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FOREST ROADS CAUSE EDGE EFFECTS ON PLANT SPECIES DIVERSITY IN ARTIFICIAL FORESTS

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ABSTRACT: To evaluate the effects of narrow forest roads on plant species diversity in the forest understory, we analyzed the relationship between the distance from the forest road and vegetation structure in young and mature artificial forests of Japanese cedar (*Cryptomeria japonica*). Although exotic species appeared along the side of the forest road, their appearance frequencies and coverage were very small, suggesting that a decline in species diversity due to exotic species did not occur. Although an obvious decrease in vegetation coverage and species number with distance from the forest road was detected in the shrub layer of the young forest, a clear distance-dependency was not observed in the mature forest. However, even though the effects on local species number (α diversity) were unclear, replacement of species was detected with distance from the forest road (β diversity) in association with species' shade tolerance. This replacement of species improved the overall diversity of forest (γ diversity). Thus, it was concluded that narrow forest roads can improve species diversity in artificial forests in association with a diversified environment and the replacement of plant species.

Keywords: Forest Road, Artificial Forest, β Diversity, Edge Effect, Forest Age

1. INTRODUCTION

Installation of forest roads enables the introduction of high-performance forestry machinery [1], which reduces costs and enhances forestry productivity [2], [3]. Thus, a greater density of forest roads is required in Japan [4]. The construction of forest roads also results in changes to the forest environment, such as temperature, humidity and light [5], [6]. Such environmental changes can impact the species diversity of the forest [6], [7].

Several studies have shown that the existence of forest roads improves species diversity [8]–[10]. However, even if the construction of a forest road initially has positive effects, its impact on the neighboring forest can change over time [8]. On the other hand, the effects of forest road construction are not always positive with respect to species diversity. Road construction enables the invasion and dominance of exotic plant species, which reduce the diversity of native species [7]. Furthermore, the influence on diversity also depends on the road width since the size of the canopy gap is related to the width of the forest road. In the case of narrow forest roads in Iran, the effects on forest species diversity were not obvious [11].

It is generally assumed that Japanese forest roads are narrow (4−6 m); therefore, their effects on species diversity may be slight. In this study, we tested the effects of Japanese forest roads on exotic plant invasion and plant species diversity in forests of different ages.

2. MATERIALS AND METHODS

2.1 Study Site

The survey was conducted in an artificial forest of Japanese cedar (*Cryptomeria japonica*) in Neba Village, Nagano Prefecture in Central Japan (Fig. 1). This area is located 35°16′N, 137°35′E. From 2007 to 2016, the annual temperature was 9.6°C and the average annual precipitation was 2,697 mm at the closest observation site (Namiai Observation Site, Japan Meteorological Agency, 35°22′N, 137°42′E). Two forest roads were surveyed in this study, the Takahashi-Gumino (TK) line (Fig. 2), which passes through a young forest, and the Anada (AN) line (Fig. 3), which passes through a mature forest (Table 1).

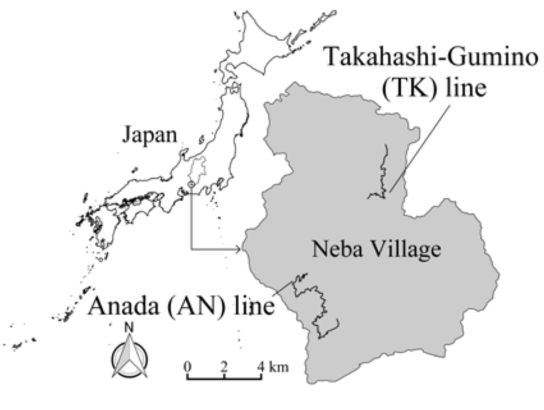

Fig. 1 Location of the study areas.

Fig. 2 Takahashi-Gumino (TK) Line

Fig. 3 Anada (AN) Line

Table 1 Outline of the surveyed forests.

	TK line	AN line
Number of plots	5	18
Altitude (m)	919-927	779-829
Road construction year	1999	1970
Road width (m)	4-6	4-5
Forest age (years)	49	63-83
Stand density (trees/ha)	1400	633
Canopy height (m)	21.4	25.9
Canopy coverage of interior forest (%)	63	55
Canopy gap width above the forest road (m)	7.1	1.3

2.2 Field Surveys and Data Collection

To evaluate the effect of forest roads on species diversity in the understory, five and 18 belt plots were established along the TK and AN lines, respectively. The average road width was 4.8 m. For vegetation investigation, belt plots of 10 m wide and 20 m depth were set from the edge of the road to the interior of the forest. Furthermore, each belt plot was divided into four sub-plots, each 10 m wide and 5 m deep, which were named Psub.1, Psub.2, Psub.3, and Psub.4 in order of distance from the forest road. All sub-plots had three major layers including the canopy layer, shrub layer, and herb layer, but lacked a sub-canopy layer. The canopy layer consisted only of planted *Cryptomeria japonica*. The characteristics of the survey area are summarized in Table 1.

We surveyed the vegetation structure of the shrub and herb layers in each sub-plot. We recorded the total vegetation coverage (%) and species coverage (%) along with the names of all vascular plants detected. The scientific name refers to botanical books [12]–[19].

2.3 Analysis Method

To characterize the change in vegetation coverage and species diversity with respect to distance from the forest road, we calculated species number and Shannon’s diversity index (*H’*) based on the species coverage for each layer of each sub-plot. We compared these characteristics among the sub-plots within each layer of each line using a repeated measure analysis of variance and Holm’s multi-comparison method.

To detect the plant species present with distance from the forest road in each layer of each line, we conducted a screening test for all species using the Jonckheere-Terpstra test in each sub-plot according to the distance from the road. Species coverage was used for the screening test, and coverage of 0.1% was used when the coverage was less than 1%. We referred to the species detected along the road side and on the forest interior as “edge species” and “interior species”, respectively.

3. RESULTS

3.1 Vegetation Structure

The vegetation survey represents a larger number of plant species in the mature forest compared to the young forest. In the young forest of the TK line, 30 and 114 plant species were recorded in the shrub and herb layers, respectively. On the other hand, in the mature forest of the line, 93 and 224 plant species were recorded in the shrub and herb layers, respectively. Vegetation coverage, species richness, and species evenness were larger in the mature forest than the young forest, with the exception of species evenness in the shrub layer (Fig. 4).

Almost all of the plants present were native species, except for the following three exotic species found in the herb layer: *Eragrostis curvula*, *Indigofera bungeana*, and *Phytolacca americana*. Exotic species were found only in sub-plots facing the forest road. However, only one individual of each of the three exotic species was detected and the coverage of each was less than 1%.

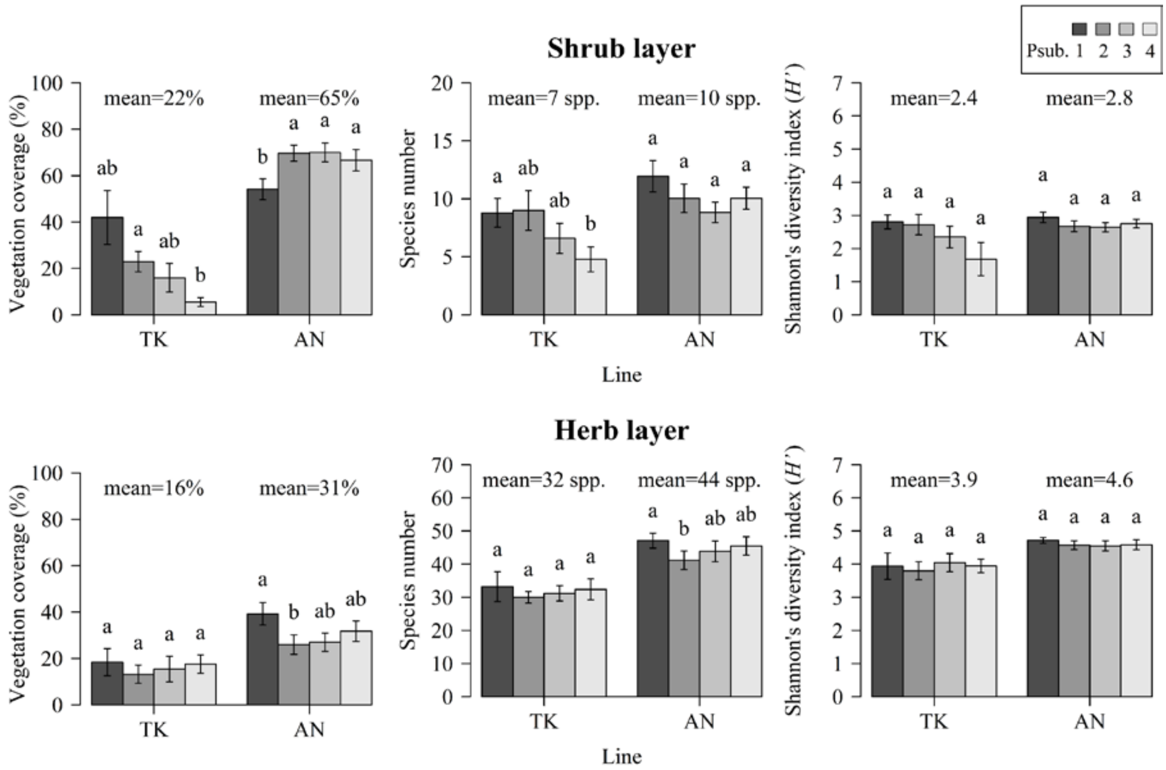

Fig. 4 Vegetation coverage and species diversity with distance from the forest road. Vegetation coverage (left), species richness (middle) and species evenness (right) of the shrub layer (upper) and herb layer (lower) of the TK and AN lines are shown. Bars represent standard error. Values with the same characteristics were not significantly different within each line. Mean values of each belt are shown above the four columns and were larger in the mature forest than the young forest with the exception of species evenness in the shrub layer (U-test at 5% level).

3.2 Changes in Vegetation Coverage, Species Number, and *H'* with Distance from Forest Road

Changes in the species number, vegetation coverage, and *H'* with respect to distance from the forest road are shown in Fig. 4. In the young forest of the TK line, both species number and vegetation coverage in the shrub layer was significantly larger in sub-plots along the road side, whereas these remained unchanged in the herb layer. On the other hand, in the mature forest of the AN line, species number and vegetation coverage in the shrub layer did not show any obvious change along the belt depth, whereas both were slightly larger in the herb layer of sub-plots along the road side. In the herb layer of both the TK and AN lines, vegetation coverage and species number show a non-linear pattern: they were larger in both edge and interior sub-plots, but smaller in sub-plots positioned in the middle. There was no significant difference in *H'* in any line or in any layer, but *H'* in the shrub layer of the TK line showed a tendency to increase toward the road side.

3.3 Species Appearance Pattern with Distance from Forest Road

The edge and interior species detected along each line are shown in Table 2. In the young artificial forest of the TK line, 30 species were detected in the shrub layer, four of which were edge species; 114 species were detected in the herb layer, two and four of which were edge and interior species, respectively. In the mature artificial forest of the AN line, two of the 93 species detected in the shrub layer were edge species; 224 species were detected in the herb layer, 11 of which were interior species. Interior species were not detected in the shrub layer of either line. Along the AN Line, two edge species (*Rubus palmatus* var. *coptophyllus* and *Dioscorea japonica*) were commonly detected along the AN line, whereas any species were commonly detected along the TK line. In both the TK and AN lines, three species were commonly detected: one edge species (*Rubus palmatus* var. *coptophyllus*) in the herb layer, and two interior species (*Lycopodium serratum* and *Disporum smilacinum*) in the herb layer.

Table 2 Edge and interior species detected in the shrub and herb layers of each line.

Layer	TK line				AN line			
	Edge species		Interior species		Edge species		Interior species	
Shrub	*Styrax japonica*	*	NULL		*Rubus palmatus* var. *coptophyllus*	*	NULL	
	Quercus serrata	*			*Dioscorea japonica*	*		
	Rhus trichocarpa	*						
	Clethra barvinervis	*						
Herb	*Celastrus orbiculatus*	*	*Lycopodium serratum*	**	*Actinidia arguta*	***	*Blechnum niponicum*	**
	Rubus palmatus var. *coptophyllus*	*	*Vaccinium smallii* var. *glabrum*	*	*Cryptotaenia japonica*	***	*Disporum smilacinum*	**
			Disporum smilacinum	*	*Dioscorea japonica*	***	*Tripterospermum japonicum*	**
			Tricyrtis affinis	*	*Clinopodium micranthum*	**	*Lycopodium serratum*	**
					Boehmeria tricuspis var. *unicuspis*	**	*Ilex crenata*	*
					Impatiens textori	**	*Ilex serrata*	*
					Rubus palmatus var. *coptophyllus*	**	*Carpesium divaricatum*	*
					Reynoutria japonica	*	*Carex parciflora* var. *macroglossa*	*
					Polystichum tagawanum	*	*Chloranthus serratus*	*
					Diplazium squamigerum	*	*Schisandra nigra*	*
					Ampelopsis brevipedunculata var. *beterophylla*	*	*stegnogramma pozoi*	*
					Wisteria floribunda	*		
					Apios fortunei	*		
					Pilea hamaoi	*		
					Athyrium vidalii	*		

Species were detected using a screening test. Asterisks represent the level of statistical significance (*5% level, **1% level, ***0.1% level). NULL means that no species of that type were detected in the layer.

4. DISCUSSION

4.1 Influence of Exotic Species on Species Diversity

Three major exotic species were detected in this study, as mentioned above. *Eragrostis curvula* and *Indigofera bungeana*, which appeared in the young forest of the TK line, are generally used for artificial greening [20], [21]. All exotic species appeared in the sub-plots facing the forest road, suggesting that these exotic species are likely to invade areas along forest roads. It has been pointed out that wide forest roads are safe sites for exotic species and enhance their dominance, which can negatively impact native species growth and reduce the species diversity of the area [7]. However, the number of individuals and coverage of the three exotic species was very small in this study. Therefore, it is thought that species diversity was not affected by exotic species along the narrow forest roads in this study.

4.2 Vegetation Coverage and Species Diversity

Both vegetation coverage and species number were larger in the mature forest of the line than the young forest of the TK line (Fig. 4). It is generally reported that thinning has positive effects on understory development and species diversification by improving the light environment [22]–[25]. Repeated thinning over time results in low stand density and a small canopy coverage (Table 1), which enhances species diversification. These findings contradict the results for secondary forests of broadleaf species in France [10] but agree with findings from artificial forests in Japan [26].

In the young forest of the TK line, vegetation coverage and species richness of the shrub layer obviously decreased from the forest edge to the interior. This result is similar to that of other studies [8]–[10]. On the other hand, vegetation coverage, species richness and evenness of the herb layer showed no significant change from the forest edge to the interior. In the young forest, the canopy gap above the forest road was larger (Table 1). However, the effect of the gap on the herb layer was relatively small due to light interception by the developed shrub layer.

In the mature forest of the AN line, species richness and evenness did not obviously change with distance from the edge in either the shrub or herb layer, as was the case with narrow forest roads in Iran [11]. However, vegetation coverage at the edge of the forest was lowest in the shrub layer and highest in the herb layer. In mature forests, because the canopy gap above the forest road is reduced (Table 1), the effect of the gap tends to be small [27]. If canopy closure is in progress, only light-sensitive species of the shrub layer at the forest edge decline and vegetative recovery is underway in the herb layer.

4.3 Enrichment of Overall Diversity by Species Replacement

In total, 20 edge species and 13 interior species were detected by a species screen test. In general, *Rubus palmatus* var. *coptophyllus*, *Clethra barbinervis*, *Boehmeria tricuspis* var. *unicuspis*, and *Fallopia japonica*, which prefer bright conditions, are detected as edge species. On the contrary, *Huperzia serrata*, *Disporum smilacinum*, and *Chloranthus serratus*, which prefer shaded conditions, are detected as interior species. These differences between edge and interior species suggest that the replacement of plant species occurs in association with their shade tolerances.

The existence of only edge species in the shrub layer (Table 2) agrees with the decline of species number with distance from the forest road (Fig. 4). A lower species number in the shrub layer was clear in the young forest of the TK line where more edge species were detected (Table 2). On the other hand, the existence of both edge and interior species in the herb layer (Table 2) suggests that edge species are replaced by interior species with distance from the forest road. It is thought that this replacement creates a non-linear distribution pattern in species number in the herb layer (Fig. 4). Edge and interior species increase in number in the forest edge and forest interior, respectively. However, both edge and interior species decrease in number in the intermediate position, where the number of species will be the lowest (Fig. 4).

Species replacement can also enhance overall species diversity. Species diversity is classified into α diversity, β diversity, and γ diversity according to a spatial scale [28]–[31]. α diversity is the diversity of one habitat, β diversity is the difference in species composition between habitats, and γ diversity is the diversity of all habitats. The overall γ diversity is a product of α and β diversities [30], [31]. Although the effects of the forest road on the local diversity (α diversity) were not always obvious in this study (Fig. 4), species replacement (β diversity, Table 2) enhanced the overall diversity (γ diversity). This suggests that forest roads have positive effects on γ diversity even if the local species richness does not change with distance from the forest road.

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