Impact of Coastal Vegetation on Beach Topography Change

Fuminori Kato [1]
Shinji Sato [2]
Kenichi Torii [1]

[1] Public Works Research Institute, Ministry of Construction,
Asahi 1, Tsukuba 305-0804, Japan
[2] University of Tokyo, Hongou 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan

ABSTRACT

Coastal vegetation on sandy beach has effects on topography change due to wind. Field observation on the effects was conducted in consideration of time scale. The short-term effect of coastal vegetation to decrease wind-blown sand on sandy beach was recognized with data of wind and wind-blown sand transport rate. The long-term effect of coastal vegetation on topography change was found to depend on plant community by measurements of beach topography and vegetation.

Key Words: Coastal Vegetation, Beach Topography, Wind-blown Sand

1. INTRODUCTION

On sandy beach, coastal vegetation has some impacts on beach topography. A evidence of the impacts is the fact that beach slope tends to change at the border between bald area and vegetation area. The other evidence is that area covered with grass tends to be higher than area in the circumference. That is because coastal vegetation on sandy beach influences sand movement due to waves, reduce wind near beach surface where wind-blown sand transport rate is maximum, and trap wind-blown sand. It is also pointed that vegetation is indispensable for dune stability.

In some coasts, sand loss toward hinterland due to wind can not be ignored to maintain the total amount of sand in coastal area, although the amount of sand transport due to wind is thought to be less than that due to waves and currents. To prevent the sand loss toward hinterland is necessary as a shore protection. Generally speaking, wind-blown sand and sand loss toward hinterland are small on coasts widely covered with grass. This indicates that impacts of coastal vegetation on beach topography change must be evaluated quantitatively.

We conducted field observation on impacts of coastal vegetation on beach topography (Kato & Sato, 1998a; 1998b). In this paper, effect of coastal vegetation to trap wind-blown sand is

classified according to time scale.

2. EFFECT OF COASTAL VEGETATION TO DECREASE WIND-BLOWN SAND

Grass on sandy beach can be divided into two categories; one is creeper which extends stem on the ground, the other is grass that extends underground stem. The latter may grow vertically to put its leaves again in the air when its reefs are buried with sand. Figure 1 shows underground stem of *Carex kobomugi*. The underground stem extends horizontally in 15-18 cm depth. It indicates that the ground surface was at 15-18 cm depth one year ago.
Vegetation response against sand deposition can be drawn in Figure 2. On sandy beach, the part of the grass in the air traps wind-blown sand. As sand deposits near the grass, the part of grass in the air is buried. The grass has no effect to trap wind-blown sand when all parts of the grass are underground. After that, the buried grass extends stems, leaves and roots

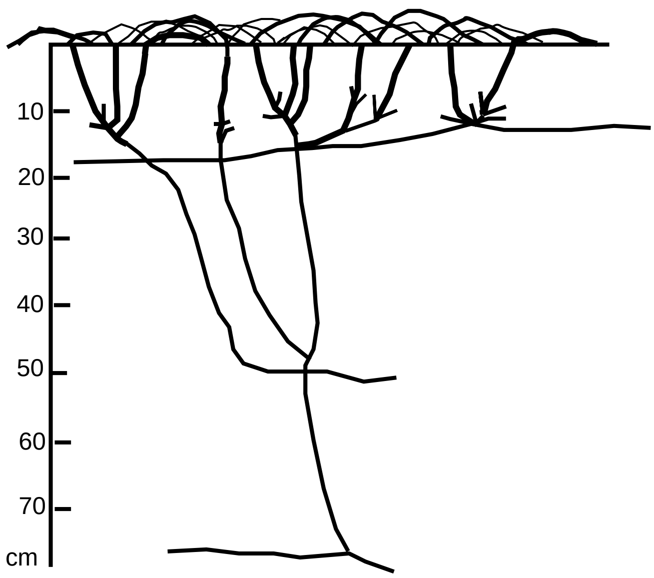

Figure 1 Underground stem of *Carex kobomugi* (Nobehara, 1975)

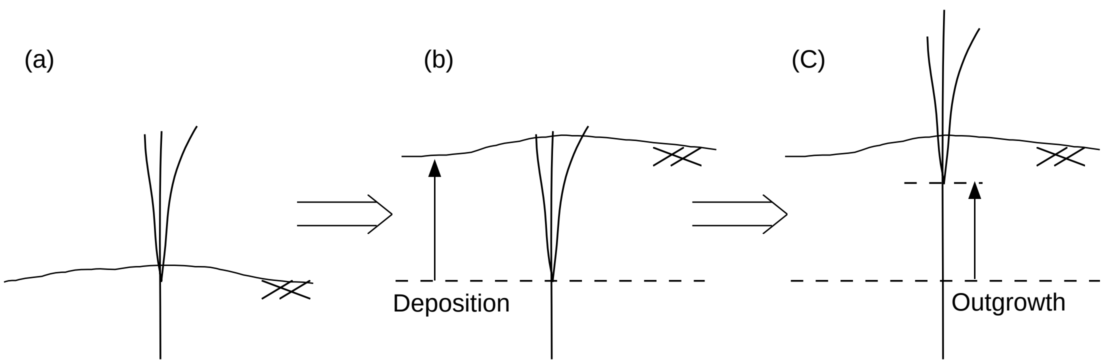

Figure 2 Vegetation response against sand deposition

out of the ground. The grass emerges again, fixes sand with underground stems and roots, and restarts to trap wind-blown sand. This phenomena indicates that effect of vegetation to trap wind-blown sand can be divided into the short-term with the part of grass in the air and the long-term due to the growth of the grass.
The short-term effect to trap wind-blown sand will be described in chapter 3, and the long-term effect will be done in chapter 4.

3. SHORT-TERM EFFECT TO DECREASE WIND-BLOWN SAND

Field observation on short-term effect to trap wind-blown sand was conducted on Komatsu Beach, where is almost at the center of Kujukuri Coast in Chiba Prefecture. Komatsu Beach is located about 4 km northeast of Fishing Port of Katakai. The width of the beach was about 100 m. Continuous sand dune was located between the beach and windbreak forest. The height of the dune was about 6 m, almost same as the height of the windbreak forest. There were many small dunes and hollows on the beach. Grass generally seen on sandy beach flourished on the beach. Figure 4 shows beach profile on 5 lines as shown in Figure 5. Survey area was about 500 m long in longshore direction, between shoreline and the front of the forest. There was a concrete embankment in the survey area. The embankment was buried with sand except its crest of about 2 m wide. Median grain size was about 0.15 mm at 4 points on the beach (shoreline, the seaward boundary of vegetation area, the center of vegetation area, the rear of vegetation area).
Beach topography change due to wind was thought to be large since grain size was small.

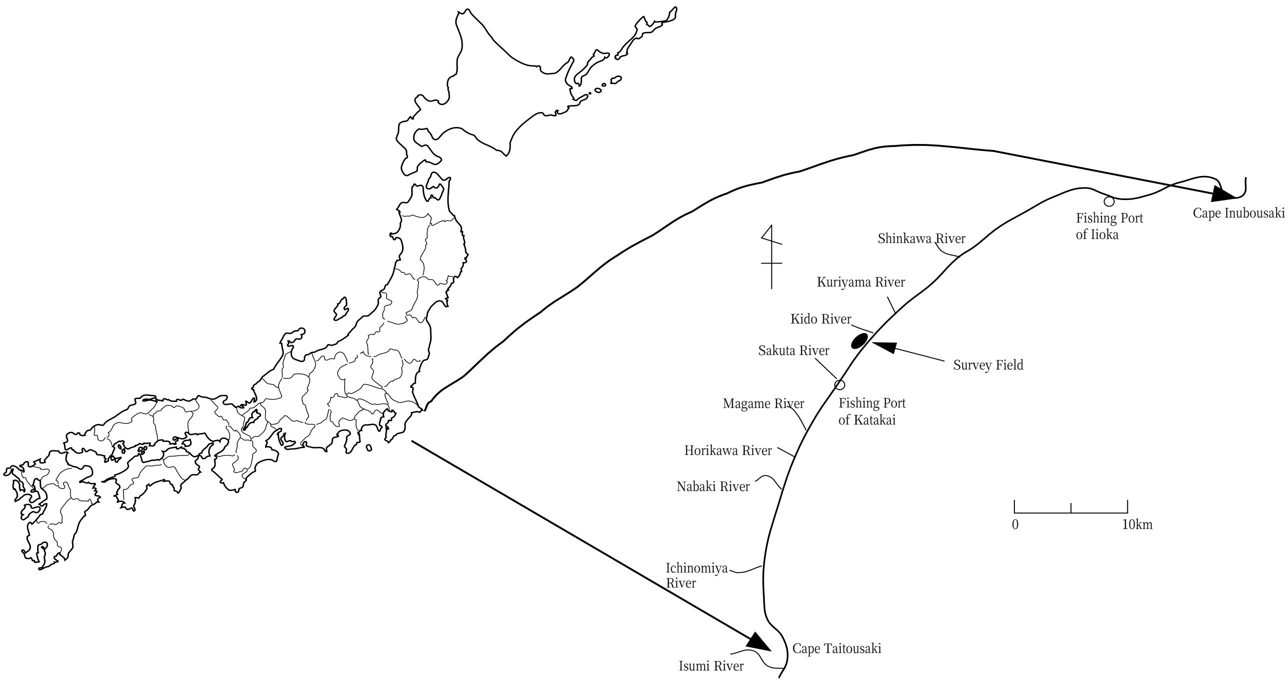

Figure 3 The location of the survey field

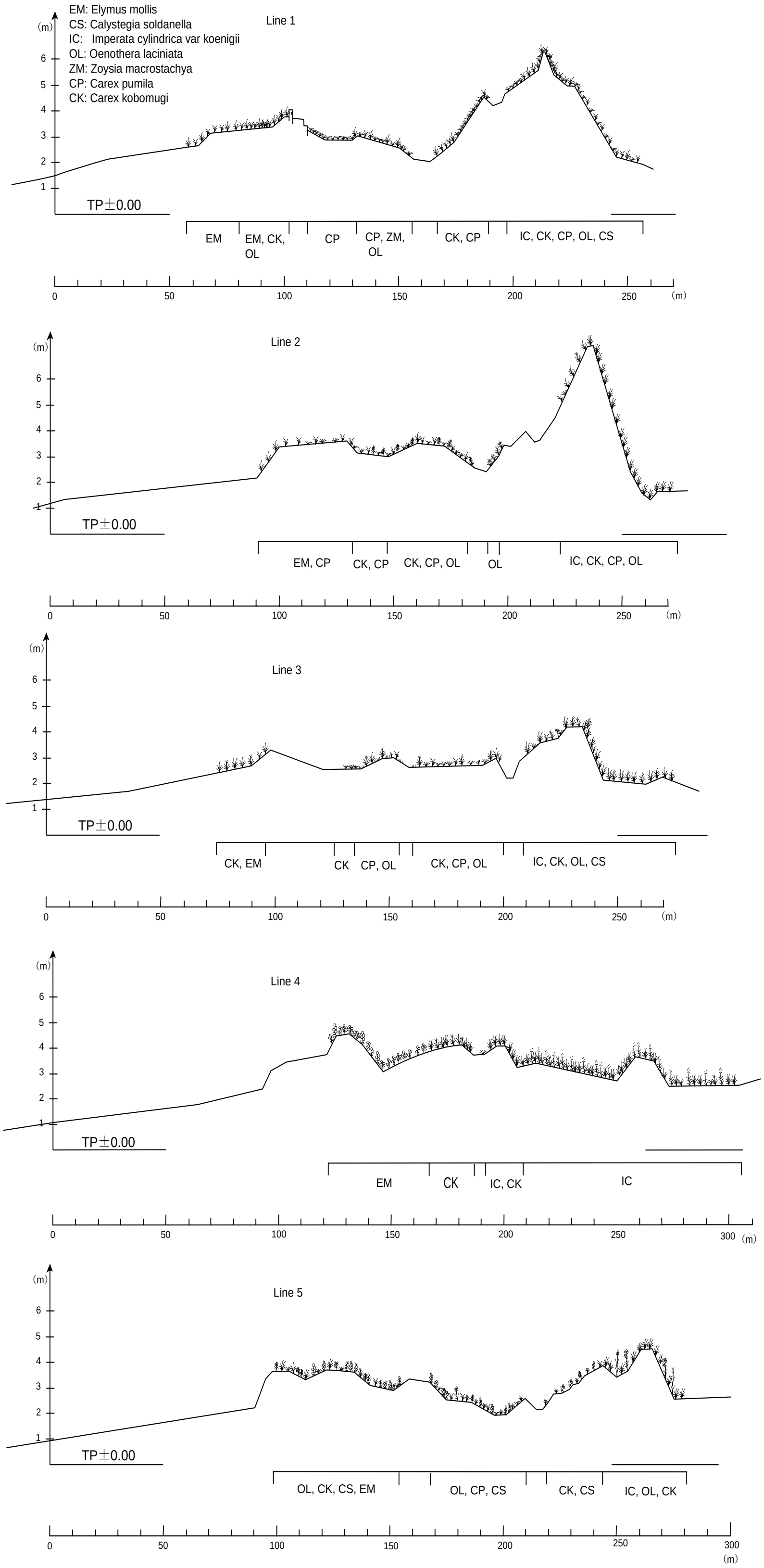

Figure 4 Beach profile in Komatsu Beach

Since wind close to the ground related to wind-blown sand directly was influenced by local topography, it was expected not to be uniform. Therefore we measured wind and wind-blown sand on site in Komatsu Beach. The measurement was conducted February 21, 1997. As shown in Figure 5, wind 1 m above the ground was measured at 4 points located in cross-shore direction (between shoreline and the seaward boundary of vegetation area, the seaward boundary of vegetation area, the center of vegetation area, in front of the dune). Wind-blown sand was also measured at 4 points in cross-shore direction in 2 lines. Wind and wind-blown sand was measured for 10 minutes every hour. Wind-blown sand was trapped by a box of 60 cm wide, 200 cm long. The box was settled in the ground in consideration of wind direction. Water content of sand was 0.3-0.4 % in trapped sand, 2.7-4.2% in the surface of the ground near sand traps. Although the weather was fine at the beginning of the measurement, it rained for several minutes before noon.

Figure 6 shows instantaneous wind velocity and wind direction at the top of a tower (T.P. 38.2 m) in Hasunuma Beach Park in February 21. The Park was located 2.5 km northeast from Komatsu Beach. This figure indicates that wind direction changed around 11:30 and that wind velocity decreased gradually.

Figure 7 shows average wind velocity for 10 minutes and wind-blown sand transport rate at

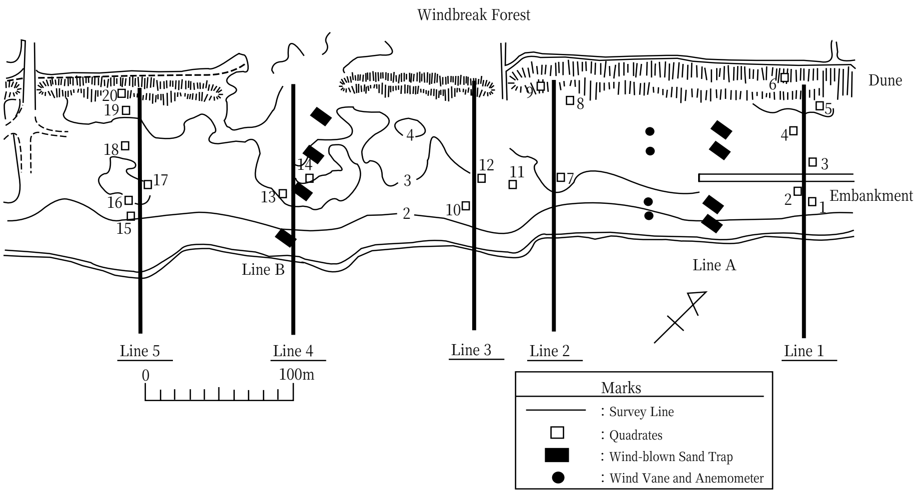

Figure 5 The location of survey lines and quadrates

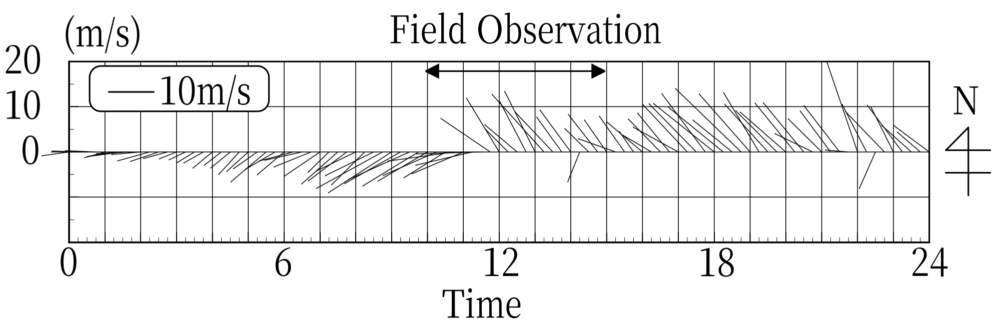

Figure 6 Wind at the top of a tower in Hasunuma Beach Park (February 21, 1997)

points on the beach. The wind-blown sand transport rate was weight of trapped sand for 10 minutes over width of sand trap for wind direction. Wind velocity was larger at 2 points offshore from the seaward boundary of vegetation area than at the center of vegetation area and in front of the dune. The wind-blown sand transport rate was large at 2 points offshore from the seaward boundary of vegetation area, and small at the center of vegetation area and in front of the dune. The wind-blown sand transport rate at points offshore from the seaward boundary of vegetation area decreased rapidly at noon just after rain, and increased after 13:00 although wind velocity decreased slightly. The wind-blown sand transport rate was larger in Line B than Line A. The reason was thought to be that there was a bald access west of Line B.
The relation between friction velocity u_* (cm/s) and wind velocity u (cm/s) at z (mm) above the ground is expressed as Equation (1).

$$u = 5.75 u_* \log \frac{z}{z'} + u'$$
$$u' = 894d \qquad (1)$$
$$z' = 10d$$

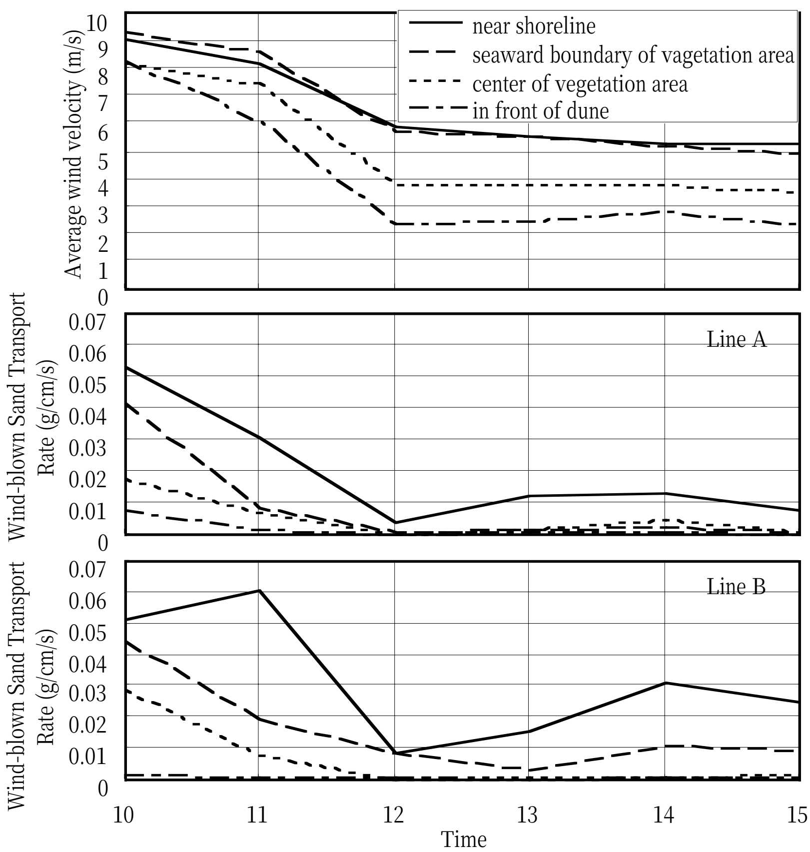

Figure 7 Wind velocity and wind-blown sand transport rate

where d is the grain size (mm), (u' (cm/s), z' (mm)) is the focal point (Horikawa *et al.*, 1985). The relation between wind velocity at the top of the tower and at 1 m above the ground is expressed as Equation (2) on the basis of Equation (1).

$$u_1 = u_t \left\{ 1 - \frac{\log(z_t / z_1)}{\log(z_t / z')} \right\} + u' \frac{\log(z_t / z_1)}{\log(z_t / z')} \qquad (2)$$

where u_1 is the wind velocity at 1 m above the ground, u_t is the wind velocity at the top of the tower, z_t is the height of the tower, and z_1 is 100 cm.
Figure 8 shows the ratio of average wind velocity measured at 4 points on the beach to wind velocity calculated with instantaneous wind velocity at the tower and Equation (2). At 11:00 when wind direction was west-southwest, measured wind velocity at points offshore from

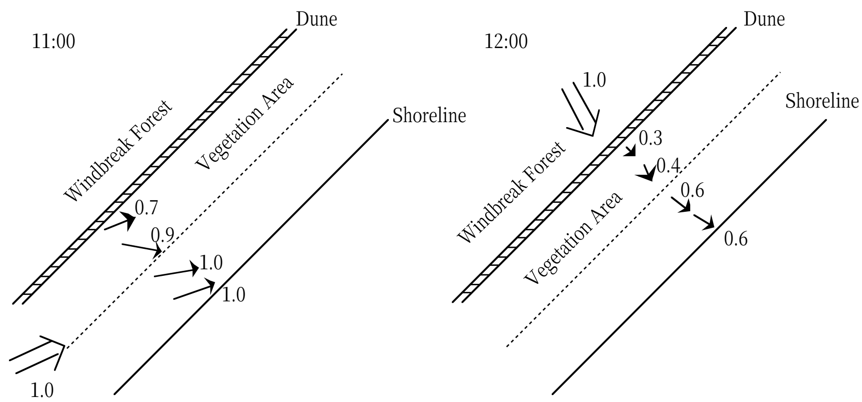

Figure 8 Wind velocity reduction on the beach

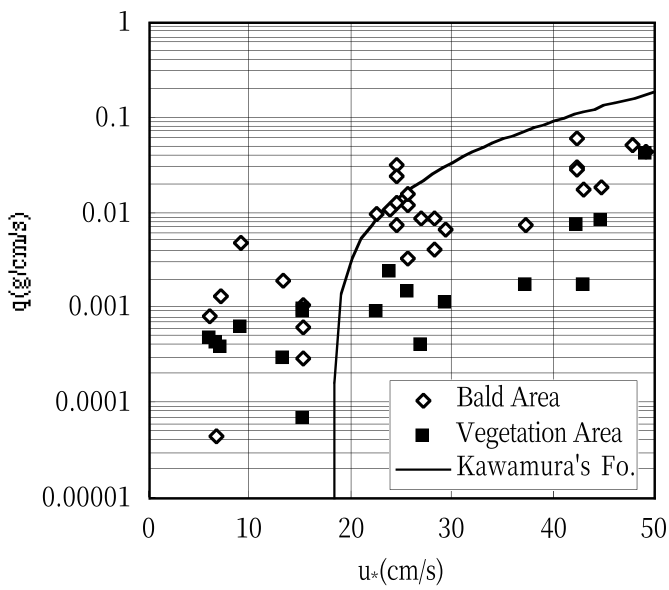

Figure 9 Friction velocity and wind-blown sand tranport rate

vegetation area was almost as strong as calculated wind velocity, and measured wind velocity at points in front of the dune was about 70% of calculated wind velocity. At 12:00 when wind direction had changed to north-northwest, measured wind velocity at points in vegetation area was less than half of calculated wind velocity, and measured wind velocity at points offshore from vegetation area was about 60 % of calculated wind velocity. Similar phenomena continued also after 13:00. It indicates that wind velocity on the beach was reduced notably when the beach was on the leeward of windbreak forest or dune, and critical wind velocity to blow sand on the ground depended largely on wind direction.
Figure 9 shows the relation between friction velocity and wind-blown sand transport rate. A solid line in the Figure is drawn with Kawamura's Formula (Kawamura, 1951) where experimental coefficient was determined at 0.1. It is demonstrated that the wind-blown sand transport rate is smaller in vegetation area when friction velocity is larger than critical friction velocity (18.1 cm/s for 0.15 mm of sand).

4. LONG-TERM EFFECT TO TRAP WIND-BLOWN SAND

To evaluate long-term effect to trap wind-blown sand, field observation on vegetation and topography change was conducted for a year from the latter part of September 1996 in Komatsu Beach.
Vegetation distribution was surveyed in September 1996 and 1997. Height and density of plants in each plant community were measured every month.

4.1 Vegetation

Figures 10 and 11 show vegetation distribution in September 1996 and 1997. A curve in the Figures correspond to the shoreline at that time. In right part of the Figures near an embankment, it was dominated with Elymus mollis offshore the embankment, and *Carex pumila*, *Zoysia macrostachya* and *Carex kobomugi* were seen inshore the embankment. In the area without the embankment, *Carex kobomugi*, *Carex pumila* and *Oenothera laciniata* were seen as well as *Elymus mollis* even offshore the extension of the embankment. *Imperata cylindrica var koenigii* dominated near the windbreak forest, independent of embankment existence. In the survey period, *Elymus mollis* had vanished near the southwest end of the embankment, but had spread in the southwest part of the survey field. *Carex kobomugi* in the front of vegetation area had vanished, and *Digitaria ciliaris* in the center of the survey field had become narrow notably in the period.
To evaluate seasonal change of vegetation, vegetation height and ratio of vegetation area in 20 quadrates of 1 m square set as shown in Figure 5 were measured every month after September 1996. Since withered plants on the ground were also expected to influence topography change, ratio of area covered with not only live plants but also withered plants was measured every month after October 1996.
Figure 12 shows the average of the vegetation height, vegetation area and covered area in each plant community.
Vegetation height averaged in all plant communities decreased after autumn and increased

after February 1997, when the height was about half of the height in September 1996. Comparatively speaking, vegetation height of *Elymus mollis* changed largely; it was about 40 cm in autumn, 16 cm in January 1997, and 67 cm in May 1997.
The ratio of vegetation area in all plant communities was less than 10 % in January 1997 after reduction in autumn. In June 1997, the ratio of vegetation area averaged in all plant

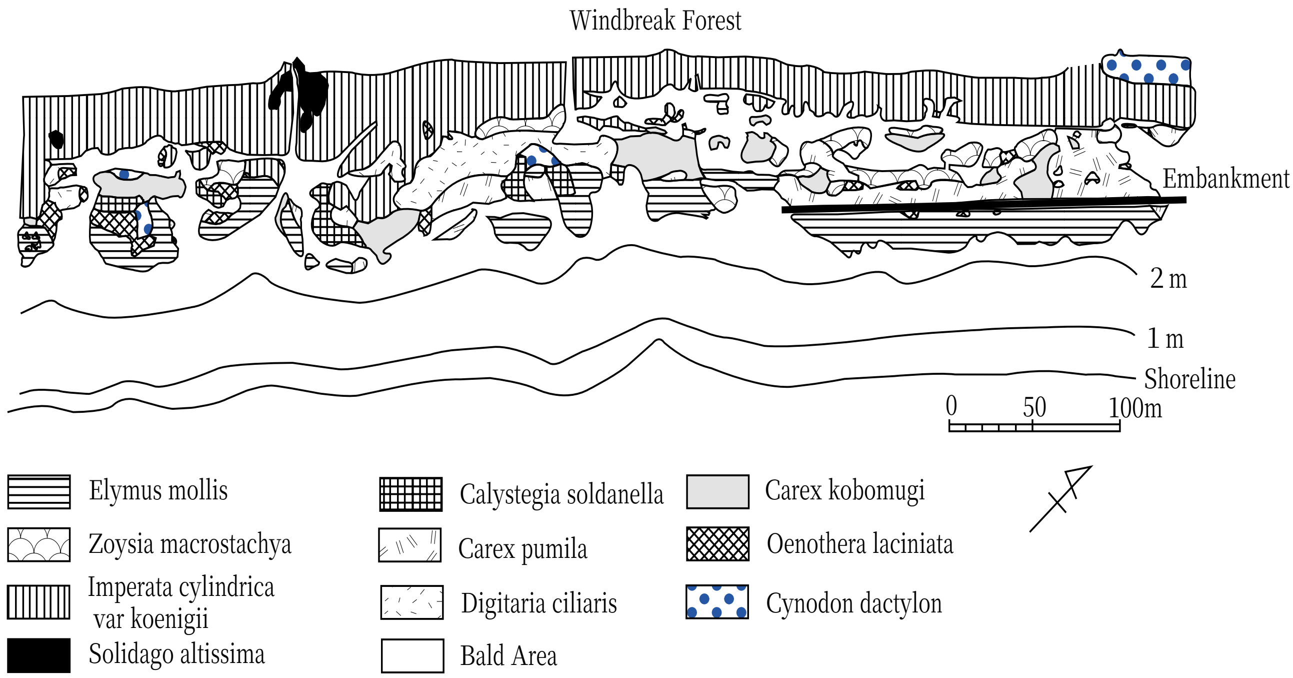

Figure 10 Vegetation distribution in September 1996

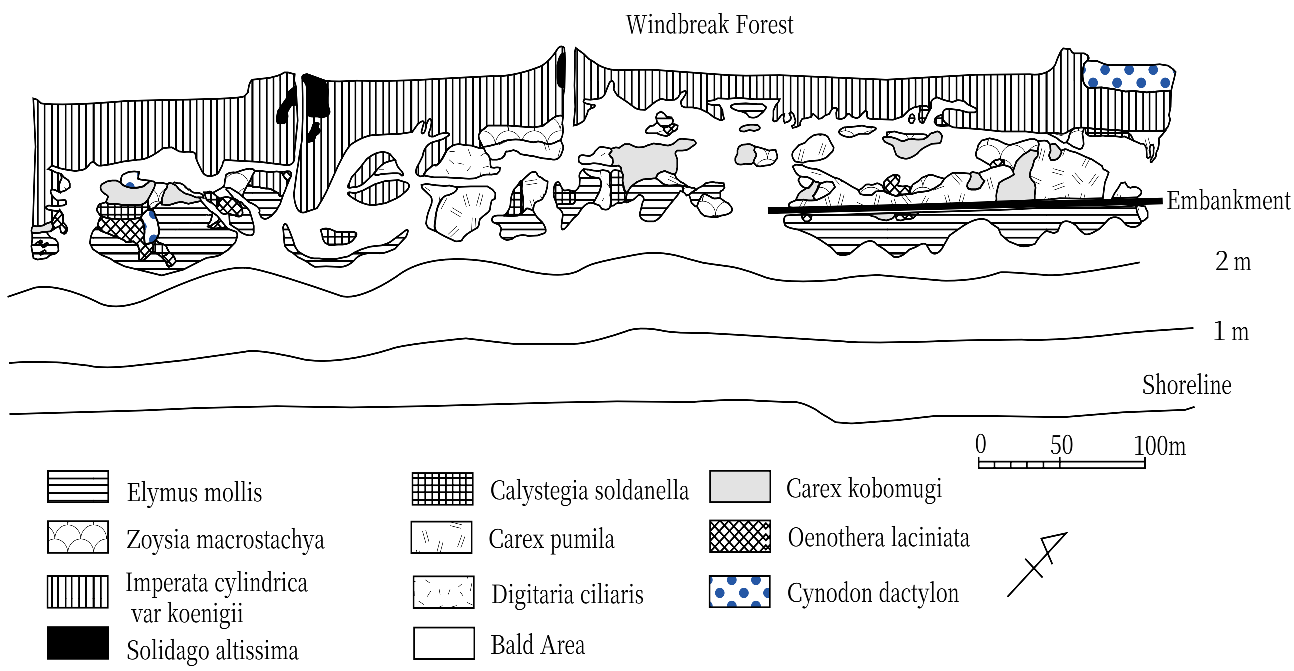

Figure 11 Vegetation distribution in September 1997

communities was about 50 % after increase in spring. Except in winter, the ratios of *Imperata cylindrica var koenigii*, *Cynodon dactylon* and *Zoysia macrostachya* were comparatively large. In winter, the ratios of *Calystegia soldanella*, *Cynodon dactylon*, *Carex kobomugi* and *Zoysia macrostachya* were almost zero.

The ratio of covered area averaged in all plant communities was about 50 % in October 1997, less than 30 % in winter, and recovered to about 50 % in June 1997. Although the ratio in most plant communities was less than 20 % in winter, the ratio of *Imperata cylindrica var koenigii* kept over 60 %. Except for *Calystegia soldanella* and *Cynodon dactylon*, the ratio of covered area in winter was larger than 10 %. Especially, the ratios of *Carex pumila*, *Carex kobomugi* and *Zoysia macrostachya*, which located onshore the embankment, were comparatively large. It is noted that the ground surface in those plant communities was covered somewhat even in winter.

4.2 Topography change

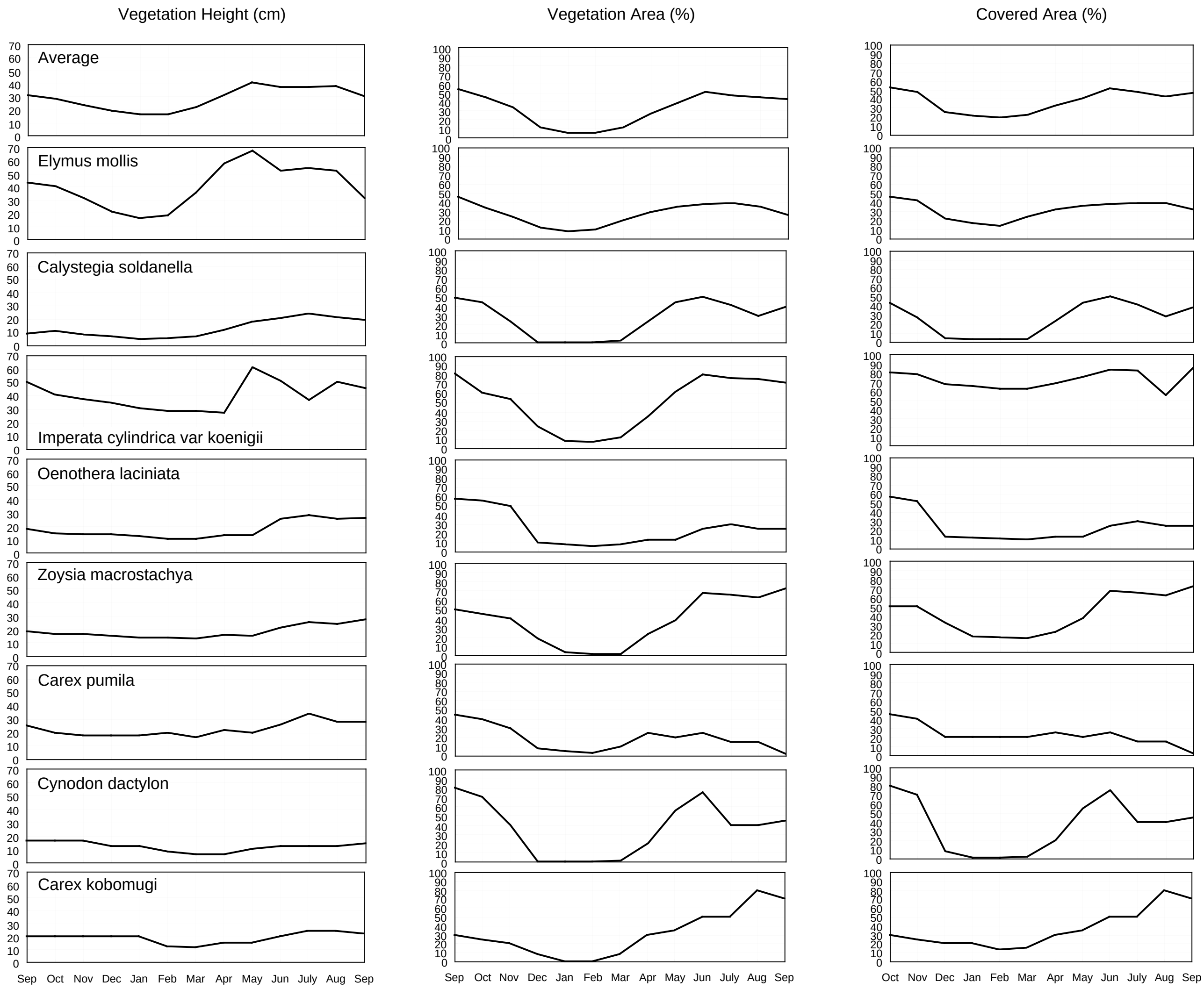

Figure 12 Vegetation height and the ratio of vegetation area and covered area

Figures 13 and 14 show change of contour lines of ground elevations at intervals of 1 m between September 1996 and March 1997 (autumn-winter), and between March 1997 and September 1997 (spring-summer). In autumn-winter, the contour line of 1 m moved offshore; topography change in small dunes was comparatively small. In spring-summer, the contour line of 1 m moved onshore although the contour line of 2 m near the embankment moved offshore. Topography change in small dunes was larger in spring-summer than in autumn-winter.

Figure 15 shows elevation change averaged in areas divided at the southwest end of the embankment in longshore direction, at the embankment and its extension in cross-shore direction. Area offshore the embankment and its extension was divided further at the contour line of 2 m as of March 1997, which corresponded maximum runup height calculated by Hunt's Formula (Hunt, 1959). Averaged in all survey field, elevation increased 4.7 cm in autumn-winter, and decreased 2.9 cm in spring-summer. In autumn-winter, elevation increased in the area lower than 2 m although elevation changed little in the other area, independent of embankment existence. It was considered that the elevation increase in the area lower than 2 m was mainly due to waves. On the other hand, in spring-summer, elevation change was different according to embankment existence. In areas with the embankment,

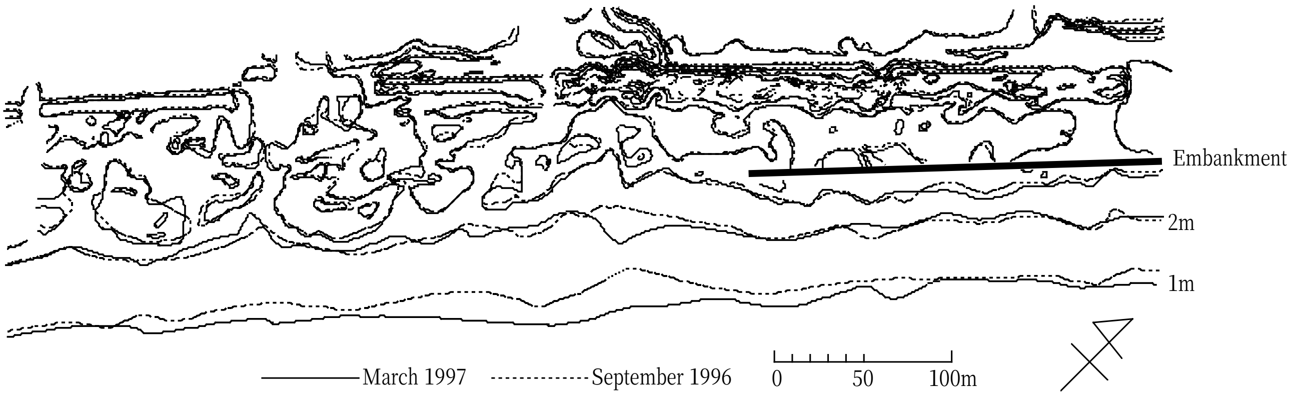

Figure 13 Topography change in autumn-winter

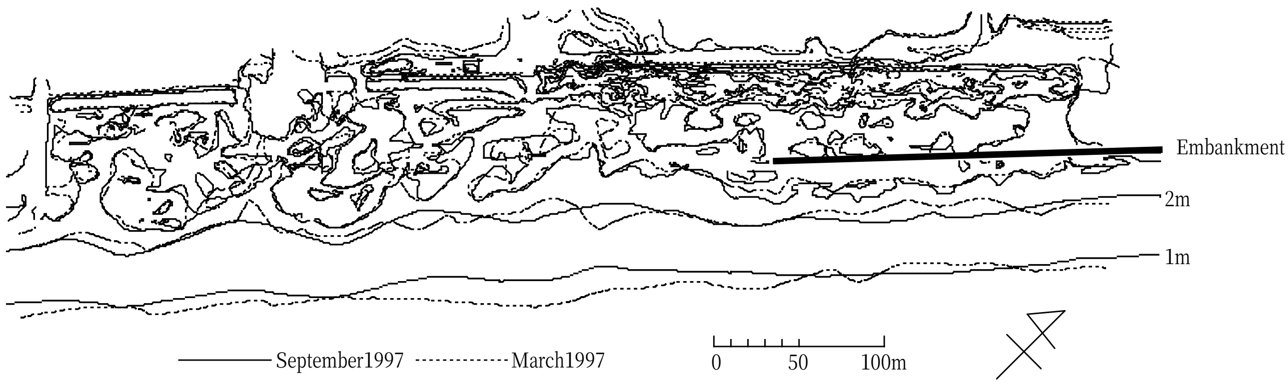

Figure 14 Topography change in spring-summer

elevation increased in areas higher than 2 m. In areas without the embankment, elevation in areas higher than 2 m changed hardly although small dunes transformed as shown in Figure 14. It indicates that volume of sand in the area of the small dunes changed little.

The cause of the difference in elevation change between the two periods with wind data, which is the primary force to cause topography change, will be discussed. Figure 16 shows a wind rose for gale (more than 10 m/s) measured at the top of the tower in Hasunuma Beach Park. Prevailing wind direction of gale was northwest and south-southwest in autumn-winter, between southwest and south in spring-summer. It indicates that, in autumn-winter, sand accumulation due to waves in the area lower than 2 m effected little in the area higher than 2 m because of strong seaward wind. In spring-summer, when sand was thought to move almost parallel to shoreline, the sand volume was expected to be constant if the ground surface condition was same in longshore direction. Elevation change in the area higher than 2 m, however, was actually different between in the area with embankment and in the area without the embankment. Therefore it is necessary to evaluate difference in vegetation distribution for the cause.

Figure 17 shows the ratios of bald area and each plant community in areas divided as in Figure 15. In areas offshore the embankment and its extension, the ratio of plant communities except *Elymus mollis* was also larger in the area without the embankment than in the area with the embankment although the ratio difference of bald area between the two areas was little. In areas offshore the embankment and its extension, the ratio of *Imperata cylindrica*

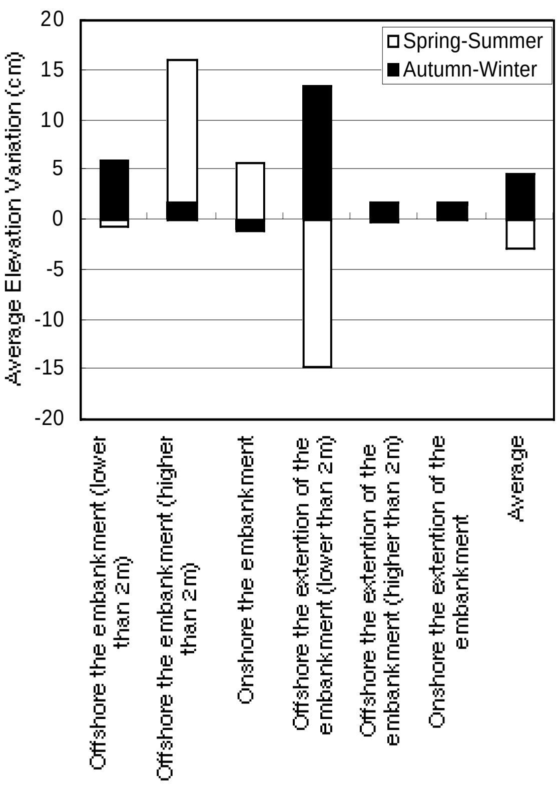

Figure 15 Elevation variation in areas divided by location

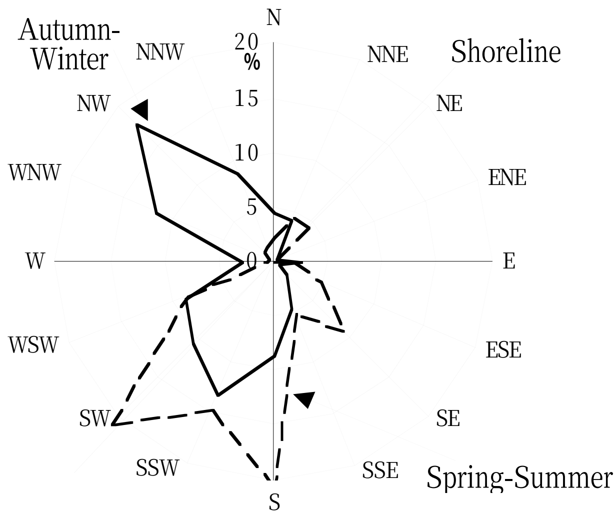

Figure 16 Wind rose

var koenigii in the area without the embankment was about 50 %, instead of *Carex pumila* or *Zoysia macrostachya*, which was seen much in the area with the embankment. It is thought that such difference in vegetation distribution caused difference in topography change. So we consider the relation between elevation change and plant community in the survey field. Figure 18 shows the average elevation change in autumn-winter and spring-summer in each plant community. The change in the bald area was similar to that in the whole survey field as shown in Figure 15. In autumn-winter, the elevation of *Cynodon dactylon* and *Elymus mollis* increased notably. In spring-summer, the elevation of *Oenothera laciniata*, *Carex pumila* and *Zoysia macrostachya* increased although the elevation of *Cynodon dactylon* decreased 33.1 cm. *Elymus mollis* was the only plant community whose elevation increased apparently both in autumn-winter and spring-summer. In the year, elevation increase of more than 10 cm was seen in *Elymus mollis* and *Oenothera laciniata*; notable elevation change was hardly seen in *Calystegia soldanella* and *Carex kobomugi*.

The relation between elevation change and measured value of vegetation with Figures 12 and 18 will be discussed. For Elymus mollis, whose elevation tended to rise throughout the year, sand accumulation was larger in autumn-winter than in spring-summer although vegetation height, vegetation area and covered area were often smaller. For *Zoysia macrostachya*, *Carex pumila* and *Oenothera laciniata*, whose elevation increased only in spring-summer, vegetation height was smaller in spring-summer. Compared with *Elymus mollis*, vegetation area and covered area of *Imperata cylindrica var koenigii* was larger throughout the year although the sand accumulation of *Imperata cylindrica var koenigii* was smaller. These indicate that elevation change in half a year depended on species of plant community rather than vegetation height, vegetation area, and covered area.

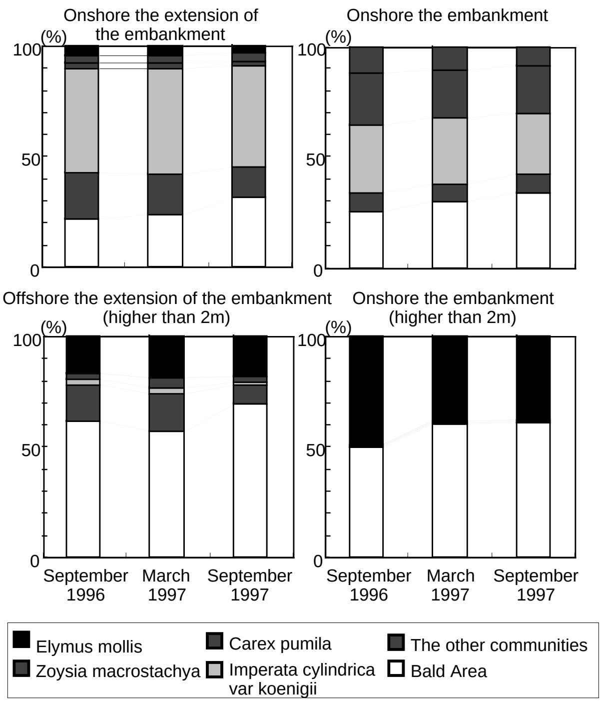

Figure 17 Proportion of each plant community in areas divided by location

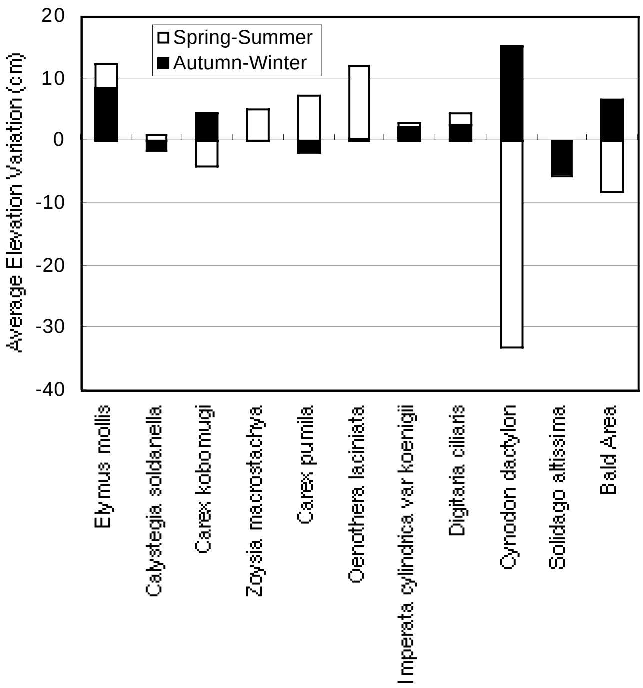

Figure 18 Elevation variation in areas divided by plant community

5. CONCLUSIONS

Main conclusions are summarized as follows:
(1) The effect of coastal vegetation to trap wind-blown sand on sandy beach can be divided into the short-term one with the part of grass in the air and the long-term one due to the growth of the grass.
(2) Wind-blown sand transport rate in vegetation area was smaller than that in bald area even if friction velocity on the surface was equivalent.
(3) The long-term effect of coastal vegetation on topography change on sandy beach depended not on vegetation height nor vegetation density but on plant community.

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