.06 (0.02)
Zoysia macrostachya	0.33 (0.10)	0.59 (1.12)	117 (51)	6.90 (0.13)	54 (9)	0.08 (0.02)
Messerschmidia sibirica	0.15 (0.09)	0.24 (0.09)	183 (46)	6.53 (0.08)	40 (9)	0.08 (0.02)
Calystegia soldanella	0.27 (0.12)	0.37 (0.33)	189 (45)	6.85 (0.11)	52 (6)	0.07 (0.02)
Vitex rotundifolia	0.31 (0.17)	0.51 (0.48)	174 (38)	6.78 (0.13)	46 (10)	0.09 (0.03)
Rosa rugosa	0.59 (0.36)	1.37 (1.08)	128 (65)	6.49 (0.13)	69 (21)	0.13 (0.02)
Ischaemum anthephoroides	0.36 (0.05)	2.08 (0.34)	134 (55)	6.51 (0.06)	50 (10)	0.09 (0.02)

rily of medium (52.84%), coarse (23.70%), very coarse (12.62%), and fine sands (10.47%). Such a habitat occurred at 22 sites -- S1 to 3, S6 to S16, S22, and S24 to S30.

In the *C. kobomugi* communities, soil (Fig. 2) consisted of medium (49.25%), coarse (29.69%), very coarse (12.54%), and fine sands (8.15%). These conditions were found at 23 sites on unstable coastal dunes -- S1 to S3, S5 to S12, S14, S15, S18 to S21, and S25 to S30.

Medium (41.89%), coarse (34.75%), fine (11.67%), and very coarse sands (10.98%) were common to the *C. pumila* communities on semi-stable, human-disturbed, or stable dunes at 10 sites -- S1, S13, S16, S17, S19, S21, S25 to S27, and S30 (Fig. 2).

The *I. repens* communities were found on unstable or human-disturbed dunes that contained mainly medium (51.85%), coarse (29.81%), very coarse (9.8%), and fine sands (8.36%). These occurred at S4, S6, S10, S12, S15, S26, and S29 (Fig. 2).

In contrast, the communities of *L. japonicus* occupied stable dunes that consisted mostly of coarse (35.36%), very coarse (24.64%), and medium sands (21.81%), as well as a high proportion of gravel (14.63%). This situation was found at S2, S3, S6, S12, S22, S25, S26, and S30 (Fig. 2).

The communities of *G. littoralis*, found at Sites S11 and S15 (Fig. 2), near high-water lines, were based on coarse (53.05%), very coarse (37.25%), and medium sands (9.10%), while those of *Z. macrostachya*, sitting atop stable and dry-sand dunes, had soil contents of primarily coarse (52.66%), medium (35.32%), and very coarse sands (10.26%). Those sites included S1, S11 to S13, S15, and S20 (Fig. 2).

Very coarse (32.69%), medium (29.83%), and coarse sands (24.20%), with some fine sand and gravel, were common to *M. sibirica* communities on unstable and dry dunes at S21, S22, and S25 to S27 (Fig. 2).

For communities of *C. soldanella*, the soils consisted of mostly medium (41.87%), coarse (33.05%), and very coarse sands (15.46%). These plants were found on low dunes that had been exposed through the aerial dispersion of salts. Such sites, 14 in all, included S2, S5 to S7, S11 to S14, S16, S20, S23, S25, S27, and S29 (Fig. 2).

V. rotundifolia communities, located on dry, unstable, or semi-stable coastal dunes as well as near windbreak forests, had soil contents of mainly medium (40.89%), coarse (33.02%), very coarse (17.96%), and fine sands (7.31%). This occurred at 20 sites, including S1, S7, S10 to S22, S25 to S28, and S30 (Fig. 2).

Plants of *R. rugosa*, near the mantle community behind the dunes, as well as on disturbed dunes or near windbreak forests, grew in soils of mostly coarse (61.91%) or medium sands (26.96%). These communities were found at S1, S3, S12, S13, and S30 (Fig. 2).

Finally, *I. anthephoroides* communities, near high-water lines, had soil contents of primarily medium (61.12%), fine (18.44%), and very coarse sands (17.46%). This situation occurred at S20, S25, and S27 to S29 (Fig. 2).

CCA eigenvalues for our first two ordination axes were 0.509 and 0.345, respectively (Table 2). In the interset correlations of soil particle sizes with axis scores, we noted that CCA Axis 1 was significantly correlated with very coarse and medium sand contents while CCA Axis 2 was significantly correlated with medium, coarse, and very coarse sand contents. On CCA Axis 1 and 2, 12 coastal plant communities could be divided into 3 groups (Fig. 3) that were positively correlated with increasing contents of medium sand, coarse sand, and very coarse sand.

Table 2. Canonical coefficients and interset correlation coefficients for 7 soil particle sizes.

Variable	Canonical coefficient		Correlation coefficient	
	Axis 1	Axis 2	Axis 1	Axis 2
Silt	0.002	-0.003	0.257	-0.067
Very fine sand	-0.001	-0.003	0.111	-0.046
Fine sand	-0.121	-0.053	-0.480	0.193
Medium sand	-0.532	-0.831	-0.814**	-0.598*
Coarse sand	-0.058	0.226	0.020	0.618*
Very coarse sand	0.600	-0.739	0.883**	-0.565*
Gravel	0.006	-0.006	0.473	0.069
Eigen value	0.509	0.345		

*, $P < 0.05$; **, $P < 0.01$.

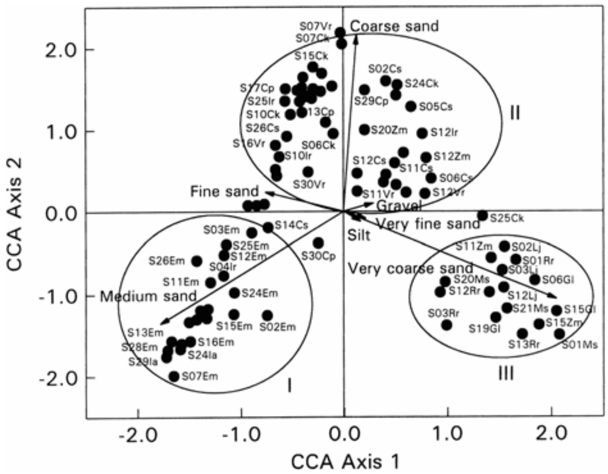

Figure 3. CCA ordination diagram of 12 coastal dune plant communities. Names for site labels are listed in Materials and Methods section. Species labels are as described for Figure 2.

DISCUSSION

The highest clay content occurred with *M. sibirica*, while the highest and the lowest silt contents were found in the *R. rugosa* and *I. anthephoroides* communities, respectively. The highest and the lowest sand contents were associated with the *G. littoralis* and *M. sibirica* communities. Our 12 coastal dune plant communities followed the gradients for soil particle sizes, where 1) *I. anthephoroides* and *E. mollis* communities were found in smaller sand particles of 250~1000 μm; 2) *C. kobomugi*, *C. pumila*, *V. rotundifolia, R. rugosa*, and *I. repens* communities were distributed in intermediate sand particles, 250~2000 μm; and (3) the communities of *C. soldanella, Z. macrostachya*, *G. littoralis*, *M. sibirica*, and *L. japonicus* were located in larger sand particles, 500~2500 μm (Fig. 2). Furthermore, these 12 communities on CCA Axis 1 and 2 were arranged into three groups: 1) 2 communities -- *E. mollis* and *I. anthephoroides* -- were positively correlated with increasing medium sand contents; 2) 6 communities -- *C. pumila*, *C. kobomugi*, *I. repens, Z. macrostachya*, *C. soldanella*, and *V. rotundifolia* -- were positively correlated with increasing coarse sand contents; and 3) 4 communities -- *L. japonicus*, *G. littoralis*, *M. sibirica*, and *R. rugosa* -- were positively correlated with increasing very coarse sand contents.

In controlling this distribution of coastal plants, both soil chemical and physical factors are believed to play major roles (Kim and Ihm, 1988; Costa et al., 1996). In PCA (principal component analysis) studies of coastal wetlands, plant communities are arranged along gradients for either soil texture and water potential or soil moisture and total nitrogen content (Boucaud and Billard, 1985; Ihm and Lee, 1998). In other coastal dune studies, CCA has shown that invasive native and exotic species are significantly segregated, based on disturbance levels as well as on the soil contents of gravel, sand, and silt (Kim, 2005). Ordination by DCA (detrended correspondence analysis) in the Eastern Cape of South Africa has demonstrated that plant communities are linked within a successional gradient, from pioneer to climax (Avis and Lubke, 1996). Biotic influences, e.g., competition, impact of parasites and herbivores, or management by grazing and cutting, are important in establishing the pattern of halophyte distribution (Bertness and Ellison, 1987; Kiehl et al., 1996; Pennings and Callaway, 1996; Piernik, 2003; Kim, 2005). An ecological role of vegetation on sand dunes is to prevent erosion and promote stabilization (Barbour, 1987; Costa et al., 1996; Kutiel et al., 2004). This vegetation also helps sustain dunes that are already disturbed (Kim, 2005). In conclusion, our CCA results indicate that these 12 community scores tend to cluster into 3 vegetation groups by soil particle sizes, which are important factors in determining the distribution patterns of coastal dune vegetation.

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