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Succession and Stand Dimension Attributes of *Pinus thunbergii* Coastal Forests after Damage from Diplodia Tip Blight around the Sakurajima Volcano, Southern Kyushu, Japan

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Abstract

In this study, the succession and stand dimension attributes related to the disaster prevention function of *Pinus thunbergii* coastal forests were examined after damage from Diplodia tip blight. In 2015, 101 years after the Taisho eruption, field investigations were performed on the vegetation, soil thickness, and pH of surface soil of *P. thunbergii* coastal forests in western Sakurajima (Hakamagoshi plot) and Taisho lava flows in southeastern Sakurajima (Seto plot). The Hakamagoshi plot had more woody plant species with larger basal areas than that in the Seto plot. The mean age and height, maximal age and height of plant species, and H/D ratio were all larger in the Hakamagoshi plot than in the Seto plot. These results may be explained by the relatively smaller effect of volcanic ash and gas on forests in the Hakamagoshi plot compared to the Seto plot, resulting in a more suitable environment for many plant species. Although *P. thunbergii* coastal forests in Sakurajima are currently recovering from damages owing to Diplodia tip blight, there has not yet been a sufficient recovery compared to the results from a 1997 study. Furthermore, the results of assessment based on the H/D ratio and abundance of trees in *P. thunbergii* forests indicate that both regions are not yet effective in disaster prevention. Thus, it is necessary to establish *Pinus* trees, which can adjust to harsh environments like coastal areas and are resistant to volcanic ash and gas, to enhance the disaster prevention function of *P. thunbergii* coastal forests in volcanic regions. It may also be helpful to establish coastal forests with ectotrophic mycorrhizal fungi and organic matter coverage. Additionally, it is necessary to ensure the continuous maintenance of stand density and soil quality, and further develop efforts to prevent Diplodia tip blight and promote forest recovery.

Key Words: Sakurajima, Taisho lava, Diplodia tip blight, *P. thunbergii* coastal forests, succession, stand dimension attributes

Introduction

Coastal forests have multiple functions, including prevention against damage (from blown sand, tsunamis, wind, and storms); protection of biological diversity (plants, animals, streams, and coastal ecosystems); and protection of the environment against the effects of climate change, promoting a clean atmosphere and providing amenities (Doing

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1985; Shao et al. 1996; Science Council of Japan 2001; Young et al. 2011; Monserrat et al. 2012). However, damage from Diplodia tip blight caused by the infection of pine trees by *Bursaphelenchus xylophilus* in coastal areas (Mamiya 1988) and sea-level rise and the subsequent change in coastal geomorphology (Hayden et al. 1995) can negatively affect the multiple functions of coastal forests, by altering the type and structure of species and their growth environment (Moreno-Casasola 1986; Costa et al. 1996; Shao et al. 1996; Young et al. 2011; Bissett et al. 2014).

In this study, the Sakurajima coastal forests in the volcanic area of Kagoshima were surveyed. This area has been affected by volcanic ash and gas from repeated eruptions of the Sakurajima volcano since 1955 (Tagawa 1964). *Pinus thunbergii*, a major plant species in Sakurajima coastal forests, was affected with Diplodia tip blight caused by *B. xylophilus* from 2000 to 2004 (Kagoshima Prefecture 2010; Sone et al. 2010). While *P. thungergii* of upper layer (≥3 m) experienced damage, *P. thunbergii* and other species of middle (1 m ≤ tree height < 3 m) and lower (< 1 m) layers were exposed to harsh wind and drought conditions, deteriorating coastal forests and reducing their protective function against blown sand, tsunami and storm surge. In 2005, Diplodia tip blight incidence began to decrease, leading to the recovery of *P. thunbergii* coastal forests (Kagoshima Prefecture 2010), and recovery of their functions is also expected.

Several studies have investigated the vegetation in the volcanic region of Sakurajima, including a plant community (Kawamura 1935), as well as studies on primary succession (Tagawa 1964), mode of distribution and succession (Tagawa 1965; Teramoto et al. 2016; 2017), seed sampling and moss reproduction (Tagawa 1966), changes in propagator properties and seed germination rate (Tagawa 1968), and effect of lava on vegetation (Uto and Suzuki 2002). However, little is known about the succession and disaster prevention function of *P. thunbergii* coastal forests following the effect of Diplodia tip blight in this region.

In this study, we examined the plant succession, tree dimensions and stand attributes related to the disaster prevention function of *P. thunbergii* coastal forests after damages from Diplodia tip blight in the region surrounding the Sakurajima volcano.

Study area

Sakurajima, located in southern Kyushu, Japan, is one of the most famous active volcanoes in the world; it has repeatedly erupted over long periods of time. Four eruptions are particularly well-known, Tenpyo-houji in 764, Bunmei in 1471, Anei in 1779, and Taisho in 1914 (Sekine and Aramaki 1979; Okuno et al. 1997; Kobayashi and Tameike 2002). In Sakurajima, the Minami-dake and Showa craters have been active since 1955 and 2006, respectively, continuously releasing volcanic ash and gas.

Data regarding volcanic activity in Sakurajima since 1955 is summarized below (Kagoshima Meteorological Office, Japan Meteorological Agency 1955-2014). The volcanic activity of Minami-dake was relatively low in the 1950s and 1960s, but increased since 1972. The number of eruptions reached approximately 200 per year between 1974 and 1986, with 474 eruptions in 1985, the highest number recorded since 1955. However, since 1999, the number of annual eruptions decreased to approximately 20 in 2003, and less than 5 times per year since 2008. In the case of the Showa volcano, the number of explosive eruptions dramatically increased every year since its first eruption in 2008, to more than 400 times per year between 2009 and 2014.

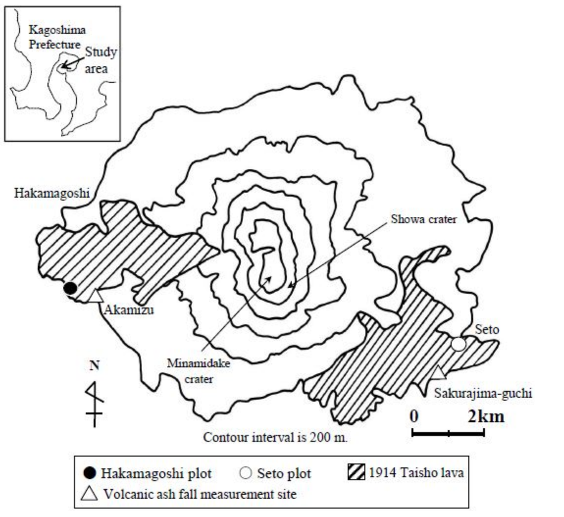

Fig. 1. Study area and distribution of lava fields from the 1914 Taisho eruption.

Damage from Diplodia tip blight caused by *B. xylophilus* in Sakurajima is summarized below, based on previous reports from the Kagoshima Prefecture (2010) and Sone et al. (2010), as well as our local investigation. Diplodia tip blight damage was extremely low from 1979 to 1986, and no damage was reported between 1987 and 1993. However, since 2000, increased damage has been observed throughout the entire Sakurajima area, with the highest annual damage recorded in 2004.

The areas surveyed in this study include western Sakurajima (the Hakamagoshi plot; N 31° 34′ 50.28″ N, 130° 35′ 52.02″ E) and southeastern Sakurajima (the Seto plot; 31° 34′ 12.71″ N, 130° 42′ 27.45″ E), which were covered by lava from the 1914 Taisho eruption (Fig. 1). Taisho lava flowed to the west and southeast of Sakurajima (Fig. 1, Sekine and Aramaki 1979; Okuno et al. 1997; Kobayashi and Tameike 2002). The surveyed area was covered with volcanic ash from the Taisho eruption, the top of which was covered with soil formed following the natural invasion of plants. Most of the volcanic ash released after the Taisho eruption is from continuous volcanic activity from 1955 to the present (Shimokawa and Jitousono 1987).

Vegetation and soil in the surveyed area was lost owing to lava from the Taisho eruption, but primary succession has since occurred (Tagawa 1964). In 2015, 101 years after the Taisho eruption, woody plant vegetation in the surveyed area consists of *P. thunbergii*, evergreen broad-leaved trees, and deciduous broad-leaved trees. The composition of Taisho lava is 60% silica, 20% aluminum oxide, 5% iron oxide, and 5% potassium oxide, and 10% of other substances (Tagawa 1964).

According to records from the local meteorological station in Kagoshima (closest to the study area) between 1981 and 2010, the average annual precipitation was 2,265.7 mm, and the average annual temperature was 18.6°C in Sakurajima (Kagoshima Meteorological Office, Japan Meteorological Agency 1981-2010).

The Hakamagoshi survey plot was approximately 150 m inland, and approximately 5.6 km and 6.1 km from the Minami-dake and Showa volcanoes (labeled with ● in Fig. 1). The altitude of the Hakamagoshi plot was 25 m. The Seto plot was located approximately 150 m inland, and approximately 5.6 km and 5.4 km from Minami-dake and Showa (labeled with ○ in Fig. 1). The altitude of the Seto plot was 25 m.

Materials and Methods

On-site investigation was performed from March to April 2015. Measuring plots with 50 m×50 m size were established in the survey areas to investigate the vegetation, soil thickness, and pH of the soil surface. A vegetation investigation was performed in the survey plot for all woody plants including *P. thunbergii*, evergreen broad-leaved trees, and deciduous broad-leaved trees. For each individual plant taller than 1.3 m, the species was identified, and the basal area was determined. For *P. thunbergii*, age and crown height were measured using knags. For each individual plant that was less than 1.3 m in height, the species was identified, and its height was measured.

In addition, the soil profiles of selected surveyed plots were investigated, including soil thickness and soil surface pH. The pH of surface soil was measured according to the methods of Miyazaki and Nishimura (2011). Dried soil samples and deionized water were added to a container at a ratio of 1:2.5 and stirred. After sitting for 1 hour, a pH sensor was inserted (WM-22EP; DKK-TOA Corporation, Tokyo, Japan) into the supernatant, the container was shaken gently and the pH was measured after a few minutes. Thirty-six soil profiles were selected and used to estimate soil thickness and surface pH. Soil profiles were selected to include samples every 10 m in the vertical and horizontal directions.

Table 1. Species richness and abundance in the Hakamagoshi and Seto plots

	Hakamagoshi	Seto
	Abundance (/2,500 m^2)	
Evergreen needle-leaved tree		
Pinus thunbergii	346	228
Evergreen broad-leaved tree		
Rhaphiolepis umbellata	3	
Eurya japonica	48	40
Vaccinium bracteatum	4	
Deciduous broad-leaved tree		
Rhus succedanea	2	
Rhus javanica	2	2
Total abundance (/2,500 m^2)	405	207

Results and Discussion

Types of species in coastal forests and during succession

P. thunbergii was the dominant species and *Eurya japonica* was another major broad-leaved tree species in both the Hakamagoshi and Seto plots (Table 1). Species richness and abundance were both higher in the Hakamagoshi plot than in the Seto plot. Comparison results of the numbers of woody plant species (taller than 0.3 m) for both plots in 1997 (Uto and Suzuki 2002) and 2015 (this study) are shown in Table 2. *P. thunbergii* was the dominant species in both 1997 and 2015, 83 and 101 years since the Taisho eruption, respectively. The numbers of individual *P. thunbergii* plants, evergreen broad-leaved trees, and deciduous broad-leaved trees were higher in the Hakamagoshi plot than in the Seto plot in both 1997 and 2015. In 2015, the abundance of *P. thunbergii* and woody plants decreased to 51% and 24% in the Hakamagoshi plot and 34% and 37% in Seto plot, respectively, compared to 1997.

Table 2. Comparison of abundance on the Hakamagoshi and Seto plots in 1997 and 2015

	Hakamagoshi		Seto	
	1997	2015	1997	2015
	Number of trees (≥0.3 m height) (/2,500 m^2)			
Pinus thunbergii	673	341	658	224
Evergreen broad-leaved tree	608	45	28	36
Deciduous broad-leaved tree	334	4	29	2
Total (/2,500 m^2)	1,615	390	715	262

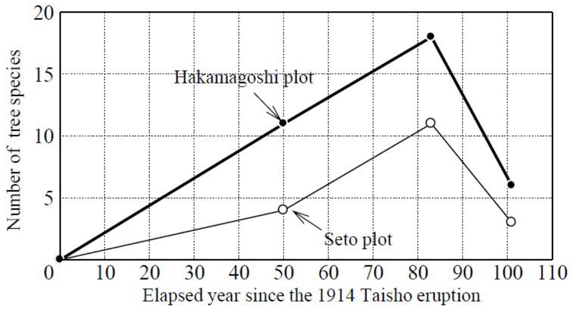

Fig. 2. Change in species richness according to elapsed year since the 1914 Taisho eruption on the Hakamagoshi and Seto plots.

Fig. 2 shows the abundance of woody plant species observed in the Hakamagoshi and Seto plots in 1964 (Tagawa 1964), 1997 (Uto and Suzuki 2002), and 2015 (this study), which were 50, 83, and 101 years after the Taisho eruption, respectively. Although vegetation in both plots was lost after the Taisho eruption, the species richness increased over 83 years as succession proceeded. For the Sakurajima lava flow examined in this study, the beginning of primary succession (Tagawa 1964) was associated with an increase in species richness (Whittaker et al. 1989). An increase in plant species in extremely harsh growth environments, such as lava regions, can be explained by chemical weathering (del Moral and Bloss 1993), physical weathering (del Moral 1993), organic matter falling (Edwards and Sugg 1993), and biological nitrogen fixation (Fritz-Sheridan 1987; Vitousek et al. 1987). Furthermore, the number of species observed in 2015 showed a decrease of approximately 30% compared to 1997. The number of woody plant species after the Taisho eruption in 1914 was higher in the Hakamagoshi plot than in the Seto plot.

Structure and growth environment of coastal forests

In both the Hakamagoshi and Seto plots, the dominant plant species was *P. thunbergii* (i.e. younger than 11 years) that invaded after 2005, after the Diplodia tip blight damage occurred (Fig. 3). In addition, the Hakamagoshi plot contained a higher abundance of *P. thunbergii* (i.e. older

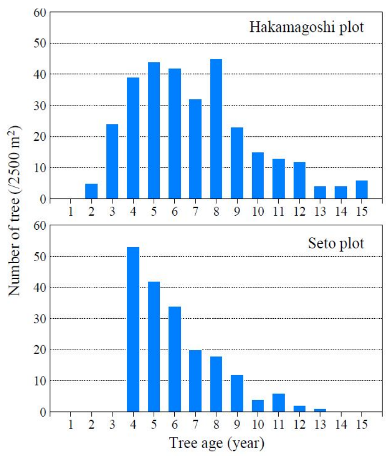

Fig. 3. Distribution of tree age for *Pinus thunbergii* exceeding 1.3 m in the Hakamagoshi and Seto plots.

than 12 years) that invaded prior to 2005 than that in the Seto plot. The maximal age of *P. thunbergii* (as of 2015) was higher in the Hakamagoshi plot than in the Seto plot at 15 years old and 12 years old, respectively.

Comparison results of the maximal ages of *P. thunbergii* for the Hakamagoshi and Seto plots in 1997 (Uto and Suzuki 2002) and 2015 (this study) are shown in Table 3. Based on the maximal age in 1997, *P. thunbergii* was introduced to the Hakamagoshi plot in 1955 and to the Seto plot in 1965, which correspond with 41 years and 51 years after the Taisho eruption, respectively. However, based on the maximal age in 2015, the estimated introduction of *P. thunbergii* to both plots was between 2000 and 2003, during the period of the Diplodia tip blight infection. This indicates a noticeable discrepancy in the maximal age of *P. thunbergii* between 1997 and 2015.

In both plots, height and diameter at breast height were positively correlated, indicating a statistical significance at the 0.1% level (Fig. 4). Based on the slopes of the linear regressions for both plots, when the diameter at breast height (DBH) was identical, plants were 1.1-fold taller in Hakamagoshi than in Seto.

Table 3. Comparison of maximal tree age for *Pinus thunbergii* on the Hakamagoshi and Seto plots in 1997 and 2015

	Hakamagoshi		Seto	
	1997	2015	1997	2015
	Maximal tree age (year)			
Pinus thunbergii	42	15	32	12

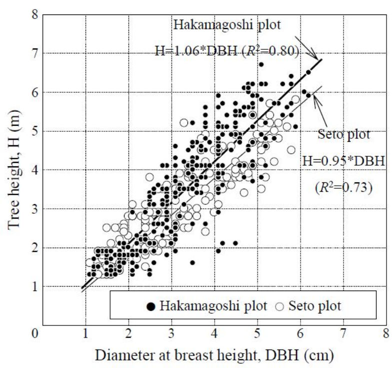

Fig. 4. Tree height against diameter at breast height for *Pinus thunbergii* exceeding 1.3 m in the Hakamagoshi and Seto plots.

Fig. 5 shows the height distribution of *P. thunbergii* and *E. japonica*, which were the most abundant coniferous and broad-leaved tree species, respectively. The average height of *P. thunbergii* was more than that of *E. japonica*. When comparing identical plant species among plots, plants in the Hakamagoshi plot were relatively taller: the maximal heights of *P. thunbergii* and *E. japonica* were 6.7 m and 3.2 m in the Hakamagoshi plot and 5.8 m and 2.6 m in the Seto plot, respectively.

Comparison results of the maximal heights of *P. thunbergii* and *E. japonica* in the Hakamagoshi and Seto plots between 1997 (Uto and Suzuki 2002) and 2015 (this study) are shown in Table 4. In a single plot, the maximal height was shorter in 2015 than in 1997 and decreased to approximately 60% and 70-80% from 1997 to 2015 for *P. thunbergii* and *E. japonica*, respectively. Within a species, the

Table 4. Comparison of maximal tree height on the Hakamagoshi and Seto plots in 1997 and 2015

	Hakamagoshi		Seto	
	1997	2015	1997	2015
	Maximal tree height (m)			
Pinus thunbergii	11.7	6.7	9.4	5.8
Eurya japonica	4.1	3.2	3.8	2.6

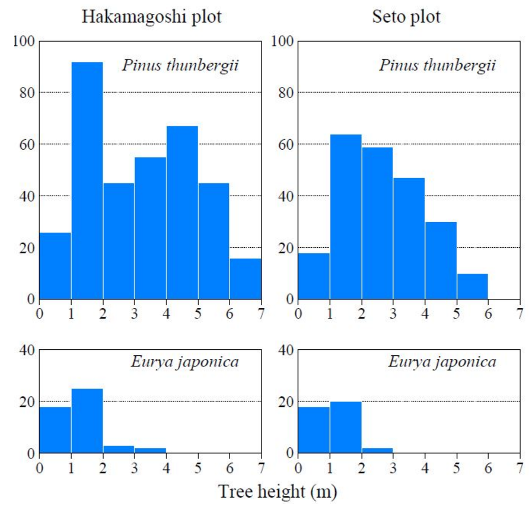

Fig. 5. Distributions of tree height for *Pinus thunbergii* and *Eurya japonica* on the Hakamagoshi and Seto plots.

Hakamagoshi plot also showed higher maximal heights than those of the Seto plot. Additionally, the maximal height was larger for *P. thunbergii* than for *E. japonica* in both plots.

In both plots, the basal area for *P. thunbergii*, the dominant species, occupied most of the total basal area. Furthermore, the basal area was lower in 2015 (this study) than in 1997 (Uto and Suzuki 2002) for both plots (Table 5).

The Hakamagoshi plot showed higher minimal, maximal, and average values for soil thickness and lower minimal, maximal, and average values for soil surface pH compared to those of the Seto plot (Table 6). A *t*-test indicated that the average soil thickness and pH at the soil surface were significantly different at the 0.1% significance level.

In summary, the results of investigation of coastal forests in 2015 after Diplodia tip blight damage revealed that the Hakamagoshi plot had higher species richness and abundance, and woody plants in this plot also had larger basal areas than that in the Seto plot (Table 1, Fig. 5). Additionally, in the case of *P. thunbergii*, the Hakamagoshi plot had more individuals that were relatively older and taller and had higher maximal ages and heights (Fig. 3, Fig. 5). *P. thunbergii* trees were taller in the Hakamagoshi plot when controlling for DBH (Fig. 4). These results suggest that the Hakamagoshi plot had a better growth environment than that of the Seto plot, possibly due to the relatively lower effect of volcanic ash and gas. In favorable environmental conditions, the growth rate of woody plants and the amount of soil organic matter increase; and as such they can be used as indicators of environmental condition (Tagawa 1964). As the amount of organic matter increases, nutrition and soil thickness increase (Olson 1963; Tappeiner and Alm 1975; Kumlung and Takeda 1991; Edwards and Sugg 1993). Soil pH decreases as the recovery of woody plants proceeds (Higashi 1991; Fujita and Nakata 2001; Isermann 2005). These results are consistent with higher soil thickness and the acidification of the soil surface in the Hakamagoshi plot, which is recovering from damage due to Diplodia tip blight (Table 6). The lower soil pH may be explained by the active production of organic acids by soil microbes (Isermann 2005) and volatile substances in volcanic ash and gas, which facilitate soil acidification (Sakamoto 2013).

In an area (Akamizu) approximately 0.8 km southeast of the Hakamagoshi plot and another area (Sakurajima-guchi) approximately 1.1 km southwest of the Seto plot, the amount of volcanic ash in soil were measured from 1979 to 2014 (labeled with △ in Fig. 1). The total amount of volcanic ash from 1979 to 2004 (when damage from Diplodia tip blight peaked) were 264.6 kg/m^2 and 445.1 kg/m^2 in Akamizu and Sakurajima-guchi, respectively. From 2005, when coastal forests started to recover, to 2014, the total amount of volcanic ash was 61.6 kg/m^2 and 81.0 kg/m^2 in Akamizu and Sakurajima-guchi, respectively (Kagoshima Meteorological Office, Japan Meteorological Agency 1979-2014), and was lower in Akamizu for both time periods. In addition, according to records for wind direction from the Kagoshima Meteorological Office (1990-2010) close to Sakurajima, 75% of observations indicated northwest winds (Kagoshima Meteorological Office, Japan Meteorological Agency 1990-2010). This suggests that the Hakamagoshi plot, west of Sakurajima, might have experienced less effect of volcanic gas released from the Minami-dake and Showa craters (Fig. 1) compared to that by the Seto plot, located southeast of Sakurajima. Additionally, it supports the observation that Akamizu, west of Sakurajima, had relatively less volcanic ash.

Although the Hakamagoshi and Seto plots exhibited significant damage from Diplodia tip blight, they have started

Table 5. Comparison of basal area on the Hakamagoshi and Seto plots in 1997 and 2015

	Hakamagoshi		Seto	
	1997	2015	1997	2015
	Basal area (m^2/2,500 m^2)			
Pinus thunbergii	1.650	1.281	1.015	0.672
Evergreen broad-leaved tree	0.063	0.028	0.373	0.007
Deciduous broad-leaved tree	0.008	0.004	0.188	0.002
Total (m^2/2,500 m^2)	1.721	1.313	1.576	0.681

Table 6. Comparison of soil depth and pH of surface soil in the Hakamagoshi and Seto plots

	Hakamagoshi			Seto		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Soil thickness (cm)	6.5	18.5	11.8	2.7	17.6	7.6
pH of surface soil	4.02	5.58	4.73	4.56	5.89	5.16

Table 7. Comparison of H/D ratio in the Hakamagoshi and Seto plots

	Hakamagoshi plot			Seto plot		
	Min.	Max.	Avg.	Min.	Max.	Avg.
H/D ratio	45.7	168.6	104.6	62.5	166.7	100.6

to recover. However, based on a comparison between the results from this study and those in 1997, 83 years after the Taisho eruption, including species richness and abundance, age, height, and DBH, the recovery is likely not complete.

Stand dimension attributes related to the disaster prevention function of coastal forests

Table 7 shows the range of the H/D ratio in the Hakamagoshi and Seto plots. The maximum and minimum values were lower in the Hakamagoshi plot, but the average was similar in the two plots. To maximize the disaster prevention function of coastal forests against blown sand, tsunami, and storm surge, the optimal H/D ratio for *P. thunbergii* is on average 60-70 (Murai et al. 1992). However, the observed average H/D ratio was approximately 1.4-1.7 times higher than the reported optimal value for both plots.

The number of *P. thunbergii* individuals that are needed to confer a disaster prevention function was computed using the maximal height (H_{max}), average height (H_a), and average crown height (H_c) of *P. thunbergii* (taller than 1.3 m), following the methods of Kanazawa et al. (1990). Based on this calculation, 878 individuals/2,500 m^2 and 1,109 individuals/2,500 m^2 were needed in the Hakamagoshi plot (H_{max}: 6.7 m, H_a: 3.5 m, and H_c: 1.1 m) and the Seto plot (H_{max}: 5.8 m, H_a: 3.0 m, and H_c: 0.9 m), respectively. In this study, the numbers of individuals observed were 308 individuals/2,500 m^2 and 192 individuals/2,500 m^2 in the Hakamagoshi plot and Seto plot, respectively, which were only approximately 17-35% of the threshold values. Based on H/D ratios and the observed numbers of individuals after Diplodia tip blight damage, neither plot appear to have a disaster prevention function.

Thus, it is essential to construct additional *P. thunbergii* coastal forests to improve the disaster prevention function in these surveyed areas. In Japan, coastal forests with *P. thunbergii* that can survive in harsh environments have been established since the mid-1600s (Murai et al. 1992; Ezaki 2009; Ohta 2012), and other plant species were introduced (Murai et al. 1992; Nakashima and Okada 2011; Ohta 2012). However, because the coastal area is a harsh environment due to sand drifts, strong wind, waves, and drought, providing unfavorable growth conditions for plants (Moreno-Casasola 1986; Murai et al. 1992; Costa et al. 1996; Shao et al. 1996; Ezaki 2009; Nakashima and Okada 2011; Ohta 2012), it was not optimal for woody plant species other than *P. thunbergii* (Murai et al. 1992; Ezaki 2009; Nakashima and Okada 2011; Ohta 2012). Therefore, it is preferable to establish coastal forests with *P. thunbergii* as the dominant species.

The growth environment in Sakurajima is very harsh, due to sand drifts, wind, waves, drought, and volcanic ash and gas. Thus, the establishment of *P. thunbergii* (which has high resistance to salt, sand drifts, wind, and volcanic ash and gas) to construct coastal forests is highly encouraged (Ezaki 2009). In addition, *P. thunbergii* can be injected with ectotrophic mycorrhizal fungi in rhizosphere soil or covered with organic matter (Ezaki 2009). Furthermore, the continuous maintenance of stand density, soil quality, and the prevention of Diplodia tip blight are necessary (Nakashima and Okada 2011; Ohta 2012).

Conclusions

To assess the succession and stand dimension attributes related to disaster prevention function for coastal forests after damage from Diplodia tip blight, the vegetation, soil thickness, and pH of surface soil were investigated in two plots of *P. thunbergii* coastal forests located in western Sakurajima, Japan. Some key results were obtained: (1) the Hakamagoshi plot showed higher woody plant species richness and abundance, and plants exhibited a greater basal area; (2) *P. thunbergii* were older, taller, and had higher maximum ages and heights in the Hakamagoshi plot than in the Seto plot; and (3) for identical DBH, *P. thunbergii* were taller in the Hakamagoshi plot than in the Seto plot. Taken together, coastal forests in the Hakamagoshi plot probably experience less effect of volcanic ash and gas than that by the Seto plot, resulting in a better environment for plant growth. In addition, although both coastal forests are recovering from damage due to Diplodia tip blight, this recovery is not yet complete, based on the species richness and abundance, and well as the observed plant age, height, and basal area in 1997. Additionally, based on an assessment of stand dimension attributes, including the H/D ratio and the abundance of *P. thunbergii*, it is not yet a fully functional coastal forest for disaster prevention.

The environment of the Sakurajima coastal area is very harsh. Therefore, it is essential to develop new pine (*P. thunbergii*) trees, which are highly resistant to salt, drifting sand, wind, volcanic ash, and gas, and to construct coastal forests using ectotrophic mycorrhizal fungi and organic matter. Furthermore, it is important to implement active efforts aimed at the prevention of Diplodia tip blight and to continuously maintain stand density and soil quality.

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