

RAILWAY TRACKS VEGETATION IN RELATION TO VARIOUS MANAGEMENT, KUMAMOTO, JAPAN

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ABSTRACT: Research on the effects of different vegetation management regimes along railway tracks is valuable for effective train operation and security and landscape conservation of the surrounding area. In addition, such surveys may offer important ecological insights into plant synanthropization and adventization. In this study, we conducted direct along-track surveys on the Minami-aso Railway after the 2016 Kumamoto Earthquake with special permission to clarify the effects of different management conditions on track vegetation and the ecological attributes of the species that make up the vegetation. The results suggested that the vegetation established along the tracks differs depending on the vegetation management regime that is employed in the region. Specifically, the use of herbicides was considered to reduce plant coverage, plant community height, and number of species (no./m²) on the tracks compared to management by physical removal the vegetation. Furthermore, in addition to the use of herbicides, percentage of plant coverage and number of species per unit area was expected to be further reduced by the operation of the train. These differences in management status also had a significant effect on the composition of species that become established on the tracks (i.e., synanthropic species), but the effect of management regime on the ecological attributes of these species, such as the proportion of non-native species (adventization) and life forms defined by Raunkiaer (e.g., dormant) and Numata (e.g., dispersal types), was considered small.

Keywords: Adventization, Kumamoto Earthquake, Railway, Synanthropization, Track vegetation

1. INTRODUCTION

Japan is one of the most disaster-prone countries in the world. In the last decade or so, numerous disasters have occurred and caused extensive damage, including the 2011 Off the Pacific Coast of Tohoku Earthquake [1], the 2016 Kumamoto Earthquake (hereafter referred to as Kumamoto Earthquake) [2], the Northern Kyushu heavy rainfall in July 2017 [3], and the Western Japan heavy rainfall in July 2018 [4].

Of these events, the Kumamoto Earthquake is the generic name given to a series of earthquakes in Kumamoto and adjacent prefectures that occurred after 21:26 on April 14, 2016 (the magnitude of the main shock was M7.3), which caused 273 deaths, total destruction of 8,667 buildings, and 190 landslides [2]. In addition, Kumamoto Castle, Aso Shrine, and other structures designated as Important Cultural Properties by the national government were severely damaged [5,6] (Fig 1 A and B). Extensive damage to utility networks and infrastructure was also reported [2,7]. As for utility networks, water was cut off to approximately 427,000 households, power was cut off to approximately 455,200 households, and gas supply was cut off to approximately 100,884 households. In terms of infrastructure, 2,266 roads (limited to Kumamoto Prefecture) sustained damage, including cracking, sinking, and uplifting of the road surface, and collapse of bridges occurred, such as the Aso Ohashi Bridge (Fig 1 C). Four railways in the

area, namely the Hohi Main Line, Minami-aso Railway Line, Kumamoto Electric Railway Line, and Kumamoto City Tram Line, also suffered extensive damage, including track uplift, rockfalls, slope failures, and damage to bridges (Fig 1 D).

As of October 2019, the Minami-aso Railway Line has been under various operations, including sections where trains are running, sections where trains are not running due to restoration work, and sections where the vegetation on the tracks is managed by spraying herbicides or by pulling up (hereafter referred to as physical removal). How do these different management conditions affect the plants that invade and establish themselves on the tracks? The answer to this question will provide us with valuable insights into train operation and security, as well as landscape preservation in the surrounding area. Furthermore, the answer may offer ecological insights into plant synanthropization and the recent acceleration in adventization.

That's because, although studies on railroads have been conducted extensively over the years, covering topics such as track structure [8,9,10], new line development [11], maintenance [12], toll systems [13], and economic impacts [14], including track vegetation, research focused on railroad vegetation remains comparatively limited. Moreover, these reports on track vegetation are not based on direct on-site inspections but rather on questionnaires administered to railway operators [15,16],



Fig 1 Damage caused by the Kumamoto Earthquake [17,18] ,A: collapsed stone wall of Kumamoto Castle; B: crushed Aso Shrine; C: collapsed Aso Ohashi Bridge; D: uplifted track of Minami-aso Railway Line

observations from outside the right-of-way [19], observations from inside trains [15], and using cameras attached to trains [20]. This is because the tracks upon which trains are operating can typically not be accessed legally. Furthermore, herbicide control is the most widespread method of controlling vegetation on railway tracks, but the physical removal as in the Minami-aso rail line mentioned above is very rare. Therefore, in this study, we conducted direct along-track surveys on the Minami-aso Railway Line with special permission to clarify the effects of different management conditions on track vegetation and the ecological attributes of the species that make up the vegetation.

2. RESEARCH SIGNIFICANCE

Despite the widespread establishment of plants along railway tracks, little research has been conducted on this phenomenon. Furthermore, none of the existing studies involved direct on-site surveys of the tracks. The significance of this study lies in its unique access to railway tracks, allowing for a direct survey of track vegetation. Additionally, this research is notable for being conducted on a section of track where a rare approach to vegetation management is implemented. The results of this study could also supplement records of the damage caused by the 2016

Kumamoto Earthquake.

3. MATERIALS AND METHODS

3.1 Study Site Overview

As of October 2019, trains have been running normally in the section between Takamori Station and Nakamatsu Station (Section A) since July 31, 2016, approximately three months after the Kumamoto Earthquake, along the Minami-aso Railway Line (17.7 km long from Takamori Station to Tateno Station, with all lines comprising single tracks) (Fig. 2). However, the section from Nakamatsu Station to Tateno Station (Section B) is still out of service after the Kumamoto Earthquake, and management continues as follows (Fig. 2). Tunnels, and bridges along the section from most of the area between Choyo Station and Tateno Station (Section B4) are under restoration; vegetation in the section from Nakamatsu Station to Kasei Station (section B1) and part of the section from Choyo Station to Tateno Station (Section B3) are managed by spraying herbicide twice a year; and the section from Kasei Station to Choyo Station (Section B2) is managed by physical removal by volunteers (once a year). Section A, where the above-mentioned trains are running normally, is managed by spraying herbicide twice a

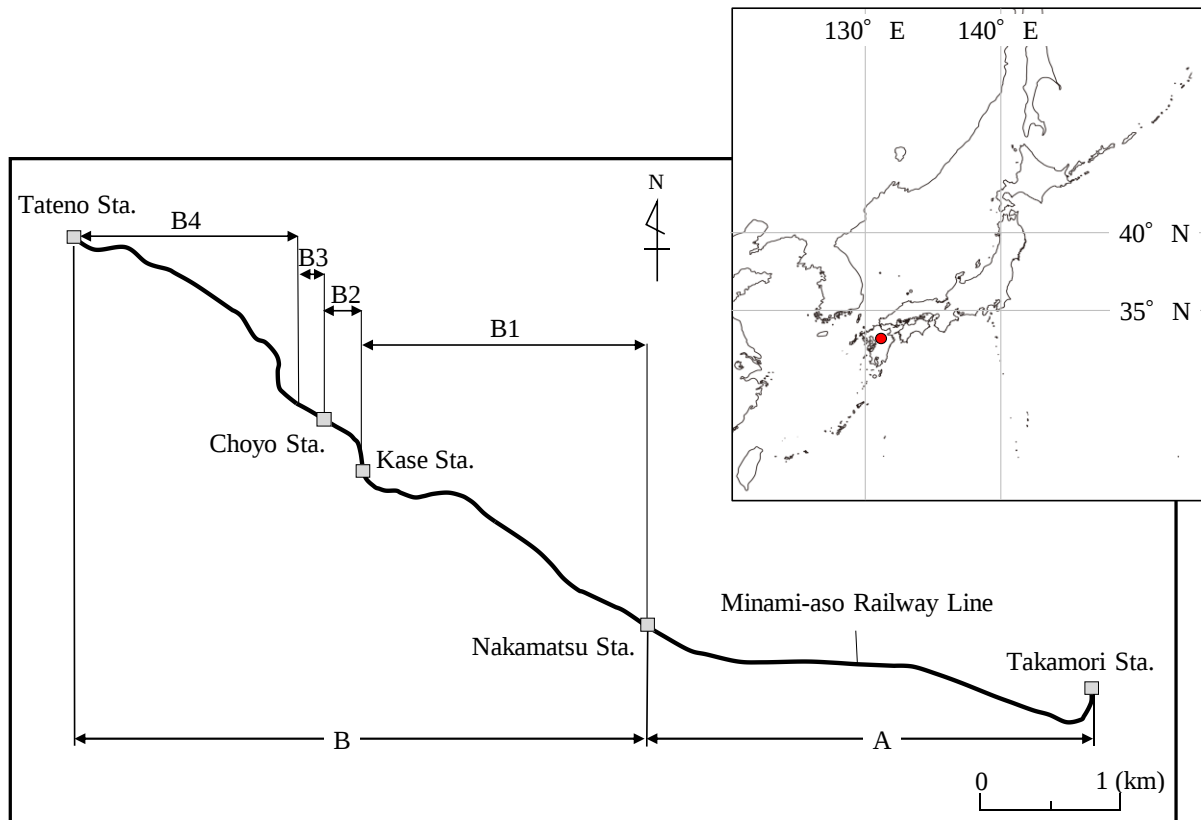


Fig.2 Geographical location and map of the study site

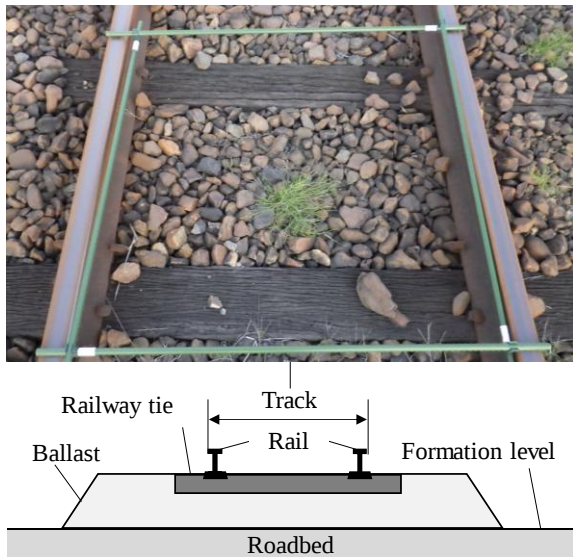


Fig.3 Physical appearance of the railway track

year. The trains in this section operate three round trips per day (three to five round trips per day on weekends and holidays).

In this study, section B2, which is managed by physical removal the vegetation, was defined as the "physical removal section"; Sections B1 and B3, which are managed by herbicide application, were defined as the "herbicide section"; and Section A, which is managed by herbicide application and in

which operation of the train have been resumed, was defined as the "normal operation section".

3.2 Measurement and Analysis

3.2.1 Surrounding Environment

In late October 2019, 1 m × 1 m quadrats were placed in the center of the track at intervals of approximately 50 m (physical removal section) and 100 m (herbicide section and normal operation section) (Fig. 3).

As elements of the surrounding environment, the percentage of the sky above the quadrat that was covered by trees (canopy rate) and the surrounding land use were recorded. The latter was divided into four categories (forest, farmland, vacant lot, and residential area) based on aerial photographs and on-site evaluations at the time of the survey.

3.2.2 Vegetation

Percentage of ground surface covered by plants (hereafter referred to as plant coverage (%)), maximum plant height (hereafter referred to as plant community height (cm)), and species cover scores within each quadrat were recorded. The species cover scores were calculated by the Braun-Blanquet total estimation method [21].

3.2.3 Analysis

The recorded cover scores were converted to

Table 1 Surrounding environment at each study section

Study section	n	Canopy rate (%) [†]	Land use (%) [‡]			
			Forest	Farmland	Vacant lot	Residential area
Physical removal	24	0.0 ± 00.0	37.5	45.8	8.3	8.3
Herbicide	50	6.0 ± 20.7	36.0	52.0	6.0	6.0
Normal operation *	40	0.0 ± 00.0	22.5	65.0	7.5	5.0

*: Herbicide application and trains have been resuming

†: Kruskal-Wallis test ($p > 0.05$)

‡: Fisher exact test ($p > 0.05$)

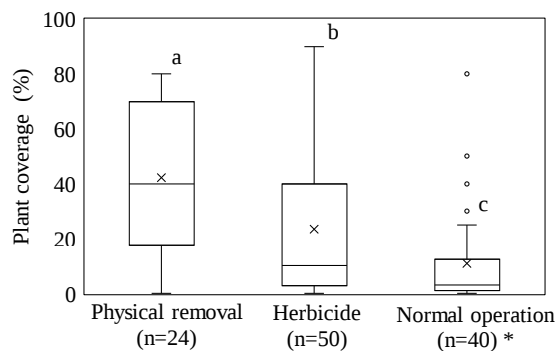


Fig.4 Box-and-whisker plot of plant coverage in each study section

*: Herbicide application and trains have been resuming

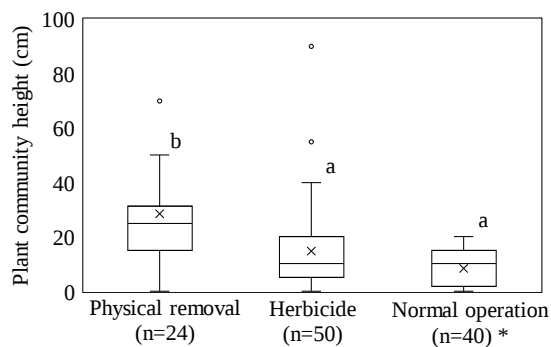


Fig.5 Box-and-whisker plot of plant community height in each study section: The explanation of the figure is the same as for Fig.4.

median values. SPSS Statistics (Ver. 24.0, IBM) and R (Ver. 3.4.0) software packages were used for statistical analysis.

4. RESULTS

4.1 Surrounding Environment

The canopy rate was 0.0% for the physical removal section and normal operation section, respectively, and 6.0% for the herbicide section, with no significant

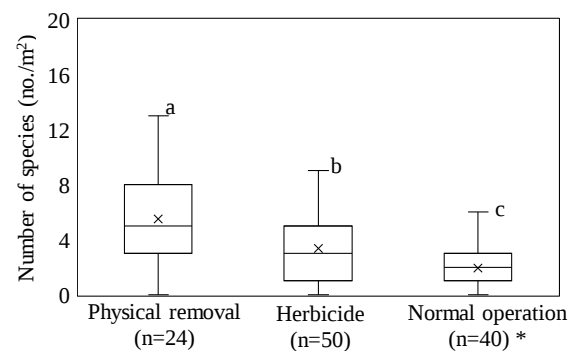


Fig.6 Box-and-whisker plot of number of species per unit area in each study section: The explanation of the figure is the same as for Fig.4.

differences observed among sections ($p > 0.05$) (Table 1).

On the other hand, land use in the physical removal section was 37.5% forest, 45.8% farmland, 8.3% vacant lot, and 8.3% residential area (Table 1). In the herbicide section, land use was 36.0% forest, 52.0% farmland, 6.0% vacant lot, and 6.0% residential area. In the normal operation section, land use was 22.5% forest, 65.0% farmland, 7.5% vacant lot, and 5.0% residential area. Thus, farmland tended to have the highest proportion in land use in all section, followed by forest. There was no significant relationship between each study section and the percentage of land use ($p > 0.05$).

4.2 Vegetation

4.2.1 Plant coverage, plant community height, number of species per unit area

Percent plant coverage in each test plot is shown in Fig. 4. In Fig 4, different alphabetic letters indicate significant differences among study sections (Kruskal-Wallis test, $p < 0.01$, Tukey's HSD test, $p < 0.05$). The top, center, and bottom lines of each box indicate the 3rd, 2nd, and 1st quartiles, respectively, and cross indicate average value. The horizontal lines above and below the box indicate maximum and minimum values. The maximum and minimum values lie within the third quartile $\pm 1.5 \times$

Table 2 Species observed in each study section

Group	Dormant *	Dispersal **	Family	Species	Study section †		
					Physical removal	Herbicide	Normal operation‡
A	Th	D ₄	Poaceae	<i>Digitaria ciliaris</i>	II ⁺⁴	III ⁺⁴	II ⁺⁴
	G	D ₁	Equisetaceae	<i>Equisetum arvense</i>	II ⁺³	II ⁺³	II ⁺³
	Th(w)	D ₄	Lamiaceae	<i>Lamium amplexicaule</i>	I ⁺	II ⁺²	II ⁺¹
	Th(w)	D ₁	Asteraceae	<i>Erigeron annuus</i> §	I ⁺¹	I ⁺¹	I ⁺¹
	Th	D ₃	Euphorbiaceae	<i>Euphorbia maculata</i> §	I ¹	I ⁺	I ⁺¹
	Th	D ₃	Geraniaceae	<i>Geranium carolinianum</i> §	II ⁺	I ⁺	I ⁺¹
B	Th(w)	D ₃	Fabaceae	<i>Vicia hirsuta</i>		I ⁺	II ⁺¹
C	Th	D ₁	Asteraceae	<i>Bidens frondosa</i> §	II ⁺⁴	I ¹⁻²	
	Th	D ₄	Commelinaceae	<i>Commelina communis</i>	II ⁺²	I ⁺¹	
	Th(w)	D ₃	Fabaceae	<i>Vicia tetrasperma</i>	II ⁺	II ⁺	
	Th	D ₁	Asteraceae	<i>Lactuca indica</i>	I ⁺	I ¹⁻²	
	Th(w)	D ₂	Apiaceae	<i>Torilis japonica</i>	I ⁺	I ⁺²	
	Th	D ₃	Fabaceae	<i>Vigna angularis</i>	I ⁺	I ⁺¹	
	M	D ₁	Apocynaceae	<i>Trachelospermum asiaticum</i>	I ²	I ⁺¹	
	Th	D ₄	Poaceae	<i>Setaria viridis</i>	II ⁺¹	I ⁺	
	H	D ₃	Violaceae	<i>Viola mandshurica</i>	I ⁺¹	I ⁺¹	
	Ch	D ₃	Oxalidaceae	<i>Oxalis corniculata</i>	II ⁺¹	I ⁺¹	
	Th	D ₃	Brassicaceae	<i>Brassica juncea</i> §	I ⁺	I ⁺	
D	M	D ₄	Poaceae	<i>Pleiblastus argenteostriatus</i>		I ²⁻⁴	
	Th(w)	D ₄	Caryophyllaceae	<i>Cerastium glomeratum</i> §		I ⁺¹	
	Th	D ₁	Asteraceae	<i>Crassocephalum crepidioides</i> §		I ⁺	
	Th(w)	D ₁	Asteraceae	<i>Sonchus asper</i> §		I ⁺¹	
	Th(w)	D ₁	Asteraceae	<i>Carthamus tinctorius</i> §		I ⁺¹	
E	H	D ₁	Poaceae	<i>Miscanthus sinensis</i>	I ²⁻³		
	Ch	D ₄	Fabaceae	<i>Pueraria lobata</i>	I ⁺²		
	Th(w)	D ₁	Asteraceae	<i>Youngia japonica</i>	I ¹		
	Th(w)	D ₄	Caryophyllaceae	<i>Silene firma</i>	I ¹		
	N	D ₁	Ranunculaceae	<i>Clematis apiifolia</i>	I ¹		
	Th(w)	D ₁	Asteraceae	<i>Erigeron canadensis</i> §	I ⁺¹		
	MM	D ₄	Euphorbiaceae	<i>Mallotus japonicus</i>	I ⁺		
	Th	D ₄	Cannabaceae	<i>Humulus scandens</i>	I ⁺		
	Th(w)	D ₄	Papaveraceae	<i>Chelidonium majus</i>	I ⁺		
	Th	D ₃	Moraceae	<i>Fatoua villosa</i>	I ⁺		
	Th	D ₁	Asteraceae	<i>Symphyotrichum subulatum</i> §	I ⁺		
	Th(w)	D ₃	Brassicaceae	<i>Cardamine tanakae</i>	I ⁺		
	Th(w)	D ₁	Rubiaceae	<i>Galium pogonanthum</i>	I ⁺		
Number of species					30	23	7

Physical removal (n=24), Herbicide (n=50), Normal operation (n=40)

*: Dormancy form of *Raunkiaer* [22], **: Dispersal form of *Numata* [23]

†: Roman numerals indicate plant frequency (I: under 20%, II: under 40%, III: under 60%, IV: under 80% and V: above 80%), and superscripts show the Braun-Blanquet cover scores (+, 1, 2, 3, 4 and 5) [21]

‡: Herbicide application and trains have been resuming

§: Non-native species

quartile range, and circles indicate outliers.

The percentage of plant coverage in each study section was 42.3%, 23.2%, and 11.0% for the physical removal section, herbicide section, and

normal operation section. Thus, the plant coverage per unit area among the sections significantly differed ($p < 0.05$), in the increasing order of normal operation section, herbicide section, and physical removal



Fig 7 Tracks of another railway without vegetation management after the Kumamoto Earthquake

section (Fig. 4).

The plant community height in each study section was 28.5 cm, 16.3 cm, and 8.4 cm for the physical removal section, herbicide section, and normal operation section, respectively, with the values for the physical removal section being significantly higher ($p < 0.05$) than the other two sections (Fig. 5).

The number of species per unit area was 5.5 in the physical removal section, 3.4 in the herbicide section, and 1.9 in the normal operation section (Fig. 6). Thus, the number of species per unit area among the sections significantly differed ($p < 0.05$), in the increasing order of normal operation section, herbicide section, and physical removal section (Fig. 6).

4.2.2 Species composition

The species composition observed in each study section is shown in Table 2. Here, species with a frequency of occurrence of 3% or less were excluded in order to exclude species that appeared by chance.

Six species in species group A (*Digitaria ciliaris* (Retz.) Koeler, *Equisetum arvense* L., *Lamium amplexicaule* L., *Erigeron annuus* (L.) Pers., *Euphorbia maculata* L. and *Geranium carolinianum* L.) were found in all study sections. In particular, the values in plant frequency and species cover scores of *Digitaria ciliaris* (Retz.) Koeler and *Equisetum arvense* L. were high in all of the surveyed sections.

The physical removal section comprised species groups A, C, and E. A total of 30 species were identified (number of quadrats, $n=24$). Of these, 13 species in Species Group E (*Miscanthus sinensis* Andersson, *Pueraria lobata* (Willd.) Ohwi subsp., *Youngia japonica* (L.) DC., *Silene firma* Siebold, *Clematis apiifolia* DC., *Erigeron canadensis* L., *Mallotus japonicus* (L.f.) Müll. Arg., *Humulus scandens* (Lour.) Merr., *Chelidonium majus* L., *Fatoua villosa* (Thunb.) Nakai, *Symphyotrichum subulatum* (Michx.) G.L. Nesom, *Cardamine tanakae* Franch., and *Galium pogonanthum* Franch.) were found only in the physical removal section. The herbicide section comprised species groups A, B, C,

and D, with a total of 23 species identified (number of quadrats, $n=50$). Of these, five species of species group D (*Pleioblastus argenteostriatus* (Regel) Nakai, *Cerastium glomeratum* Thuill., *Crassocephalum crepidioides* (Benth.) S. Moore, *Sonchus asper* (L.) Hill, and *Carthamus tinctorius* L.) were found only in the herbicide section. The normal operation section comprised species groups A and B. Although the number of quadrats in the normal operation section was not small ($n=40$), the emergent species was markedly lower than that in the other sections, totaling only 7 species.

On the other hand, no significant relationship was observed between each study section and the ecological attributes of the emergent species (non-native, native, dormant, and dispersal types) (Fisher exact test, $p > 0.05$).

5. DISCUSSION

Differences in the percentage of plant coverage, plant community height, and number of species per unit area were observed among the study sections (Fig. 4, Fig. 5 and Fig. 6). However, the fact that there were no differences in the canopy rate and land use of the surrounding environment among the study section (Table 1) suggests that the differences in the vegetation at the study section were likely caused by management conditions. Specifically, compared to vegetation management by physical removal, the use of herbicides was considered to reduce the percentage of plant coverage, plant community height, and the number of species per unit area on the tracks (Fig. 4, Fig. 5 and Fig. 6). Furthermore, in addition to the use of herbicides, the percentage of plant coverage and number of species per unit area was considered to be further reduced by operation of the trains (Fig. 4 and Fig. 6). The number of species was also remarkably lower in the normal operation section compared to the other sections, even when the number of quadrats is considered (Table 2), suggesting that the operation of the train itself, in addition to the physical removal and herbicide regimes, contributed significantly to the suppression of plant establishment.

Differences in the management regime employed also had a significant effect on the composition of species that became established on the track (i.e., synanthropic species), but the effect on the ecological attributes of these species (such as the proportion of non-native species (adventization) and dormant and dispersal types), was considered to be small (Table 2).

On the other hand, the species in Species Group A, such as *Digitaria ciliaris* (Retz.) Koeler., *Equisetum arvense* L., *Lamium amplexicaule* L., *Erigeron annuus* (L.) Pers., *Euphorbia maculata* L., and *Geranium carolinianum* L., were observed in all of the study sections and these species, especially *Digitaria ciliaris* (Retz.) Koeler and *Equisetum arvense* L., which were dominant, were considered to

be typical species that established themselves along the railway in this area, regardless of the management regimes employed (Table 2). The findings show that these species-based measures are relatively useful for the vegetation management regimes along this railway. In addition, species group D, which comprises *Pleiblastus argenteostriatus* (Regel) Nakai, *Cerastium glomeratum* Thuill., *Crassocephalum crepidioides* (Benth.) S. Moore, *Sonchus asper* (L.) Hill, and *Carthamus tinctorius* L., were observed only in the herbicide section, suggesting that these species are more susceptible to physical disturbance, such as physical removal and train operations, than to chemical application. Species in species group E, such as *Miscanthus sinensis* Andersson and *Pueraria lobata* (Willd.) Ohwi, were observed only in the physical removal sections, so chemical application may be more effective in suppressing these species than physical removal.

Unfortunately, no untreated section (control section) could be established in this study. The application of such a section could have demonstrated the effectiveness of the physical removal treatment for vegetation control along the track (Fig 7) — in fact, interestingly, although the values of percentage of plant coverage, plant community height, and number of species per unit area were higher than those in the other sections, the plant community height in the physical removal section was just only 28.5 cm (Fig. 4, Fig. 5 and Fig. 6).

6. CONCLUSION

The objective of this study was to examine the effects of different vegetation management regimes (physical removal and herbicide application), as well as train operation, on track vegetation and the ecological attributes of the species that compose these plant communities. After obtaining special permission, we conducted direct along-track vegetation surveys on the Minami-aso Railway line after the 2016 Kumamoto Earthquake. The results showed that, first, compared to management by physical removal, the use of herbicides reduced the percentage of plant cover, community height, and the number of species per unit area on the track. Second, in addition to the use of herbicides, percentage of plant coverage and number of species per unit area was observed to decrease more due to train operation. Third, differences in vegetation management regimes had a marked effect on the composition of species on the tracks, but the effect of regimes on the ecological attributes of these species (proportion of non-native, dormant, and dispersal types) was considered to be small.

Since it is typically illegal to access the railway tracks that are in operation, few previous studies have been conducted on track vegetation. In cases where

such studies have been conducted, the findings are based on questionnaires administered to, observations from outside the right-of-way, and observations from inside the trains. In other words, the ecological significance of this study is that it provided knowledge obtained through direct in-track surveys of such sites. In addition, with the increasing frequency of herbicide applications in recent years, obtaining data on the track vegetation management through physical removal can be highly valuable. The findings are also considered to be socially significant as they provide a record of the damage caused by the 2016 Kumamoto Earthquake.

Finally, the observation that the operation of the train itself had a marked influence on the vegetation in this study was considered to be interesting. We would therefore like to investigate the relationship between train frequency, speed, route, region, area (urban or suburban), and track vegetation in the future.

7. ACKNOWLEDGMENTS

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