The Effective Wind Velocity and the Patterns of Morphological Change in the Coastal Dune Area

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해안사구에서의 유효풍속과 지형변화

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Abstract : This research is aimed to investigate the relationship of the effective wind velocity and the morphological change in coastal dune at Sindu-ri in Korea. Sediment flux was estimated by the measurement of elevation change along eight transects deployed in the study area from July 1999 to July 2000. The results of this study indicated that, first, based on the occurrence of morphological change and winds effective for sand movement, two distinct seasons were identified: a season of deposition and that of erosion. During the depositional season, spanning from November to April, effective winds were dominant and sand accumulation occurred mainly in foredunes and sequentially in dune plains. During the erosional season, from May through October, volume change was small and erosion or sand loss occurred mostly at the dunefoot of foredunes. Secondly, the research revealed that the sediment budget of Sindu coastal dune turned out to be surplus on the whole, but there are some regional differences. Deficit budgets were observed partly in secondary dunes. The utmost northern part of Sindu coastal dune was provided with abundant sand, whereas the central and northern parts were poorly supplied.
Key words : Morphological change, Sediment budget, Effective wind velocity, Foredune, Secondary dune

요약 : 이 연구의 목적은 태안반도 신두해안사구의 유효풍속과 지형변화의 관계를 밝히는 것이다. 퇴적물의 유동은 8개의 횡단면에서 침식핀을 이용하여 1999년 7월부터 2000년 7월까지 고도변화를 측정한 후 계산되었다. 연구결과가 시사하는 바는 다음과 같다. 첫째, 사구지역에서의 지형변화와 유효풍속에 근거하여 퇴적기와 침식기가 구분되었다. 퇴적기는 11월부터 4월까지로 모래의 집적이 주로 전사구에서 일어났으며 순차적으로 사구평지로 이어졌다. 침식기는 5월부터 10월까지로 전사구의 말단부에서 소규모 침식과 퇴적이 반복되는 패턴을 보였다. 둘째, 조사기간 동안 조사지역에서의 전체 퇴적물수지는 10.2 $m^3/m/yr$로 잉여로 나타났으나 지역적인 차이가 나타났다. 이차사구에서는 결핍되는 곳도 나타났다. 사구지역의 북단에서는 모래의 공급이 활발하게 이루어지고 있는 반면 중앙부와 남부지역에서는 모래의 공급이 빈약했다.
주요어 : 지형변화, 퇴적물수지, 유효풍속, 전사구, 이차사구

INTRODUCTION

The coastal dunes are very dynamic landform, therefore, they are subjected to rapid changes. They are eroded at the time of storm attack, and restored by aeolian deposition through onshore wind effects. These processes of erosion and deposition are controlled by several physical and biological factors: wind velocity, littoral sediment supply, grain size, moisture content, topography, and vegetation etc. (Short and Hesp 1982; Pye 1982; Psuty 1988; Pye and Lancaster 1993). The sediment supply determines the volume of the dunes and controls the dune morphology.

Sediment budget and dune/beach interaction studies are quite abundant (Psuty 1988; Pye and Lancaster 1993; Arens 1994; Davidson-Arnott and Law 1996). These studies have made an attempt to measure and predict sediment transport from the beach to the dunes under different conditions. However, little study has been done on the eolian processes and the dynamic sediment budget of the Korean

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foredunes.

Although many coastal dunes were formed along the coastline, most of them were destroyed, cultivated or artificially vegetated etc. Recently in Korea, public interests about the value and ecological function of the coastal dunes are growing, and also the efforts for conservation and restoration of the coastal dunes are increasing (Ministry of Environment, 2001). For an instance, the Sindu coastal dune field was designated as a Natural Monument No.431 by the Government in Nov. 2001. Therefore, the knowledges about the natural dune forming processes should be researched.

This study is aimed at investigating the morphological change in coastal dunes at Sinduri, and to estimate the annual sediment budget for Sindu coastal dunefield. The sediment budget was estimated with the investigation of elevation change along eight transects in coastal dunes over the period of one year from July 1999 to July 2000.

STUDY SITE AND METHODS

Characteristics of study site

The West Coast of Korea is formed by tidal flats and salt marshes with sandy beaches and rocky shores. Coastal sand dunes are not large or abundant but are regularly present behind the sandy beach (Bird and Schwartz, 1985). Sinduri, a representative coastal dune field, is located in the northwestern part of Tae-an Peninsula (Figure 1). It is one of the largest (3.5kms long and 1km wide) and well-preserved dune field, and it is also the only Natural Monument designated by the Government among the coastal dunes in Korea.

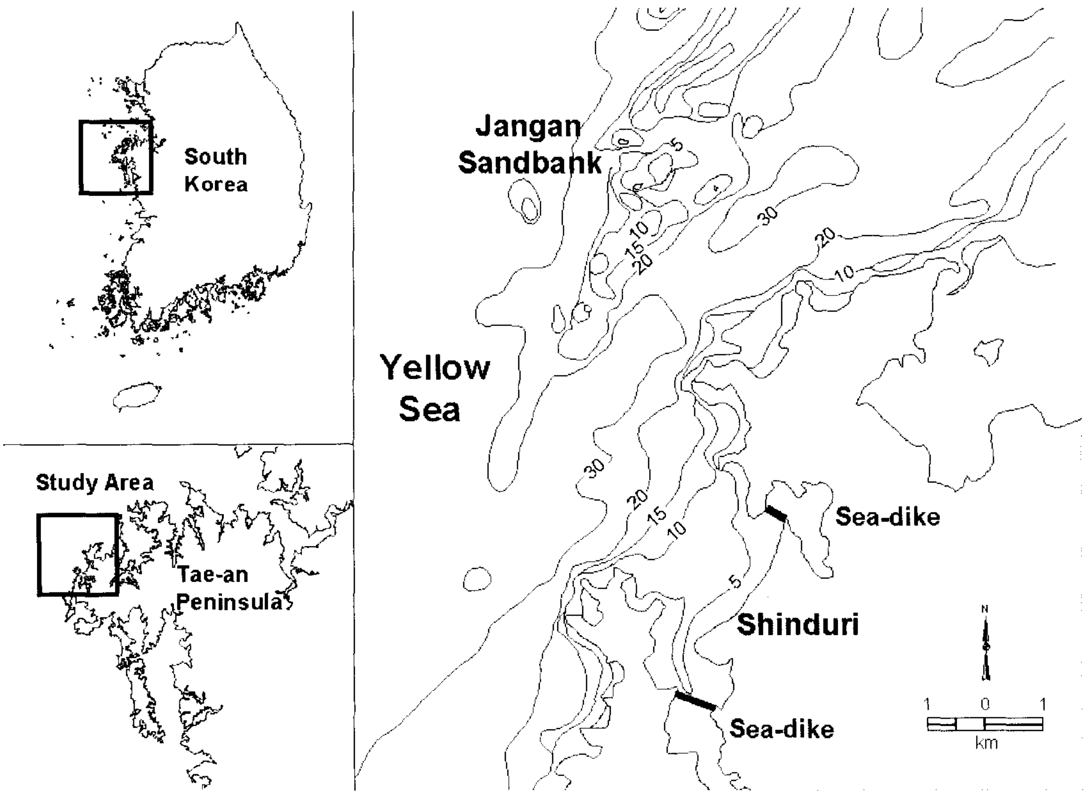

Figure 1. Location map of study area (values mean water depth(m))

The Sindu coastal dune has many conditions that favor dune formation. Firstly, the northwesterly prevails in the winter season when its wind speed is high. Since the orientation of the coastline of Sindu-ri is perpendicular to this wind direction, a landward transport of beach sand during this season is possible. The wind direction during the other seasons is irregular. Secondly, because the landward side of the dune field is confronted with mountains, the velocity of the onshore wind is dropped suddenly, thus blowing sands are deposited. Thirdly, since the beach of the Sindu-ri coast has a moderate low gradient (2-4 degree) and a large tidal range (about 7m), it is a macro tidal environment; a wide beach (200 × 400m) is exposed at low tide. The beach consists of fine grains with a mean size of approximately 0.25㎜. Fourthly, the sea floor, northwest of Tae-an Peninsula, consists of many large sand banks at a depth of approximately 40m (Choi et al., 1992). The above mentioned facts suggest that large amounts of beach sand will be provided to the coastal dune field.

Despite these favorable conditions, Sindu-ri also has many unfavorable factors for dune building. They are land use for agriculture, tree planting to prevent sand encroachment, and cattle grazing, etc. And Sindu coastal dune field has recently experienced various, serious problems such as sand dredging, constructing villa for

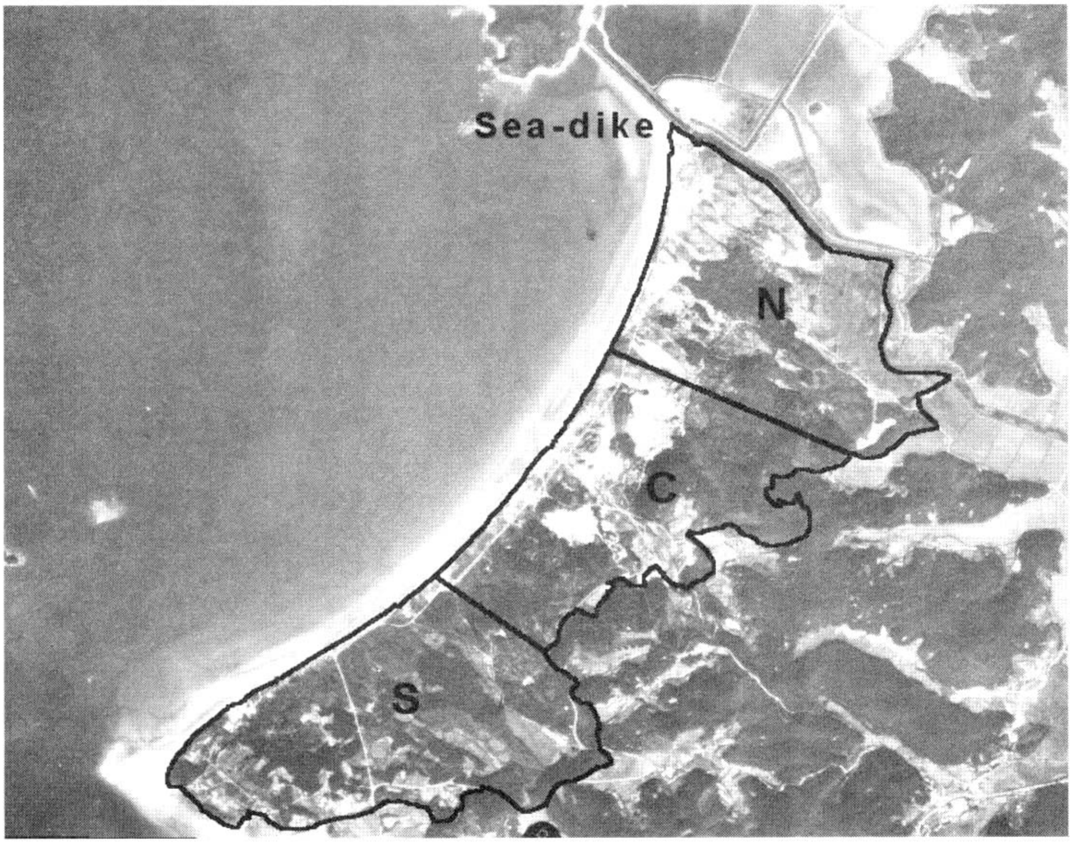

Figure 2. Aerial photograph of Sinduri region (Solid line indicates the dune area).
Data : National Geographic Information Institute

N: Northern part, C: Central part, S: Southern part.

leisure, constructing a sea-dike and a sea-wall, etc. Small bays, consisted of muddy tidal flats and tidal creeks had existed in the north and south of the dune field. However, they were embanked for the purpose of farming by the construction of a sea-dike. A sea-wall, which is made of large stones, was constructed in front of the foredune in the southern part. These factors will have undesirable effects, such as modification of the dune morphology, destruction of the vegetation cover, acceleration of the beach erosion, and reduction of sand supply to dune field.

The Sindu coastal dune is devide into three areas according to dune landscape: a northern, central and southern area (Figure 2). The northern area of the dune field consists of a high foredune and several high, undulating secondary dunes. Both are covered by grass and shrub plants such as *Carex kobomugi, C. pumila, Ischaemum anthephoroides, Elymus mollis, Messerschmidia sibirica, Imperata cylindrica, Vitex roundifolia* and *Rosa rugosa* etc. The central area consists of a low foredune, a low and flat slack, and a single, high secondary dune. Its vegetation type is similar to the northern part. The southern area consists of a low foredune, a broad low and flat slack, and several high secondary dunes, but it is largely covered by tree species *Pinus thunbergii, Salix koreensis,* and *Robinia pseudo-acasia.* These trees were planted about two decades ago.

Methods

During the study period, meteorology and morphological change in Sindu dunefield were monitored through the Automated Weather Station (AWS) and eleven selected transects on which erosion pins were deployed. Meteorological data were used to complement the climate data from Seosan station and to calculate the statistics on effective winds that could transport beach sands to the dunefield. The morphological changes in Sindu dunefield were approached through traditional erosion pin method.

Meteorological data capturing

Meteorological data including temperature, precipitation, wind velocity and direction were collected from the Automatic Weather Station set up on the central area of the dunefield during the study period (Figure 3). Temperature and precipitation were measured 1.5m above the ground. Wind velocity was measured with Gill -type 3 cup anemometers and wind direction with a wind vane at 10m above the ground. Data were monitored at 1-hour intervals and the statistics of the data (mean and maximum wind speeds, and etc.) were calculated from these data.

Effective wind velocity

The effective wind velocity is defined as the wind velocity over which aeolian sand transport occurs on the surface. In Sindu coastal dune, the effective winds usually transported beach sand to the dunefield. The velocity of effective wind was calculated from the measurements at 10m above the ground in this study, using Bagnold's equation and general wind profile equation. In Bagnold (1941) the threshold shear velocity V_{*t} is calculated as:

$$V_{*}t = A\sqrt{\frac{\sigma - \rho}{\rho} gd} \qquad \text{(1)}$$

where

A : a dimensionless constant (0.1)

σ : grain density (quartz: 2,650 kg/m^3)

ρ : air density (1.248 kg/m^3 at t = 10 and p = 1013 hP)

g : acceleration due to gravity (9.8 m/s2)

d : grain diameter (m)

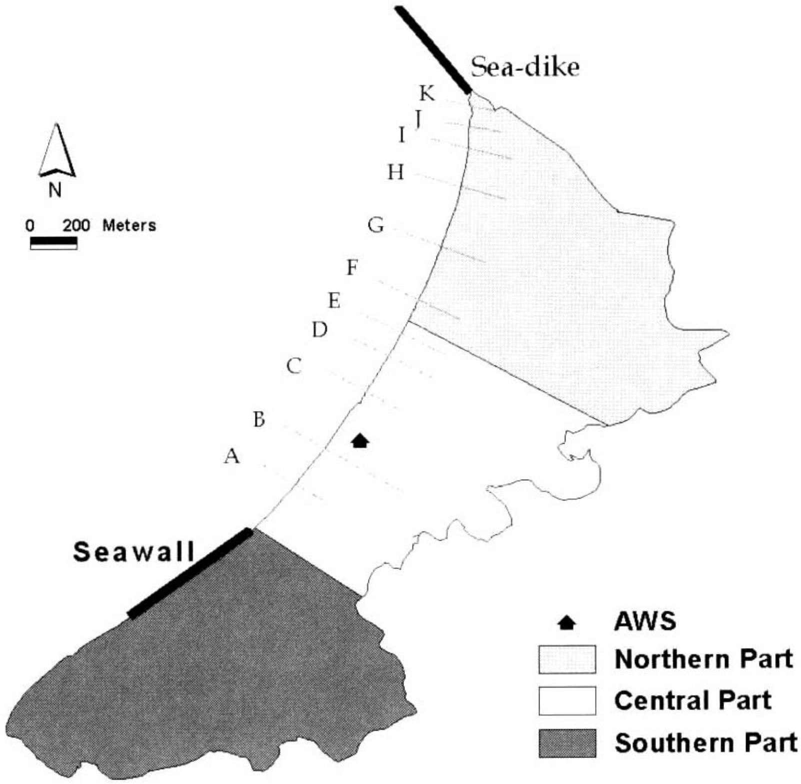

Figure 3. Location of AWS and transects

According to the general wind profile equation, wind velocity at height z for sand transport (V_z) is calculated as:

$$V_z = \frac{V_{*t}\left(\ln\left(\frac{z}{z_0}\right)\right)}{\kappa} \quad \cdots\cdots (2)$$

where

- z : height of measurement of wind velocity (10m)
- z_0 : the roughness length of dune sand (corresponding to the elevation at which wind speed goes to zero)
- κ : von Karman's Constant (0.4)

According to these equations, the range of effective wind velocity in the study area is calculated between 5.9 and 10.1m/s because more than 98% of the sand is in the size range from 0.13㎜ to 0.50㎜. Thus, the wind whose velocity is faster than 6m/s is regarded as the effective wind in this area.

Monitoring of elevation change at each transect

Morphological changes in coastal dunes were monitored at the eleven selected transects (Figure 3). Five transects were installed in the central area and six transects in the northern area. However, three transects, A (central), B (central), and K (northern), were excluded since they were disturbed by human actions such as road and building construction and sightseeing over the study period. The actual monitoring was performed at eight transects (Figure 4). Each transect had 15 to 20 measuring points.

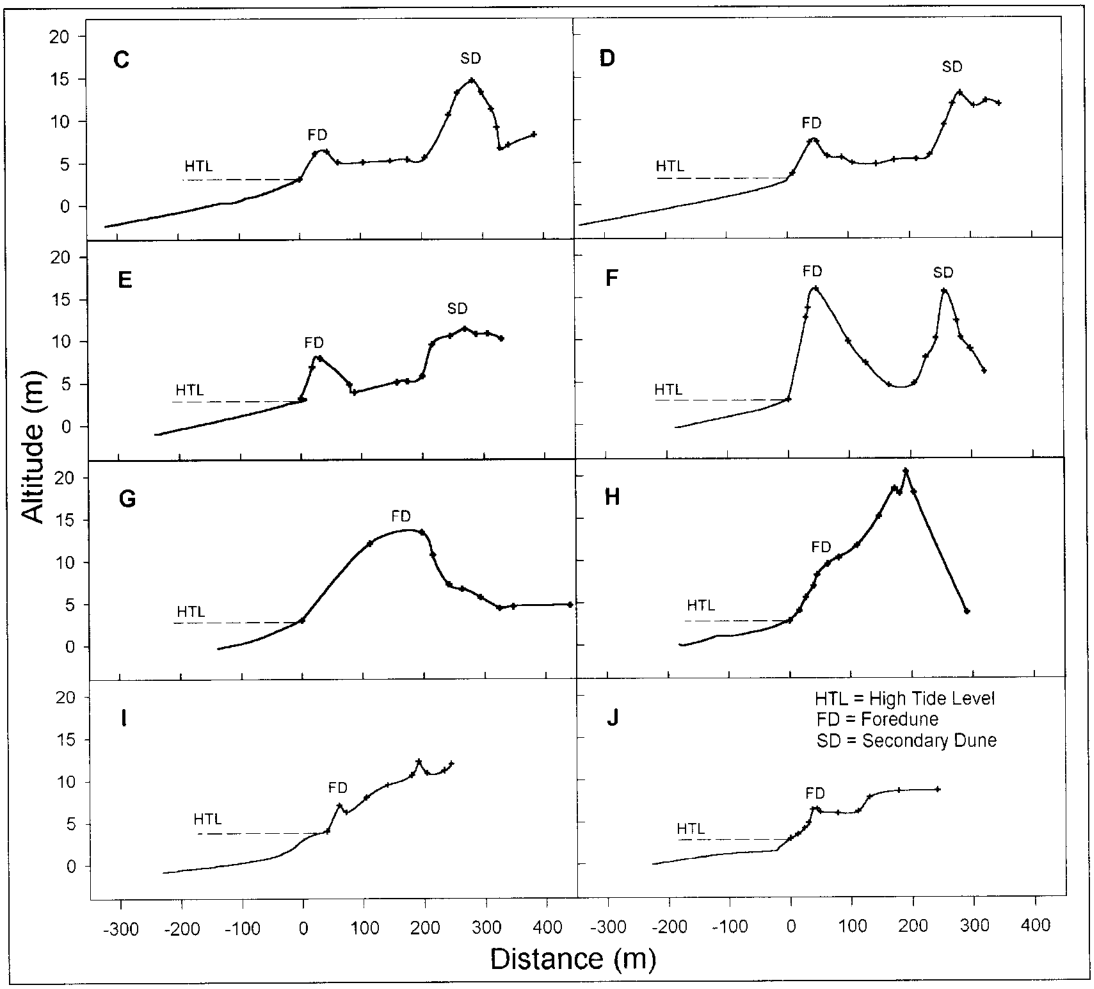

Figure 4. Dune Profiles of the each transect and location of the surveying points (+ symbol)

Erosion pins, 5cm by 5cm by 50cm, were deployed at each point. The vertical differences between the top of each pin and the surface of the ground were measured 21 times from July 24, 1999 to July 25, 2000.

The transects C, D, and E were located in the central section of the study area. The heights of foredunes were measured at 5-7m above mean sea level. Their slope was gentle (approximately 10-20 degree). The area behind the foredunes was rather flat and its elevation was only around 4-5m. Various sizes of dune slack wetlands were also apparent. A large secondary dune with an elevation of 15-20m lies behind them.

The transects F and G were located in the northern section of the study area. The heights of the foredunes were around 15-17m above mean sea level. They have a steep slope (approximately 40-60). Well developed dune cliffs were found in front of the foredunes. The area behind the crest was highly undulating with an altitude ranging from 5 to 19m above mean sea level.

The transects H, I, and J were also located in the northern section of the study area. The heights of the foredunes were approximately 6-8m, with a gentle slope (approximately 10-20). The landward side of the foredune ridge was relatively smooth.

Based on the morphology and height of the dunes, C, D, E and F were subdivided into three sections such as foredune (FD), and dune plain (DP), and secondary dune (SD), whereas transects G, I, and J were subdivided into two sections such as foredune (FD) and dune plain (DP). Transect H was subdivided into two sections such as foredune (FD) and secondary dune (SD).

The volume changes at each transect were calculated based on

$$\frac{\Delta V}{w} = \Delta S = \sum_{i=1}^{m-1} Li \cdot \frac{\delta_i + \delta_{i+1}}{2} \quad \cdots\cdots\cdots\cdots (3)$$

where

w : the distance between midlines of two adjacent transects

ΔV , ΔS: change of volume, change of cross section

L_i : distance between (i)-th erosion pin and (i+1)-th one

δ_i : elevation change at i-th erosion pin.

Using this equation, volume change per unit length of the shore was calculated for the totals and sub-sections of each transect.

The transects C, D, and E were located in the central part of the study area. The height of foredune was approximately about 5-7m, and its slope was gentle (approximately 10-20 degree). The backdune area was very even and its height was only around 4-5m. Various sizes of wet dune slacks appeared in this area. The landward edge of the dune field consisted of a large secondary dune of with a height of 15-20 m.

The transects F and G were located in the northern part of the study area. They were approximately 15-17m high and had a steep slope (approximately 40-60 degree). A well-developed dune cliff was found in front of the foredune. The backdune area was highly undulating with an altitude ranging from 5-19m.

The transects H, I, and J were located in the northern part of the study area. They were approximately 6-8m high with a gentle slope (approximately 10-20 degree). The foredune on the landward side was relatively smooth.

RESULTS AND DISCUSSION

Meteorological data

Temperature and Precipitation

The annual average temperature of Sinduri is 11.6℃. In winter, the daily minimum temperature often falls below 0℃. As a result, the dune surface is frozen and consequently no movement occurs. The annual precipitation is 1371.5㎜. Most of the precipitation is concentrated in the summer, especially between June and September (Figure 5). The rainy season in Korea, a.k.a. Jangma, usually starts late June and finishes late July. Approximately more than a half of the annual precipitation falls during this period. After Jangma season, intensive rainfall is mainly caused by Typhoons. On average, typhoons pass through Korea during this period twice a year.

General wind regime and effective winds

The annual mean wind velocity was approximately

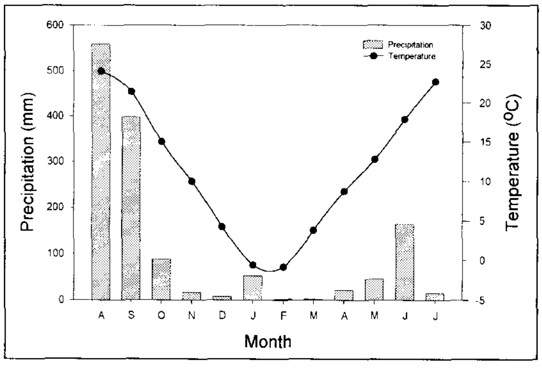

Figure 5. Temperature and Precipitation in Sinduri from Aug. 1999 till Jul. 2000.

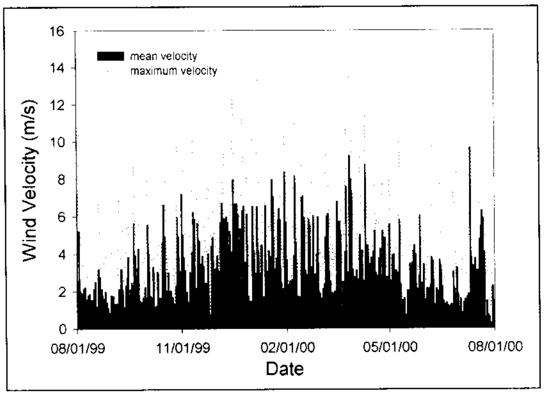

Figure 6. Distribution of daily mean and maximum wind velocity

3 m/s. The wind speed was usually higher in the winter season, especially from November to April (Figure 6). Furthermore, the prevailing wind direction during the winter season is northwesterly, therefore, a large amount of sand can move from the beach into the dune field (Seo, 2001; Woo et al., 2002).

The effective wind velocity, which is able to transport sand from the beach and dune surface, was calculated from AWS data using Bagnold's equation. In the study area, more than 98% of the sand is in the size classes from 0.125㎜ to 0.5㎜ (Seo, 2001). Solving these equations for the values of d and, Vz at 10m height resulted in measurements between 5.9 and 10.1m/s. Thus, the threshold wind velocity for sand transport calculated in this way is approximately 6 m/s.

Effective wind was mainly occurred from November 1999 to May 2000 (Figure 7). This result agreed with the above facts, which showed a general distribution of wind velocities. Table 1 shows the cumulative time with wind velocities over 6m/s during each monitoring period. The effective wind speed appears to concentrate between December and early April; during this period, effective winds blew over 3.8 hours a day on average. The competence or capacity of winds was high during the winter and spring seasons, from December and early April, in the study area. The main directions of effective winds were N and NNW, or roughly onshore in direction, in the study area, and are well in accordance with those of the sand movement from beach to the dunefield (Figure 8).

Morphological changes

The spatial and seasonal pattern of the sand volume changes were analyzed by using the

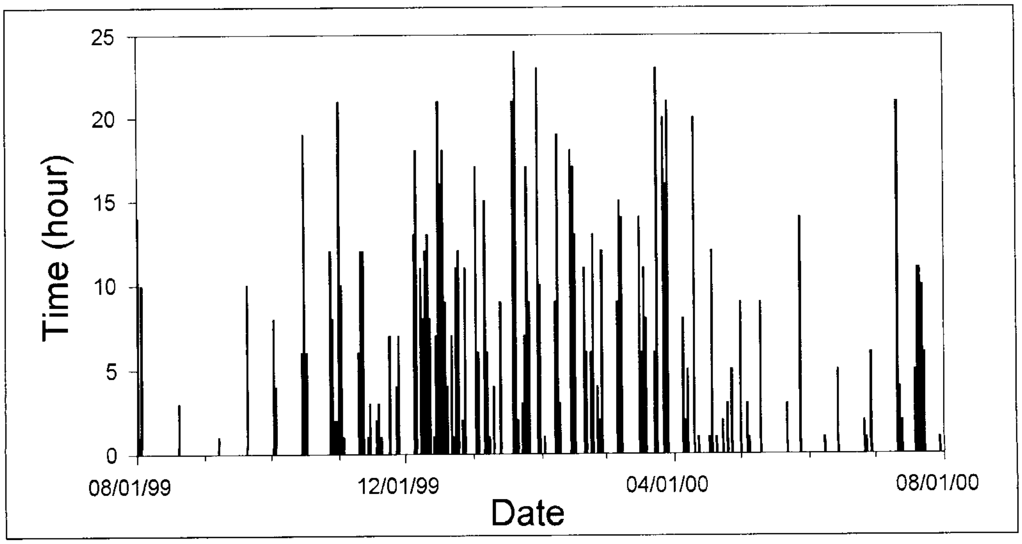

Figure 7. Distribution of effective wind with over 6 m/s

Table 1. The characteristics of Effective winds over the study period

Period	Hours of effective winds	Mean daily hours of effective winds	Period	Hours of effective winds	Mean daily hours of effective winds
'99. 08.01-08.10	23	2.3	'00. 01.15-02.12	146	5.0
08.11-09.04	3	0.1	02.13-02.26	84	6.0
09.05-10.02	16	0.6	02.27-03.11	49	3.8
10.03-10.23	33	1.6	03.12-03.25	65	4.6
10.24-11.06	55	3.9	03.26-04.08	71	5.1
11.07-11.20	37	2.6	04.09-04.22	32	2.3
11.21-12.01	16	1.5	04.23-05.08	20	1.3
12.02-12.17	123	7.7	05.09-06.05	26	0.9
12.18-12.30	62	4.8	06.06-07.02	14	0.5
12.31-01.14	57	3.8	07.03-07.24	67	3.0

** Note. Figures in shadow tones indicate mean daily hours of effective winds above 3.8 hours/day. It shows that high values were concentrated upon the period from December to April.

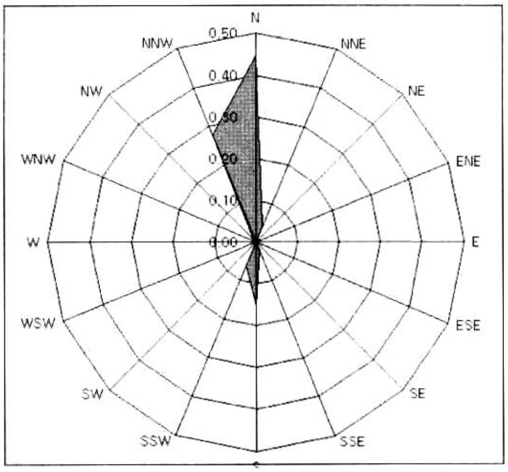

Figure 8. Distribution of wind direction for effective winds

monitored elevation data. The term of 'spatial' means the differences in the volume changes among transects in the study area and differences among the monitoring sites on each transect.

Seasonal pattern of the elevation changes

Because the numerous factors such as wind speed, wind direction, vegetation cover, and moisture content of the dune surface, etc. are different from the variable conditions, a sediment transport pattern in the coastal dune area is also different from time to time. In the study area, the competence of winds varied with the seasons (see above section). This resulted in the observation of a recognizable seasonal pattern of morphological change in Sindu dunefield.

Usually, the sand transport from the beach into the foredune area is related with increasing wind velocity in winter. In the study area, because offshore winds (blowing from the northwest) exceeded the threshold velocity for sand transport between October and March (Figure 7), cross shore transport could be generated in these period. Table 2 and Figure 9 illustrate the seasonal variation in volume change of the dunefield. From the standpoint of morphological change, there were two distinct seasons: a depositional season and an erosional season.

The depositional season spanned from November to April during which effective winds were more dominant than over other periods. Over this period, the rate of total volume change reached as high as 52.7 m^3/m/yr. Total volume increase was caused mainly by the growth of foredunes, and as time went on, the volume of the dune plain grew. This indicated that the sand moved again from foredunes to inland. Erosion or sand loss occasionally occurred at the

Table 2. Seasonal pattern of the elevation changes (unit = cm)

	9/4	10/2	10/28	11/6	11/20	12/1	12/17	12/30	1/14	1/29	2/12	2/26	3/11	3/25	4/8	4/22	5/8	6/5	7/2	7/24
C	0	-25	5.1	0	0	-1.8	41	22	31	17	-0.8	32.1	4.9	1	0	0	0	0	-8	-4
D	0	0	0	0	5.2	4	20	27	5	0	-15	15	0	0	-5	0	2	-3	-4	2
E	0	0	-8	-3	12	0	0	-30	16	-13	2	3	-4	0	4	0	0	-14	0	4
F	0	0	0	0	0	0	3	0	0	8	0	0	0	0	0	0	0	-0	0.2	0
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	0	20	0	-4	16	1	0	25	2	-5	9	24	-1	-10	3	0	0	-4	0	-9
I	0	0	0	0	3	14	-1	27	42	15	0	0	7	8	-2	0	3	0	0	-7
J	0.4	0	2	0	1	54	61	75	56	54	33	47	3	0	9	1	0	0	0	0
TOT	0.4	-5	-0.9	-7	37.2	71.2	124	146	152	76	28.2	121	11.9	-1	9.1	1	5	-26	-7	-14

secondary dune during the same period, although the rate of sand loss was lower than that of sand gain in the foredunes. The wind erosion was due to the poor vegetation conditions of the secondary dunes. The transportation of dune sands inland was mainly by means of this mechanism.

On the contrary, an erosional season was between May and October. During this period, the amount of volume change was smaller than that over the depositional season. In contrast to the observation that erosion or sand loss was dominant in secondary dunes during the depositional season, erosion occurred mainly at

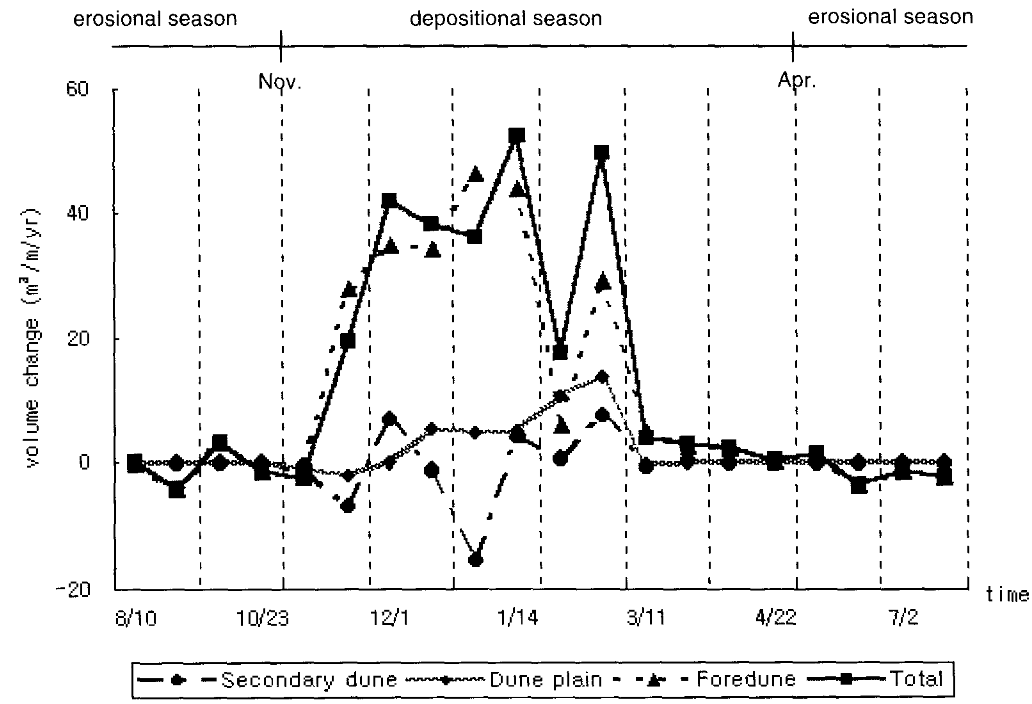

Figure 9. Seasonal volume change in Sindu dunefied

the dune foot of foredune ridges over this period. This may have been due to the wave attack generated by storms, and by means of this mechanism, dune sands in the foredune ridges were transported to the beach and tidal flats.

As a result, almost all the volumetric changes occurred in the winter season, especially from December to February. In the other period, deposition and erosion processes alternated on a small scale (Figure 9).

Spatial pattern of the elevation changes

Table 3 presents the cumulative volume of elevation changes on each transect between Jul 1999 and Jul 2000. To calculate the volumes, the width of the profiles is assumed to be 1m. The annual deposition and erosion volume for each profile has been acquired by adding up the positive and the negative elevation changes respectively. The annual sediment budget is the difference between the annual deposition and erosion volume, positive in case of net deposition, negative in case of net erosion, that is divided by the length of the profile. This results in the annual deposition or erosion 'disc' respectively.

Deposition and erosion processes in the study area show three spatial patterns (Figure 11). Firstly, In the transects C, D, and E, deposition occurred at the front side of the foredune and the landward side of the secondary dune, and erosion occurred at the front of the secondary dune. Erosion in the secondary dune was especially extreme on transect E. In transects C and E, deposition occurred at the front or seaward side of the foredune and the landward side of secondary dunes, and erosion occurred at the front of the secondary dunes. The erosion of the secondary dunes was extreme in transect E, but erosion processes were not observed in the secondary dunes in transect D. These patterns of morphological changes can affect the dune plants, therefore, a zonation in the vegetation distribution results in the dune area. *Elymus mollis* and *Carex kobomugi* with a sparse density are dominant species in the foredune area, and *Imperata cylindrica* with a high density in the backdune area. *E. mollis* and *C. kobomugi* are growing well on the unstable sand dune, *I. cylindrica* is a mesic species which grows in the general environments (Min and Je, 2002).

Secondly, in the transects F and G, small or no amount of sediment was deposited at the dunefoot area, and significant changes were not detected at the backdune area, especially at

Table 3. Sediment volume changes in the study area

Trans	Beach width(m)	Annual depostion volume(m^3/yr)	Annual erosion volume(m^3/yr)	Annual sediment budget(m^3/yr)	Annual sediment budget(m^3/m/yr)
C	109	1,954	978	976	8.95
D	103	887	0	887	8.61
E	129	374	1,299	-925	-7.17
F	219	672	0	672	3.07
G	285	0	0	0	0
H	202	1,641	0	1,641	8.12
I	123	3,686	0	3,686	29.97
J	136	8,421	0	8,421	61.92
TOT	1,307	17,635	2,227	15,358	11.75

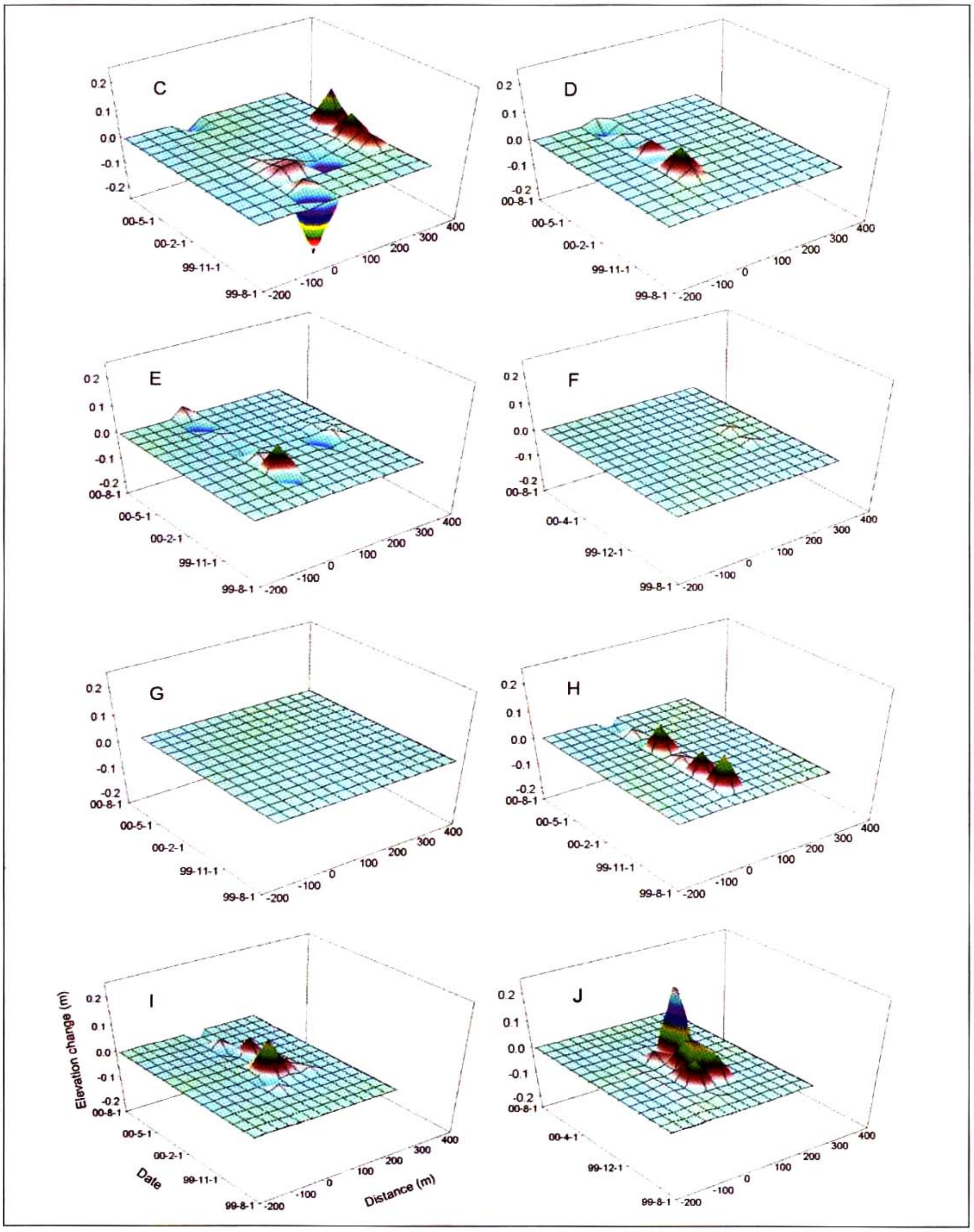

Figure 11. Seasonal and Spatial patterns of the elevation changes from 8 transects

Profile G. Vegetation densely covers the dune surface, except for small blowouts in these transects. *I. cylindrica* are the dominant species in the foredune and backdune area, except for the dunefoot area with *E. mollis*. These facts reveal that no net input occurred. And in the foredune area of transect G no natural vegetation occurs, because the upper part of the foredune has been destroyed.

Thirdly, in the transects H, I, and J, deposition occurred rapidly on the front side of the foredune; erosion did not occur anywhere. The changes in elevation of transect J were remarkably large. *E. mollis* and *Ischaemum anthephoroides* are the dominant species in the foredune area, and *I. cylindrica* in the backdune area. *I. anthephoroides* is another species which grows in unstable conditions (Min and Je, 2002).

The changes in elevation of eight transects were converted to annual volumetric variations between July 1999 and July 2000 (Table 3). The total sediment accumulation during the study period was 15,358 m^3/yr or 11.75 m^3/m/yr for the overall area. The differences between the sand transport rates of the eight transects are very high, from -7.17 m^3/m/yr or -925 m^3/yr at the transect E to 61.92 m^3/m/yr or 8,421 m^3/yr at the transect J. These facts reveal that deposition exceeds erosion, and two processes occur at the different places; deposition process occurred at all transects except G, but erosion was observed in only two transects, C and E.

Consequently, two patterns were discovered from this study. Firstly, the sand deposition occurred at all transects, especially ones in the northern part, but the sand erosion occurred in the central part of the dune field among the eight transects. Secondly, in the point of the each transect, the sand deposition mainly occurred in the front of the foredune and the rear side of the secondary dunes, but the deposition occurred in the front of the secondary dunes.

According to preexisting studies, a mean value of 11.75 m^3/m/yr or a highest value of 61.92 m^3/m/yr is very high compared to other values from coastal dune areas (Table 4). This means that Sindu coastal dune field is very active. But a careful access is necessary, because these active processes could be derived from man-made structures, such as sea-dikes on both sides and the seawalls in front of the foredune.

CONCLUSION

Seasonal and spatial patterns of the morphological change in the Sindu coastal dune field were investigated during one year. The total sediment accumulation during the study period was 15,358 m^3/yr or 11.75 m^3/m/yr, and it's value is very high, compared to other coastal dune areas. But the morphological changes mainly occurred in winter, from November 1999 to February 2000, and also deposition and erosion of sediment occurred in the different places.

In the winter and spring season, the sand transports from the beach into the foredune area actually occurred, and the transported sands were deposited at and near the foredune area

Table 4. Examples of sand transport rates or sediment budget measured in other area

Researcher	Sand transport or sediment input (m^3/m/yr)	Study site
Goldsmith et al. (1990)	0.1~0.2	Israel coast, Israel
Nordstrom and McClucskey (1985)	1.95	Fire island, NY, USA
Lin (1995)	6.9 (4.97~7.25)	North Carolina, USA
Illenberger and Rust (1988)	21 (15~30)	Alexandria coast, SAR
Hunter et al. (1983)	34~42	Oregon coast, US

and at the rear side of the secondary dunes. It is assumed that a high speed (over 6 m/s) northwesterly wind might have caused the beach sands to transport. The largest amount of sand was deposited in transects I and J, near the sea-dike in the northern tip of the dune field. In the summer and early fall season, most of foredune front was eroded, but its amount was very small. But irregular stormy conditions will cause a large scale erosion in the foredune area.

From these results, we found Sindu coastal dune filed is very active and has a large variation in the seasonal and spatial patterns. There is few information for the Korean coastal dune fields, therefore, much more researches and concerns about the coastal dunes are needed.

The annual sediment budget and the morphological change of the Sindu dunefield were estimated through the traditional approach of employing the pin method. The results are as follows.

The seasonal pattern in volume change reveals two seasons could be identified in Sindu dunefield: a depositional season and an erosional season. The depositional season, spanning from November to April, was the time when effective winds were most concentrated. The main directions of the effective winds were roughly towards shore, N and NNW, resulting in more opportunities for beach sand to be transported to the dunefield. The rate of volume increase rose up to 52.7 m^3/m/yr. During this season, aeolian sands settled first in the foredunes and later on the dune plain. In secondary dunes, however, sand loss occurred, mainly due to wind erosion, whose directions were roughly landward. On the contrary, during the erosional season, form May to October, the amount of volume change was rather small. Erosion took place at the foot of foredunes, largely owing to wave attacks generated by storms.

Sindu dunefield showed globally positive sediment budget over the study period, but there were spatial variations in volume change. The utmost northern area was provided with abundant sediment; even the dune plain experienced volume increase. However, the central and northern areas were supplied relatively poorly. Most of the imported aeoliansand was stored up in the foredune ridges, and sand movement landward from foredune ridges seemed not to be active even during the winter and spring seasons. Finally, the value of mean annual sediment budget in Sindu dunefield appears to be among the highest of coastal dunes over the world.

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