

Blown sand, and revegetation and growth environment of coastal forest 13 years after Japanese black pine mortality in the Fukiage sand dunes, Kagoshima

Yukiyoshi Teramoto^{1*} and Etsuro Shimokawa¹

Abstract: From the mid-1980s until 1997, Japanese black pines growing in the Fukiage sand dunes were devastated by pine wilt disease. We investigated the characteristics of the blown sand mass as well as the recovery conditions and growth environment of coastal forest 13 years after this forest mortality. We placed three 250-m transects (Transects 1–3) perpendicular to the shoreline from the top of the fore-dune to the inland area. Transects 1 and 2 were in areas of black pine forest that had been severely damaged by pine wilt disease, and Transect 3 was in an area that was almost undamaged. We investigated the spatial distribution of the blown sand mass and conducted vegetation and soil surveys along the three transects. The blown sand along Transects 1 and 2 originated from the fore-dune and had moved approx. 200 m inland, while that along Transect 3 was restricted to the area around the fore-dune because of a protective forest that provided a barrier against blown sand. The coastal forest in Transects 1 and 2 was poorly developed compared with that in Transect 3. Artificial formation of coastal forest in the frontal (fore-dune) area is necessary to protect forests and to allow regeneration.

1 Introduction

The Fukiage sand dunes are located in the western part of the Satsuma Peninsula, Kagoshima Prefecture, Kyushu Island. For at least 300 years, protective forests have been planted in this area to provide barriers against blown sand and salt-laden wind and to stabilize the sand dunes (Kyushu Erosion Control Association, 1966; Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996). From the late 1970s to the first half of the 1990s, the coastal forest situated in the southern part of Fukiage sand dunes suffered catastrophic damage from pine wilt disease, and many of the trees died. The decline of the coastal forest greatly decreased its protective function. There has been almost no damage to Japanese black pines from pine wilt disease in this area since the late 2000s (Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996; Kagoshima Prefecture, 1996-2004).

Energetic studies on the formation of the fore-dune in the Fukiage sand dunes were conducted from the 1950s to 1960s (Kyushu Erosion Control Association, 1966). Moreover, Teramoto, and Shimokawa (2007, 2010) detailed the blown sand and revegetation process of coastal forest following the Japanese black pine mortality, and the effects of differences in coastal forests on the spatial distribution of the blown sand mass and the grain size characteristics of blown sand in the Fukiage sand dunes.

The purpose of this study is to clarify the

characteristics of the blown sand mass, and to examine the recovery conditions and growth environment of coastal forest 13 years after mortality of the Japanese black pine in the Fukiage sand dunes. This study provides important data to clarify the relationship between coastal forest conditions and the disaster prevention functions of coastal forest.

2 Temporal changes in annual volume of Japanese black pine trees damaged by pine wilt disease

The coastal forest in the Fukiage sand dunes is dominated by Japanese black pine, which was severely damaged by pine wilt disease. The first report of damage to Japanese black pines from pine wilt disease in this area was ca. 1907. It was recorded that 4589 Japanese black pines damaged by pine wilt disease within the area were deforested in 1911. More outbreaks of the disease occurred around the time of the Second World War, and outbreaks gradually increased from ca. 1965 onwards (Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996).

Figure 1 shows the annual volume of Japanese black pines damaged by pine wilt disease from 1973 to 2004 within the national forest reserve area in the Fukiage sand dunes (Kumamoto Regional Forest Office and Japan Forest Technical Association, 1996; Kagoshima Prefecture, 1996-2004). Since the 1970s, the volume of Japanese black pine trees damaged by the disease increased. Japanese black pines were severely damaged during the 1980s, and even more so in the 1990s. The annual volume of Japanese black pines damaged in 1994 was approximately 10 m³/ha, the largest annual value for the period from 1973 to 2004. Coastal vegetation

¹Faculty of Agriculture, Kagoshima University, 1-21-24 Korimoto, Kagoshima 890-0065, Japan

*Corresponding author: sabot@agri.kagoshima-u.ac.jp

comprising the middle and lower canopy layers was subjected to strong winds and desiccation because of mortality of Japanese black pine, which occupies the upper canopy. Therefore, the destruction of coastal vegetation occurred progressively in one long sustained mortality event (Teramoto and Shimokawa, 2007). Moreover, because of this severe damage by pine wilt disease, most of the Japanese black pines died, and so some forest lands were left only with a sparse covering of broad-leaf species, with barely any remaining forest. Since 1995, the annual volume of Japanese pine damaged by the disease has steadily decreased.

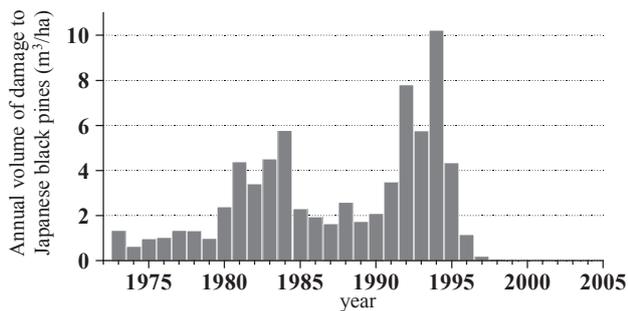


Figure 1: Annual volume of Japanese black pines damaged by pine wilt disease from 1973 to 2004 in the national forest reserve area in the Fukiage sand dunes

3 Study area and methods

3.1 Study area

The study area was situated in the western part of Satsuma peninsula, Kagoshima Prefecture, within the national forest reserves area in the Fukiage sand dunes (Figure 2). Much of the coastal forest in the study area is classified as protective forest. It forms a barrier against blown sand and salt-laden wind, stabilizes sand dunes, and provides a recreational area. The width of the coastal forest zone in the study area ranges from approximately 300 to 500 m.

The coastal forest located in the area north of the Manose River mouth (Figure 2) declined from the 1980s to 1997 because of damage from pine wilt disease, and because of blown sand and salt-laden wind. However, the coastal forest has regenerated gradually since 1998. In the area north of the Isaku River mouth (Figure 2), the coastal forest has suffered little damage since the 1980s because of cultivation of Japanese black pines as storm- and blown-sand-breaks around the fore-dune. These trees have been maintained to protect them against disease, e.g. by injecting anti-pine wilt fungicide into tree trunks (Teramoto and Shimokawa, 2007).

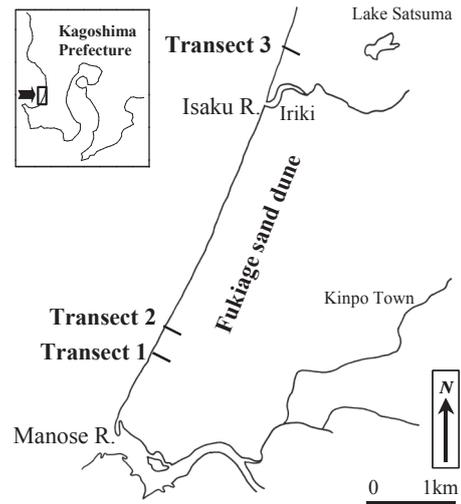


Figure 2: Location of the study area

3.2 Methods

Our aims were to investigate the spatial distribution of the blown sand mass and the recovery conditions and growth environment of coastal forest 13 years after Japanese black pine mortality in 1997. We installed two survey lines in the area north of the Manose River mouth. The two 250-m transects (Transects 1 and 2) were placed perpendicular to the shoreline from the top of the fore-dune and extended inland (Figure 2). For comparison, we also investigated the spatial distribution of the blown sand mass and the conditions and growth environment of coastal forest in an area that was barely affected by the pine wilt disease. Therefore, we installed one 250-m transect (Transect 3) in the area north of the Isaku River mouth. It was placed perpendicular to the shoreline from the top of the fore-dune and extended inland (Figure 2).

We measured the blown sand mass as described previously (Teramoto and Shimokawa, 2007), as follows: the litter layer formed in the Japanese black pine forest that invaded after the Japanese black pine mortality was collected in a block state every 50 m along each transect. After the collected litter layer was dried in an oven, all sand particles were removed and the weight of the particles was determined. Therefore, the measured weight of the blown sand represents the sand that was blown into the forest after Japanese black pine mortality.

To study recovery conditions of coastal forest 13 years after the Japanese black pine mortality in 1997, we established 5×5 m vegetation survey quadrats every 50 m along each transect. Species, their abundance, and the height and diameter at breast height of trees greater than 1 m tall were recorded in each quadrat. The volume of

trees per 25 m² was calculated from the data on species, height, and diameter at breast height using a volume-of-tree conversion table (Japan Forestry Investigation Committee, 1970).

In each quadrat, we measured dry density of surface layer soil, pH of surface layer soil, corrosion layer depth, and air-dried weight of litter. The dry density of surface layer soil was determined using undisturbed cores collected in metal cylinders (55 mm in diameter, 60 mm in height). The pH was determined by mixing an air-dried sample and pure water in a container at a ratio of 1:2.5 (w/v), shaking the container, and then measuring the pH with a pH meter.

We used aerial photographs to clarify the temporal changes of coastal forest distribution in the area north of the Manose River mouth. For these analyses, we used five pairs of aerial photographs taken in February 1987, February 1995, March 2000 (Teramoto and Shimokawa, 2007), October to November 1992, and September to October 2006.

Field investigations were conducted during 2010 and 2011, 13 years after the Japanese black pine mortality caused by pine wilt disease in 1997.

4 Results and discussion

4.1 Temporal changes of coastal forest distribution

Figure 3 shows distribution charts of the temporal changes of coastal forest from 1987 to 2006. These data were derived from aerial photographs of the area north of the Manose River mouth taken in February 1987, October to November 1992, February 1995, March 2000, and September to October 2006. The range enclosed by the rectangular solid line in the figure shows the area covered by the aerial photograph. The coastal forest in the near-shore area was partly damaged in February 1987, and all parts of the coastal forest were damaged in October to November 1992 and February 1995. The coastal forest has regenerated gradually since March 2000.

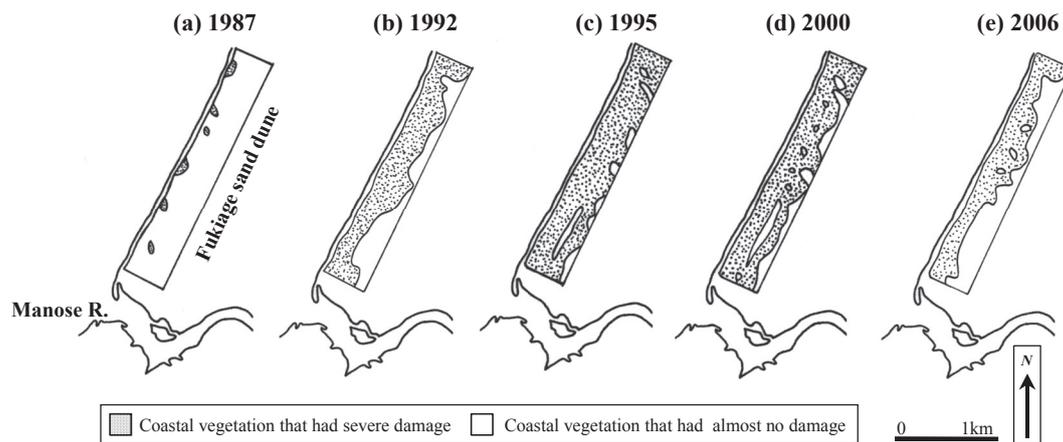


Figure 3: Distribution charts of temporal changes of coastal forest. Data was obtained by interpreting aerial photographs of the area north of the Manose River mouth

4.2 Blown sand following severe damage to Japanese black pines

Figures 4 (a), (b) and (c) show the pattern of coastal forest along Transects 1, 2 and 3, respectively, and Figure 4 (d) shows the spatial distribution of the blown sand mass (weight per unit area) along each transect. The blown sand mass along Transects 1 and 2 decreased with increasing distance from the top of the fore-dune (Figure 4 (d)), and had moved from the top of the fore-dune to approx. 200 m inland. This reason for this large-scale movement of sand is that the coastal forest in transects 1 and 2 was devastated from the top of the fore-dune to around 250 m inland, and during its recovery, the trees in

the forest were not restored to their original density and height (Figure 4 (a) and (b)). The blown sand along Transect 3, on the other hand, had moved from the top of the fore-dune to approx. 50 m inland (Figure 4 (d)), because the tall trees in the Japanese black pine forest growing approx. 40 m inland acted as a protective forest, presenting a barrier against blown sand and salt-laden wind (Figure 4 (c)). The coastal forest along Transect 3 was composed mainly of tall Japanese black pine trees because the trees had been protected against disease. Thus, the different coastal forest conditions greatly affected the spatial distribution of the blown sand mass.

Teramoto and Shimokawa (2007) showed that the

spatial distribution of blown sand mass measured along Transects 1–3 in the Fukiage dunes was governed by the distance from the top of the fore-dune and the coastal forest conditions. The results of the present study are consistent with those findings.

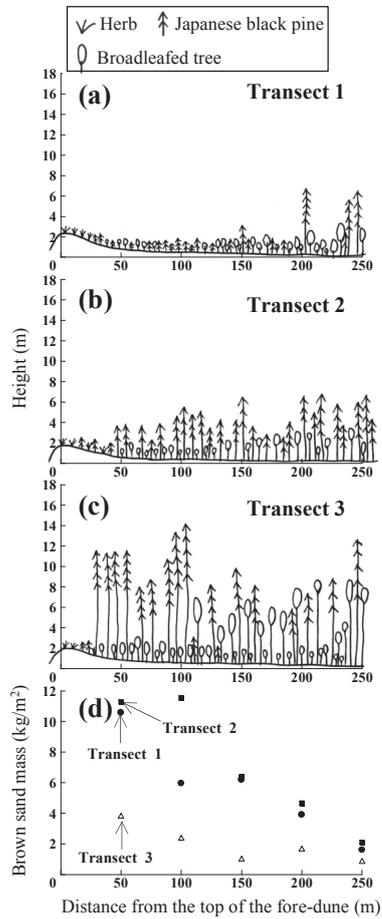


Figure 4: Spatial distribution of blown sand mass and coastal forest composition along Transects 1–3

4.3 Growth environment of coastal forest

Figure 5 shows the air-dried weight of litter (a), corrosion layer depth (b), dry density of surface layer soil (c) and pH of surface layer soil (d) in the quadrats placed every 50 m along the three transects. The air-dried weight of litter (a) and the depth of the corrosion layer (b) increased with increasing distance from the top of the fore-dune; whereas the dry density of surface layer soil (c) and the pH of surface layer soil (d) decreased with increasing distance from the top of the fore-dune. At the same distance along transects from the top of the fore-dune, the air-dried weight of litter (a) and the corrosion layer depth (b) in Transects 1 and 2 were smaller than those in Transect 3. Conversely, the dry

density of surface layer soil (c) and the pH of surface layer soil (d) in Transects 1 and 2 were greater than their corresponding values at equivalent distances along Transect 3. Fujita and Nakata (2001) measured soil pH during vegetation succession in a coastal forest in Niigata Prefecture, and showed that as the succession progressed, soil pH decreased. According to Figure 4 (a), (b) and (c), vegetation succession progressed with increasing distance from the top of the fore-dune. The decrease in the soil pH as the succession proceeded is associated with the accumulation of humus within soil and soil acidification caused by growth of coastal and forest floor vegetation (Fujita and Nakata, 2001).

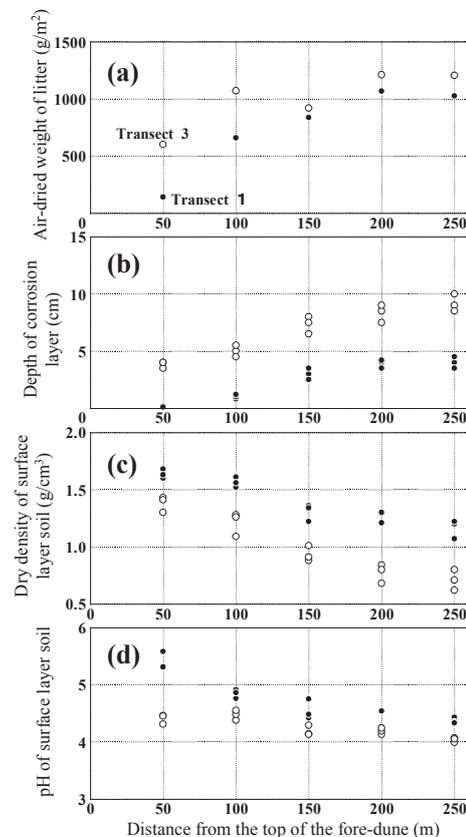


Figure 5: Air-dried weight of litter (a), depth of corrosion layer (b), dry density of surface layer soil (c) and pH of surface layer soil (d) along Transects 1 and 3

Litter from coastal Japanese black pine forests was once used as fuel, but as lifestyles have changed, it is no longer used for this purpose, and maintenance of the Japanese black pine forest was thus not carried out. The natural vegetation succession resulted in a mixture of broad-leaf tree species and Japanese black pine forest (Figure 4 (a), (b) and (c)), which affected soil

development and soil properties in the coastal forest.

Transects 1–3. Figure 6 shows the maximum tree height (a), maximum tree diameter at breast height (b) and tree volume (c) in the vegetation survey quadrats along Transects 1–3.

4.4 Revegetation of coastal forest

Table 1 shows the species and abundance (number of trees per 25 m²) of trees in the survey quadrats along

Table 1: Tree species and abundance in vegetation survey quadrats along Transects 1–3

Transect Number	1					2					3				
Distance from the top of the fore-dune (m)	50	100	150	200	250	50	100	150	200	250	50	100	150	200	250
Quadrat area (m ²)	25														
	Number of tree (tree height >1 m)														
Evergreen needle-leaved tree															
<i>Pinus thunbergii</i>	7	2	1	4		6	5	3	9	27	1	3	2	1	1
Evergreen broad-leaved tree															
<i>Quercus glauca</i>			3		1										1
<i>Machilus thunbergii</i>												2	1	2	3
<i>Ilex chinensis</i>	3			6	6	3	3	3	4	2			2		
<i>Elaeagnus pungens</i>	3		4												
<i>Vaccinium bracteatum</i>	1						2	1	1	1					1
<i>Ligustrum japonicum</i>	2		10	5	4	9	4	7	3	2	3	2	7		11
Other species	1				1								2	2	
Deciduous broad-leaved tree															
<i>Mallotus japonicus</i>			1		4		2	3	1						
<i>Rhus succedanea</i>						1	1	1	8	4	2				
<i>Rhus javanica</i>	1														
<i>Weyela floribunda</i>							3								

Japanese black pine had not invaded in the vegetation survey quadrat at the 50-m point along Transect 1 (Table 1). Comparing the constituent tree species and their abundance among the three transects at the same distance from the top of the fore-dune, the number of Japanese black pines and the number and species of deciduous broad-leaved trees in Transect 2 tended to be greater than those in Transects 1 and 3 (Table 1). Comparing maximum tree height, maximum tree diameter at breast height, and tree volume among the three transects at the same distance from the top of the fore-dune, their values in Transects 1 and 2 were lower than their corresponding values in Transect 3 (Figure 6). In particular, comparing quadrats at the 50- and 100-m points among the three transects, there were marked differences in forest conditions between Transects 1 and 2, and Transect 3 (Figures 6). This was because the growth environment in the coastal forest inland of a protective forest favored plant growth. That is, the forest barrier located approx. 40 m inland from the top of the fore-dune in Transect 3 (Photo 1) reduced the wind speed and the amount of blown sand and salt into the

forest.



Photo 1: Protective forest forming a barrier against blown sand and salt-laden wind. Forest is located approx. 40 m inland from the top of the fore-dune in Transect 3

In the coastal forest sampled by Transects 1 and 2, Japanese black pine was devastated by pine wilt disease in 1997. The forest in this area was poorly developed

compared with that in Transect 3, which suffered almost no damage from pine wilt disease. In Transects 1 and 2, the coastal forest located approx. 250 m inland from the top of the fore-dune had not fully recovered to its original values for height, diameter at breast height, and density. Consequently, this forest had not fully regained its function as a protective forest to shield against strong winds, sand, and salt. Therefore, early artificial formation of coastal forest is necessary to provide sufficient protection to allow regeneration of coastal forests.

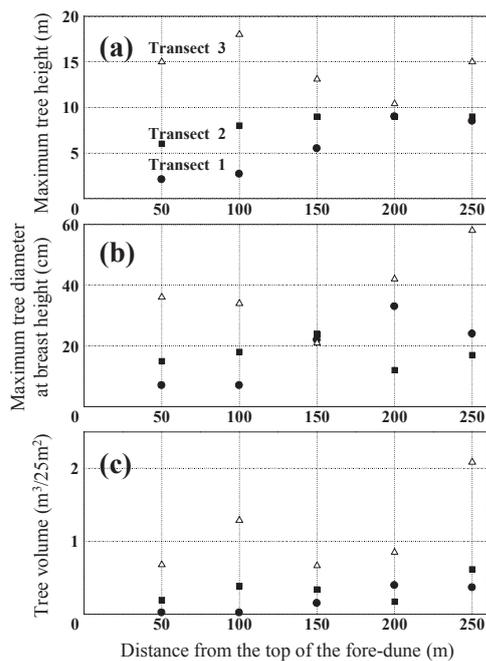


Figure 6: Maximum tree height (a), maximum tree diameter at breast height (b) and tree volume (c) in vegetation survey quadrats along Transects 1–3

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