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Grain size characteristics of blown sand following severe damage to Japanese black pines in the Fukiage sand dunes, Kagoshima

Yukiyoshi Teramoto[1*] and Etsuro Shimokawa[1]

Abstract: We investigated grain size characteristics of blown sand following severe damage to Japanese black pines in the Fukiage sand dunes. The dominant constituent coastal vegetation species from the top of the fore-dune to 50 m along the four survey lines was similar. The dominant species from 50 m to 300 m in Transects 1 and 2 (survey lines that had severely damaged Japanese black pine forest) were the same as those from 50 m to 200 m in Transects 3 and 4 (survey lines that had almost no damage). Dry bulk densities along the four transects decreased with increasing distance from the top of the fore-dune. At the same distances along transects from the top of the fore-dune, the dry bulk densities in Transects 1 and 2 were greater than those in Transects 3 and 4. D_{10} of blown sand along the four transects decreased with increasing distance from the top of the fore-dune. D_{10}, D_{50} and D_{90} of the blown sand in Transects 1 and 2 were greater than those in Transects 3 and 4.

1 Introduction

Japanese black pine forest on the Fukiage sand dunes located in the western coastal region of Satsuma peninsula, Kagoshima prefecture, were severely damaged by pine wilt disease from the late 1980s to the first half of the 1990s (Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996). Coastal vegetation comprising the middle and lower canopy layers was subjected to strong winds and desiccation due to mortality of Japanese black pine occupying the near-shore areas and upper canopy. Therefore, destruction of coastal vegetation occurred progressively in one long sustained mortality event (Teramoto and Shimokawa, 2007). Because of coastal vegetation decline, damage to crops from blown sand and salt occurred in agricultural land bordering the Fukiage sand dunes.

Teramoto and Shimokawa (2007) demonstrated that the spatial distribution of blown sand mass in the Fukiage dunes was governed by distance from the top of the fore-dune, and coastal vegetation conditions such as the presence or absence of forest for prevention of sand transport. The studies of the Kyushu Erosion Control Association (1966), Suzuki (1981), Tsukamoto *et al*. (2001), Hagino *et al*. (2007) and Teramoto and Shimokawa (2007) demonstrated the decrease in blown sand mass from the fore-dune to inland areas. However, insufficient studies have been conducted on the effects of coastal vegetation conditions and on how distance from the fore-dune to inland areas controls grain size distribution.

[1]Faculty of Agriculture, Kagoshima University, 1-21-24 korimoto, Kagoshima 890-0065, Japan
*Corresponding author: sabot @ agri.kagoshima-u.ac.jp

The purpose of this study is to clarify the grain size characteristics of blown sand following severe damage to Japanese black pines in the Fukiage sand dunes, including the effect of different coastal vegetation conditions.

2 Study area and methods

2.1 Study area description

The study area, which is located in the western part of Satsuma peninsula, Kagoshima prefecture, is within a national forest area in the Fukiage sand dunes (Figure 1).

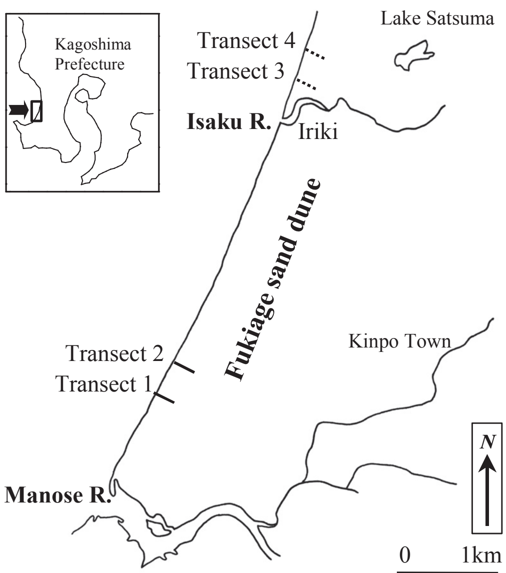

Figure 1: Location of the study area

Much of the coastal vegetation in the study area is classified as protective forest for sand dune stability and as a barrier to salt-laden wind, forest for health of people and for recreation. The annual volume of trees damaged by pine wilt disease within the forest was 6,200 m^3 in

1981 and 8,200 m^3 in 1984, and the annual volumes during 1985 and 1990 were 2,000 m^3 to 3,000 m^3, respectively. Since 1991, the volume of damage to Japanese black pine has been increasing rapidly. The annual volume of Japanese black pine damage in 1994 was 14,000 m^3, the largest annual value for the 1981-to-1994 period. Since 1995, the annual volume of damage to Japanese black pine has been decreasing with time (Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996).

The coastal vegetation situated at the northern part of the Manose river mouth declined from the late 1980s to 1994 because of damage from pine wilt disease and storm winds. However, since 1995, the coastal vegetation has regenerated gradually. Coastal vegetation situated at the northern part of the Isaku river mouth, however, has suffered little damage since the 1980s because of cultivation of Japanese black pines as storm- and blown-sand-breaks around the fore-dune, and because of tree maintenance, such as spraying injection of anti-pine wilt fungicide into tree trunks (Teramoto and Shimokawa, 2007).

2.2 Methods

To investigate the grain size distribution of blown sand following severe damage to Japanese black pine, two survey lines were installed in the northern area of the Manose river mouth. The two 300 m transects (Transects 1 and 2) were placed perpendicular to the shoreline from the top of the fore-dune and extended inland (Figure 1, Photo 1). To investigate the grain size distribution of blown sand where Japanese black pine mortality was minimal, two 300 m transects (Transects 3 and 4) were installed in the northern area of the Isaku river mouth perpendicular to the shoreline from the top of the fore-dune and extended inland (Figure 1, Photo 2).

Soil tests and vegetation surveys were conducted every 50 m along each transect. Soil tests on blown sand determined grain size distribution (Kawakami, 1983) and dry bulk density. Dry bulk density was determined by collecting undisturbed surface layer samples in metal cylinders 55 mm in diameter and 60 mm in height. Vegetation surveys determined broad vegetation community composition along each transect.

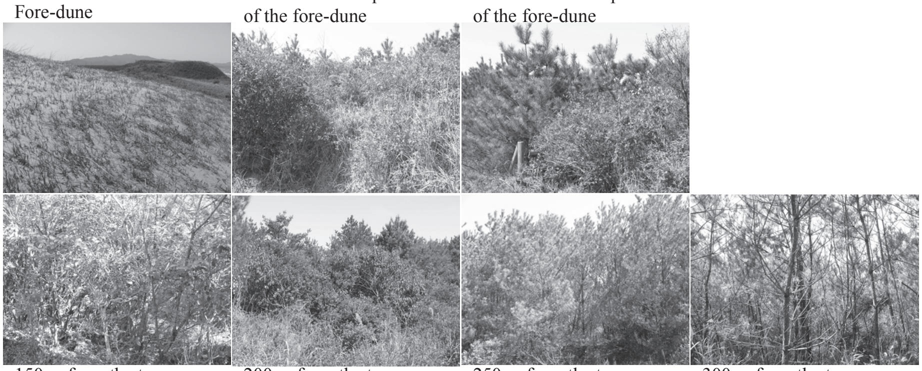

Photo 1: Coastal vegetation along Transect 1

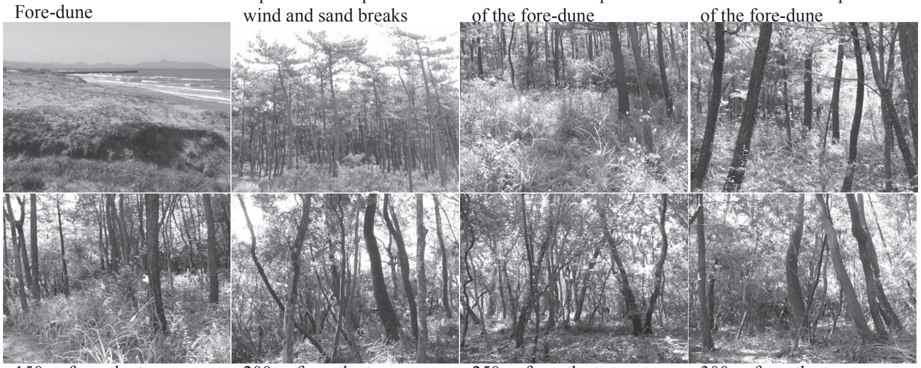

Photo 2: Coastal vegetation along Transect 3

3 Results and discussion

3.1 Coastal vegetation composition and soil conditions

Figure 2 shows vegetation and surface layer dry bulk densities of along Transects 1 and 2, and Figure 3 shows vegetation and surface layer dry bulk densities of along transects 3 and 4. Tables 1 and 2 present the dominant constituent species in Transects 3 and 4 and Transects 1 and 2, respectively.

Table 1: Dominant constituent species along Transects 3 and 4

Distance from the top of the fore-dune (m)	Hierarchy of vegetation	Dominant constituent species
0～50	Tree height > 1 m	*Pinus thunbergii*
	Tree height < 1 m	*Rosa multiflora*
	Forest floor	*Imperata cylindrica var. koenigii.*
50～200	Tree height > 1 m	*Pinus thunbergii* *Ilex chinensis* *Ligustrum japonicum*
	Tree height < 1 m	*Ilex chinensis* *Ligustrum japonicum*
200～300	Tree height > 1 m	*Pinus thunbergii* *Machilus thunbergii* *Ligustrum japonicum*
	Tree height < 1 m	*Machilus thunbergii* *Ligustrum japonicum*

Table 2: Dominant constituent species along Transects 1 and 2

Distance from the top of the fore-dune (m)	Hierarchy of vegetation	Dominant constituent species
0～50	Tree height > 1 m	*Pinus thunbergii*
	Tree height < 1 m	*Rosa multiflora*
	Forest floor	*Imperata cylindrica var. koenigii.*
50～300	Tree height > 1 m	*Pinus thunbergii* *Ligustrum japonicum* *Mallotus japonicus*
	Tree height < 1 m Forest floor	*Ilex chinensis* *Ligustrum japonicum* *Miscanthus sinensis*

In Transects 3 and 4, the growth environment improved moving inland. Coastal vegetation species from the top of the fore-dune to 50 m were limited because of the severe growth environment caused by blown sand and salt. The dominant species ≥1 m in height was *Pinus thunbergii* and the dominant constituent species <1 m in height was *Rosa multiflora*. The dominant forest floor species was *Imperata cylindrica var. koenigii*. The coastal vegetation growth environment from 50 m to 200 m was better the first 50 m. The dominant species ≥1 m in height were *Pinus thunbergii*, *Ilex chinensis* and *Ligustrum japonicum*, and the dominant species <1 m in height were *Ilex chinensis* and *Ligustrum japonicum*. From 200 m to 300 m the dominant species ≥1 m in height were *Pinus thunbergii*, *Machilus thunbergii* and *Ligustrum japonicum*, and the dominant species <1 m in height were *Machilus thunbergii* and *Ligustrum japonicum*. Tree height and breast height diameter of tree species ≥1 m in height from 200 m to 300 m were greater than those from the top of the fore-dune to 200 m.

Transects 1 and 2 (Table 2) showed the same general vegetation patterns as in Transects 3 and 4 from the top of the fore-dune to 50 m, and vegetation composition from 50 m to 300 m was similar to that from 50 m to 200 m in Transects 3 and 4. This is due to the dominant constituent coastal vegetation species from 200 m to 300 m in Transects 3 and 4 retreating inland because of the decline in coastal vegetation caused by destruction of Japanese black pine.

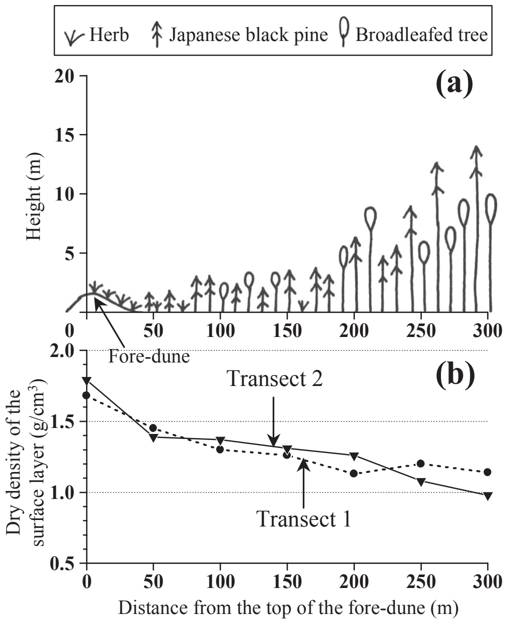

Figure 2: Coastal vegetation composition and surface layer dry densities along Transects 1 and 2

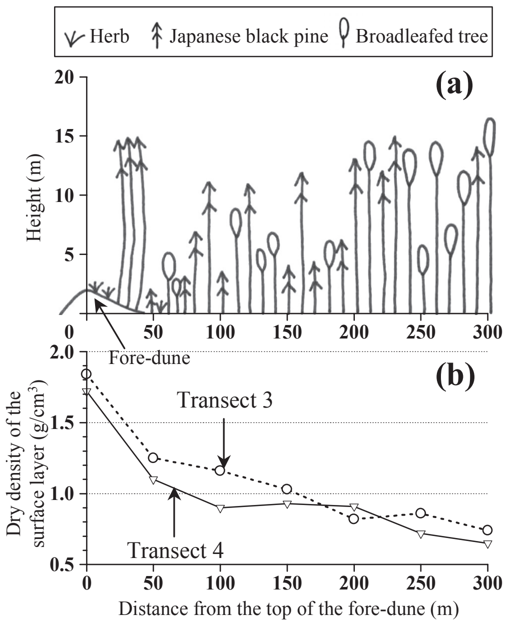

Figure 2: Coastal vegetation composition and surface layer dry densities along Transects 3 and 4

Surface layer dry bulk densities along the four transects decreased with increasing distance from the top of the fore-dune (Figures 2 and 3). This is due to the surface layer void ratio increasing with increasing distance from the top of the fore-dune. At the same distance along transects, dry densities in Transects 1 and 2 were greater than those in Transects 3 and 4. The increase in voids with distance from the fore-dune is thought to result from root growth and improvement of soil physical properties by recovering coastal vegetation further inland. Teramoto and Shimokawa (2007) showed that the dry bulk density of the surface layer tended to decrease with increasing distance from the top of the fore-dune in the Fukiage sand dunes, and that tree height and breast height diameter of the dominant tree species also increased further inland. These results are similar to those of the present study.

3.2 Grain size characteristics of blown sand

Figure 4 shows D_{10}, D_{50} and D_{90} of blown sand along each transect. The D_{10}, D_{50} and D_{90} express grain size corresponding to passed mass percentage of 10 %, 50 % and 90 % in the grain size distribution curve (Kawakami, 1983), respectively.

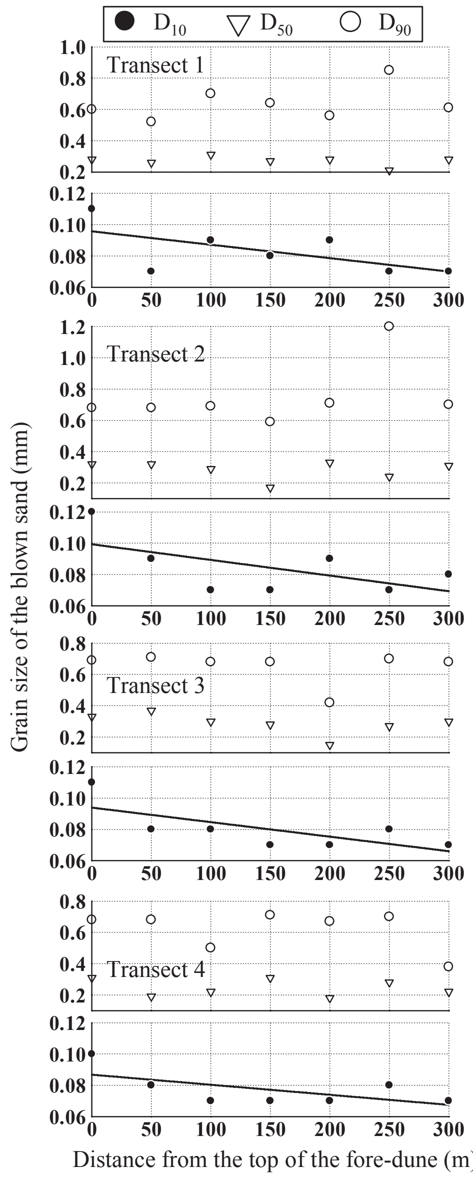

Figure 4: Grain size of blown sand along four transects according to distance from top of the fore-dune

D_{10} of the blown sand along all transects decreased with increasing distance from the top of the fore-dune. Regression analysis showed that the correlation coefficient between the distance from the top of the fore-dune and D_{10} of the blown sand was 0.62 in Transect 1, 0.60 in Transect 2, 0.71 in Transect 3, and 0.62 in Transect 4. There were low correlations in blown sand D_{50} and D_{90} values along all four transects.

D_{10} of the blown sand was between 0.07 mm and 0.12 mm (average 0.084 mm) in Transects 1 and 2, and was between 0.07 mm and 0.11 mm (average 0.079 mm) in Transects 3 and 4. D_{50} of the blown sand was between 0.17 mm and 0.33 mm (average 0.276 mm) in Transects 1 and 2, and was between 0.15 mm and 0.37 mm (average 0.265 mm) in Transects 3 and 4. D_{90} of the blown sand was between 0.52 mm and 1.20 mm (average 0.695 mm) in Transects 1 and 2, and was between 0.38 mm and 0.71 mm (average 0.634 mm) in Transects 3 and 4. D_{10}, D_{50} and D_{90} of the blown sand in Transects 1 and 2 were greater than those in Transects 3 and 4. This is thought to result from decrease in wind velocity and less blown sand due to wind and sand breaks comprised of Japanese black pine planted 30 m from the top of the fore-dune in Transects 3 and 4 (Photo 2, Figure 3).

4 Conclusions

The results of the present study can be summarized thus:

(1) The dominant constituent coastal vegetation species from the top of the fore-dune to 50 m along the four survey lines was similar. The dominant species from 50 m to 300 m in Transects 1 and 2 (survey lines that had severely damaged Japanese black pine forest) were the same as those from 50 m to 200 m in Transects 3 and 4 (survey lines that had almost no damage). Dry bulk densities along the four transects decreased with increasing distance from the top of the fore-dune. At the same distances along transects from the top of the fore-dune, the dry bulk densities in Transects 1 and 2 were greater than those in Transects 3 and 4.

(2) D_{10} of the blown sand along the four transects decreased with increasing distance from the top of the fore-dune. D_{10}, D_{50} and D_{90} of the blown sand in Transects 1 and 2 were greater than those in Transects 3 and 4.

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