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Association of Non-native Plant Species With Recreational Roads in a National Park in the Eastern Himalayas, China

Mingyu Yang[1], Zheng Lu[1], Xia Liu[2], Robert De Wulf[3], Luc Hens[4], and Xiaokun Ou[1]*
** Corresponding author: mingyu.yang@ynu.edu.cn; mingyuyang@gmail.com*

[1] Institute of Ecology and Geobotany, Yunnan University, 2 Northern Green-Lake Road, Kunming 650091, China
[2] College of Forestry, Nanjing Forestry University, 159 Longpan Road, Nanjing 210037, China
[3] Laboratory of Forest Management and Spatial Information Techniques, Universiteit Gent, Coupure Links 653, Gent 9000, Belgium
[4] Flemish Institute for Technological Research, Boeretang 200, Mol 2400, Belgium

Although the eastern Himalayas have high plant biodiversity, we know very little about plant invasions in the region. This study is the first to examine non-native plant distribution in a popular eastern Himalayan national park. A total of 61 non-native plant species were found in roadside plant communities, which are frequently disturbed by hikers, pack animals, and recreational vehicles. These species were annual or biennial herbs, most of which originated in America or Europe. Non-native plant richness varied with the degree of anthropogenic disturbance. Specifically, greater numbers of non-native species were found at road heads and ends, which are generally subject to intense human activity. The average number of non-native species also varied according to the type of road and road use, with more present along motor roads and horse-riding trails than along hiking trails. These results highlight the role of vehicles and pack animals as dispersal vectors and provide a foundation for future invasion management decisions. To prevent the spread of non-native plants from park roads to the adjacent landscape, we also recommend the development of educational and monitoring programs that encourage tourist participation in conservation efforts.

Keywords: *Non-native plants; recreational roads; tourist-mediated dispersal; national parks; eastern Himalayas, southwest China.*

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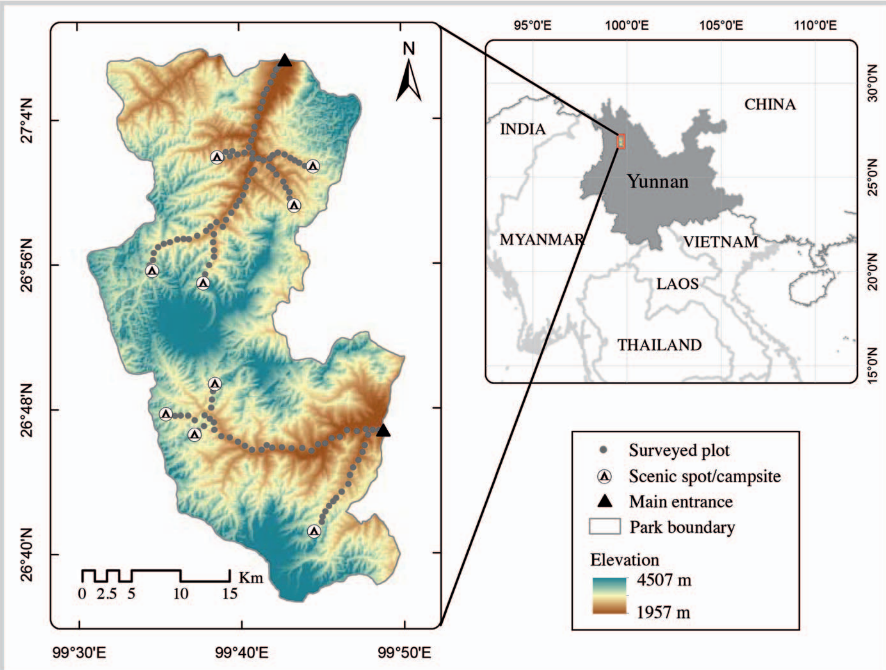
Introduction

Spreading of non-native plants often depends on humans (Hodkinson and Thompson 1997; Lonsdale 1999). As tourism has increased during recent decades, one might hypothesize that the number of non-native plants and the areas they occupy have also increased with recreational use (Pauchard et al 2009; Pickering and Mount 2010; Barros and Pickering 2014). The impacts of increasing tourism are of particular concern for protected areas such as national parks, heritage sites, and nature reserves (Foxcroft et al 2013; Spear et al 2013; Tolvanen and Kangas 2016).

The introduction of non-native plants through tourism to protected areas can occur intentionally or unintentionally. Examples of intentional introduction are ornamental or vegetable plants in gardens and greening/amenity planting on recreational roads and ski runs (Wilson 1992; Johnston and Pickering 2001; Hulme 2011). Examples of unintentional introduction include transport of plant parts by vehicles (Lonsdale and Lane 1994; Zwaenepoel et al 2006; von der Lippe and Kowarik 2007; Ansong and Pickering 2013a); on clothes, shoes, or equipment (Clifford 1956; Whinam et al 2005; Mount and Pickering 2009); and in the fur and dung of pack animals (Fischer et al 1996; Campbell and Gibson 2001; Ansong and Pickering 2013b).

Recreational activities also create habitats that favor non-native plant establishment and encourage further spread in protected areas. For example, native vegetation is frequently damaged by trampling or soil alteration during the construction and maintenance of tourism infrastructure (eg roads, trails, and accommodations) (Törn et al 2009; Wells et al 2012; Wolf and Croft 2014), in addition to direct tourist activities such as driving, hiking, biking, and horse riding (Newsome et al 2008; Pickering

FIGURE 1 Location of the surveyed plots in Laojun Mountain National Park. (Map by Mingyu Yang)



and Mount 2010; Hammitt et al 2015). Fertilizers used in gardening or site rehabilitation and the manure of pack animals also facilitate the establishment of non-native plants in many protected areas (Campbell and Gibson 2001; Gower 2008; Quinn et al 2008).

Mountain regions host one-third of the world's protected terrestrial areas (Kollmair et al 2005; Price 2007). Because of their harsh climate and limited accessibility, they have traditionally been assumed to be at low risk from plant invasions (Millennium Ecosystem Assessment 2005), but climatic change and growing human influence have altered the situation (Blyth et al 2002; Gurung et al 2012; Pauchard et al 2016). Nearly 1000 non-native plant species have now been reported in mountain areas around the world (Alexander et al 2011; McDougall et al 2011; Seipel et al 2012), and their diversity and abundance have increased dramatically in recent decades (Becker et al 2005; Pyšek et al 2011; Kalwij et al 2015).

The eastern Himalayan region of China covers southeast Tibet, west Sichuan, and northwest Yunnan. The region possesses a majority of China's biological assets and is home to several large protected areas (Xu and Melick 2007; Zachos and Habel 2011). The landscape, ethnic cultures, and constantly improving infrastructure have attracted increasing numbers of domestic and international tourists since the 1990s (Fang 2002; Zhou and Grumbine 2011), elevating the likelihood of non-native flora introduction. However, few studies have examined the distribution and diversity of non-native plants in this region, particularly as they relate to tourist-mediated introduction of these species.

In this study, we therefore investigated non-native plant distribution in a national park (Laojun Mountain Area) in northwest Yunnan Province (Figure 1). We hypothesized that the study site has been experiencing tourist-mediated dispersal of non-native plants for the past few decades. Using data from vegetation surveys, we aimed to determine (1) which non-native plant species occur in the park, particularly along recreational roads, (2) how non-native plant composition varies with travel distance from the park entrance, and (3) whether non-native plant presence differs along different road types with different uses: motor roads, horse-riding trails, and hiking trails. Our results can contribute to an improved understanding of non-native plant distribution patterns in protected areas of the eastern Himalayas. This basic information can help clarify the management methods needed to mitigate the negative effects of plant invasions on eastern Himalayan ecosystems.

Material and methods

Study area

Laojun Mountain Area (26°37′–27°09′N, 99°30′–99°50′E) is a national park and part of a World Heritage site (Three Parallel Rivers of Yunnan Protected Areas) (Figure 1). It extends over 1084 km^2 with an elevational range of 1957–4507 m above sea level.

Featuring the typical mountainous terrain of the eastern Himalayas, the park's annual average temperature and precipitation are around 11.6°C and 900–1000 mm, respectively. Three natural or seminatural vegetation patterns can be found in the park: grassland with deciduous oak shrubs in the lowlands (<2500 m), cold-temperate coniferous forests (pine, spruce, and fir) at middle elevations (2500–3200 m), and subalpine mosaics (meadow and scree) at high elevations (>3200 m).

Once isolated and hard to access, the area was populated only by small, local ethnic groups (Lisu, Yi, Naxi, and Tibatan) who practiced subsistence farming and herding (Buntaine et al 2007; Grumbine 2012). Since the 1990s, however, tourism has become a viable option for local communities to alleviate poverty and support nature conservation (Zhou and Grumbine 2011; Zinda 2014). The park has become an important site for outdoor recreation in southwest China; in 2015 more than 150,000 tourists visited it to hike, mountain climb, and view the wildlife and landscape.

Plant sampling

Definition of non-native plants and nomenclature: Following definitions by Richardson et al (2000) and Pyšek et al (2004), we determined non-native plants in the Laojun Mountain Area to be those not endemic to southwest China. Plant nomenclature, origin, growth form, dispersal mode, and reproduction mode were recorded based on *The Plant List* (URL: www.theplantlist.org), *Flora of China* (URL: http://frps.eflora.cn), and other publications (Ding et al 2006; Xu and Lu 2006; He 2012; Ma et al 2013; Mo et al 2013). To ensure that we did not over-report the number of non-native species, plants that could be identified only to the genus level were considered natives.

Field sampling: During 2014–2016, plant surveys were conducted in the growing season (August to October), when plant species composition is relatively stable and at its peak. With the assistance of park managers, 125.5 km of roads were identified as frequently used by tourists and were sampled.

To achieve systematic data collection, recreational roads were segmented into 2 km bands, each containing 2 plots, 1 m × 2 m each, with the long axis parallel to the road. Plot size was determined based on pilot surveys in 2013 that revealed that most non-native plants in the area are herbs (rather than shrubs or trees). Sites with recent natural disturbances (eg landslide or fire) or non-tourism-related anthropogenic disturbances (eg settlement or farming) were avoided. A total of 122 plots were sampled.

Within each plot, native and non-native species were identified and their percentage covers were estimated according to the Brann-Blanquet scale (Peet and Roberts 2013; also see footnote to Table 1). The location and elevation of each plot were recorded using a global positioning system (GPS, Garmin eTrex Vista HCx). Plot distance from the park entrance was measured using a distance-measuring wheel (Topmeasure DM60).

Data analysis

Pearson's correlation was applied to detect the relationship between non-native species richness (the number of non-native species per plot) and distance from the park entrance. To explore the difference between non-native and native species richness, the corresponding pattern of native species was analyzed with the same method. A Brown-Forsythe multiple comparison test was used to compare the number of non-native plants along 3 road types (motor roads, horse-riding trails, and hiking trails). This method was preferred to Dunnett's T3 test, because it does not assume equal variances among the types. All statistical computations were performed using SPSS 21.0 software (SPSS Inc., Chicago, IL, USA). Significance was determined at an alpha level of 0.05 unless otherwise stated.

Results

Non-native plant species

In total, 61 non-native plant species were identified in the surveyed plots (Table 1), which accounted for ~20% of local roadside flora. The dominant family was Compositae (23 species), followed by Amaranthaceae (8), Solanaceae (4), and Poaceae (3). Only 1 or 2 species were found in the remaining families. Non-native plants mainly originated in America (38 species) (*Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00012.S1); others came from Europe (8), Eurasia (8), Africa (4), and Asia (3). Herbs (33 annual, 15 perennial, and 5 biennial) were the most abundant, followed by semishrubs (6) and climbers (2). Fifty species reproduced solely by seed, while 11 species reproduced in both seed and vegetative modes. Common dispersal modes included anemochory (42), epizoochory (20), and endozoochory (14). More than half of the species (33) were unintentionally introduced; the remainder were intentionally brought to southwest China, primarily for ornamental, food, fodder, or medicinal purposes.

The most frequently encountered non-native plant was *Galinsoga quadriradiata*, occurring in 47 plots (Table 1). The second most frequently occurring species (in >10 plots) were *Plantago asiatica*, *Oxalis corniculata*, *Bidens pilosa*, *Bidens bipinnata*, *Chenopodium serotinum*, *Bidens alba*, *Erigeron sumatrensis*, *Erigeron canadensis*, *Taraxacum mongolicum*, *Setaria viridis*, and *Nicandra physalodes*. However, most non-native plants (72%) were present in fewer than 5 plots. Similarly, a majority had relatively low (<25%) percentage cover, with several exceptions that exhibited 50–75% coverage: *Anredera cordifolia*, *Opuntia ficus-indica*, *Tagetes patula*, *Ricinus communis*, *Trifolium repens*, and *Datura stramonium* (Table 1).

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TABLE 1 Non-native plant species recorded along recreational roads in Laojun Mountain National Park. (Table continued on next page.)

Scientific name	Family	Number of plots in which species was found[a)]	Average cover[b)]
Agave americana	Asparagaceae	1	2
Ageratina adenophora	Compositae	1	2
Ageratum conyzoides	Compositae	1	+
Alternanthera philoxeroides	Amaranthaceae	1	3
Amaranthus caudatus	Amaranthaceae	4	2
Amaranthus polygonoides	Amaranthaceae	1	2
Amaranthus spinosus	Amaranthaceae	2	2
Amaranthus tricolor	Amaranthaceae	1	2
Anredera cordifolia	Basellaceae	1	5
Aster subulatus	Compositae	2	2
Bidens alba	Compositae	14	3
Bidens bipinnata	Compositae	18	2
Bidens pilosa	Compositae	28	2
Calendula officinalis	Compositae	1	1
Cannabis sativa	Cannabaceae	1	2
Capsella bursa-pastoris	Brassicaceae	1	1
Cardamine flexuosa	Brassicaceae	1	2
Chenopodium hybridum	Amaranthaceae	1	2
Chenopodium serotinum	Amaranthaceae	14	2
Chloris virgata	Poaceae	1	2
Cosmos bipinnatus	Compositae	2	1
Crassocephalum crepidioides	Compositae	1	1
Cuscuta europaea	Convolvulacea	1	3
Dahlia pinnata	Compositae	1	2
Datura stramonium	Solanaceae	4	4
Dysphania ambrosioides	Amaranthaceae	4	3
Equisetum ramosissimum	Equisetaceae	4	3
Erigeron bonariensis	Compositae	7	2
Erigeron canadensis	Compositae	13	2
Erigeron sumatrensis	Compositae	14	2
Euphorbia peplus	Euphorbiaceae	1	2
Fagopyrum esculentum	Polygonaceae	2	3
Galinsoga parviflora	Compositae	8	3
Galinsoga quadriradiata	Compositae	47	3

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TABLE 1 Continued. (First part of Table 1 on previous page.)

Scientific name	Family	Number of plots in which species was found[a)]	Average cover[b)]
Ipomoea purpurea	Convolvulaceae	5	3
Lantana camara	Verbenaceae	1	2
Mimosa pudica	Leguminosae	2	3
Mirabilis jalapa	Nyctaginaceae	1	3
Nicandra physalodes	Solanaceae	10	3
Oenothera glazioviana	Onagraceae	1	1
Oenothera rosea	Onagraceae	2	1
Opuntia ficus-indica	Cactaceae	1	4
Oxalis corniculata	Oxalidaceae	34	2
Phytolacca americana	Phytolaccaceae	1	1
Plantago asiatica	Plantaginaceae	43	2
Ricinus communis	Euphorbiaceae	1	4
Senecio vulgaris	Compositae	1	1
Setaria palmifolia	Poaceae	1	2
Setaria viridis	Poaceae	11	2
Sida acuta	Malvaceae	4	3
Solanum aculeatissimum	Solanaceae	2	3
Solanum pseudocapsicum	Solanaceae	1	+
Sonchus arvensis	Compositae	1	2
Sonchus asper	Compositae	2	1
Sonchus oleraceus	Compositae	7	2
Tagetes erecta	Compositae	1	3
Tagetes patula	Compositae	3	4
Taraxacum mongolicum	Compositae	11	1
Trifolium repens	Leguminosae	4	4
Verbascum thapsus	Scrophulariaceae	6	2
Zinnia elegans	Compositae	1	2

[a)] Total number of plots = 122.
[b)] Cover: +, occasional; 1, 0–5%; 2, 5–25%; 3, 25–50%; 4, 50–75%; 5, >75%.

Species richness and composition by travel distance

Species richness and distance from the park entrance were significantly correlated ($r = -0.24$; $P = 0.01$). Most non-native plants were found closer to park entrances (<5 km) (Figure 2). The fewest non-natives (less than one species in plot on average) were found at distances of 15–20 km. Near road ends, the number of non-natives gradually increased, with >2 species per plot. In contrast, native plant richness showed a hump-shaped relationship with distance from park entrances (Figure 2), being the highest in middle-distance plots and less abundant near road heads or ends.

Almost half of the species were distributed only near park entrances (<5 km, Figure 3). Only 17 species (*B. bipinnata*, *C. serotinum*, *Galinsoga parviflora*, *G. quadriradiata*, *N. physalodes*, *O. corniculata*, *P. asiatica*, *Cosmos bipinnatus*,

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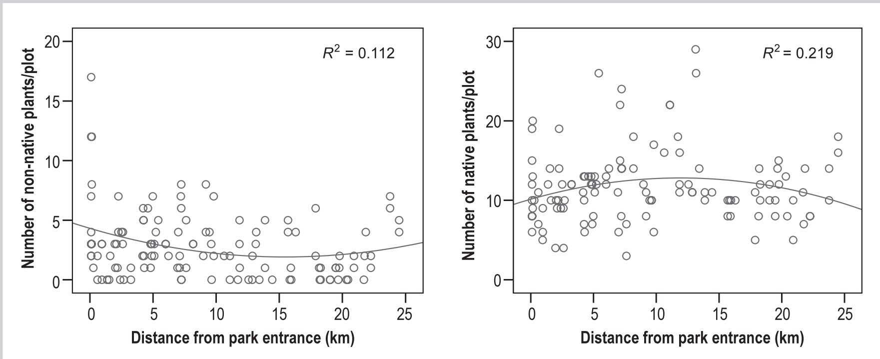
FIGURE 2 Distribution of species richness along recreational roads in Laojun Mountain National Park for non-native and native plants. Each circle represents the number of species in a surveyed plot. The fitted lines indicate a quadratic relationship between species and distance ($P < 0.05$).

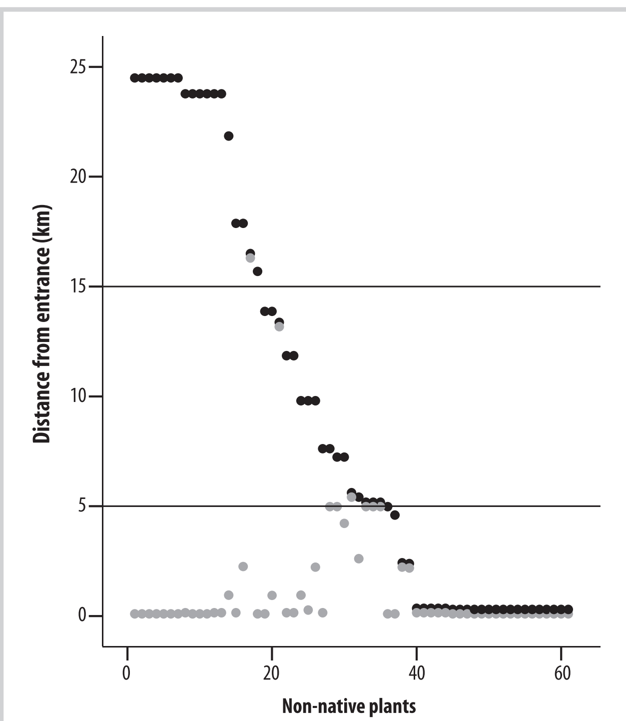


Sonchus oleraceus, *T. mongolicum*, *Amaranthus spinosus*, *B. pilosa*, *E. canadensis*, *S. viridis*, *B. alba*, *T. patula*, and *E. sumatrensis*) were found in plots more than 15 km from the entrances (*Supplemental material*, Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00012.S1).

Species richness and composition by road type

Non-native plants occurred in 44 of the 53 plots (83%) along motor roads, 32 of the 36 plots (89%) along horse trails, and 19 of the 33 plots (58%) along hiking trails.

FIGURE 3 Distance from park entrances of the 61 non-native plant species recorded along recreational roads in Laojun Mountain National Park. Each species is represented by 2 dots, black for maximum distance and grey for minimum distance. Species are ranked along the x-axis according to the maximum distance.



Multiple comparison testing showed that the average number of non-native plant species per plot differed among the 3 road types ($F_{2,119} = 9.163$, $P < 0.001$) and was significantly lower along hiking trails than along motor roads and horse trails (Table 2). In contrast, the number of native plant species did not differ across the 3 road types ($F = 2.60$, $P = 0.078$). Moreover, plots along hiking trails had a significantly lower non-native to native ratio than plots along the other 2 road types (Table 2).

In total, 55 non-native species were identified along motor roads and 31 species along horse trails. Only 15 non-native species were recorded along hiking trails. The 3 most frequent non-native species (*G. quadriradiata*, *O. corniculata*, and *P. asiatica*) occurred along all 3 road types. *B. pilosa*, *E. sumatrensis*, *B. bipinnata*, and *B. alba* were also relatively common along motor roads and horse trails, while *T. mongolicum* and *C. serotinum* were more frequently encountered on hiking trails.

Discussion

This study is the first to examine plant invasion in a popular national park of the eastern Himalayas. The region has seen a considerable rise in tourism to its protected areas but no corresponding rise in research on how the influx of human activity has contributed to non-native flora occurrence. Such paucity of knowledge poses a real challenge for local biodiversity conservation. In this study, we inventoried 61 non-native vascular plants and described their distribution along recreational roads in the park. Our results highlight potential threats of tourism to local ecosystems.

Most identified non-native plants were from America, Europe, and other temperate regions, which may suggest an overlap in climatic conditions (Khuroo et al 2007; Kosaka et al 2010; Sekar 2012), while also partially reflecting travel or trade patterns between the eastern Himalayas and source regions (Weber and Li 2008).

Non-native plants in the study area were predominantly herbaceous and annual or biennial, rather than woody or perennial. Non-natives depended more on

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TABLE 2 Results of multiple comparison test on non-native/native plant richness and the ratio of non-native to native plants per plot for 3 road types ($\alpha = 0.05$). Different letters indicate significant differences between road types.

Road use type	N	Mean ± SD		
		Number of non-native plants per plot	Number of native plants per plot	Ratio of non-native to native plants
Motor road	53	3.60 ± 3.43a	10.68 ± 3.45a	0.36 ± 0.34a
Horse trail	36	3.19 ± 1.99a	12.03 ± 5.00a	0.30 ± 0.18a
Hiking trail	33	1.18 ± 1.42b	12.91 ± 5.47a	0.09 ± 0.11b

seed output, and few had the capacity to spread vegetatively. These findings indicate that non-native plants in the Laojun Mountain Area are mainly early succession species that are widely considered to benefit from human disturbance and can take advantage of roadside environments (Weber 2003; Pickering and Hill 2007; Wells et al 2012).

Non-native plants that exhibited high frequency and coverage were from the families Compositae (eg *G. quadriradiata*, *B. pilosa*, *T. patula*, *E. sumatrensis*), Amaranthaceae (eg *C. serotinum*), and Solanaceae (eg *D. stramonium*), consistent with previous research on mountain regions worldwide (McDougall et al 2011; Seipel et al 2012; Kueffer et al 2013). These species possess shared traits that contribute to their successful dispersal and establishment in the study area, such as prolific seed production, easily spread seeds, and rapid initial growth (Figure 4). Because of these traits, continued introduction or spread of these species by tourism activities may lead to their proliferation in the park, with substantial ecological and economic impacts.

Non-native plants were recorded more frequently in plots close to entrances. This effect might be associated with higher tourist presence and greater disturbance in these areas. Disturbance may result in an increase of resource availability (eg light and soil nitrogen) and provide new niches for colonization by new plants (Hobbs and Huenneke 1992; Pyšek et al 2010). Simultaneously, hikers, pack animals, and vehicle traffic can also bring high quantities of seeds to sites near the entrances. This propagule pressure is likely a major reason that non-native richness dropped with increasing distance from park entrances (von der Lippe and Kowarik 2012; Lockwood et al 2013).

In middle-distance plots, species richness of non-native plants was lower than that of native plants (Figure 2). In addition to having lower levels of disturbance and propagule pressure, roads in this portion of the park are lined with dense forests. Lack of sufficient sunshine and high competition from native species thus hamper germination and colonization of non-native plants. This suggests that the types of native vegetation that are present in an area influence the extent and pattern of non-native plant invasions (Davis et al 2000; Davies et al 2011).

Plots close to road ends contained a higher diversity of non-native species than roads in the middle distances. Road-end plots were all in or close to subalpine meadows, where park tourists commonly visit to enjoy the scenic views and often camp overnight. Visitors frequently bring pack animals into the meadows, resulting in intense grazing and manure accumulation, which combine with the meadows' high light intensity and wet soils to facilitate the establishment of non-native species (McDougall et al 2005; Yang et al 2009).

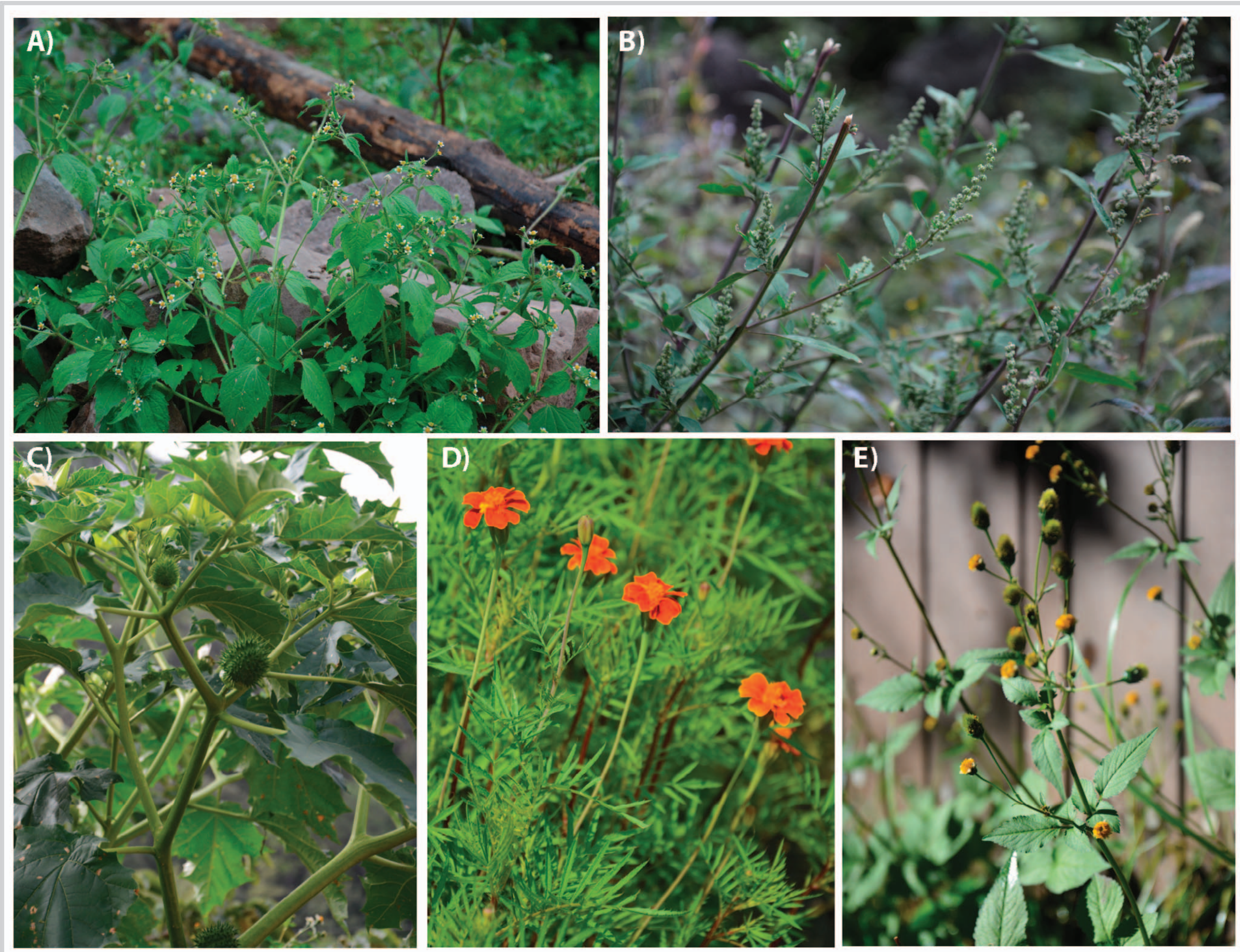
Non-native plants appeared to prefer plots along motor roads and horse trails to those along hiking trails. Likewise, the ratio of non-native to native species was higher along the former 2 road types than along hiking trails. These patterns confirm the importance of vehicle traffic and pack animals in spreading non-native plants in the park (Campbell and Gibson 2001; Quinn et al 2008). The effectiveness of these vectors is attributable to the presence of multiple dispersal modes including vehicle surfaces, tire mud, horse dung, fur, and hooves, as well as traffic-related disturbances such as to road width or ground hardness (Landsberg et al 2001; Quinn et al 2010). Tourists themselves are only modest vectors of plant dispersal.

The above findings allow us to recommend several strategies for managing plant invasions in protected areas of the eastern Himalayas. These appear most timely given the growing number of tourists visiting the area and the effects of rapid climate change.

First, education programs should be developed that focus on changing public perception and behavior related to non-native plants. Specifically, educators must emphasize the negative impact of non-native plants and detail appropriate actions tourists can take to avoid disturbances and introductions (Burt et al 2007). Encouraging tourists to identify and report the occurrence of non-native plants during their stay will contribute to improved stewardship and might be an effective instrument for managing local invasions. The increasing popularity of mobile apps provides a powerful opportunity for developing a tool that allows tourists to participate with ease.

Second, management of non-native species in protected areas of the eastern Himalayas should focus on dispersal corridors and other tourist-disturbed habitats

FIGURE 4 Examples of biological characteristics that enable non-native species to become established in Laojun Mountain National Park. (A) *Galinsoga quadriradiata* can produce 3000 flower heads and up to 7500 seeds per plant. (B) *Chenopodium serotinum* produces an abundant amount of very small seeds (1.2–1.8 mm in diameter) that are easily spread and can germinate immediately upon contact with moist soil. (C) *Datura stramonium* has a seed capsule that is 3–8 cm in diameter; at maturity, the capsule splits into 4 chambers, each with dozens of seeds. Seedlings establish quickly to become large thickets with big leaves that shade out all surrounding vegetation. (D) *Tagetes patula* is a fast-growing and light-demanding pioneer species, establishing readily and densely in disturbed sites. The dense growth makes it highly competitive to native plant species. (E) *Bidens pilosa* has seeds with 2 to 4 barbed spines that increase the likelihood of attaching to animal fur or human clothing (*Global Invasive Species Database*, URL: www.iucngisd.org; *European Network on Invasive Alien Species*, URL: www.nobanis.org; Weber 2003). (Photos by authors)



(eg campsites and viewing spots). These habitats are especially vulnerable to colonization by non-native flora but are also far easier to control than adjacent rugged environments, where management efforts become extremely unwieldy and costly (Kueffer et al 2013). Possible actions that can prevent invasion into difficult terrain include minimizing seed production of non-native plants, especially those with ecological significance and high dispersal potential. In addition, native species can be planted in these habitats to reduce opportunities for non-native establishment.

Third, park managers should carefully reevaluate the use of vehicles and pack animals, given their role as the primary vectors of non-native plants. Specifically, we recommend the establishment of effective quarantine procedures, including wash units to clean vehicles arriving and leaving protected areas (Pickering and Mount 2010) and a certified weed-free forage program for pack animals, to discourage the introduction of hay infested with non-native plants (McDougall et al 2011).

Finally, the results of our study indicate 3 possible directions for future research. First, systematic surveys of non-native species must be prioritized in protected areas of the eastern Himalayas. Most such areas are currently assumed to be free of biological invasions. But this study has clearly shown that non-native species have already invaded. Second, future studies should investigate factors that encourage human-mediated dispersal and establishment of non-native species. We still do not have basic information such as the maximum travel distance of a seed carried by human agents, the characteristics of plant communities particularly susceptible to invasion, and how environmental factors (eg climate, soil, or even elevation) determine plant growth and success. Third, researchers should aim to build an information-sharing network across the region that includes neighboring nations (eg Bhutan, India, and Nepal). The increased

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availability of relevant data will both support local management capacities and contribute to understanding plant-invasion mechanisms across the Himalayan region.

Conclusion

In contrast to the prevailing perception, a wide range of non-native plant species were identified in protected areas of the eastern Himalayas. Repeated disturbances and propagule introduction by tourists and their animals and vehicles have increased the establishment of non-native species in this region, although different vectors vary in the degree of their contribution. Education, monitoring, and quarantines are the recommended defense strategies for invasion management in these areas because of their rugged terrain and limited management resources. Mechanisms by which successful dispersers invade local ecosystems should be further explored, particularly in response to increased tourism and climate change.

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REFERENCES

Alexander JM, Kueffer C, Daehler CC, Edwards PJ, Pauchard A, Seipel T, MIREN Consortium. 2011. Assembly of nonnative floras along elevational gradients explained by directional ecological filtering. *Proceedings of the National Academy of Sciences of the United States of America* 108(2):656–661.

Ansong M, Pickering C. 2013a. Are weeds hitchhiking a ride on your car? A systematic review of seed dispersal on cars. PLoS ONE 8(11):e80275.

Ansong M, Pickering C. 2013b. A global review of weeds that can germinate from horse dung. *Ecological Management and Restoration* 14(3):216–223.

Barros A, Pickering C. 2014. Non-native plant invasion in relation to tourism use of Aconcagua Park, Argentina, the highest protected area in the southern Hemisphere. *Mountain Research and Development* 34(1):13–26.

Becker T, Dietz H, Billeter R, Buschmann H, Edwards PJ. 2005. Altitudinal distribution of alien plant species in the Swiss Alps. *Perspectives in Plant Ecology, Evolution and Systematics* 7(1):173–183.

Blyth S, Lysenko I, Groombridge B, Miles L, Newton A. 2002. *Mountain Watch: Environmental Change and Sustainable Development in Mountains*. Cambridge, United Kingdom: UNEP [United Nations Environment Programme] World Conservation Monitoring Center.

Buntaine MT, Mullen RB, Lassoie JP. 2007. Human use and conservation planning in alpine areas of Northwestern Yunnan, China. *Environment, Development and Sustainability* 9(3):305–324.

Burt JW, Muir AA, Piovia-Scott J, Veblen KE, Chang AJ, Grossman JD, Weiskel HW. 2007. Preventing horticultural introductions of invasive plants: Potential efficacy of voluntary initiatives. *Biological Invasions* 9(8):909–923.

Campbell JE, Gibson D. 2001. The effect of seeds of exotic species transported via horse dung on vegetation along trail corridors. *Plant Ecology* 157(1):23–35.

Clifford HT. 1956. Seed dispersal on footwear. *Proceedings of the Botanical Society of the British Isles* 2(1):29–131.

Davies KF, Cavender-Bares J, Deacon N. 2011. Native communities determine the identity of exotic invaders even at scales at which communities are unsaturated. *Diversity and Distributions* 17(1):35–42.

Davis MA, Grime JP, Thompson K. 2000. Fluctuating resources in plant communities: A general theory of invasibility. *Journal of Ecology* 88(3):528–534.

Ding L, Du F, Zhang DC. 2006. Alien and invasive plants in Yunnan [in Chinese with English abstract]. *Western Forestry Science* 35(4):98–108.

Fang YP. 2002. Ecotourism in western Sichuan, China: Replacing the forestry-based economy. *Mountain Research and Development* 22(2):113–115.

Fischer SF, Poschlod P, Beinlich B. 1996. Experimental studies on the dispersal of plants and animals on sheep in calcareous grasslands. *Journal of Applied Ecology* 33(5):1206–1222.

Foxcroft LC, Pyšek P, Richardson DM, Genovesi P, editors. 2013. *Plant Invasions in Protected Areas: Patterns, Problems and Challenges*. Dordrecht, the Netherlands: Springer.

Gower ST. 2008. Are horses responsible for introducing non-native plants along forest trails in the eastern United States? *Forest Ecology and Management* 256(5):997–1003.

Grumbine RE. 2012. Living natural history in the mountains of Southwest China. *Frontiers in Ecology and the Environment* 10(5):274–275.

Gurung AB, von Dach SW, Price MF, Aspinall R, Balsiger J, Baron J, Sharma E, Greenwood G, Kohler T. 2012. Global change and the world's mountains: Research needs and emerging themes for sustainable development. *Mountain Research and Development* 32(S1):S47–S54.

Hammitt WE, Cole DN, Monz CA. 2015. *Wildland Recreation: Ecology and Management*. 3rd edition (1st edition 1987). Oxford, United Kingdom: Wiley Blackwell.

He JQ. 2012. *Exotic Plants in China* [in Chinese]. Shanghai, China: Shanghai Science and Technology Press.

Hobbs RJ. Huenneke LF. 1992. Disturbance, diversity, and invasion: Implications for conservation. *Conservation Biology* 6(3):324–337.

Hodkinson DJ, Thompson K. 1997. Plant dispersal: The role of man. *Journal of Applied Ecology* 34(6):1484–1496.

Hulme PE. 2011. Addressing the threat to biodiversity from botanic gardens. *Trends in Ecology and Evolution* 26(4):168–174.

Johnston FM, Pickering C. 2001. Alien plants in the Australian Alps. *Mountain Research and Development* 21(3):284–291.

Kalwij JM, Robertson MP, van Rensburg BJ. 2015. Annual monitoring reveals rapid upward movement of exotic plants in a montane ecosystem. *Biological Invasions* 17(12):3517–3529.

Khuroo AA, Rashid I, Reshi Z, Dar GH, Wafai BA. 2007. The alien flora of Kashmir Himalaya. *Biological Invasions* 9(3):269–292.

Kollmair M, Gurung GS, Hurni K, Maselli D. 2005. Mountains: Special places to be protected? An analysis of worldwide nature conservation efforts in mountains. *International Journal of Biodiversity Science and Management* 1(4):181–189.

Kosaka Y, Saikia B, Mingki T, Tag H, Riba T, Ando K. 2010. Roadside distribution patterns of invasive alien plants along an altitudinal gradient in Arunachal Himalaya, India. *Mountain Research and Development* 30(3):252–258.

Kueffer C, McDougall K, Alexander J, Daehler C, Edwards P, Haider S, Milbau A, Parks C, Pauchard A, Reshi ZA, Rew LJ, Schroder M, Seipel T. 2013. Plant invasions into mountain protected areas: Assessment, prevention and control at multiple spatial scales. *In:* Foxcroft LC, Pyšek P, Richardson DM, Genovesi P, editors. *Plant Invasions in Protected Areas: Patterns, Problems and Challenges*, Dordrecht, the Netherlands: Springer, pp 89–113.

Landsberg J, Logan B, Shorthouse D. 2001. Horse riding in urban conservation areas: Reviewing scientific evidence to guide management. *Ecological Management and Restoration* 2(1):36–46.

Lockwood JL, Hoopes MF, Marchetti MP. 2013. *Invasion Ecology*. 2nd edition (1st edition 2006). Chichester, United Kingdom: Wiley-Blackwell.

Lonsdale WM. 1999. Global patterns of plant invasions and the concept of invasibility. *Ecology* 80(5):739–751.

Lonsdale WM, Lane AM. 1994. Tourist vehicles as vectors of weed seeds in Kakadu National Park, Northern Australia. *Biological Conservation* 69(3):277–283.

Ma HY, Shu GB, Liu C, Zhao F. 2013. Alien invasive plants in Southwest China. *In:* Ma JS, editor. *The Survey Reports on Chinese Alien Invasive Plants* [in Chinese]. Beijing, China: High Education Press, pp 806–926.

McDougall KL, Alexander JM, Haider S, Pauchard A, Walsh NG, Kueffer C. 2011. Alien flora of mountains: Global comparisons for the development of local preventive measures against plant invasions. *Diversity and Distributions* 17(1):103–111.
McDougall KL, Morgan JW, Walsh NG, Williams R. 2005. Plant invasions in treeless vegetation of the Australian Alps. *Perspectives in Plant Ecology, Evolution and Systematics* 7(1):159–171.
Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.
Mo N, Wu W, Zhang XM. 2013. *Common Weeds in Southwest China* [in Chinese]. Kunming, China: Yunnan Science and Technology Press.
Mount A, Pickering C. 2009. Testing the capacity of clothing to act as a vector for non-native seed in protected areas. *Journal of Environmental Management* 91:168–179.
Newsome D, Smith A, Moore SA. 2008. Horse riding in protected areas: A critical review and implications for research and management. *Current Issues in Tourism* 11(2):144–166.
Pauchard A, Kueffer C, Dietz H, Daehler CC, Alexander J, Edwards PJ, Arévalo RJ, Cavieres LA, Guisan A, Haider S, Jakobs G, McDougall K, Millar CI, Naylor BJ, Parks CG, et al. 2009. Ain't no mountain high enough: Plant invasions reaching new elevations. *Frontiers in Ecology and the Environment* 7(9):479–486.
Pauchard A, Milbau A, Albihn A, Alexander J, Burgess T, Daehler C, Englund G, Essl F, Evengard B, Greenwood GB, Haider S, Lenoir J, McDougall K, Muths E, Nuñez MA, et al. 2016. Non-native and native organisms moving into high elevation and high latitude ecosystems in an era of climate change: New challenges for ecology and conservation. *Biological Invasions* 18(2):345–353.
Peet RK, Roberts DW. 2013. Classification of natural and semi-natural vegetation. *In:* van der Maarel E, Franklin J, editors. *Vegetation Ecology*. 2nd edition (1st edition 2004). Chichester, United Kingdom: Willey-Blackwell, pp 28–70.
Pickering C, Hill W. 2007. Roadside weeds of the Snowy Mountains, Australia. *Mountain Research and Development* 27(4):359–367.
Pickering C, Mount A. 2010. Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism* 18(2):239–256.
Price MF, editor. 2007. *Mountain Area Research and Management: Integrated Approaches*. London, United Kingdom: Earthscan.
Pyšek P, Jarosík V, Hulme PE, Kühn I, Wild J, Arianoutsou M, Bacher S, Chiron F, Didžiulis V, Essl F, Genovesi P, Gherardi F, Hejda M, Kark S, Lambdon PW, et al. 2010. Disentangling the role of environmental and human pressures on biological invasions across Europe. *Proceedings of the National Academy of Science of the United States of America* 107(27):12157–12162.
Pyšek P, Jarošík V, Pergl J, Wild J. 2011. Colonization of high altitudes by alien plants over the last two centuries. *Proceedings of the National Academy of Sciences of the United States of America* 108(2):439–440.
Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J. 2004. Alien plants in checklists and floras: Towards better communication between taxonomists and ecologists. *Taxon* 53(1):131–143.
Quinn LD, Kolipinski M, Coelho VR, Davis B, Vianney JM, Batjargal O, Alas M, Ghosh S. 2008. Germination of invasive plant seeds after digestion by horses in California. *Natural Areas Journal* 28(4):356–362.
Quinn LD, Quinn A, Kolipinski M, Davis B, Berto C, Orcholski M, Ghosh S. 2010. Role of horses as potential vectors of non-native plant invasion: An overview. *Natural Areas Journal* 30(4):408–416.
Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ. 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Diversity and Distributions* 6(1):93–107.
Seipel T, Kueffer C, Rew LJ, Daehler CC, Pauchard A, Naylor BJ, Alexander JM, Edwards PJ, Parks CG, Arevalo JR, Cavieres LA, Dietz H, Jakobs G, McDougall K, Otto R, et al. 2012. Processes at multiple scales affect richness and similarity of non-native plant species in mountains around the world. *Global Ecology and Biogeography* 21(2):236–246.
Sekar KC. 2012. Invasive alien plants of Indian Himalayan Region—Diversity and implication. *American Journal of Plant Science* 3(2):177–184.
Spear D, Foxcroft LC, Bezuidenhout H, McGeoch MA. 2013. Human population density explains alien species richness in protected areas. *Biological Conservation* 159(1):137–147.
Tolvanen A, Kangas K. 2016. Tourism, biodiversity and protected areas—Review from northern Fennoscandia. *Journal of Environmental Management* 169:58–66.
Törn A, Tolvanen A, Norokorpi YR, Tervo R, Siikamäki P. 2009. Comparing the impacts of hiking, skiing and horse riding on trail and vegetation in different types of forest. *Journal of Environmental Management* 90(3):1427–1434.
von der Lippe M, Kowarik I. 2007. Long-distance dispersal of plants by vehicles as a driver of plant invasions. *Conservation Biology* 21(4):986–996.
von der Lippe M, Kowarik I. 2012. Interactions between propagule pressure and seed traits shape human-mediated seed dispersal along roads. *Perspectives in Plant Ecology, Evolution and Systematics* 14(1):123–130.
Weber E. 2003. *Invasive Plant Species of the World: A Reference Guide to Environmental Weeds*. London, United Kingdom: CABI Publishing.
Weber E, Li B. 2008. Plant invasions in China: What is to be expected in the wake of economic development? *Bioscience* 58(5):437–444.
Wells FH, Lauenroth WK, Bradford JB. 2012. Recreational trails as corridors for alien plants the rocky mountain, USA. *Western North American Nationalist* 72(4):507–533.
Whinam J, Chilcott N, Bergstrom DM. 2005. Subantarctic hitchhikers: Expeditioners as vectors for the introduction of alien organisms. *Biological Conservation* 121(2):207–219.
Wilson SD. 1992. The suppression of native prairie by alien species introduced for revegetation. *Landscape and Urban Planning* 17(2):113–119.
Wolf ID, Croft DB. 2014. Impacts of tourism hotspots on vegetation communities show a higher potential for self-propagation along roads than hiking trails. *Journal of Environmental Management* 143:173–185.
Xu CD, Lu SG. 2006. The invasive plants in Yunnan [in Chinese with English abstract]. *Guangxi Botany* 26(3):227–234.
Xu J, Melick DR. 2007. Rethinking the effectiveness of public protected areas in southwestern China. *Conservation Biology* 21(2):318–328.
Yang MY, Hens L, Ou XK, De Wulf R. 2009. Impacts of recreational trampling on sub-alpine vegetation and soils in Northwest Yunnan, China. *Acta Ecologica Sinica* 29(3):171–175.
Zachos FE, Habel JC, editors. 2011. *Biodiversity Hotspots: Distribution and Protection of Conservation Priority Areas*. London, United Kingdom: Springer.
Zhou DQ, Grumbine RE. 2011. National parks in China: Experiments with protecting nature and human livelihoods in Yunnan province, People's Republic of China (PRC). *Biological Conservation* 144(5):1314–1321.
Zinda JA. 2014. Varying impact of tourism participation on natural resource use in communities in Southwest China. *Human Ecology* 42(5):739–751.
Zwaenepoel A, Roovers P, Hermy M. 2006. Motor vehicles as vectors of plant species from road verges in a suburban environment. *Basic and Applied Ecology* 7(1):83–93.

Supplemental material

TABLE S1 Attributes of non-native plants recorded in Laojun Mountain National Park.
TABLE S2 Distance ranges of non-native plants recorded in Laojun Mountain National Park.

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