ARTICLE

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Revegetation on steep slopes prone to shallow landslides in an abandoned clear-cut plantation forest, Kuma-mura, Kumamoto Prefecture

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Abstract: This paper addresses present conditions of revegetated steep slopes susceptible to shallow landslides; and temporal changes in the role of root networks in preventing shallow landslides due to vegetation recovery in abandoned forests after plantation clear cutting. The study site is 0.89 km^2, and is located near Kuma-mura, Kumamoto Prefecture. To conduct vegetation surveys of present revegetation conditions, we installed quadrats on four slopes: three with steep slopes of not less than 40 degrees and one with a relatively gentle slope of 30 degrees. Vegetation on steep slopes prone to shallow landslides was poorer than that on the relatively gentle slope. When clears slope are reforested immediately after harvesting, the prevention function increases over time and is restored after approximately 20 to 30 years. Conversely, on slopes abandoned after clear cutting the prevention function is restored after 50 to 60 years due to the slower processes of natural vegetation succession. This indicates that the risk of landslides on steep slopes in abandoned plantations persists for 40 to 60 years after abandonment, considerably longer than in actively managed and re-planted forestry plantations.

1 Introduction

In recent years the area of abandoned forests after plantation clear cutting has increased due to deteriorating forestry profits, declining wood prices and the effect of depopulation and aging in mountain villages. The area of abandoned forests after plantation clear cutting in the Kyushu region of Japan is more than 12 km^2 (Murakami *et al.*, 2007) and this is increasing with time. Plantation abandonment creates a significant alteration of the ecological, hydrologic and erosion regime in forested areas (Yamagawa *et al.*, 2006; Teramoto and Shimokawa, 2009).

We propose a hypothesis on the effect of abandonment of reforested areas on the occurrence of shallow landslides, as follows. After plantation harvesting, the prevention function of forest root networks on shallow landslides is maintained for a while, then lost after 5 to 10 years. If reforestation is not conducted after deforestation, recovery of the root network prevention function is delayed. Moreover, the conditions prone to causing shallow landslides on steep deforested slopes persist, and debris flows caused by shallow landslides occur in storm events.

Much of the sediment produced by shallow landslides on steep slopes in abandoned plantation forests flows to the lower reaches of mountain basins via debris flows, and causes considerable damage to coastal forest growth. We consider the abandonment of reforestation to be related closely the transport of eroded sediment transported to lower slopes via debris flows.

The purpose of this study is to characterize current revegetation conditions on steep slopes prone to shallow landslides, and temporal changes in the landslide prevention function of forest root networks due to vegetation recovery after plantation clear cutting.

2 Study area and methods

The study area is an abandoned former plantation forest that has been clear-cut, located near Kuma-mura, Kumamoto Prefecture (Figure 1, Photo 1). The area's elevation is 180 m to 660 m above sea level. Clear cutting was conducted in 2002, and the area of abandoned forest after this time is 0.89 km^2. The plantation forest was cedar and cypress, planted in 1962, and the tree age was 40 years at the time of cutting. The geology of the area consists of sandstone and shale.

Slopes in the study area were calculated using a 1:25,000 scale topographic map from the Geographical Survey Institute, and were divided into 10° intervals. Slopes of 0-10° comprised 3.4% of the total area, slopes of 10-20° comprised 15.3%, slopes of 20-30° comprised 23.2%, slopes of 30-40° comprised 51.7%, and slopes >40° comprised 6.4%.

To study the current revegetation conditions on shallow landslide-prone slopes, 5 m × 5 m vegetation survey quadrats were installed (Figure 2). The quadrats were placed on four separate slopes; three (No.1, No.2 and No.3) on steep slopes >40 degrees and one (No.4) on a relatively gentle slope of 30° (Photo 2). Species, height, diameter at breast height and position of trees >1 m height were recorded. Species and position trees <1 m height in 1 m × 1 m sub-quadrats within the 5 m × 5 m

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quadrats were recorded. Vegetation surveys were conducted in 2007, 5 years after clear cutting.

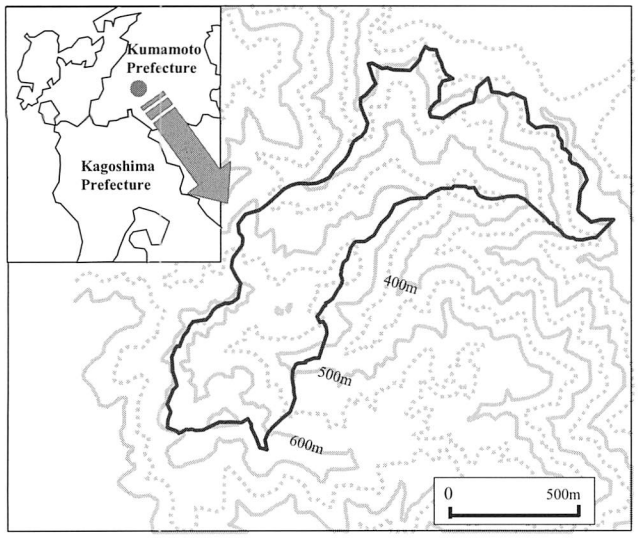

Figure 1: Study area location

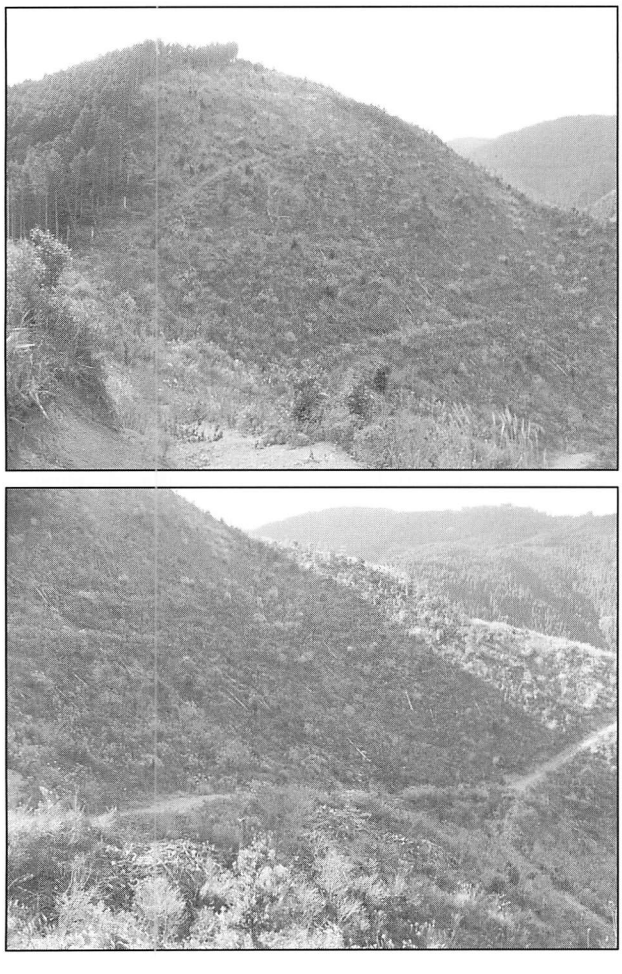

Photo 1: Study area condition

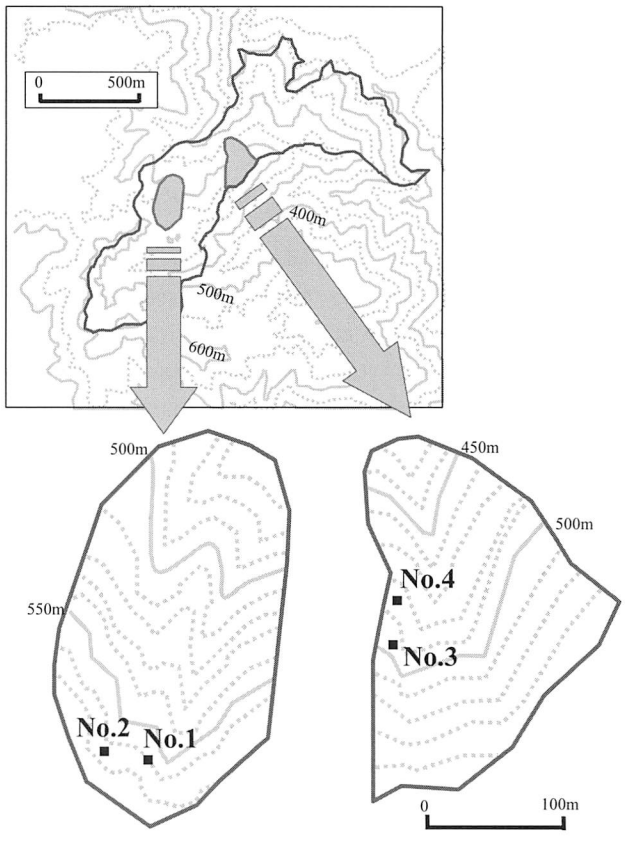

Figure 2: Location of vegetation survey quadrats

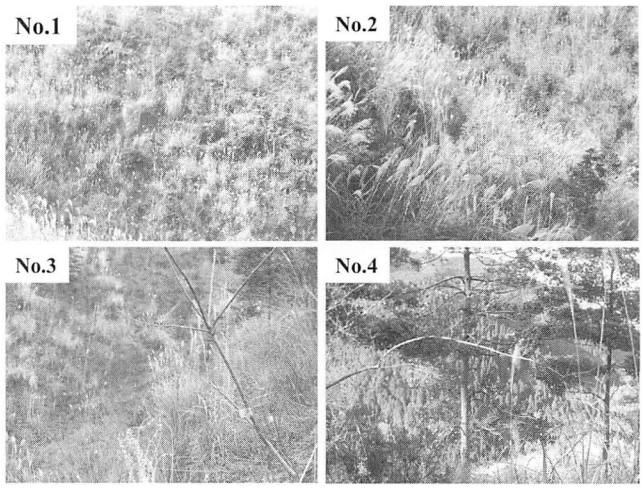

Photo 2: Vegetation survey quadrats

3 Results and discussion

3.1 Constituent species and vegetation structure on steep slopes

Table 1 shows constituent tree species and numbers in the survey quadrats. Figure 3 shows the distributions of tree height and diameter at breast height. Figure 4 shows the spatial distribution of diameter at breast height. The

filled circles in Figure 4 indicate tree positions and diameter at breast height. Tree diameter at breast height was divided into three groups based on size.

Table 1: Constituent tree species and number in the vegetation survey quadrats

Number in Figure 2	1	2	3	4	1	2	3	4
Slope (degree)	43	42	42	30	43	42	42	30
Quadrat area (m^2)	25				1			
Tree height	Not less than 1 m				Less than 1 m			
	Number of tree				Number of tree			
Evergreen broad-leaved tree								
Quercus glauca		1						
Cinnamomum japonicum	1							
Machilus thunbergii	4	3		1				
Neolitsea sericea		1						
Rubus buergeri					1	3	5	
Camellia japonica	1	2						
Eurya japonica	1			4			1	7
Elaeagnus pungens				1				
Symplocos lucida				2				
Deciduous broad-leaved tree								
Hydrangea scandens	1	4	9	4	2	3	2	2
Fagara mantchurica			1	3				
Rhus javanica			16	3			2	2
Callicarpa mollis	1	5	3	6	1			
Weyela floribunda	1	2	2		2	3		

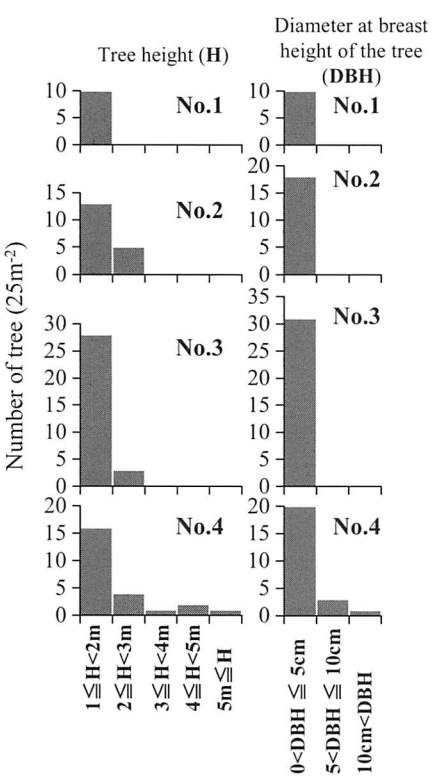

Figure 3: Distribution of tree height and diameter at breast height for trees >1 m height in the vegetation survey quadrats

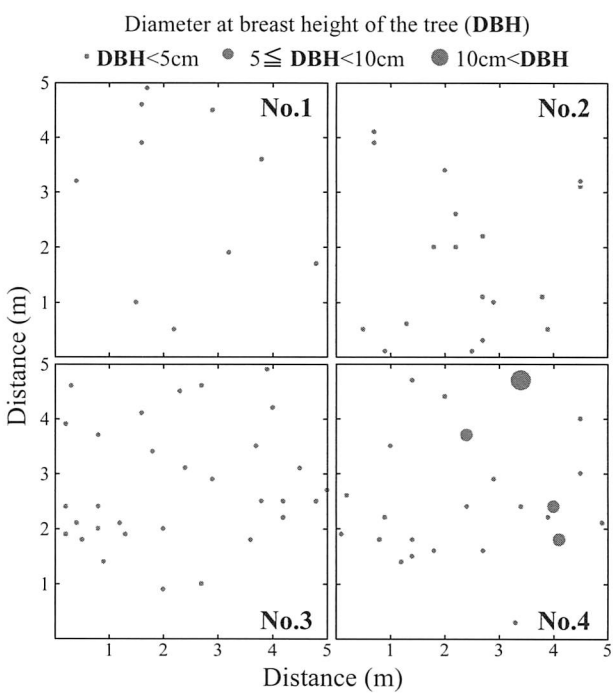

Figure 4: Spatial distribution of diameter at breast height of the trees >1 m height in the vegetation survey quadrats

There was no difference in constituent tree species and number between sites on slopes >40 degrees (No.1, No.2 and No.3) and site No.4 on the 30° slope (Table 1). However, at sites No.1, No.2 and No.3 tree heights were <3 m and diameter at breast height was <5 cm, while at site No.4 tree heights were >3 m and >5 cm of the diameter at breast height (Figures 3 and 4).

Tree species <1 m at sites No.1, No.2 and No.3 were composed chiefly of climbing *Rubus buergeri*, deciduous herbs and shrubs, with rare evergreen broad-leaved >1 m height (Table 1). Constituent species <1 m height at site No.4 were mostly evergreen *Eurya japonica* saplings >1 m height.

Vegetation at sites No.1, No.2 and No.3 on steep slopes >40° prone to shallow landslides was poorer than that at site No.4, and revegetation recovery at sites No.1, No.2 and No.3 was slower than that at site No.4. Delay in revegetation recovery on the steep slopes resulted in delay of recovery of the shallow landslide prevention function of forest root networks. Accordingly, conditions favoring shallow landslides are considered to persist (Shimokawa and Iwamatsu, 1983; Tsukamoto, 1998; Jakob, 2000).

3.2 Temporal changes in revegetation and recovery of the shallow landslide prevention function of forest root networks

Results indicate 5 years elapsed between plantation clear cutting and the surveys. There is a lack of research on vegetation succession on steep slopes >40° prone to shallow landslides, and on the recovery process of the ability of forest root network to prevent landslide. We therefore examined these revegetation and landslide prevention function processes through reviewing past research (Matsumoto *et al.*, 1999) on shallow landslide scars located on slopes >40°.

Figure 5 shows revegetation processes on shallow landslide scars on steep slopes (Matsumoto *et al.*, 1999). In the 30 years after landslide occurrence, small evergreen trees and shrubs and deciduous trees dominated. From 30 to 70 years evergreen trees such as *Castanopsis sieboldii* and *Machilus thunbergii* dominated the vegetation. After approximately 70 years, the bulk of vegetation on steep slopes was evergreen trees, and the vegetation succession reached its climax. The landslide prevention function of evergreen tree root networks on steep slopes was established after 20 years. In the succession process on shallow landslide scars, these evergreen trees are established after 50 to 60 years. Based on this, we consider it will take 50 to 60 years after clear cutting for the shallow landslide prevention function of forest root networks to be effective on steep slopes after abandonment of clear-cut plantations.

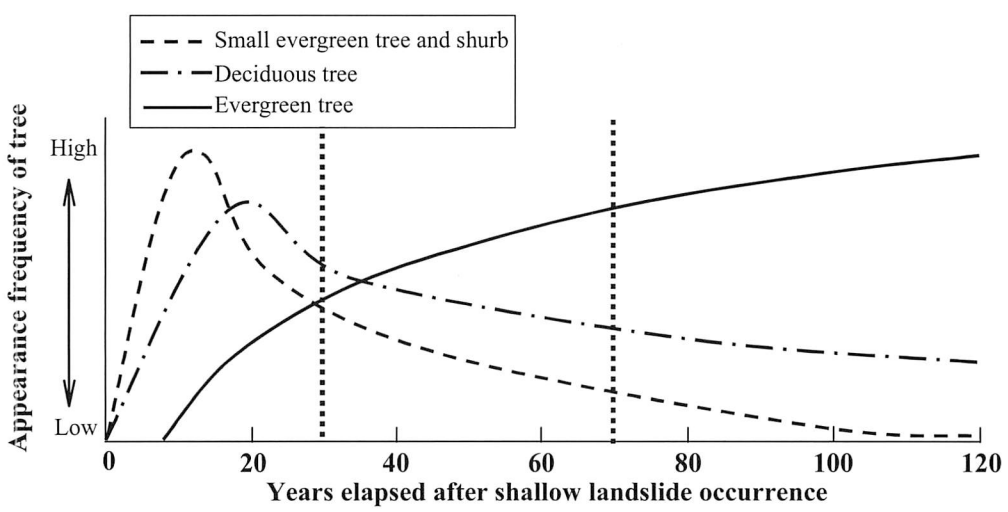

Figure 5: Revegetation process on steep slope on shallow landslide scars based on past research

Based on the succession model presented in Figure 5, we propose a model of change in the ability of forest roots networks to prevent shallow landslides on steep slopes following plantation harvesting. Figure 6 shows schematically the relationship between years elapsed after clear cutting and the shallow landslide prevention function of forest root networks. Following clear cutting, the root networks' ability to prevent landslide decreases

over time, and is lost after 5 to 10 years due to withering of the root network (solid curve in Figure 6, Tsukamoto, 1998). When clears slope are reforested immediately after harvesting, the prevention function increases over time and is restored after approximately 20 to 30 years (dashed curve in Figure 6). Conversely, on slopes abandoned after clear cutting the prevention function is restored after 50 to 60 years due to the slower processes of natural forest vegetation succession (dash-dot-dash curve in Figure 6). This indicates that the risk of landslides on steep slopes in abandoned plantations persists for 40 to 60 years after abandonment, considerably longer than in actively managed and re-planted forestry plantations.

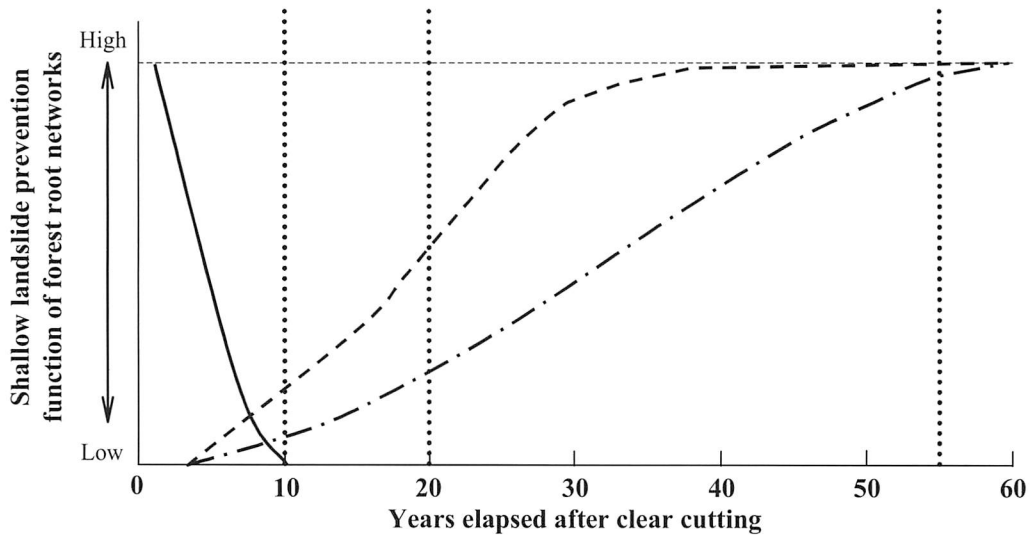

Figure 6: Relationship between years elapsed after clear cutting and the shallow landslide prevention function of forest root networks

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