International Journal of GEOMATE, April 2019, Vol.16, Issue 56, pp. 85 - 91
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2019.56.4587
Special Issue on Science, Engineering & Environment

EFFECT OF SUSPENDING TRAFFIC ON A HIGHWAY IN A MOUNTAINOUS REGION ON THE SUCCESSION OF SLOPE VEGETATION

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*Corresponding Author, Received: 20 Dec. 2018, Revised: 05 Jan. 2019, Accepted: 20 Jan. 2019

ABSTRACT: Gonbei Highway, a winding road in a mountainous region in central Japan, was damaged by typhoons in the autumn of 2004, and a 9-km stretch of the highway has remained closed (without being restored). We established 11 survey sites to examine slope vegetation along Gonbei Highway in the summer of 2004 (just before the area was damaged), and we conducted surveys again in 2016 (12 years after the damage), including at 5 survey sites along the closed section of the road. At each survey site, a quadrat (2 m × 5 m) was established on the mountain side and the valley side of the road. The deterioration of the road surface was also observed. Here, we examine the effects of suspending traffic on roadside vegetation and road surface deterioration. Our results showed that succession to arboreal vegetation was not observed at the roadside sites along the closed section of the road: vegetation coverage increased significantly along the closed section with increasing coverage of shrubs (mainly bamboo grass). In contrast, tree seedlings increased in the passable sections. Thus, the suspension of traffic and the subsequent long-term absence of roadside vegetation management allowed bamboo grass to increase, and the community of bamboo grass prevented invasion and growth of tree seedlings. Obvious deterioration of the road surface was not observed, excepting sparse cracks and weed invasion. Consequently, the dominance of bamboo grass may be one of the criteria by which to judge the necessity of vegetation management along roads closed to traffic.

Keywords: Roadside Slope, Road surface, Vegetational succession, Suspension of traffic, Gonbei Hyghway

1. INTRODUCTION

Recently, fewer winding roads with tunnels or elevated bridges have been newly built as highway construction has focused on roads with higher traffic volume and improved safety. While the necessity of maintaining old highways is reduced in this strategy, abandoning these highways may lead to disasters such as landslides: since roads placed on hillsides can disrupt the natural flows of surface water and ground water unless they are properly engineered [1], lack of maintenance will spoil the road and roadside slopes by uncontrolled water and sediment flows.

Plant growth prevents erosion on roadside slopes [2]: leaves mitigate the direct impact of raindrops on the soil surface, roots retain soil, and transpiration reduces excessive soil water in the ground. To maintain these functions, it is necessary to monitor and manage the roadside slope vegetation. Inadequate management leads to undesirable vegetation on roadside slopes, narrowed fields of view, and even damage to the road by fallen trees or landslides [3]. There are few reports on the vegetation succession along old or closed roads to date. Since the lifespan of asphalted road is usually planned to be around 10 years in Japan [4], vegetation succession on roadside slopes should also be surveyed 10 to 12 years after traffic is suspended.

Gonbei Highway, an asphalt mountain road in Nagano Prefecture in central Japan, has fulfilled an important role in joining the two regions (Kami-ina and Kiso regions) on either side of the Kiso Mountains. This highway is a winding mountain road that crosses the Gonbei Pass at an elevation of 1550 m and was designated as a national highway (Route 361). In the autumn of 2004, rainfall and winds from several typhoons passing over the area (Fig. 1) damaged the highway, and a 9 km section located on Mt. Kyogatake was closed [6]. In 2006, a new and less winding highway (bypass of Route 361) traversing the newly constructed 'Gonbei tunnel' was opened to traffic [6]. This road construction was undertaken in order to improve access to medical services for residents in the Kiso region, where there are no general hospitals. Subsequently, Old Route 361 was closed without being restored following the disaster in 2004 and the designation as a national highway was removed (Fig. 2). Despite the change in designation, this road remains important: the area along this road is a Japanese larch (*Larix kaempferi*) forest, and some radio facilities are

located there. Further, if traffic on the new Route 361 is suspended, the Old Gonbei Highway will be the only road joining these two regions. Due to infrequent access, it is difficult to monitor and maintain this road and the surrounding roadside slopes.

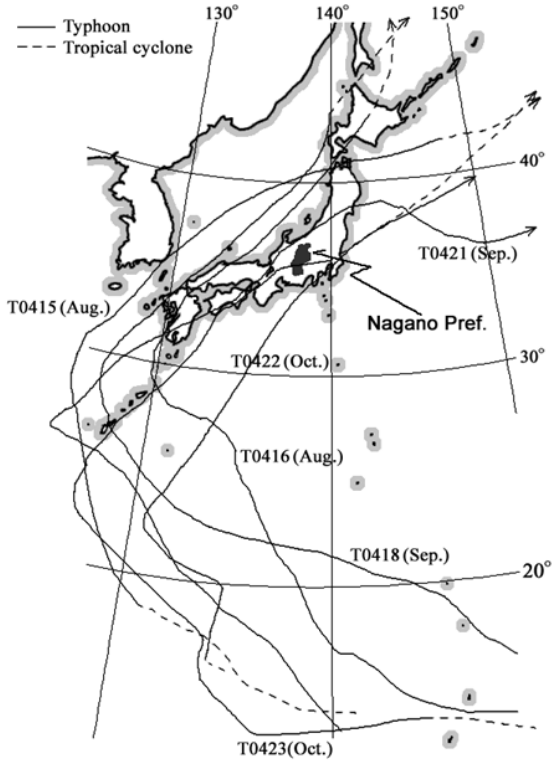

Fig. 1 Paths of typhoons that produced heavy rains and strong winds in the research area in 2004. Figure is based on original data and graphs reported in [5].

In the present study, we surveyed roadside slope vegetation in the summer of 2004 (just before the area was damaged by typhoons) and again in 2016 (12 years after the damage) to examine the effect of suspending traffic on roadside vegetation. The original survey was designed to evaluate wild herbaceous plants for utilization in vegetation technology [7], but the sites were damaged by the passing typhoons soon after the vegetation survey in 2004, and the subsequent follow-up study described here was planned. Based on analyses of the changes in vegetation based on coverage percentage and species composition, we discussed how and when to manage roadside slope vegetation along closed roads.

2. METHODS

2.1 Vegetation Survey

The research area is the roadside area along Old Gonbei Highway in Nagano Prefecture, central Japan. This winding highway joined Ina City (Kami-ina region) and Shiojiri City (Kiso region), but a 9 km length of this highway has

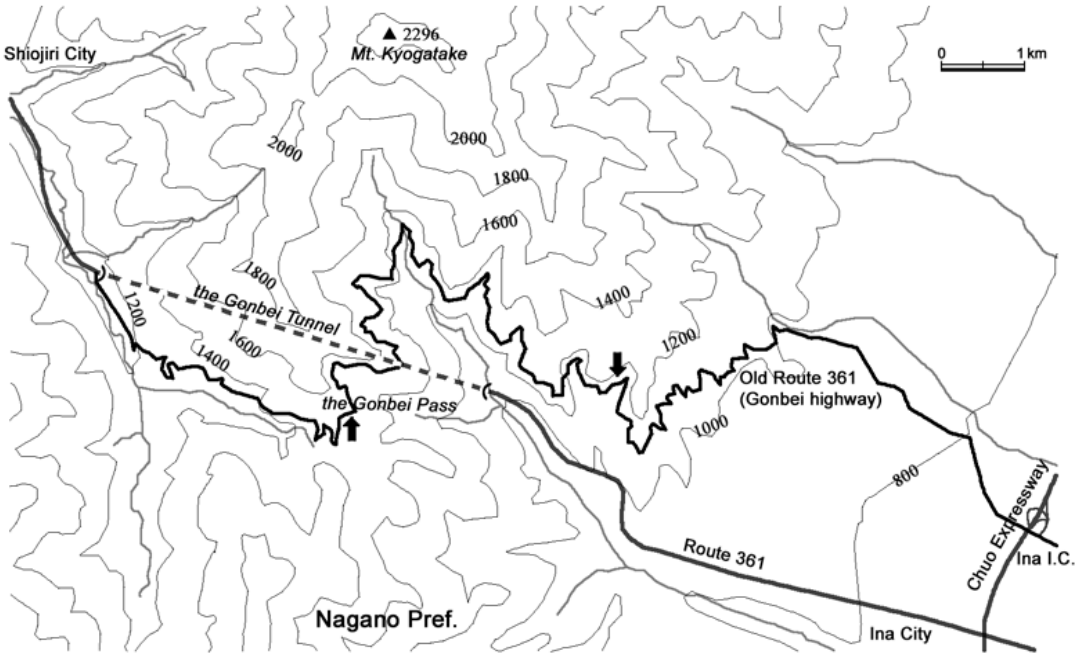

Fig. 2 Old Route 361 (Gonbei Highway) and newly constructed Route 361
Arrows indicate the placement of gates for closing the road to traffic.

been closed since the autumn of 2004.

In July 2004, eleven sites (labeled A to K) were established at approximately regular intervals along the road for a vegetation survey. Each site is comprised of two plots of roadside slopes (2 m × 5 m per plot, mountain side and valley side). The section of road closed in autumn 2004 included 5 sites (labeled E to I) out of the 11 sites. The elevation and slope direction at each site are described in Table 1.

Table 1 Vegetation survey sites

No.	Elevation (m)	Slope direction	Condition	Location
A	955	SW	Passable	Ina City
B	1150	SW		↑
C	1110	SW		
D	1180	E		
E	1260	SE	Closed	
F	1330	S		
G	1419	S		
H	1530	E		
I	1550	S		↓
J	1390	SW	Passable	Shiojiri
K	1235	S		City

In 2004 (just before the area was damaged by typhoons) and in 2016 (after the damage), coverage of each plant species in each plot was measured in each of the tree, shrub and herb layers. Plant coverage was ranked using the classes of the Braun-Blanquet scale as follows:

+, sparse vegetation with coverage by area of less than 1% over the total plot area;
1, vegetation coverage between 1% and 10% of total plot area;
2, vegetation coverage between 10% and 25% of total plot area;
3, vegetation coverage between 25% and 50% of total plot area;
4, vegetation coverage between 50% and 75% of total plot area;
5, vegetation coverage of more than 75% of total plot area.

2.2 Observation of Road Surface

To conduct the 2016 vegetation survey, we accessed sites in the closed section of the road by walking in from the gate closing the road. Consequently, we explored the entire closed section of Gonbei Highway while conducting the vegetation survey.

Since there was no current information regarding the condition of the road in the closed section, we observed the road surface for parameters including the presence or absence of cracks, dips, accumulation of fallen branches or leaves, and invasion of weeds to gather preliminary information in the investigation of the deterioration of the road surface in the survey area.

2.3 Data Analysis

To compare the total vegetation coverage percentage, each coverage class was reported as a single medium percentage (e.g., class 5, which had coverage percentages ranging between 75% and 100%, was reported as being 87.5%). The change in coverage percentage (Δ = coverage percentage in 2016 - coverage percentage in 2014) was calculated for each slope and was considered for combinations of two factors (section: passable or closed, slope: mountain side or valley side). Significant differences among coverage percentages were detected by analyses of variance and Tukey's HSD test.

Because of the large dominance in the herb layer in 2016, we additionally noted of the dormancy form [8] for each plant species. Each plant species was categorized into a corresponding dormancy form, and the total coverage percentage by form was calculated. The composition differences of dormancy forms were analyzed by the analysis of variance (F-test). Dormancy forms were categorized in the present study as follows:

A, annual or biennial herb;
P, perennial herb with dormant bud close to the ground;
N, shrub with dormant bud 0.3 to 2 m above the ground (includes bamboo grass);
M, tree with dormant bud 2 to 8 m above the ground; and
MM, large tree with dormant bud over 8 m above the ground.

In this analysis, if a small seedling of an MM species was detected in the herb layer, the coverage data of the species was categorized as 'MM'. Therefore, the composition of the dormancy form can be used to evaluate the potential progression of vegetation succession.

Table 2 Change in vegetation coverage percentage in each layer

Section	Slope	year	Layer					
			Tree		Shrub		Herb	
Passable (n=6)	Mountain side	2004	31.8		8.8		52.3	
		2016	10.4		54.9		48.2	
		Δ	-21.3	a	46.2	ab	-4.2	ab
	Valley side	2004	38.1		19.1		54.3	
		2016	23.4		70.3		16.6	
		Δ	-14.7	a	51.2	a	-37.8	b
Closed (n=5)	Mountain Side	2004	12.5		23.6		52.9	
		2016	7.5		32.5		81.9	
		Δ	-5.0	a	8.9	c	29.0	a
	Valley side	2004	23.6		16.7		29.3	
		2016	37.5		35.8		55.4	
		Δ	13.9	a	19.1	bc	26.1	a

Each value denotes the average percentage obtained from plots.
Different letters in columns denote significantly different means as determined by Tukey's HSD test (p <0.05).

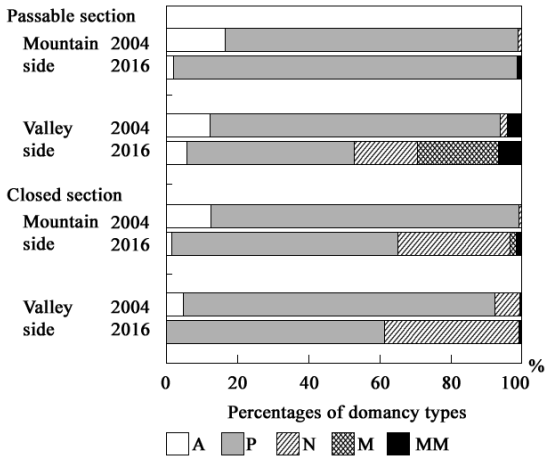

Fig. 3 Changes of composition of dormancy forms of plants as the total coverage percentage in the herb layer

3. RESULTS

3.1 Roadside Slope Vegetation

Table 2 shows the changes in vegetation coverage percentage (*Δ*) in each layer after 12 years. In the tree layer, the effect of section (passable road or closed road), slope direction, and their interaction were not significant, and the change trend was not apparent (ranged from -15% to +20%). In the shrub layer, the effect of section was significant (F-test, p <0.05). The coverage percentage increased by around +50% in the passable section, and it increased by less than +20% in the closed section. In the herb layer, the effect of section was also significant (F-test, p <0.02); coverage percentage decreased in the passable section, with a notable decrease of around -40% on the valley side, whereas it increased by around +30% in the closed section.

Fig. 3 shows the change of the composition of dormancy forms of plants in the herb layer. The effects of year (2004 or 2016), section (passable or closed) and slope (mountain side or valley side) were significant (F-test, p <0.0001, 0.02, 0.005, respectively). The effect of interaction of year × section was also significant (F-test, p <0.005), indicating that the change in composition of dormancy forms after 12 years differed between the passable and closed sections.

In 2004, each slope was primarily dominated by P (perennial herbs) and around 5% to 15% of A (annual or biennial herbs). At 12 years later, A (annual or biennial herbs) decreased on each slope, and M or MM (tree seedlings) markedly increased in the passable section. In contrast, the dominance of N (shrub) became obvious in the closed section. The following representative plant species were categorized into each dormancy form in the survey plots:

A, *Amphicarpaea bracteata* ssp. *edgeworthii* (Fabaceae), *Oplismenus undulatifolius* (Poaceae);

P, *Artemisia indica* var. *maximowiczii* (Asteraceae), *Miscanthus sinensis* (Poaceae);

N, *Sasa* spp. (Poaceae), *Rubus* spp. (Rosaceae);

M, *Lindera praecox* (Lauraceae), *Deutzia crenata* (Hydrangeaceae); and

MM, *Quercus* spp. (Fagaceae), *Alnus hirsuta* (Betulaceae).

Fig. 4 Colonized bamboo grass in the closed section of Gonbei Highway in 2016. Length of the red and white striped pole = 2 m. The gate (at the lower right) is located at the Ina City side for closing the road to traffic.

Fig. 5 Deterioration of road surface in the closed section of Gonbei Highway. Cracks, accumulated fallen leaves, and scattered invading weeds can be observed. Length of the red and white striped pole = 2 m.

Of the N (shrub) in the herb layer, bamboo grass (*Sasa* spp.: *S. borealis*, *S. sikokiana* and *S. senanensis*) comprised the majority of the species (Fig. 4). Although THE coverage percentage was sparse in 2004, it increased to rank 4 (50% to 75%) or 5 (75% to 100%) in 2016 in some plots in the closed section of the highway.

To examine the relationship between the shrub layer and herb layer, the correlation of coverage percentages between these layers was determined. As a result, the correlation coefficient was not significant in the passable section ($r = 0.223$; F-test, ns), but it was significant ($r = -0.542$; F-test, $p < 0.02$) in the closed section.

3.2 Road Surface

In the section of closed road, obvious dips or differences in level were not observed. However, mash-like or linear cracks were sparsely observed (Fig. 5). The former is caused by deterioration of asphalt and the latter seems to occur where paving different construction was conducted.

Accumulation of fallen branches and leaves was especially observed on the shoulder of the road, and fine fallen leaves (e.g., needle-like leaves of Japanese larch) accumulated on linear cracks (Fig. 5).

Weeds growing in the road surface were scattered and were concentrated where fine leaves accumulated in cracks in the road. The number of weed species was as small as 0 to 5 per site, and no tree seedlings were observed. Representative species were *Plantago asiatica* (Plantaginaceae), *Erigeron annuus* (Asteraceae) and *Juncus tenuis* (Juncaceae). Most of the species growing in the road surface were not present in the adjacent roadside slope vegetation: in the road surface, on average only 0.6 (0 to 2) species per site were observed out of 13.4 (6 to 20) species growing on the adjacent roadside slope vegetation.

4. DISCUSSION

In the closed section of Gonbei Highway, we found that tree and shrub layer coverage percentages did not increase markedly (Table 2), despite the long-term suspension of traffic creating a disturbance-free environment. In other words, the composition of tree seedlings (M and MM) occupying the herb layer was larger in the passable section than in closed section (Fig. 3), suggesting the advanced progression of vegetation succession occurred in the passable section. These unexpected results are due to the presence or absence of N (especially bamboo grass) in the herb layer, since there is a negative correlation between the coverage percentages of shrub layer and herb layer in the closed section.

Colonization of bamboo grass has been reported to suppress the establishment of tree seedlings (e.g., [9] [10]). In the present study, it is considered that the disturbance due to vegetation management in the passable section prevented colonization of bamboo grass, allowing tree seedlings to grow. However, in the disturbance-free environment of the closed section, the colonization of bamboo grass was accelerated, suppressing the recruitment and growth of tree seedlings. It is generally considered that the growth of bamboo grass should be controlled in forestry practice, but it can also be useful for preventing the growth of trees in the management

of roadside slope vegetation. The colonization of a sedge (*Carex oxyandra*: Cyperaceae) has also been reported to suppress tree seedlings [9] [10] and might be preferable over bamboo grass in the management of roadside slope vegetation.

The road surface of Gonbei Highway in the closed section was not deteriorated or heavily invaded by weeds, probably due to the asphalt coverage and its location in a cool climate at high elevation. In contrast, there is a report of an unpaved working path for forestry becoming almost covered with plants, including tree seedlings, after only 3 years [11]. In that case, the road surface is not usually paved, and the rapid development of vegetation is desirable to reduce the risk of erosion [12]. Compared to unpaved working paths, the road surface of Gonbei Highway seems to be well maintained, even in the closed section after 12 years. The weeds on the road surface included a small number of species that had little relation to the species found in the slope vegetation, suggesting that unique vegetation, though in an early stage, was extending along the closed highway. This vegetation succession, even in a mountain area, shows similarities to vegetation growing in cracks in roads in urban areas [13]. The seeds of weeds might have been gradually introduced in the area by water, wind or wild animals and birds from outside the area since there has been little automobile or human traffic after the suspension.

5. CONCLUSION

In the present study, we surveyed Gonbei Highway, a winding road in a mountainous region in central Japan. It was damaged by typhoons in the autumn of 2004, and a 9 km stretch of the highway has remained closed. We established 11 survey sites to examine slope vegetation along Gonbei Highway in the summer of 2004 (just before the area was damaged by typhoons), and we conducted surveys again in 2016 (12 years after the damage), including at 5 survey sites along the closed section of the road. Our results were as follows:

(1) On the roadside slopes, succession to arboreal vegetation was not observed at the sites along the closed section of the road. In herb layer, vegetation coverage increased significantly along the closed section with increasing coverage of shrub species (mainly bamboo grass). In contrast, tree seedlings increased in the passable sections.

(2) On the road surface in the section of closed road, obvious deterioration was not observed, excepting mash-like or linear cracks. The road surface vegetation was seemed to be just in the early stage of succession: weeds growing in the road surface were scattered and were concentrated where fine leaves accumulated in cracks in the road. No tree seedlings were observed, and most of the species growing in the road surface were not present in the adjacent roadside slope vegetation.

The suspension of traffic and the subsequent long-term absence of roadside vegetation management allowed bamboo grass to increase, and the community of bamboo grass prevented invasion and growth of tree seedlings. Bamboo grass might also be useful to prevent the invasion of weeds, especially non-native species, through the road into roadside slope vegetation. Consequently, the dominance of bamboo grass in roadside slope vegetation may be one of the criteria by which to judge the necessity of vegetation management along roads closed to traffic.

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