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EVALUATING THE DYNAMICS OF ALIEN SPECIES (POACEAE) USED FOR EROSION CONTROL ON SAKURAJIMA VOLCANO

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ABSTRACT: Alien species in the family Poaceae play an important role as cover plants for erosion control on slopes, particularly in Japan. However, concerns have arisen regarding the adverse effects of these species on the local ecosystem and biodiversity. This study therefore examined the succession and seed propagation of alien Poaceae that are used for erosion control on the cut slopes of Sakurajima volcano in southwestern Japan. The results were as follows: Although the alien species used as cover plants were dominant for the first couple of years following their introduction to the slopes, they were displaced entirely by native species after the sixth year, which is considerably faster than ordinary succession. In addition, heading (flowering) of alien species was also rarely observed in this period. It is considered that the observed results were caused by the oligotrophic conditions of the slopes on Sakurajima volcano.

Keywords: Cover plant, Cut slope, Exotic grass, Seed propagation, Succession

1. INTRODUCTION

There are numerous active volcanoes around the world. The slopes of many of these volcanoes are typically bare or sparsely vegetated due to volcanic ejecta, such as pumice, scoria, ash, and volcanic gas, causing soil erosion and debris/mud flows. Consequently, volcano slopes are intentionally covered with plants for erosion control. In Japan, numerous alien species in the family Poaceae have been used for this purpose, including *Agrostis stolonifera*, *Cynodon dactylon*, *Dactylis glomerata*, *Eragrostis curvula*, *Festuca arundinacea*, *Festuca rubra*, *Lolium multiflorum*, *Lolium perenne*, *Paspalum notatum*, *Phleum pretense* and *Poa pratensis*. These species, which are indigenous to Europe, South Africa and South America, are well suited to growing in Japan where they typically grow at much faster rates than the native species.

However, concerns have arisen regarding the negative effects that these alien plant species have on the ecosystems and biological diversity present in the areas that they invade. Although numerous studies have been conducted on plant succession on volcanoes, e.g. [3], [5], [6], [8], [13], [15]-[17], [24]-[31], [33], [36], [37], only a few have examined the succession of alien species used as cover plants for erosion control on volcanoes [14], [18], [20], [21], [34]. It is therefore important to further clarify the succession of alien plant species on volcanoes for preventing soil erosion and debris/mud flows, and conserving ecosystem integrity and biological diversity.

Kondo et al. [14] reported that within six years after being introduced, all of the alien species in the family Poaceae that were used for erosion control on Sakurajima volcano were completely displaced by native plant species. Although they suggested that the potential of these alien plants to disperse had decreased in this area, the risk of seed dispersal by these species in this six-year period has not yet been assessed. We therefore reinvestigated the succession of alien plant species in the family Poaceae that are used as cover plants for erosion control on Sakurajima and examined the seed-propagation ability of these species.

2. METHODS

2.1 Study Site

The archipelago of Japan, which is located on the Pacific Ring of Fire, has as many as 110 active volcanoes [11]. Of these, Sakurajima in Kagoshima Prefecture in southwestern Japan (Fig. 1), which is where this study was performed, is one of the most active. Sakurajima is located in the warm temperature zone where the mean annual temperature and annual precipitation over the last decade (2006-2015) have ranged from 18.2 to 19.3°C and 1,530 to 3,664 mm, respectively. Volcanic activity accompanied by ash fall, soil erosion and debris/mud flows continues to this day.

In this study, the 85 cut slopes that resulted from the construction of check dams were

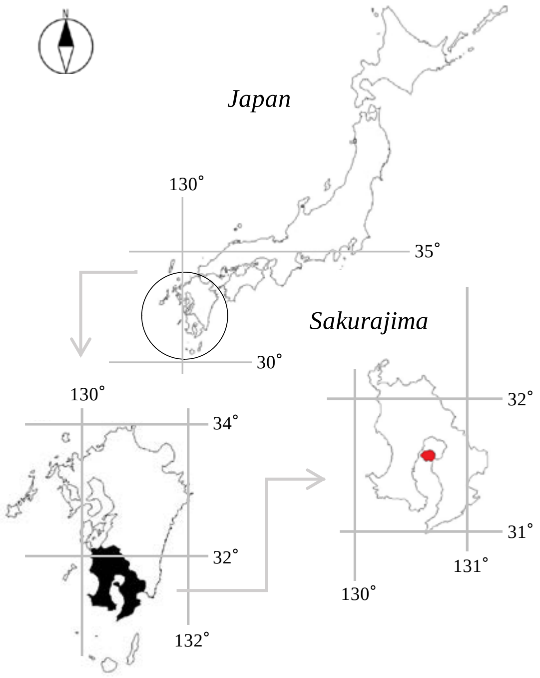

Fig. 1 Location of the study site.

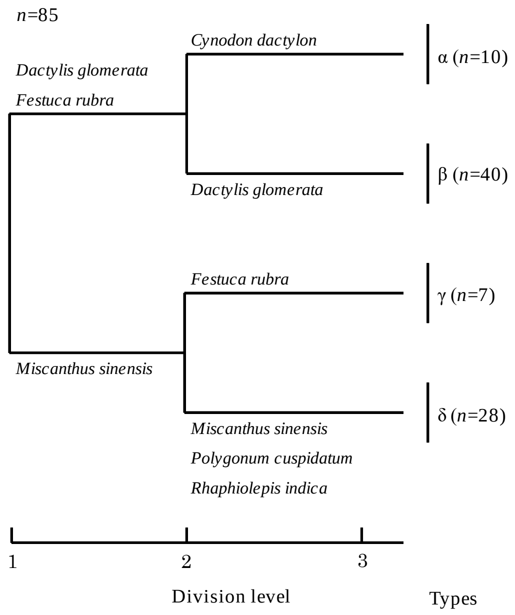

Fig. 2 Classification of vegetation on cut slopes by TWINSPAN, using species composition (coverage data, %). Cut levels of 0, 20, 40, 60, and 80 were employed in the analysis.

surveyed on the western side of Sakurajima; these sites included some of the same sites investigated by Kondo et al. [14]. The slopes, which were created during 2005-2014, were located at an altitude of 366 to 655 m above sea level and their angles of inclination ranged from 25 to 82°. Volcanic gas appeared to have no effect on the vegetation on the cut slopes, but ash-fall was constantly observed on the slopes.

Alien species belonging to Poaceae, such as *A. stolonifera*, *C. dactylon*, *D. glomerata*, *E. curvula*, *F. arundinacea* and *F. rubra*, have been introduced for erosion control on the cut slopes in this area using a bioengineering technique known as the slurry application method, which is an aerial seeding method. While the method typically calls for the repeated application of additional fertilizer [12], [18], [22], no additional fertilizer has been applied to the slopes of Sakurajima.

2.2 Vegetation Surveys

Surveys of the vegetation on the cut slopes were conducted in October 2015. Three survey quadrats (1 × 1 or 2 × 2 m) were randomly placed on each cut slope. The species composition of the plants in each quadrat was recorded and scored using the Braun-Blanquet cover-abundance scale [2]. All of the recorded plant species were categorized as native or alien, and as ferns, herbaceous plants or woody plants based on published literature [1], [10], [19], [23]. In addition, heading (flowering) of *Miscanthus sinensis* (native) and *F. rubra* (alien) was observed at this time, and the number of scapes in each quadrat was also enumerated.

The number of years that had passed since the bioengineering techniques had been implemented (NYPSB) was obtained from the Kagoshima District Forest Office, Kyushu Regional Forest Office, Forestry Agency. The Braun-Blanquet cover-abundance scale (r, +, I, II, III, IV, and V) was transformed as follows: r and + were taken as 0.1%; I as 5.0%; II as 17.5%; III as 37.5%; IV as 62.5%, and V as 87.5%. The cut slopes were classified into vegetation types based on their species composition by a two-way indicator species analysis, TWINSPAN, using the PC-ORD statistical software package (ver. 4.0 for Windows, MjM Software Design, OR).

3. RESULTS

3.1 Vegetation Type

The vegetation on the 85 cut slopes was classified into four types (α, β, γ and δ) using TWINSPAN (Fig. 2); types α, β, γ and δ were

Table 1 Plant coverage for each vegetation type classified by TWINSPAN.

	Vegetation types			
Species	α (*n*=10)	β (*n*=40)	γ (*n*=7)	δ (*n*=28)
<Alien species>				
Cynodon dactylon #, †	63.17	2.92	0.96	0.01>
Festuca rubra #, †	19.00	30.09	10.26	0.01>
Dactylis glomerata #, †	3.77	32.09		
Trifolium repens #	0.51	2.07	0.24	
Phalacroloma annuum #		0.01>		
<Native species>				
Miscanthus sinensis #		1.54	17.38	53.51
Polygonum cuspidatum #	0.01>	0.01	0.02	2.65
Alnus firma ω		0.01>	0.01	1.23
Eurya japonica ω			0.01>	1.33
Artemisia indica #		0.05	0.01>	0.06
Lespedeza cuneata #	0.01>		0.01>	
Pinus thunbergii ω				0.39
Rhododendron obtusum ω				0.06
Rhaphiolepis indica ω				1.05
Albizia julibrissin ω				0.01>
Boehmeria spicata #				0.01>
Dennstaedtia hirsuta θ				0.01>
Indigofera pseudotinctoria ω				0.01>
Ligustrum japonicum ω				0.01>
Frequency ‡	10/10	40/40	7/7	2/28
NYPSB (Min.-Max.)	1.8 (1-2)	2.0 (1-4)	3.4 (3-5)	6.6 (4-10)

#, herbaceous plant (excluding fern); †, species (Poaceae) used as cover plants for erosion control; ω, woody plant; *θ*, fern and ‡, number of slopes which had alien species/total number of slopes. See Fig. 2.

found on 10, 40, 7 and 28 slopes, respectively. *M. sinensis*, *D. glomerata*, *F. rubra*, *Polygonum cuspidatum*, *Rhaphiolepis indica* and *C. dactylon* were used as indicator species.

Type α plants were dominated by the alien species *C. dactylon* and *F. rubra*, which had been used as cover plants for erosion control and reached 82.17% in coverage (Table 1). Type β plants were dominated by the alien species *F. rubra* and *D. glomerata*, which are also used for erosion control. However, the extent of coverage by these alien species was lower (62.18%), while that of native species was higher than it was for Type α plants. For Type γ plants, coverage of alien and native species was generally similar; for example, coverage for *F. rubra* and *M. sinensis* was 10.26% and 17.38%, which was the highest coverage for the alien and native species of this type, respectively. Conversely, Type δ plants were characterized as having almost no alien species (coverage <0.01%; frequency was 2/28 slopes) and native species, mainly *M. sinensis* (53.51%), were dominant.

The NYPSB for each type is shown in Table 1. In terms of succession, the findings show that the plant communities on cut slopes would likely progress through types α, β, γ and finally δ after the bioengineering technique had been implemented.

3.2 Relationship between NYPSB and Component Species

The relationship between NYPSB and component species is shown in Fig. 3. At two years after the bioengineering technique had been implemented, most of the species on the cut slopes were alien species. Of these, almost all (98.4%) were species that had been used as cover plants for erosion control (i.e. *C. dactylon*, *F. rubra* and *D. glomerata*). However, the coverage of these species decreased markedly after the third year, before disappearing completely by the sixth year after implementation of the bioengineering technique. Native species were observed from the first year, and *M. sinensis* and woody plants were observed from the third year onwards; these species became dominant after the fourth year, particularly *M. sinensis* (83.7%).

3.3 Seed Propagation

Scapes of *M. sinensis* were observed three years after implementing the bioengineering technique (Fig. 4). Scape numbers increased gradually thereafter, reaching 22.0 m^{-2} by the tenth year.

Festuca rubra scapes were observed in the first year after implementation of the bioengineering technique, but they were not observed by the fourth year; specifically, the number of *F. rubra* scapes was 0.1 m^{-2} in the first year, 1.8 m^{-2} in the second year, and 0.2 m^{-2} in the third year, which are significantly low compared to those for *M. sinensis* at the experimental sites (Fig. 4), and for general *F. rubra*.

4. DISCUSSION

It is considered that implementation of the bioengineering technique would result in the composition of the plant communities on the cut

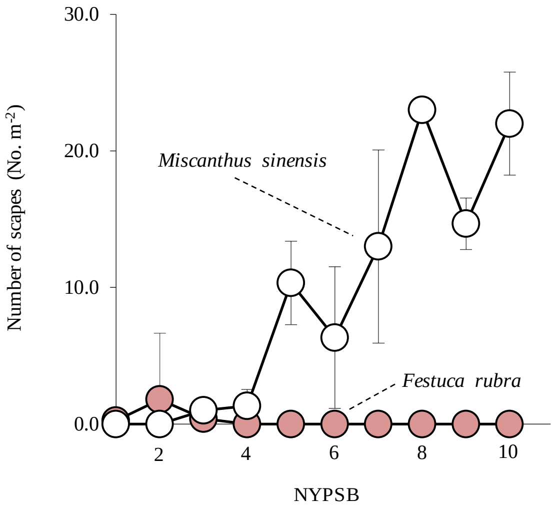

Fig. 4 Changes in the number of scapes after implementation of the bioengineering technique.
Error bars indicate the standard deviation.

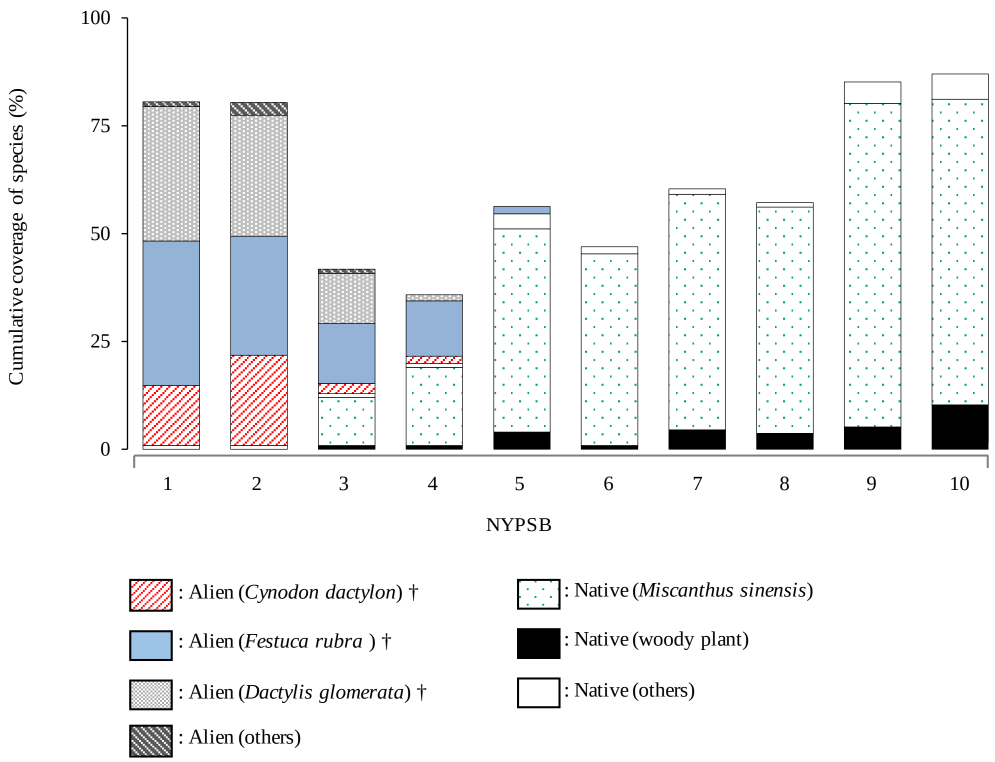

Fig. 3 Relationship between NYPSB and component species on the cut slopes of Sakurajima.
†, species (Poaceae) used as cover plants for erosion control.

slopes of Sakurajima progressing gradually from communities dominated by alien Poaceae, which have been used extensively as cover plants for erosion control, to communities dominated by native species (Fig. 2 and Table 1). In this study, native species became dominant after the fourth year and alien species disappeared entirely by the sixth year (Fig. 3). As also reported by Kondo et al. [14], the rate of alien plant succession on Sakurajima was markedly higher than succession on other active volcanoes where alien species have remained established for more than 10 years (10-33 years) after implementation of the bioengineering technique [18], [20], [34]. In addition, scapes of alien species such as *F. rubra*, which have been used extensively as cover plants, were rarely observed on Sakurajima (Fig. 4).

It is therefore considered that alien species used for erosion control on Sakurajima have little effect on ecosystem integrity and biological diversity when compared to other active volcanoes [18], [20], [34]; however, we cannot state with certainty that these alien species will not disperse to other areas, and further investigation is needed. Meanwhile, although alien species disappeared rapidly on the slopes of Sakurajima, their coverage was initially relatively high after implementation of the bioengineering technique (Fig. 3). It is therefore considered that these plants played an important role in erosion control on Sakurajima. Indeed, none of the slopes examined in this study showed any evidence of erosion.

By the way, why did all of the alien species in the family Poaceae rapidly disappear on the cut slopes of Sakurajima? Since the nutrient (fertilizer) demand of alien species in the family Poaceae is typically very high [4], [7], [9], [32], [35], the alien plants on Sakurajima would initially have flourished due to the eutrophic conditions that would have accompanied the implementation of the bioengineering technique. Conversely, the subsequent decrease observed in alien plant coverage may have occurred rapidly due to the establishment of oligotrophic conditions resulting from chemical properties of volcanic ash (e.g. N, CaO and K_2O leaching, and fixation of P_2O_5) (Fig. 5), as well as no more fertilizer being applied to the slopes. These findings would be supported by reports of alien species at other active volcanoes being present more than ten years after being introduced, where ash-fall associated with volcanism was not observed, and fertilization schemes including the use of a thick cultivation base, additional fertilizer at a later date and arbuscular mycorrhizal fungi were also employed [18], [20], [34]. Incidentally, of *C. dactylon*, *F. rubra* and *D. glomerata* which have been used as cover plants for erosion control, *C. dactylon* is warm-season grass, and the rest belong to cool-season grass. It seems therefore that the difference between the two is not directly related with the above succession of alien species on the cut slopes of Sakurajima (see Table 1 and Fig. 3).

Fig. 5 Eruption accompanied by a massive amount of volcanic ash, which continues even now on Sakurajima.

It is not clear why heading (flowering) of *F. rubra* was rarely observed on the slopes of Sakurajima, but we consider that ash-fall might have some influence on seed propagation of alien species in the family Poaceae in a negative way.

The high germination rate and rapid growth of alien plants in the climate of Japan mean that using alien species as cover plants would be indispensable for erosion-control efforts in Japan. In addition, the market for these species is already well established and they can be obtained more easily and cost more effectively than indigenous Japanese species. However, as the concerns have increased in recent years regarding the adverse impacts of alien species on ecosystems and biological diversity, accumulating knowledge on the invasiveness of alien species as cover plants is important for developing future erosion control measures. Thus we consider that findings of this study on the succession of alien plants used for erosion control on the slopes of Sakurajima would be very meaningful.

5. CONCLUSIONS

Our study provides information on the succession of alien Poaceae, which have been used as cover plants for erosion control on the cut slopes of Sakurajima volcano. Although alien plants used for erosion control were dominant for the first couple of years from implementation of the bioengineering technique, native species were dominant thereafter and alien species completely vanished by the sixth year, which corresponded well with previous report by Kondo et al. [14]; this trend of succession on the slopes of Sakurajima would have been caused by the oligotrophication of soil resulting from volcanic ash, and fertilizer management (i.e. low fertilizer application) employed on Sakurajima. In contrast, the difference between grass types (warm- or cool-season grass) of alien species used for erosion control would not likely have an effect on their succession on the slopes of Sakurajima. It was also clarified that heading (flowering) of alien species, e.g. *F. rubra*, was hardly formed in the succession on the cut slopes of Sakurajima.

The markedly rapid succession observed in this study suggests that alien Poaceae used for erosion control could have little adverse effect on ecosystem integrity and biological diversity on Sakurajima. Meanwhile, they would play the role of starter for succession, contributing to erosion control on the cut slopes of Sakurajima.

6. ACKNOWLEDGEMENTS

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