The role of road disturbance in the dispersal and spread of *Ageratina adenophora* along the Dian–Myanmar International Road

S K DONG*,†, B S CUI*, Z F YANG*, S L LIU*, J LIU*, Z K DING*, J J ZHU*, W K YAO* & G L WEI*

**State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, China, and †Department of Natural Resources, Cornell University, Ithaca, NY, USA*

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Summary

This study was conducted to examine the roles of both environmental variables and road factors in explaining the spatial patterns of the exotic plant, *Ageratina adenophora* (Crofton weed), within the roadside habitats along the Dian–Myanmar International Road. The results indicate this plant was comparatively abundant along the middle part of this International Road and significantly less common along the northern section. The highest presence of *A. adenophora* was found at the site of new roads. This plant invaded more easily into spoil ground where road soil or construction waste was piled up. This road was confirmed as a corridor of *A. adenophora* invasion and should be considered as an important target of local and regional efforts to prevent and control cross-border and interior invasions of this exotic plant.

Keywords: crofton weed, invasive plant, environment, roadside, weed control, management.

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Introduction

Roads facilitate the spread of exotic plants by providing corridors for invasion (Spellerberg, 1998) and habitat suitable for exotic plants (Forman & Alexander, 1998). Invasion occurs when all 'barriers' that previously excluded a plant species are removed (Johnstone, 1986). Also important are disturbances along roads, notably road construction. Traffic and maintenance activities may facilitate some biological process such as dispersal, may remove some biological barriers such as competitors, may overcome some physical barriers such as closed-canopy forest and may modify environmental characteristics, such as light levels in potential invasion sites (Parendes & Jones, 2000). The effect of a road project on the invasion of exotic plants may vary with the road types and the distances along the road (Flory & Clay, 2006).

Ageratina adenophora (Sprengel) R. King and H. Robinson (Crofton weed), native to South America, was introduced as a garden plant in Europe, Australia and Asia in the 19th century (Wang & Wang, 2006). It has spread rapidly worldwide and become a weed in many countries in different continents (Qiang, 1998). This plant invaded southern Yunnan Province (Dian in Chinese) of China from Myanmar along the Dian–Myanmar International Road through border communication and traffic transportation around 1940 (Sun *et al.*, 2004; Wang & Wang, 2006). Since then, it has been spreading rapidly, particularly in the southern and south-western China and has caused serious economic loss (Sun *et al.*, 2004; Xu *et al.*, 2006). The State Environmental Protection Administration of China has listed this plant together with other 15 invasive plants in the White Paper, Chinese Government Obligatory Protocol for controlling

Correspondence: Shikui Dong, State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, China. Tel: (+86) 10 58802078; Fax: (+86) 10 58800397; E-mail: dongshikui@sina.com

invasive species. As this plant has caused very serious environmental, economic and social problems, many Chinese scientists have conducted research on the biological and ecological characteristics of this plant and the control and prevention strategies since the 1980s (Xiong, 1987; Sun *et al.*, 2004; Wang *et al.*, 2006). Few studies have been done on the effects of roads and traffic on the invasion of this plant, although some researchers have assumed that roads seemed to be the main channels for the spread of *A. adenophora* in Southwest China (Lu & Ma, 2006).

The present study was conducted to determine: (1) What is the overall invasion and distribution pattern of *A. adenophora* along the Dian–Myanmar International Road? (2) How do the road type, infrastructures (such as bridges, tunnels and re-vegetated slope) and the distance from the road influence the presence and abundance of *A. adenophora*? Answers to these questions will help to develop a predictive framework for invasion of *A. adenophora* along the Dian–Myanmar International Road and to better inform management strategies.

Methods

Site description

The distribution and abundance of *A. adenophora* were surveyed repeatedly in November to January (dry season) of 2004 and 2005 along the Dian–Myanmar International Road, starting from Kunming, the capital city of Yunnan Province, China and ending in Yangguang, the capital of Myanmar. China's part of this International Road is located in the Longitudinal Range-Gorge Region of Yunnan Province of Southwest China (Fig. 1), a very important eco-region and biodiversity hotspot in the world (He *et al.*, 2005). The sampling sites are diverse in soil types and texture, topographic condition and vegetation type (Table 1).

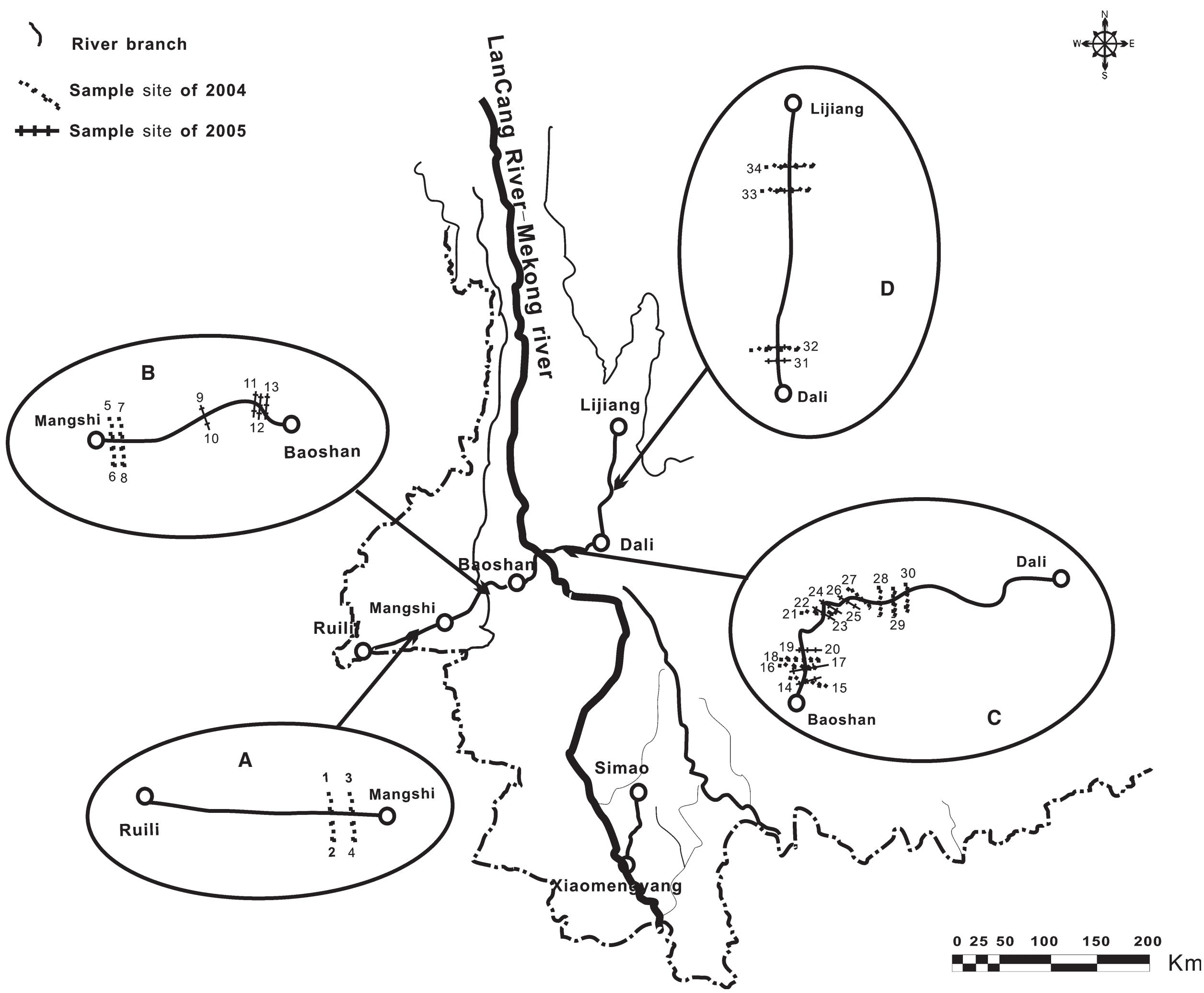

Fig. 1 Location of road sections and sampling sites along the Dian–Myanmar International Road (A, Ruili–Mangshi; B, Mangshi–Baoshan; C, Baoshan–Dali; D, Dali–Lijiang).

Table 1 Location, soil type, vegetation type and the road factors on the sampling sites along the Dian–Myanmar International Road

			Road features							Environmental features	
Site no.	Quadrate numbers	Location*	Type†	Age	Auxiliary projects‡	Latitude	Longitude	Altitude (m)	Soil type§	Vegetation types¶	Dominant plant species
1	4	A	NR	25	–	N24º20′	E98°24′	1076–1093	CY	EBF	*Castanopsis fargesii*; *Camptotheca acuminata*
2	3	A	NR	25	–	N24º20′	E98°24′	1042–1071	CL	EBF	*Colona floribunda*; *Dalbergia yunnanensis*
3	1	A	NR	25	–	N24º34′	E98°40′	1637	CL	PT	*Cunninghamia lanceolata*
4	3	A	NR	25	–	N24º36′	E98°42′	1423–1472	CL	EBF	*Cyclobalanopsis glaucoides*; *Choerosponodins axillaris*
5	1	B	NR	25	–	N24°37′	E98°45′	1840	CL	PT	*Cunninghamia lanceolata*
6	2	B	NR	25	–	N24°48′	E98°53′	1015–1026	CL	PT	*Phyllanthus emblica*
7	2	B	VR	35	–	N24°54′	E99°25′	1531–1543	CL	NBF	*Pinus kesiya* var. *langbianensis*; *Schima argentea*
8	7	B	NR	25	–	N24°58′	E98°55′	968–889	LM	NS	*Dodonaea viscosa*
9	1	B	NR	25	–	N25°	E99°07′	1997	LC	EBF	*Cyclobalanopsis glaucoides*
10	2	B	NR	25	TT	N25°	E99°07′	1993–2001	LC	ENF	*Pinus kesiya* var. *langbianensis*
11	2	B	NR	25	–	N25°	E99°04′	1710–1720	CY	ENF	*Pinus kesiya* var. *langbianensis*
12	2	B	HW	0	–	N25°	E99°05′	1810–1875	LM	SV	*Ageratina adenophora*
13	4	B	HW	0	–	N25°	E99°04′	1761–1862	LC	ENF	*Pinus kesiya* var. *langbianensis*
14	1	C	HW	5	TT	N25°	E99°42′	2373	LC	EBF	*Lyonia ovalifolia*; *Castanea seguinii*
15	5	C	HW	5	SP	N25°	E99°42′	2344–2399	LC	PG	*Festuca rubra*; *Ageratina adenophora*
16	4	C	HW	5	–	N25°15′	E99°13′	1780–1805	LM	SV	*Ageratina adenophora*
17	4	C	HW	5	SP	N25°25′	E99°30′	1680–1730	LM	PG	*Festuca rubra*
18	6	C	HW	5	–	N25°26′	E99°26′	2004–2134	CY	NBF	*Pinus yunnanensis*; *Quercus serrata*
19	2	C	HW	5	TT	N25°27′	E99°24′	1994–1999	CL	NBF	*Castanopsis delavayi*; *Keteleeria evelyniana*
20	2	C	HW	5	–	N25°27′	E99°23′	1900–1985	CL	EBF	*Lindera caudata*; *Castanopsis delavayi*
21	3	C	HW	5	–	N25°27′	E99°50′	1730–1740	CL	ENF	*Pinus yunnanensis*
22	2	C	HW	5	CB	N25°27′	E99°50′	1640–1648	CL	ENF	*Pinus yunnanensis*
23	3	C	HW	5	CB	N25°27′	E99°50′	1550–1566	CL	NBF	*Castanopsis delavayi*
24	2	C	HW	5	–	N25°27′	E99°24′	2042–2053	CL	NBF	*Castanopsis delavayi*; *Keteleeria evelyniana*
25	5	C	HW	5	SP	N25°27′	E99°24′	1960–2010	LC	PG	*Festuca rubra*
26	3	C	HW	5	–	N25°27′	E99°24′	1950–1960	CY	EBF	*Castanopsis delavayi*; *Eurya groffii*
27	3	C	HW	5	SG	N25°27′	E99°24′	1985–2015	LM	SV	*Ageratina adenophora*
28	2	C	HW	5	–	N25°27′	E99°24′	1980–1988	CY	EBF	*Castanopsis delavayi*; *Lindera caudata*
29	4	C	HW	5	–	N25°29′	E99°55′	1384–1445	CY	EBF	*Castanea seguinii*
30	2	C	HW	5	–	N25°29′	E99°56′	1388–1415	CY	EBF	*Castanopsis delavayi*
31	6	D	PR	35	–	N26°02′	E100°07′	2144–2180	CY	SV	*Ischaemum bartatum*
32	3	D	PR	35	–	N26°07′	E100°13′	2442–2561	LM	SV	*Bidens pilosa*

Table 1 *Continued*

			Road features								Environmental features	
Site no.	Quadrate numbers	Location*	Type†	Age	Auxiliary projects‡	Latitude	Longitude	Altitude (m)	Soil type§	Vegetation types¶	Dominant plant species
33	6	D	PR	35	–	N26°08′	E100°17′	2221–2517	LM	NS	*Cotoneaster horizontalis*; *Osteomeles schwerinae*
34	5	D	PR	35	–	N26°46′	E100°17′	2382–2414	LC	PT	*Pinus yunnanensis*

*A, Ruili-Mangshi; B, Mangshi-Baoshan; C, Baoshan-Dali; D, Dali-Lijiang.

†NR, national road; VR, village road; HW, highway; PR, provincial road.

‡TT, tunnel top; SP, slope protection; CB, cross bridge; SG, spoil ground.

§CY, clay; CL, clay-loam; LC, loam-clay; LM, loam.

¶EBF, evergreen broadleaf forestry; PT, planted trees; NBF, needleleaf and broadleaf mixture forestry; ENF, evergreen needleleaf forestry; NS, native shrub; SV, secondary vegetation; PG, planted grasses.

The roads in the study are classified into four categories of decreasing size, according to the Chinese road classification system: highway (HW), national road (NR), provincial road (PR) and village road (VR). These roads were located in four administrative regions: (A) Ruili–Mangshi (67 km); (B) Mangshi–Baoshan (191 km); (C) Baoshan–Dali (194 km) and (D) Dali–Lijiang (180 km). The first three (A, B, C) are the main body of the International Road and the last one (D) is a branch of the International Road (Fig. 1). These roads are situated in different geographical locations with different soils and vegetation, as shown in Table 1.

Field survey and data collection

Field survey was conducted following the modified design from Flory and Clay (2006). In each road section, several sites were sampled to cover diverse physical conditions. In total, there were four sites in road section A, nine sites in road section B, 17 in road section C and four sites in road section D (Fig. 1). In each site (either native or planted), one (for flat area) or two (for slope area) transects of 0.3–0.5 km in length and 20 m in width were set perpendicular to the road, starting at the edge of vegetation and ending at the point where vegetation structure and composition were unchanging. Along each transect, 10 by 10 m quadrats were arranged for sampling vegetation at 10, 50, 200 and 500 m from the road (actual quadrat numbers varied with transect length and number). To get more accurate records for the target plant, *A. adenophora*, we divided each quadrat further into four 5 by 5 m sub-quadrats and measured the number, total cover and mean height of this plant in two diagonal sub-quadrats, following Dong *et al.* (1997) methods. The density was quantified as the plant number of *A. adenophora* per square metre. The prominence values (Dinerstein, 1979) were calculated to quantify the abundance of *A. adenophora* in the sampling sites. The dominance of *A. adenophora* in the plant community was estimated following the method of Dong *et al.* (1997) by calculating the means of relative height, relative density and relative cover.

Results

Overall distribution pattern of Ageratina adenophora

The existence of *A. adenophora* was observed in 25 out of 34 sites surveyed along the Dian–Myanmar International Road. In general, the presence of *A. adenophora* varied with both road section and sampling site. Similarly, the dominance of *A. adenophora* in the plant community varied with road section and sites (Fig. 2). The average dominances of *A. adenophora* within road sections A, B, C and D were 6.8%, 5.5%, 22.1% and 0.67% respectively.

In addition, the dominance of *A. adenophora* varied with vegetation type. This plant was dominant in plant communities of planted grasses (site 25), secondary vegetation (site 27); subdominant in planted trees (site 3), planted grasses (sites 15 and 17), secondary vegetation (site 16) and evergreen broad-leaved forest (sites 20, 28), and was a companion species in the remaining plant communities. Among all geographic factors, latitude was positively ($P < 0.05$) correlated with the density of this plant; longitude was negatively ($P < 0.05$) correlated with both the abundance and density of this plant; aspect was strongly ($P < 0.05$) correlated with the presence of this plant.

Effect of road factors on distribution of Ageratina adenophora

ANOVA analysis indicate that *A. adenophora* was more frequent ($P < 0.05$) and more abundant beside HW than beside the other three types of road (Table 2). Higher ($P < 0.05$) presence, abundance and dominance of this invasive plant were detected along new road

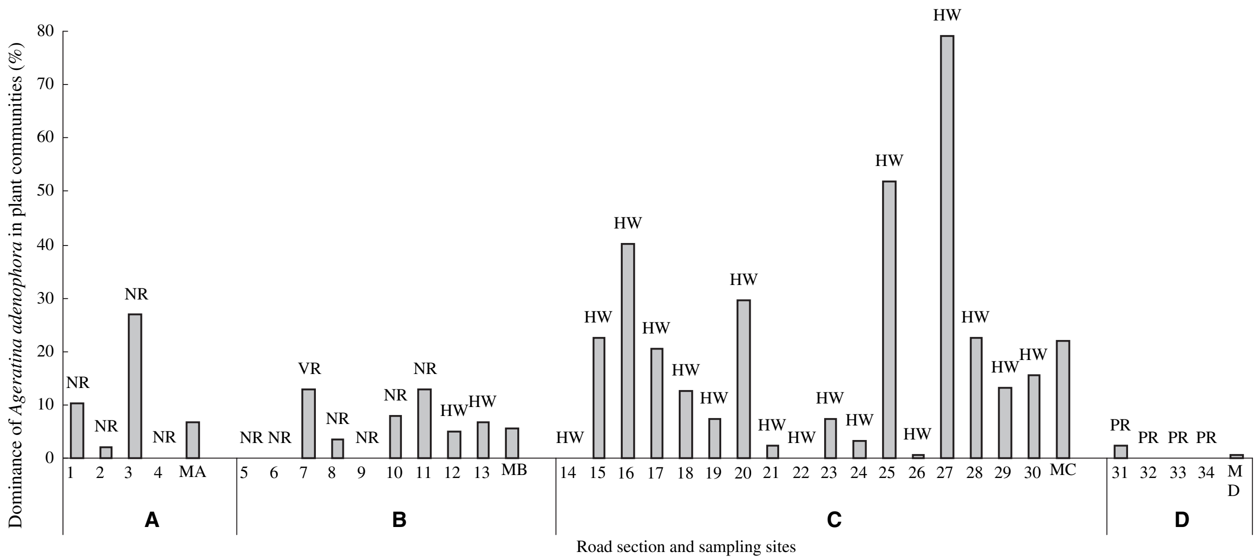

Fig. 2 Dominance of *Ageratina adenophora* in plant communities along the Dian–Myanmar International Road (NR, national road; VR, village road; PR, provincial road; HW, highway; MA, mean of section A; MB, mean of section B; MC, mean of section C; MD, mean of section D).

Table 2 Effect of road disturbance on the values (mean ± SE) of presence, abundance, dominance, density and coverage of *Ageratina adenophora*

Variables	Number of samples	Presence (%)	Abundance (%)	Dominance (%)	Density (stem m^{-2})	Coverage (%)
Road types						
HW	20	64.4 ± 12.6a	1.32 ± 0.26a	20.5 ± 2.7a	42.9 ± 49.7	24.9 ± 24.2
NR	11	34.6 ± 9.2b	0.23 ± 0.39b	5.4 ± 4.1b	16.7 ± 20.2	11.6 ± 18.7
PR	7	10 ± 0.5c	0.089 ± 0.4b	0.7 ± 0.27b	1.1 ± 2.2	2.5 ± 18.2
VR	2	50 ± 10ab	0.65 ± 1.4ab	12.7 ± 10.6ab	10.5 ± 21.2	9.0 ± 18.4
Road ages (years)						
0	2	66.7 ± 24.7a	0.17 ± 0.81ab	6.1 ± 8.4ab	10.0 ± 30.2	8.1 ± 12.9
5	18	69.8 ± 20.4a	1.45 ± 0.27a	22.1 ± 2.8a	46.6 ± 10.2	26.9 ± 4.3
25	11	29.4 ± 24.5ab	0.23 ± 0.39ab	5.4 ± 4.4b	16.8 ± 20.1	11.6 ± 8.6
35	9	10 ± 10.5b	0.089 ± 0.4b	0.7 ± 0.3b	1.1 ± 2.2	2.5 ± 18.2
Distance to road (m)						
10	41	57.8 ± 16.7a	1.83 ± 0.47a	24.8 ± 5.9a	50.2 ± 15.7	34.6 ± 7.3a
50	36	35.9 ± 16.9ab	1.23 ± 0.38a	19.3 ± 3.4a	42.2 ± 18.3	28.7 ± 6.4ab
200	14	31.6 ± 12.4ab	0.21 ± 0.23b	4.6 ± 3.2b	28.2 ± 16.2	10.8 ± 6.6b
500	9	21.5 ± 14.4b	0.35 ± 0.34b	11.9 ± 4.9ab	25.4 ± 17.5	9.5 ± 7.1b
Auxiliary road infrastructures						
CB	2	87.5 ± 21.5ab	3.45 ± 1.11ab	38.1 ± 9.7ab	50.0 ± 25.5	46.2 ± 11.0ab
SP	6	50.0 ± 21.2b	1.33 ± 1.09ab	20.3 ± 9.3b	14.4 ± 39.8	11.5 ± 14.6b
TT	2	62.5 ± 12.4ab	0.27 ± 0.47b	12.1 ± 9.6b	75.1 ± 32.5	14.0 ± 11.9b
SG	2	100 ± 27.2a	4.87 ± 1.81a	69.9 ± 15.2a	73.3 ± 46.0	54.7 ± 16.8a

Means followed by different letters within a column of same variables are significantly different ($P < 0.05$).

sections compared with old ones. This plant was distributed more frequently ($P < 0.05$) at sampling locations near the road compared with those far from road and the abundance and dominance of this plant significantly ($P < 0.05$) dropped with increasing distance to road. Higher ($P < 0.05$) occurrence, abundance and dominance of this plant were observed at the site used as spoil ground, where the road soil and construction waste were piled up.

Coverage of this exotic plant decreased significantly ($P < 0.05$) from 34.6% to 9.5% with increasing distance away from the road from 10 to 500 m. Highest ($P < 0.05$) coverage (54.7%) occurred at the site of spoil ground where the road soil and construction waste were piled up. There were some variations of plant coverage with both road type and road age, but the effects of these two road factors were not statistically significant ($P > 0.05$).

Discussion

Although Lu and Ma (2004) reported that the abundance and coverage of *A. adenophora* increased with altitude and stabilised at around 2000 m, no boundary elevation for the invasion of this plant was detected along this International Road. Two possible explanations are: (1) the road disturbance might alter the distribution pattern of *A. adenophora* along the altitude gradient; (2) the influence of other factors may overwhelm the effect of altitude, as we initially found that *A. adenophora* can manage better in higher potassium soil. Further studies are needed to clarify this phenomenon.

Higher presence, abundance and dominance of *A. adenophora* at the roadsides of HW in the present study can further support previous findings that verges along improved roads had more abundant exotic species than the relatively narrow verges adjacent to primitive roads (Gelbard & Belnap, 2003). In our study, higher presence, abundance and dominance of *A. adenophora* in the habitat at the sides of new roads (5-year-old) which have been frequently disturbed can be attributed to a combination of higher light availability (Levine & Feller, 2004), more resources for propagules (Pauchard & Alaback, 2004) and better growth conditions due to open canopy conditions (Flory & Clay, 2006).

In agreement with Lu and Ma (2006), we also found in this study that the invasion (cover, abundance and number of clusters) of *A. adenophora* declined significantly with distance from the road. Better survival and growth of the invasive plant at the sites near the road might be due to better growth conditions, including higher light conditions or increased nutrient or water availability (Watkins *et al.*, 2003) and due to decreased competition with native understory species (Flory & Clay, 2006), especially the shrubs, which have same life-form species as *A. adenophora*.

Conclusion

Our results confirmed the importance of roads as a corridor for *A. adenophora* invasion. This International Road should be considered an important target for local and regional efforts to prevent and control cross-border and interior invasions away from the road of this exotic plant. Management strategies need to be developed for controlling *A. adenophora* invasion within roadside ecosystems.

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