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Ecological Restoration of Coastal Sand Dunes in South Korea

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ABSTRACT

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The sand dune areas in coastal regions of South Korea are very important ecosystems because of their small sizes, habitats of rare species, and beautiful landscape. Our studies aim to investigate vegetation status of sand dunes on representative three sides of Korean peninsula and estimate plant distribution condition. We established plots along line transects perpendicular to the coastal line of sand dunes to estimate cover and enumerate individual number of all species. TWINSPAN (Two-Way Indicator Species Analysis) and CCA (Canonical Correspondence Analysis) were performed to classify communities on sand dunes and assess species composition variation. The dominant species at plots of the east, the south, and the west coast were different. *Carex kobomugi*, *Elymus mollis*, *Lolium multiflorum - Calystegia soldanella*, and *Vitex rotundifolia* communities were classified from TWINSPAN. CCA showed that species composition varied according to sand dune structure, exotic species number, and slack width. Shinduri is considered as representative Korean natural sand dune ecosystem because of undisturbed status composed of primary dune including foredune and slack, and secondary dune and higher species richness than the other sand dunes. Therefore, other disturbed sand dunes should be restored following Shinduri sand dune structure and vegetation composition. The restoration options for sand dune areas in South Korea are as follows: the restoration of other sand dune areas toward the condition of Shinduri sand dune, introduction plant species of Shinduri sand dune into other sand dune areas, prohibition of artificial building and exotic soils, and conservation of sand dune surrounding areas.

ADITIONAL INDEX WORDS: *Canonical correspondence analysis, restoration options, TWINSPAN.*

INTRODUCTION

Korea has three coastal sides. So, they have 133 various sand dunes on the Korean peninsula and Jeju Island, except other islands (MOE, 2001). The artificial extension to sand dunes destructed the sand dunes. The military actions and facilities and beach recreational constructions wrecked original sand dunes in Korea. Therefore, these sand dunes are focused areas for restoration. But, there are rare data and materials about the structure and vegetation on the sand dunes in South Korea. The objective of this study is to investigate on the structural and vegetation status of the Korean sand dunes and suggest appropriate restoration options.

METHODS

Site Description

The investigation was carried out in the coastal sand dunes of Korean peninsula and Jeju Island. Korea is located in middle latitudes of the Northern Hemisphere and the Temperate Zone with four distinct seasons (Figure 1). Geographically, it lies on the east coast of the Eurasian Continent adjacent to the West Pacific. The annual mean temperature of Korea ranges from 10 to 16°C except in the high mountain areas. The monthly mean temperature ranges from 20 to 26°C in August and from -5 to 5°C in January. The annual precipitation is about 1,500mm in the southern part of Korea and 1,300 mm in the central part. More than half of the annual precipitation falls during the East-Asian Monsoon season when a stationary front lingers across the Korean peninsula for about a month in summer. The winter precipitation is less than 10% of the total (KMA, 2003).

Vegetation Analysis

The 110 sand dune sites were surveyed on June to August 2003. Of these, total vegetation inventory was recorded at the 52 sand dune sites (Figure 1). The number of sand dune sites surveyed in the east, the south, and the west coast on Korean peninsula were 25, 7, and 8 and that of Jeju Island, the greatest island in Korea were 12. We established mean 2 line transects perpendicular to the coastal line of 17 sand dune sites. The line transect numbers per site were adjusted according to vegetation patch number and size. Five meters distant, 11 m size plots contiguously along each line transect were set up to estimate cover and enumerate individual number of all species. Mean plot number per sand dune site was 9 (SD = ±5). Total plot numbers on Korean peninsula and Jeju Island were 217 and 54. All plants were classified into native and exotic plants. Exotic species were defined as not indigenous in Korea, introduced intentionally or unintentionally, and having their origins outside of Korea. Importance values were calculated from adding relative cover and relative density of all species recorded in plots. Nomenclature of the vascular plants follows EUN (1989), LEE (1985), LEE (1997), LEE (2002), LEE et al. (2001), PARK (1995), and PARK (2001).

Ordination Analysis

TWINSPAN (Two-Way Indicator Species Analysis) was performed to classify communities on sand dunes and assess species composition variation. Plant community name were designated as dominant species followed by subdominant species on the quadrats. The domination degree of plants was estimated as their covers in quadrats. The environmental variables following were measured in plots: distance from coastal line, disturbance level, exotic species number, sand dune length, sand dune structure, sand dune width, slack width, vegetation size, and vegetation width. CCA (Canonical Correspondence Analysis) were conducted to elucidate the relationships between species composition variation and environmental variables. Disturbance level is additive numbers of presence (+1) or absence (0) of afforestation, aggregate collections, bank, beach resort, building, dune falling, farmland, fence, graveyard, herb gathering, horse grazing, housing, leisure facilities, military training, quay facilities, railroad track,
Recreation park, road, stability activities, and troops facilities around the study sites. It means the intensity of disturbance. Sand dune structures are classified as 11 categories: driftline +

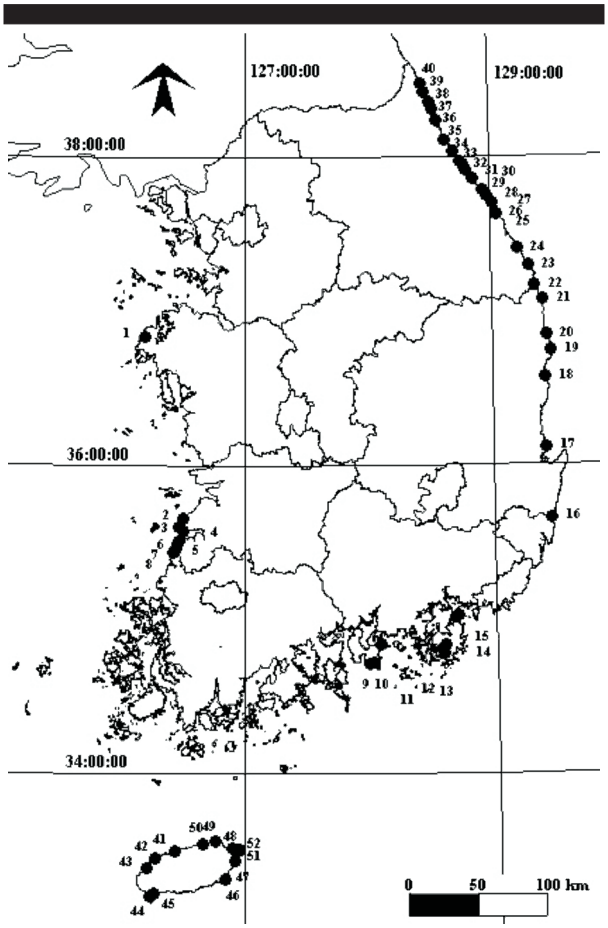

Figure 1. Map of South Korea showing the coastal sand dune areas where total vegetation inventory was conducted (Quadrat survey sites: 1 = Shinduri, 2 = Kosapo, 17 = Gokgang, 18 = Goraebul, 19 = Gusan, 21 = Hujeong, 23 = Yonghwa, 24 = Maengbang, 31 = Jikyung, 33 = Dongsan, 36 = Bongpo, 41 = Iho, 44 = Daejeong, 46 = Pyoseon, 47 = Sinyang, 48 = Hadori, 49 = Gimnyeong).

foredune + flat slack with grasslands + fence, driftline + foredune + elevated slack with grasslands + fence, driftline + foredune + flat slack with grasslands + disturbed Rosa rugosa afforestation land + fence, driftline with rocks + flat foredune + flat slack with grassland + fence, driftline + foredune + slack with disturbed grassland + fence, driftline + foredune + collapsed slack with grassland + fence, driftline + steep slack with grassland + fence, driftline + basalt area + flat slack with grassland, driftline + basalt area + elevated slack with grassland, driftline + basalt area + flat slack with grassland + windbreak Pinus thunbergii forest, driftline + basalt area + flat slack with grassland.

RESULTS

Vegetation Status of Korean Sand Dunes

267 species were found on the sand dunes. The mean species number per site was 27±12 (mean±SD). The average ratio of exotic species number to total species number per site was 0.23±0.09. Vegetation were divided into species typical of the sand dunes (sand dune specific species) and natives and exotics from surrounding terrestrial communities (Table 1). Of sand dune specific species, *Calystegia soldanella* was the most frequent species at 96% and other species appeared in following decreasing frequency order: *Carex pumila*, *Ixeris repens*, *Elymus mollis*, *Glehnia littoralis*, *Carex kobomugi*, *Lathyrus japonica*, *Salsola komarovi*, *Vitex rotundifolia*, *Tetragonia tetragonoides*, *Messerschmidia sibirica*, *Cynodon dactylon*, and *Salsola collina* (Table 1). Of terrestrial specific species, *Artemisia princeps* var. *orientalis* was the most frequent species at 55% and other species appeared in following decreasing frequency order: *Digitaria sanguinalis*, *Zoysia sinica*, *Phragmites communis*, *Rumex crispus*, *Oenothera biennis*, *Chenopodium album*, *Lepidium virginicum*, *Bromus tectorum*, and *Conyza bonariensis* (Table 1). *Carex kobomugi* community was typical community that invaded sand dune slack situated on the middle parts of all sand dune areas, stabilized sand mobility, and formed small mounds and then spread concentrically (JUNG and KIM, 1998).

Community Classification of Korean Sand Dunes

Korean Peninsula

From results of TWINSPAN, 11 communities were classified as follows: *Carex kobomugi* community, *Carex kobomugi - Ixeris repens* community, *Carex kobomugi - Oenothera biennis* community, *Carex pumila* community, *Cocculus trilobus* community, *Elymus mollis* community, *Elymus mollis - Artemisia princeps* var. *orientalis* community, *Digitaria sanguinalis* community, *Hemarthria sibirica* community, *Rumex crispus* community, *Spergularia marina* community,

Jeju Island

8 communities were classified as follows: *Carex kobomugi* community, *Lolium multiflorum - Calystegia soldanella* community, *Lolium perenne* community, *Suaeda asparagoides - Tetragonia tetragonoides* community, *Vitex rotundifolia* community, *Vitex rotundifolia - Carex kobomugi* community, *Vitex rotundifolia - Elymus mollis* community, *Vitex rotundifolia - Peucedanum japonicum* community.

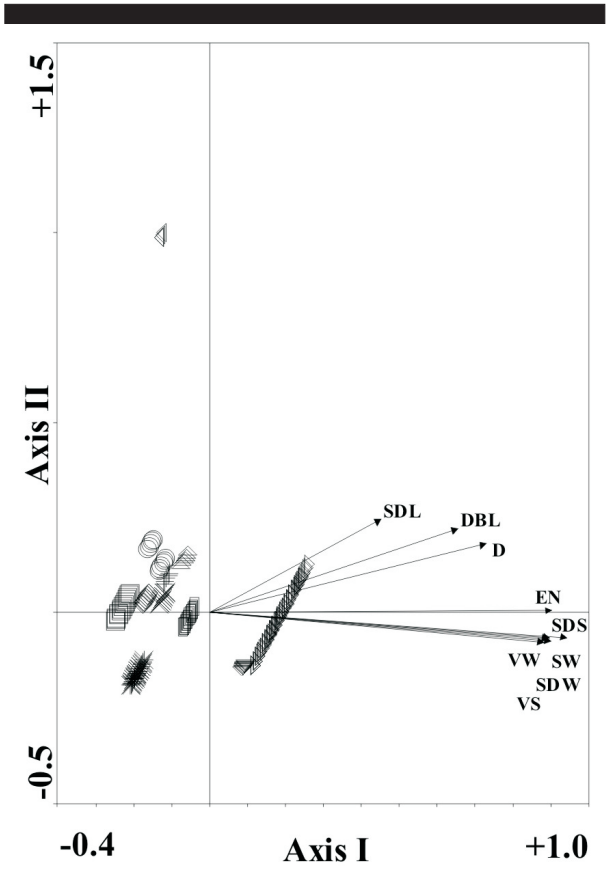

Figure 2. Results of canonical correspondence analysis (CCA) showing the relationships between measured environmental factors and species composition in sand dune areas on the coastal regions of South Korea. D = distance from coastal line, DBL = disturbance level, EN = exotic species number, SDL = sand dune length, SDS = sand dune structure, SDW = sand dune width, SW = slack width, VS = vegetation size, VW = vegetation width.

Table 1. *List of plants recorded at over 30% frequency on Korean sand dunes. The number in parenthesis represents the frequency of each species.*

Sand dune specific species:		Terrestrial specific species:	
		Natives:	Exotics:
Calystegia soldanella (96.15)	*Salsola komarovi* (50)	*Artemisia princeps* var. *orientalis* (55.76)	*Rumex crispus* (67.30)
Carex pumila (86.53)	*Vitex rotundifolia* (48.07)	*Digitaria sanguinalis* (34.61)	*Oenothera biennis* (53.84)
Ixeris repens (69.23)	*Tetragonia tetragonoides* (36.53)	*Zoysia sinica* (34.61)	*Chenopodium album* (50)
Elymus mollis (65.38)	*Messerschmidia sibirica* (36.53)	*Phragmites communis* (30.76)	*Lepidium virginicum* (48.07)
Glehnia littoralis (63.46)	*Cynodon dactylon* (34.61)		*Bromus tectorum* (38.46)
Carex kobomugi (61.53)	*Salsola collina* (34.61)		*Conyza bonariensis* (36.53)
Lathyrus japonica (61.53)			

Ordination Results of Korean Sand Dunes

Korean Peninsula

The quadrats were first ordinated to examine the degree of vegetation homogeneity of the site samples and their relationship with the environmental variables. The first two axes of the canonical correspondence analysis are shown in Figure 2. The length of the arrows corresponds with the magnitude of greatest variation in the total data set. The first axis of the canonical correspondence analysis is positively correlated with sand dune structure (R = 0.94), exotic species number (R = 0.90), and slack width (R = 0.89). So, sand dune structure, exotic species number, and slack width are the factors explaining most of the variation in species composition.

Jeju Island

The first axis of the canonical correspondence analysis is negatively correlated with vegetation width (R = -0.87) and slack width (R = -0.63). So, vegetation and slack width are the factors explaining most of the variation in species composition.

DISCUSSION

General Ecological Status of Korea Sand Dunes

Korean sand dune specific species recorded in study sites are similar to species recorded in northeast Asia, especially Japan (YANO et al., 1983). Specially, *Calystegia soldanella*, *Carex kobomugi*, *Carex pumila*, *Cnidium japonicum*, *Elymus mollis*, *Glehnia littoralis*, *Ischaemum anthephoroides*, *Ixeris repens*, *Limonium tetragonium*, *Linaria japonica*, *Messerschmidia sibirica*, *Peucedanum japonicum*, *Raphanus sativus* var. *hortensis f. raphanistroides*, *Rosa rugosa*, *Setaria viridis* var. *pachystachys*, *Vitex rotundifolia*, *Wedelia prostrata*, and *Zoysia macrostachya* appeared at both the study sites and coast sand dunes of northeast Asia. Many unstable belts caused by human activities seemed to be expanded in the sand dune sites of Korea. Shinduri sand dune is composed of primary dune including foredune and slack, and secondary dune (RYU, 2002). This structure is valuated as Korean natural and representative sand dune structure.

Soil Conditions of Sand Dunes

Coastal dune soils are generally poor in nutrient materials (PURER, 1936). However, the places connected with terrestrial streams or sewage were nutritious. So, biological diversity was very high in these areas. Total mean gravel, sand, and silt contents Restoration of Korean Sand Dunes of Korean sand dunes are 1.1±1.7 (%±SD), 96.7±3.6, and 2.2±3.2, respectively (MOE, 2001).

Disturbance Causes of Korean Sand Dunes

Except natural factors such as typhoon and less intensive storms, many anthropogenic activities are threats to demolish physical and biological elements of Korean sand dunes. We used these factors as disturbance level in terms of environmental variables: afforestation, aggregate collections, bank, beach resort, building, dune falling, farmland, fence, graveyard, herb-gathering, horse grazing, housing, leisure facilities, military training, quay facilities, railroad track, recreation park, road, stability activities, and troops facilities. Of these, beach resort was the most frequent cause to disturb Korean sand dunes according to field observation. The remaining causes are less frequent in following order: leisure facilities > troops facilities > housing > road > bank = farmland > graveyard = quay facilities > fence = stability > aggregate collecting = building > afforestation = dune falling = herb-gathering = horse grazing = railroad track = recreation park = military training.

Ecological Status of Shinduri, A Representatively Well Conserved Sand Dune in Korea

Shinduri sand dune is composed of primary dune including foredune and slack, and secondary dune (RYU, 2002). This structure is valuated as Korean natural and representative sand dune structure. But, the coastal dune area of Shinduri has been affected by man-made effects such as afforestation and coastal developments (SEO, 2002). The inner parts of Shinduri sand dune have been destroyed by car entry, private housing construction and human trampling. These disturbances caused exotic and terrestrial plants to invade the sand dune areas considerably. *Ambrosia artemisiaefolia*, *Bromus tectorum*, *Chenopodium album*, *Chenopodium ficifolium*, *Conyza Canadensis*, *Erigeron annuus*, *Lepidium virginicum*, *Medicago sativa*, *Oenothera biennis*, *Polygonum dumetorum*, *Trifolium repens*, *Xanthium italicum*, *Xanthium strumarium*, *Vulpia myuros* were widespread exotic species in Shinduri sand dune area. *Pueraria thunbergiana* population, commonly growing in forested areas, flourish in the northwest coastal sand dune of Shinduri. So, this vine species must be managed to provide other sand dune specific species with light and nutrient.

Restoration Options of Korean Sand Dunes

The role of vegetation in sand dune is preventing sand dune erosion, promoting dune stabilization, and holding underground water. In particular, sand dune vegetation plays an important role in sustaining disturbed sand dune. It is recommended that sand dune surrounding areas be well conserved for restoring the sand dunes because of the fragmentation by artificial activities and the necessities of background supporting areas in South Korea, compared with Shinduri sand dune. The restoration options for sand dune areas in South Korea are as follows: the restoration of other sand dune areas toward the condition of Shinduri sand dune, introduction plant species of Shinduri sand dune into other sand dune areas, prohibition of artificial building and exotic soils, and conservation of sand dune surrounding areas. When introduced plant species, high regenerative capacity of rhizome fragments of sand dune grasses can be used (CORDAZZO and DAVY, 1999).

CONCLUSIONS

The vegetation inventories and quadrat survey on Korean peninsula and Jeju island, the greatest island in Korea were conducted to investigate on the current ecological status and find out the restoration options for Korean sand dunes. As a result, Shinduri sand dune is estimated as a well-conserved model sand dune. The other sand dunes have been destructed by artificial activities, especially such as beach resort and leisure facilities. Communities of sand dunes in Korean peninsula and Jeju Island were classified as 11 and 8. Ordination results show that sand dune structure, exotic species number, and slack width on Korean Peninsula and vegetation width and slack width on Jeju Island are significantly important environmental factors to explain species composition variation. So, It is recommended that conservation of sand dune structure, prevention of exotic species invasion, and expansion of vegetation and slack width are reasonable measures to increase biological diversity on Korean sand dunes.

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