

# EFFECTIVE CUTTING TO CONTROL THE REGROWTH OF BAMBOO GRASS FOR THE CONSERVATION OF MOUNTAIN TRAILS

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**ABSTRACT:** Vegetation control is important for the conservation of mountain trails, access to alpine areas, and the safety of hikers. However, in Japan, mountain trails are often obstructed by bamboo grass because of its vigorous growth. This study aimed to identify effective methods to control the regrowth of bamboo grass along mountain trails after cutting. We focused on Nagaone trail in the Kiso Mountains, Central Japan, where the bamboo grass was cut in 2020. Nineteen survey plots were set along the trail at elevations ranging from 1500 to 1900 m, with a quadrat (2 m long × the trail width) established at each site. The cutting height in 2020 and the culm height and density in 2022 were measured. Bamboo grass on the trailside slope was also measured because it obstructed the trail, and elevation, trail gradient, and slope gradient were recorded as the habitat environment. The results indicated that residual living bamboo grass on the trailside slope was significantly positively correlated with both regrowth on the trail and the density of the leaning culm from the trailside after 2 years. Cutting height was significantly positively correlated with the density of the regrowing culm and influenced by the trail gradient, but not the culm density or height. Thus, the growth of bamboo grass on the trailside slope and the cutting height appear to be critical for the regrowth of bamboo grass on the trail. This finding could lead to more effective methods to control the regrowth of bamboo grass along mountain trails.

*Keywords:* Mountain trail, Bamboo grass, Regrowth, Cutting

## 1. INTRODUCTION

Bamboo grass, including many species of the genera *Sasa* and *Sasaella* (Poaceae), often becomes dominant on the forest floor in montane and subalpine zones in Japan [1]. Generally, bamboo grass species show longevity and monocarpy, often surviving from several decades to a hundred years with simultaneous mass flowering and withering at the end of the generation before recovering from seeds [2,3]. Bamboo grass forms a large population with thick elect culms, which prevents the invasion or survival of other plants from outside [4,5]. In addition, underground rhizomes contribute to the tight binding of soil, which helps prevent soil erosion [6].

The relatively fast expansion of the bamboo grass population has been reported. Sparse populations of bamboo grass were found to have become a dominant species with almost 100% coverage on a slope along a highway 12 years after the suspension of traffic [4]. The annual expansion rates of tall-type (*Sasa borealis* Makino et Shibata) and small-type bamboo grass (*Sasa nipponica* Makino et Shibata and *Sasaella ramosa* Makino) have been estimated to be 117 m<sup>2</sup> and 50 m<sup>2</sup> per year, respectively [7].

Such growth characteristics are beneficial for revegetation and soil protection, but often become

harmful. One of the typical cases where bamboo grass needs to be suppressed is mountain trails. On mountain trails, overuse by hikers causes widening of the trail and soil erosion through the deterioration of trailside vegetation; however, this can be mitigated by bamboo grass [6]. By contrast, the underuse of mountain trails can lead to the excessive growth of bamboo grass, which also creates difficulties in terms of maintaining the trail [5]. It has been reported that only 1%–2% of sunlight reaches the ground surface under bamboo grass populations [8], and the trace after cutting bamboo grass (i.e., the renewed trail) remains as dark as it was before cutting because the trail width is extremely narrow compared with the entire bamboo grass population [5]; the ground surface of the renewed trail would remain too dark for the survival of other plants, causing the condition of bare ground to continue [5].

On the other hand, bamboo grass has the ability to transport storage substances through underground rhizomes within the population [9], which implies that the regrowth of bamboo grass on mountain trails would be supported by the residual living part of the population on the trailside. Cutting and removing bamboo grass rhizomes is known to be an effective method to restrain regrowth [10], but is not recommended because it enhances the risk of erosion. Thus, the control of bamboo grass on

mountain trails is distinct from the large-scale cutting of forest floors in forestry, and consequently, little information has been available to date.

Given this background, in the present study, we aimed to establish a research area where bamboo grass had covered the mountain trail abandoned for decades. Two years after cutting, we investigated the regrowth of the bamboo grass and environmental factors and analyzed their relationships with the objective of developing more effective methods to control the regrowth of bamboo grass for the conservation of mountain trails.

## 2. RESEARCH SIGNIFICANCE

The significance of the study is that it aims to contribute to the conservation of mountain trails, where vegetation can become excessively thick as a result of underuse. This issue involves the existence of the large living part of bamboo grass populations after cutting, which can transport storage substances to the stubble on the trail through rhizomes. Based on the analysis of the regrowth and environmental factors, we discuss effective cutting methods to control the regrowth of bamboo grass for the conservation of mountain trails.

## 3. METHODS

### 3.1 Research Area

The research area in the present study was Nagaone trail (from an elevation of 1500 m to 2532 m), which leads to a peak on the ridge running from Mt. Shogi-gashira in the north of the Kiso Mountains, Central Japan (Figs. 1 and 2). Nagaone trail has not been very popular among general hikers because it passes through two research forests, Oguro Research Forest of Kami-ina Agricultural High School and Nishikoma Research Forest of Shinshu University. Recently, this trail became nearly abandoned after accessibility worsened following bridges across the Ogurogawa River (at elevations of 1420 m and 1500 m) being washed away by repeated floods. The convenience of hiking the trail also worsened because the roof of the mountain hut near the middle of the trail (at an elevation of 1900 m) collapsed as a result of heavy snowfall.

The vegetation around the trail consists of an afforested Japanese larch forest in the montane zone (the lower area up to the elevation of 1600 m), and a mixed forest of conifers and deciduous trees in the subalpine zone (the upper area). Bamboo grass, mainly *Sasa senanensis* Rehder, is distributed in the area up to an elevation of about 1900 m.

### 3.2 Establishment of Survey Plots

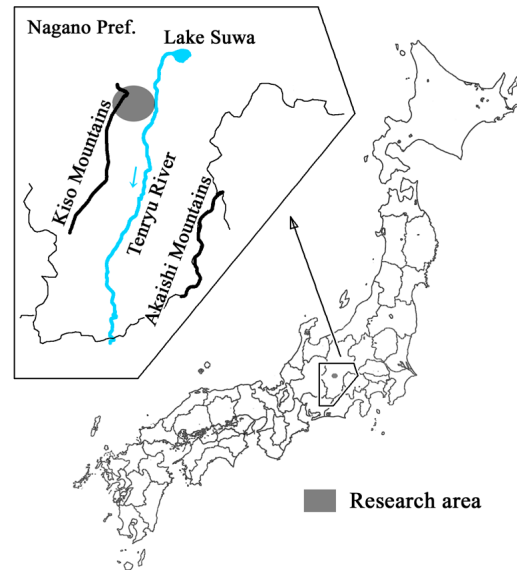


Fig.1 Location of the research area in Japan

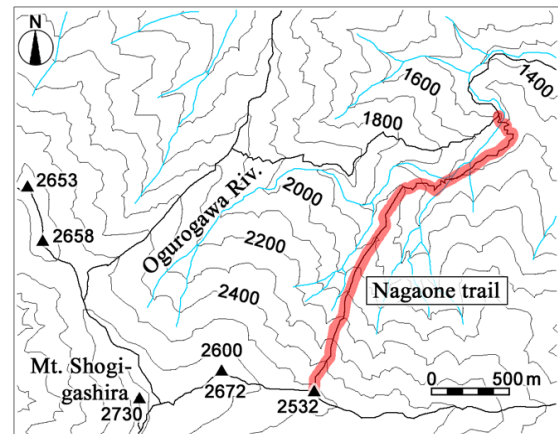


Fig.2 Topographical map of around the research area (Nagaone trail). Black solid lines indicate other mountain trails.

Table 1 Properties of the tools used for cutting bamboo grass

Tools	Cutting edge length (cm)	Handle length (cm)	Efficiency of cutting work
Long-handle sickle	27.0	118.0	High but rough
Billhook	17.5	32.0	(Middle)
Pruning shears	4.8	9.0	Low but careful

To recover Nagaone trail, we cut bamboo grass on the trail by human power in 2020. The tools used for cutting work were a long-handle sickle, a billhook, and pruning shears (Table 1). The trail before the cutting conducted in 2020 had become

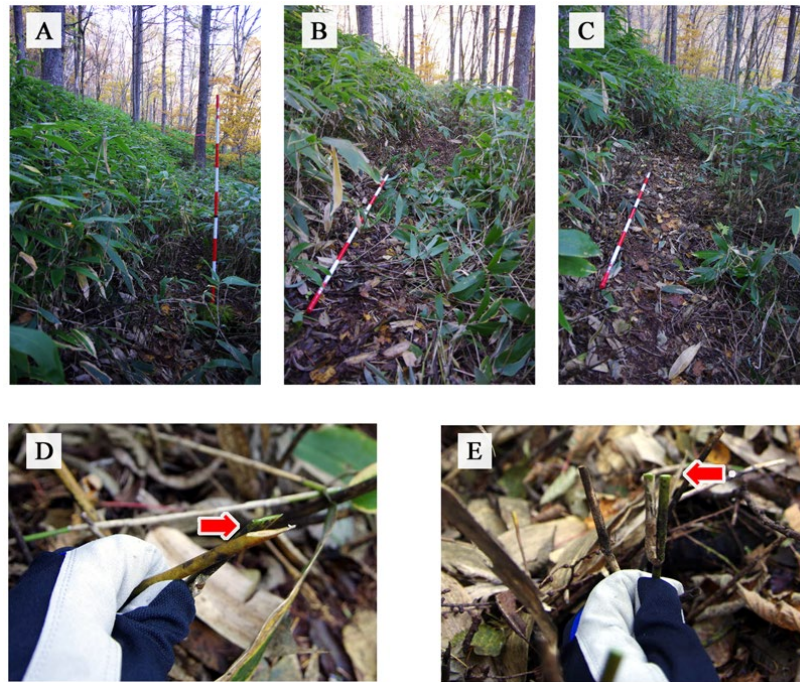


Fig.3 States of the trail before and after the cutting work in 2020.

A: Before cutting, B: After cutting with a long-handle sickle, C: After cutting with pruning shears (Length of the red and white striped pole = 2 m), D: A cut section of culm with a long-handle sickle, E: A cut section of culm with pruning shears (the red arrow indicates the section).

almost completely obstructed and unrecognizable because of the growth of thick bamboo grass (Fig. 3 (A)). The long-handle sickle was the most effective cut tool for cutting the bamboo grass, but the cut culms and leaf blades remained scattered on the trail (Fig. 3 (B)) and the cutting section of the culm often became sharp (Fig. 3 (D)), which can be dangerous for hikers. By contrast, the pruning shears required a lot of time and effort, but the harvested culms and leaf blades were often thrown off the trail because of the necessity to grasp them before cutting (Fig. 3 (C)). Moreover, the cutting section of the culm became blunt, which is safer for hikers (Fig. 3 (E)). The efficiency of the cutting with a billhook and the resultant state of the trail were somewhere between those of the long-handle sickle and pruning shears. After confirming the efficiency of each tool, the tools were allotted to three persons (one tool per person), and the cutting work was performed through collaboration.

In 2022 (2 years after the cutting), 19 survey plots were established to examine the regrowth of the bamboo grass. The locations of the plots were determined at regular intervals of approximately 50 m. The size of the quadrat in each plot was 2 m long × the trail width. The conditions of each survey plot are shown in Table 2.

### 3.3 Measurement and Analysis of the Regrowth of Bamboo Grass

Table 2 Conditions of the location at each survey plot

No.	Elevation (m)	Slope direction	Trail gradient (°)	Width of trail (m)
1	1498	E	6.8	0.50
2	1510	NW	6.8	0.56
3	1538	NW	13.5	0.60
4	1555	NW	8.3	0.65
5	1564	NW	2.0	0.75
6	1562	N	2.6	0.72
7	1576	N	1.4	0.77
8	1566	N	2.3	0.78
9	1575	N	2.0	1.15
10	1583	N	4.3	0.60
11	1593	N	2.0	0.65
12	1674	NE	3.1	0.55
13	1680	E	12.7	0.47
14	1695	E	11.3	0.35
15	1770	E	12.4	0.50
16	1861	NE	7.4	0.50
17	1892	NE	4.0	0.45
18	1904	NE	4.0	0.50
19	1904	NE	10.8	0.40

For the survey of the regrowth of the bamboo grass on the trail at 2 years after cutting, aboveground bamboo grass (hereafter “regrowing

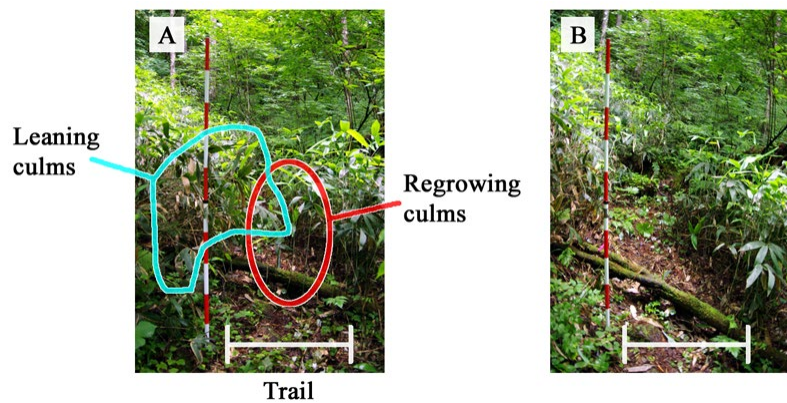


Fig. 4 States of the trail before and after the cutting work in 2022. A: Before cutting, B: After cutting (both at plot No. 2). Length of the red and white striped pole = 2 m.

culm” on the trail, Fig. 4 (A)) was harvested with pruning shears and measured in the summer of 2022. The culm height and diameter at the base were recorded after harvesting. In addition, the culm along the trailside leaning over the trail (hereafter “leaning culm”, Fig. 4 (A)) was counted at each plot because it also obstructed the trail. The density of the leaning culm was calculated as the number of culms divided by the longitudinal length of the trail (2 m for each plot), as they existed linearly along the trail, unrelated to the trail width.

Regarding the environmental factors that could affect the regrowth of the bamboo grass, we considered the geographical conditions and residual living bamboo grass. Concerning the geographical conditions, we recorded the elevation, slope direction, trail gradient, and slope gradient for each plot at the same time the plot was established.

Concerning the residual living bamboo grass, the height of the remaining stubble on the trail was measured at the time of harvesting. The height of the remaining stubble was measured by examination of the basal part of each harvested culm. This height was considered to provide an estimation of the cutting height in 2020. However, after inspecting the data, we reached a reasonable conclusion using the maximum value for each plot to avoid underestimation, as some of the stubble had been already dead and decayed before the survey. The reason we were unable to design the cutting height experimentally in 2020 was that the work of cutting the thick population of bamboo grass and recovering the trail was excessively difficult, and the future regrowth on the trail was unknown immediately after cutting.

Besides, both the culm height and density of the bamboo grass along the slope of the trailside were measured at the time of harvesting. The culm height and density along the trailside slope at each plot, which was left intact in 2020, considered to be associated with the storage mass to invest in the

regrowth of bamboo grass on the trail after cutting.

The relationships between these environmental factors and the regrowth of bamboo grass on the trail were analyzed using Pearson’s correlation coefficient.

## 4. RESULTS

### 4.1 Regrowth of Bamboo Grass

Among the 19 survey plots, bamboo grass appeared in 17. Each of the bamboo grass appeared on the trail in these 17 survey plots was the regrowth from remaining stubble or rhizome; seedlings of bamboo grass raised from seed were not observed at all during the survey. Two plots (Nos. 11 and 16) and their trailside slopes were devoid of bamboo grass.

The diameter at the base showed no significance among plots (analysis of variance, F-test), and the mean diameter  $\pm$  standard deviation of all 17 plots was  $3.73 \pm 0.92$  mm.

Table 3 shows the estimated cutting height and regrowth of the bamboo grass. The estimated cutting height was 0–56 cm. Regrowing culms were observed in all 17 plots, with a density of 1.3–7.1 culms/m<sup>2</sup> and a height of 24–147 cm. The density of the leaning culms, mostly from the uphill slope, was 0.0–18.5 culms/m.

All 17 plots and trailside slopes could be considered replications of the regrowth of bamboo grass on the trail after cutting and leaving natural growth intact, respectively. Fig. 5 shows the results of a comparison of culm density and height between the plots and trailside slopes. The culm density was significantly larger on the trailside slope than on the trail (84.0 vs. 3.9 culms/m<sup>2</sup> on average, respectively; Tukey’s honestly significant difference (HSD) test,  $p < 0.001$ ). The culm height was also significantly larger on the trailside slope than on the trail (81.0 vs. 64.8 cm, respectively; Tukey’s HSD test,  $p < 0.01$ ).

Table 3 Regrowth of bamboo grass on Nagaone trail at 2 years after cutting for each survey plot

No.	Estimated cutting height (cm)	Regrowing culm on the trail		Leaning culm Density per m
		Density per m <sup>2</sup>	Height (cm)	
1	13	4.0	88	5.5
2	44	7.1	147	18.5
3	21	2.5	50	4.0
4	38	4.6	65	3.5
5	44	4.6	76	3.0
6	21	4.2	84	1.5
7	29	5.8	97	4.0
8	25	3.2	122	2.0
9	29	3.0	126	7.0
10	56	5.0	65	6.5
11	-	-	-	-
12	29	2.7	35	1.0
13	0	3.2	98	2.0
14	6	2.9	25	2.0
15	20	3.0	34	0.0
16	-	-	-	-
17	29	4.4	48	0.5
18	32	6.0	67	3.0
19	0	1.3	24	2.0

**4.2 Relationships between Environmental Factors and the Regrowth of Bamboo Grass**

Table 4 shows the relationships between environmental factors and the regrowth of bamboo grass. Regarding the factor of geographical conditions (Table 4 (A)), significant negative correlations were found between the trail gradient and regrowing culm density, between elevation and regrowing culm height, and between elevation and leaning culm density (around  $r = -0.5, p < 0.05$ , F-test). Although trail width was also planned to be an environmental factor, it was excluded from the analysis because it was considered to contain an outlier (1.15 m at plot No. 9, Table 2) and therefore to disturb the correlation.

Regarding the factor of geographical conditions (Table 4 (A)), significant negative correlations were found between the trail gradient and regrowing culm density, between elevation and regrowing culm height, and between elevation and leaning culm density (around  $r = -0.5, p < 0.05$ , F-test).

Regarding the factors related to the residual living bamboo grass (Table 4 (B)), the culm density in the trailside slope was significantly positively correlated with regrowing culm height and leaning culm density (around  $r = 0.7, p < 0.01$ , F-test), the

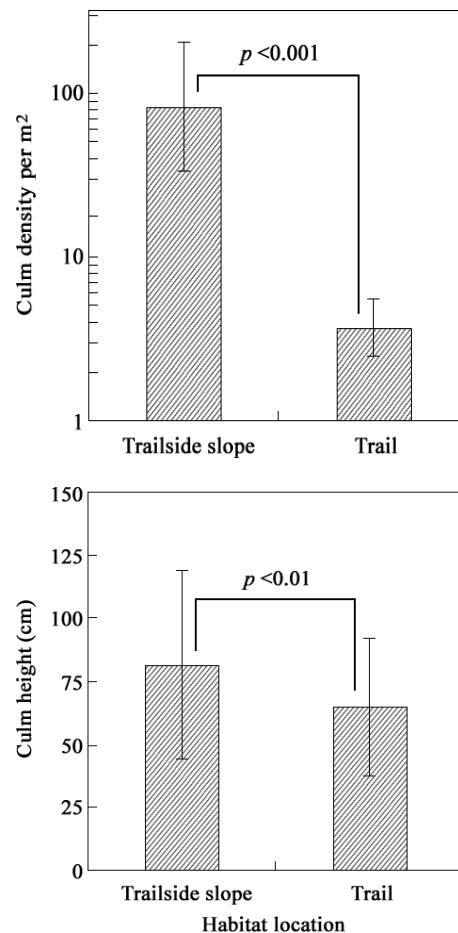


Fig. 5 Culm density and height of bamboo grass on the trailside slope (natural growth left intact) and Nagaone trail (regrowth at 2 years after cutting). The line on each bar indicates the range of  $\pm 1$  standard deviation ( $n = 17$ ).

culm height on the trailside slope was significantly positively correlated with regrowing culm height ( $r = 0.914, p < 0.001$ , F-test), and the estimated cutting height was significantly positively correlated with regrowing culm density ( $r = 0.689, p < 0.01$ , F-test).

Concerning the relationships between the regrowing culm density, height on the trail, and leaning culm density, significant positive correlations were observed ( $r = 0.5-0.6, p < 0.05$ , F-test).

The factors related to the residual living bamboo grass were more important than those of the geographical conditions because the former can be controlled by cutting work, whereas the latter cannot. Table 5 shows the relationships with the factors related to the residual living bamboo grass. Regarding the factors of geographical conditions (Table 5 (A)), culm height was significantly negatively correlated with elevation ( $r = -0.516, p < 0.05$ , F-test), and trail gradient was significantly negatively correlated with estimated cutting height ( $r$

= -0.571,  $p < 0.05$ , F-test). The factors related to the residual living bamboo grass were not influenced by the slope gradient.

Regarding the relationships between the factors related to the residual living bamboo grass (Table 5 (B)), a significant correlation was detected only between the culm density and height on the trailside slope ( $r = 0.567$ ,  $p < 0.05$ , F-test).

Table 4 Relations between environmental factors and the regrowth of bamboo grass (Pearson's correlation coefficient,  $r$ ;  $n = 17$ )

Factors	Regrowing culm on the trail		Learning culm
	Density per m <sup>2</sup>	Height (cm)	Density per meter
(A) Geographical conditions			
Elevation	ns	-0.515*	-0.538*
Trail gradient	-0.487*	ns	ns
Slope gradient	ns	ns	ns
(B) Residual living bamboo grass			
Culm density	ns	0.648**	0.713**
Culm height	ns	0.914***	0.427
Cutting height	0.689**	ns	0.439

Correlation coefficients less than  $p < 0.1$  are shown. \*, \*\*, and \*\*\* denote significance at  $p < 0.05$ , 0.01, and 0.001, respectively. Culm density and height were measured on the trailside slope, and cutting height was estimated at 2 years after cutting.

Table 5 Relations with the factors related to residual living bamboo grass (Pearson's correlation coefficient,  $r$ ;  $n = 17$ ).

Factors	D	H	C
(A) Geographical conditions			
Elevation	-0.414	-0.516*	ns
Trail gradient	ns	ns	-0.571*
Slope gradient	ns	ns	ns
(B) Residual living bamboo grass			
Culm density (D)	1		
Culm height (H)	0.567*	1	
Cutting height (C)	ns	ns	1

Correlation coefficients less than  $p < 0.1$  are shown. \* denotes significance at  $p < 0.05$ .

## 5. DISCUSSION

### 5.1 Cutting Work

Concerning the cutting work, the culms and leaf blades of bamboo grass are recommended to be removed from the trail after cutting so as not to hide the trail [5]. Besides, the surface roughness of bamboo grass is considerably minute even 2 years after cutting ( $R_{max}$  around 0.01 mm, unpublished

data by the authors). Surface roughness is reported to be related to the coefficient of friction between material and snow [13]; therefore, failing to remove scattered culms and leaf blades (Fig. 3 (B)) would increase the risk of not only falls by hikers, but also a snowslide in winter.

On the other hand, the sharp cutting sections of culms (Fig. 3 (D)) are also detrimental to the safety of hikers and cutting-work operators. It is recommended first to cut culms effectively using a long-handle sickle or billhook, and then to make the cutting section blunt with pruning shears and remove the harvested culms and leaf blades from the trail.

### 5.2 Regrowth of Bamboo Grass

Bamboo grass was observed to regrow on the trail at 2 years after cutting. However, the density of the bamboo grass on the trail was still far lower than that on the trailside slope. By contrast, the culm height on the trail appeared to have already become close to that on the trailside slope, even though there was a significant difference between them (Fig. 5). The bamboo grass population on the trail would scarcely be distinguishable from the population on the trailside slope if the culm density were left to increase in the near future. Because dwarfing of bamboo grass is one of the signs of animal damage, primarily by sika deer [11], the damage caused by cutting was considered to disappear after 2 years.

Among the geographical condition factors, elevation and trail gradient had a negative influence on the regrowth of bamboo grass (Table 4 (A)). However, because these factors are uncontrollable, this implies a favorable habitat for bamboo grass. Most bamboo species (subfamily Bambusoideae, containing bamboo grass) are distributed in tropical areas, and the species group of bamboo grass is distributed in northern areas [1]. High elevation, i.e., low temperatures, deep snow, and short growing periods, are considered to restrain the growth of bamboo grass. Trail gradients are not supposed to be related to temperature, but may be unfavorable for producing erect culms or rhizome growth.

The culm density and height on the trailside slope were positively correlated with not only the regrowth of bamboo grass on the trail, but also leaning culms (Table 4 (B)). Although we had considered that the gap on the trail after cutting would increase the growth of leaning culms from the trailside, no negative correlation was observed between them, and both were encouraged by the trailside population. This suggests that bamboo grass can transport storage substances from adjacent trailside populations through rhizomes [9]. To date, most of the literature on controlling the growth of bamboo grass focuses on forestry on a large scale, not leaving bamboo grass intact in experimental plots. Therefore, considering the absence of residual

living populations with abundant storage substances, reports that bamboo grass is suppressed for many years after large-scale cutting or the application of chemicals are reasonable [7,8,12]. On the other hand, the positive correlation observed between cutting height and regrowing culm density was considered to have been caused by the remaining lateral buds: shooting from lateral buds gives bamboo grass a broom-like branching form, which has been reported as a sign of animal damage, primarily by sika deer [11]. Cutting at a high position tends to leave many lateral buds intact, which can lead to rapid regrowth from the residual culm itself, photosynthesis, and increased storage substances, thereby encouraging the production of new culms on rhizomes, in addition to the support received from the trailside population.

Concerning the factors that affect the regrowth of bamboo grass on the trail, if we suppose that the population on the trail before cutting corresponded approximately to that of bamboo grass on the trailside slope, then it is important to consider that the cutting height was not influenced by the culm density or height, but rather, by the trail gradient (Table 5). The reason behind this relationship is unclear in the present study, but it seemed easier for the cutting-work operators to see and reach the base of the culms on a steep compared with a gentle slope. This finding suggests that attention should be paid to the slope gradient during cutting work, as opposed to cutting at a high position on a gentle slope and flat land.

On the other hand, the negative correlation with elevation (Table 5 (A)) showed similar relationships in Table 4 (A), implying a favorable habitat for bamboo grass: high elevation would decrease the growth of natural bamboo grass populations. The positive correlation observed between culm height and density (Table 5 (B)) is therefore reasonable because each indicates the growth of the population.

However, missing the important data, such as the height and density of bamboo grass before cutting in 2020 in each survey plot, would undermine the quality and reliability of the results in the present study. Hereafter, survey plots should be established before the population of bamboo grass on the mountain trail becomes too thick.

## 6. CONCLUSION

In the present study, we established a research area where bamboo grass had covered a mountain trail abandoned for decades. Two years after cutting, the regrowth of bamboo grass and environmental factors were investigated and their relationships were analyzed.

Concerning cutting work, it is recommended to cut effectively with a long-handle sickle or billhook at first, and then to make the cut sections blunt with

pruning shears and remove the harvested culms and leaf blades from the trail for the safety of hikers and cutting-work operators themselves. Concerning the regrowth of bamboo grass on the trail after cutting, the results were as follows.

(1) The residual living population of bamboo grass on the trailside slope was significantly positively correlated with both the regrowth on the trail and the leaning culm density from the trailside after 2 years, probably because of the transportation of storage substances through rhizomes.

(2) The cutting height was significantly positively correlated with the regrowing culm density, probably because of the increase in storage substances caused by the rapid regrowth from lateral buds on residual culm.

(3) Concerning the factors related to the regrowth of bamboo grass, the growth of the population on the trailside slope was influenced by elevation, and the cutting height was influenced by the trail gradient, but not by the culm density or height.

In conclusion, monitoring the growth of bamboo grass on the trailside is important: low cutting or recutting at shorter intervals is needed if the growth of the trailside population is vigorous. In addition, monitoring the slope gradient is important to avoid cutting at a high position on gentle slopes and flat land.

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