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Shallow landslide prevention due to natural vegetation recovery on Shirasu steep slopes 4 years after plantation clear-cutting in Kagoshima Prefecture

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Abstract: We investigated the current vegetation conditions on Shirasu steep slopes susceptible to shallow landslides, and particularly the role of root networks and topsoil in preventing shallow landslides, in abandoned forests 4 years after plantation clear-cutting. The study area was located near Kagoshima Airport, Kagoshima Prefecture. To conduct vegetation surveys and take topsoil thickness measurements, we established quadrats on seven slopes: five with steep slopes (>40°) and two with relatively gentle slopes (30°). Vegetation on the steep slopes prone to shallow landslides was less abundant than that on the relatively gentle slopes. If there is no reforestation after clear cutting on steep slopes, vegetation recovery is substantially delayed in comparison with that on reforested slopes, and recovery of the role of forest root networks to prevent shallow landslides is substantially delayed. Moreover, the average value of topsoil thickness on the steep slopes was approximately 40 cm. Based on the relationship between shallow landslide occurrence and topsoil development, this value of approximately 40 cm indicated that shallow landslides could be expected to occur.

1 Introduction

In recent years, there has been an increase in the area of abandoned forests after plantation clear cutting. In the Kyushu region of Japan, the area of abandoned forests after plantation clear cutting is, at present, more than 12 km^2 (Murakami *et al*., 2007) and this is increasing over time. Plantation abandonment significantly alters the hydrologic and erosion regime of forested areas (Tsukamoto, 1998; Jakob, 2000; Teramoto and Shimokawa, 2009, 2011). Specifically, it increases the amount of rain water runoff, sediment yield and discharge, which can cause considerable damage to the hillslope and coastal vegetation habitat. Clarifying the effects of deforestation following plantation abandonment on rain water runoff, sediment yield and discharge will aid the conservation of hillslope and coastal ecosystems.

The effects of deforestation on rain water runoff, sediment yield and discharge can be divided into short-term effects and medium-term effects. The short-term effects begin with a decrease in soil infiltration capacity, arising from the land disturbance during the preparation of the yarding road and logging operations, which causes an increase in the amount of rain water runoff (Teramoto and Shimokawa, 2009, 2011). The amount of rain water runoff into rivers increases because of a decrease in rain water interception by the forest canopy following deforestation. However, the amount of rain water runoff into rivers is small in comparison to the amount of rain water runoff caused by the changes in the soil infiltration capacity. Because of this increase in rain water runoff, there is an increase in sediment yield and discharge due to sheet erosion in the yarding road and its periphery as well as from erosion of the river bank and bed.

Deforestation also has medium-term effects. After plantation harvesting, the forest root networks initially continue to prevent shallow landslides for a while, but this function is lost after 5 to 10 years (Shimokawa and Iwamatsu, 1983; Tsukamoto, 1998; Jakob, 2000). If the cleared slopes are reforested immediately after harvesting, this prevention function of the roots increases over time and can be restored after approximately 20 to 30 years (Teramoto and Shimokawa, 2009, 2011). However, if there is no reforestation, recovery of the root network prevention function is delayed, and there is a risk of shallow landslides on steep deforested slopes, and debris flows caused by shallow landslides can occur during storm events.

The purpose of this study was to characterize the medium-term effects of deforestation following plantation abandonment on rain water runoff, sediment yield and discharge using vegetation surveys and investigations of topsoil, which becomes the material of the shallow landslides on steep slopes.

2 Study area and methods

The study area was an abandoned former plantation forest, situated to the northeast, at a location of about 0.5 km away, from Kagoshima Airport, Kagoshima Prefecture, Japan (Figure 1). The plantation forest was cedar and cypress, planted in 1964, and the tree age was

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43 years at the time of cutting in 2007. The geology of the area is a pyroxene andesite and Kakuto pyroclastic flow deposits base covered with Shirasu (Ito pyroclastic flow deposits). The thickness of the Shirasu layer exceeds 100 m at the thickest point. Moreover, the Shirasu layer is covered by volcanic ash and pumice, resulting from successive eruptions of the Kirishima and Sakurajima Volcanoes. The volcanic ash and pumice are a few meters thick. Many erosion valleys are developed in the Shirasu layer. The slope of the valleys is 35–45° though the slope along the ridge is gentle.

To study the current vegetation conditions 4 years after the plantation clear-cutting on the shallow landslide-prone steep slopes, 5 × 5 m vegetation survey quadrats were established (Figure 1). The quadrats were placed on seven separate slopes: five (No.1–5) on steep slopes (>40°) and two (No.6 and No.7) on relatively gentle slopes (approximately 30°) (Photo 1). Species, height, diameter at breast height and age of trees with >1 m height were recorded. Measurement of topsoil thickness on five steep slopes was conducted using a penetrator. To evaluate tree succession in each quadrat, the Fisher-Williams index of diversity (a) was calculated. The value of the index (a) in each quadrat was determined using the equation: $S = a \log_e(1+N/a)$; where S is the number of tree species and N is the number of trees in each quadrat (Tagawa, 1964, 1973). Vegetation surveys were conducted in 2011, about 4 years after clear cutting.

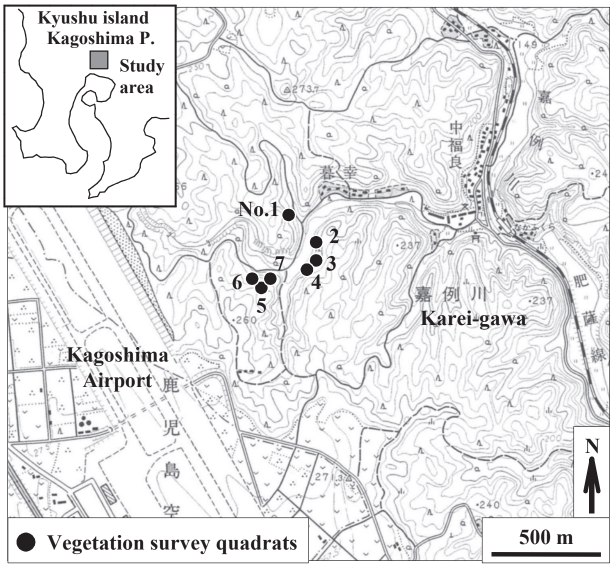

Figure 1: Study area location

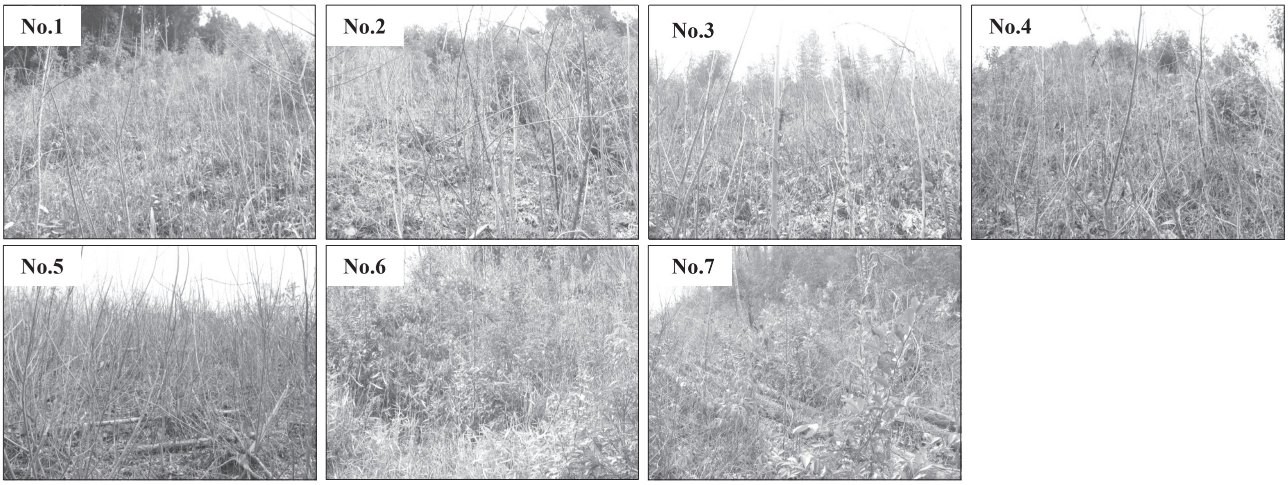

Photo 1: Vegetation survey quadrats

3 Results and discussion

3.1 Tree species and tree structure on steep slopes

Table 1 shows the tree species and numbers in the survey quadrats. Figures 2 and 3 show the distributions of tree height and diameter at breast height, respectively, and figure 4 shows the distribution of tree age. The number of trees is the number per 25 m^2 survey quadrat. The distributions of tree height and diameter at breast height in Figures 2 and 3 are separated for evergreen broad-leaved and deciduous broad-leaved trees.

The numbers of tree species and numbers of evergreen broad-leaved trees on the steep slopes (>40°) (No.1–5) were smaller than those on the relatively gentle slopes (30°) (No.6 and No.7). Similarly, the numbers of tree species and numbers of deciduous broad-leaved trees on the steep slopes were greater than those on the relatively gentle slopes (Table 1). Tree height and diameter at breast height on the steep slopes were smaller than those on the relatively gentle slopes. On the steep slopes, tree height and diameter at breast height were usually <2 m and <2 cm, respectively. Most of the relatively large measurements of tree height and diameter at breast height on the relatively gentle slopes were of evergreen broad-leaved tree (Figures 2 and 3). There was no difference in average tree age between quadrats on the steep slopes and those on the relatively gentle slopes (Figure 4).

Table 1: Tree species and numbers in the vegetation survey quadrats

Survey quadrat Slope direction Slope (degree)	No.1 W 40	No.2 NW 42	No.3 E 40	No.4 NE 42	No.5 W 42	No.6 NNW 28	No.7 N 30
	Number of tree						
Evergreen broad-leaved tree							
Quercus glauca	6	3	2			4	8
Ligustrum japonicum				1			
Camellia japonica L.				1			
Machilus thunbergii						4	
Eurya japonica Thunb.						5	3
Deciduous broad-leaved tree							
Mallotus japonicus	12	19	16	13	20	6	6
Zanthoxylum ailanthoides	5	10	8	10	10		4
Total (per 25m^2)	23	32	26	25	30	19	21

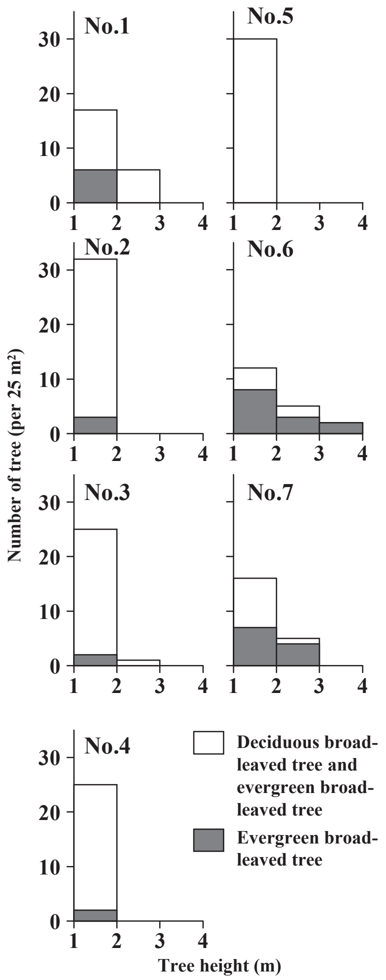

Figure 2: Distribution of tree height for trees >1 m height in the vegetation survey quadrats

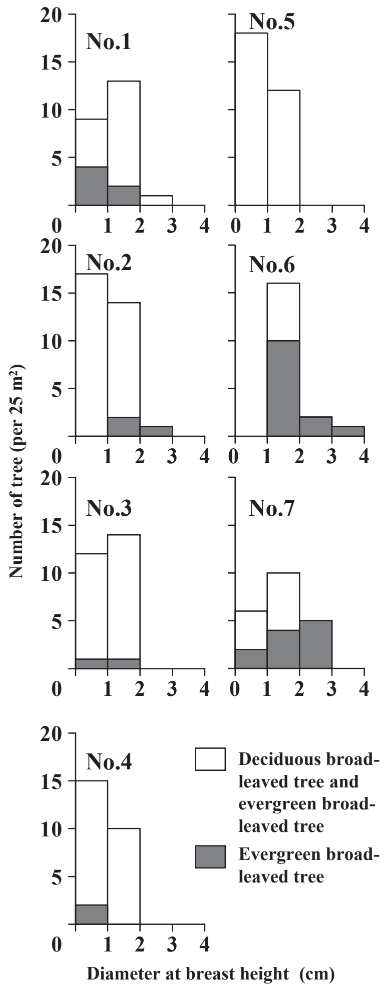

Figure 3: Distribution of diameter at breast height for trees >1 m height in the vegetation survey quadrats

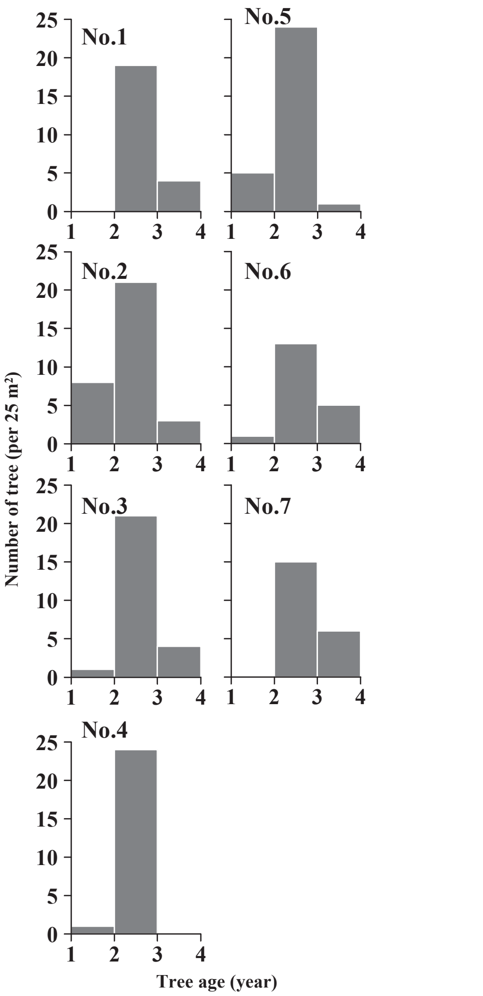

Figure 4: Distribution of tree age for trees >1 m height in the vegetation survey quadrats

Figure 5 shows the proportion of trees that were evergreen broad-leaved, the sum of the cross-sectional trunk area and the Fisher-Williams index of diversity in each survey quadrat. The proportion of evergreen broad-leaved trees and the sum of cross-sectional area of trunk on the steep slopes were smaller than those on the relatively gentle slopes. The Fisher-Williams index of diversity on the steep slopes was lower than that on the relatively gentle slopes. Vegetation succession on the steep slopes was not as progressed as that on the relatively gentle slopes.

Result of the vegetation surveys show that the vegetation in quadrats on the steep slopes was less abundant than that in quadrats on the relatively gentle slopes. The revegetation recovery rate in quadrats on the steep slopes was slower than that in quadrats on the relatively gentle slopes.

Teramoto and Shimokawa (2009, 2011) conducted vegetation surveys on three steep slopes of >40° and on a relatively gentle slope of 30° in an abandoned forests 5 years after plantation clear cutting, located near Kuma-mura, Kumamoto Prefecture. They found that vegetation on the steep slopes was poorer than that on the relatively gentle slope. This result is similar to that of the current study.

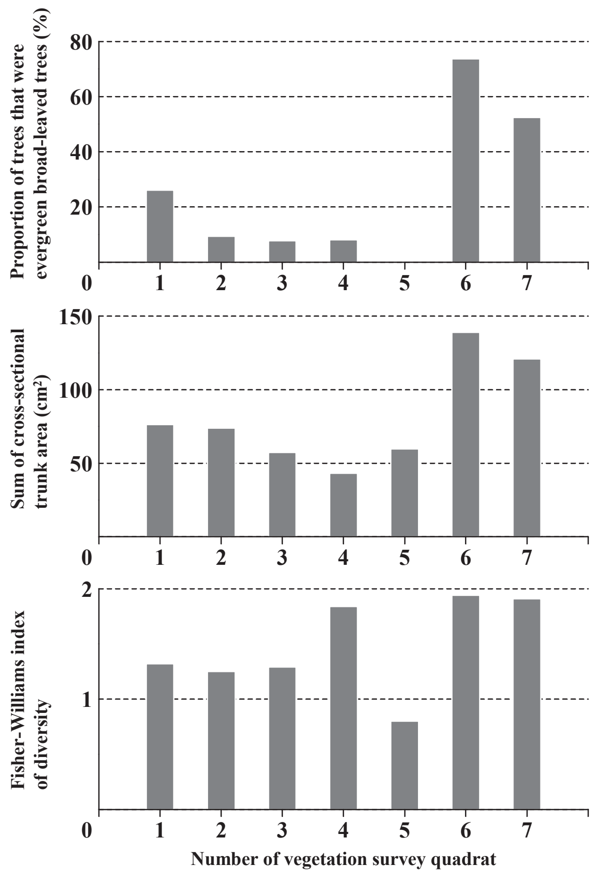

Figure 5: Proportion of trees that were evergreen broad-leaved trees, the sum of cross-sectional trunk area and the Fisher-Williams index of diversity in the vegetation survey quadrats

3.2 Shallow landslide prevention on Shirasu steep slopes

If there is no reforestation after deforestation on steep slopes, the role of forest root networks to prevent shallow landslides declines over time as the root network dies, and is eventually lost after 5 to 10 years. As a result, slopes abandoned after clear cutting become shallow landslide-prone slopes (Shimokawa and Iwamatsu, 1983; Tsukamoto, 1998; Jakob, 2000; Teramoto and Shimokawa, 2009, 2011).

Moreover, if there is no reforestation after deforestation on steep slopes, vegetation recovery on the steep slopes is substantially delayed in comparison with that on reforested slopes (Matsumoto *et al*., 1999; Teramoto and Shimokawa, 2009, 2011) and recovery of the preventive function of forest root networks on shallow landslides is substantially delayed in comparison with that on reforested slopes (Teramoto and Shimokawa, 2009, 2011).

Table 2 shows topsoil thickness measured in the quadrats (No.1–5) on the steep slopes (>40°). The average value of topsoil thickness on the steep slopes was approximately 40 cm. Shimokawa *et al*. (1989) indicated that the thickness of the topsoil, which becomes the material of shallow landslides, had a limit effect on the stability on Shirasu steep slopes. Furthermore, they found that during the formation of the topsoil and when it had reached its maximum thickness, shallow landslides were increasingly likely to occur on the steep slopes. The maximum value of the topsoil thickness was 40 cm on the Shirasu steep slopes (Shimokawa *et al*., 1989).

Table 2: Topsoil thickness measured in the vegetation survey quadrats on steep slopes

Survey	Topsoil thickness (cm)		
quadrat	Min.	Max.	Average
No.1	29	54	41
No.2	30	55	40
No.3	30	52	37
No.4	31	52	40
No.5	30	46	36

Based on the average value of topsoil thickness of approximately 40 cm (Table 2) measured on the steep slopes in our survey, shallow landslides can be predicted to occur on these slopes.

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