Tropical Ecology **59**(1): 45–55, 2018 ISSN 0564-3295

www.tropecol.com

Altitudinal distribution of native and alien plant species along roadsides in Kashmir Himalaya, India

PERVAIZ A. DAR[1*], ZAFAR A. RESHI[2] & AYAZ BASHIR SHAH[2]

[1]*Department of Botany, Amar Singh College, Srinagar*
[2]*Biological Invasions Research Laboratory, Department of Botany, University of Kashmir, Srinagar 190006*

Abstract: Presently alien species are invading least invaded areas largely because of anthropogenic activities. The distribution of alien plant species is determined by many factors and in mountainous areas altitude is one of the most important factors determining the distribution of plant species. In order to understand the role of roads in distribution of alien plant species along elevational gradient, two road transects were selected. These two road transects were divided into equally spaced altitudinal zones and at each site 3 plots were selected. A total of 200 species were recorded out of which 133 were native and 67 were alien. Total species richness decreased with altitude while as native species richness increased. Level of invasion expressed as proportion of alien plant species decreased with altitude in all the three plots. In addition, floristic similarity between plots decreased with increasing altitudinal difference. From the present study it is clear that alien plant species have not invaded the alpine areas to a large extent but anthropogenic activities like unplanned road development and promotion of tourism in the area is likely to threaten the uninvaded high altitude areas of the region.

Key words: Alien, altitude, level of invasion, similarity, species richness.

Introduction

Mountains are of great significance owing to the fact that they support very diverse ecological communities, including many endemic species (Körner 2003), and have great value for historic, aesthetic and economic reasons. Many factors are known to determine distribution of alien plant species. In mountain areas, altitude has the most obvious effect on distribution of plant species with many environmental factors varying simultaneously along elevation gradients (Körner 2007).

Presently mountain ecosystems are being subjected to drastic changes in vegetation (Brown 2001; Lomolino 2001) on account of variations in climate from the base to the summit of mountain and as such are likely to provide important model systems for studying distribution of alien plant species. Recent studies have shown that mountain ecosystems, although previously assumed to be at low risk, are not inherently imune to invasion than other types of ecosystems and are experiencing many threats (McDougall *et al*. 2011; Pauchard *et al*. 2009). Anthropogenic activities like increased human land use (e.g. intensification of human activities, human population growth, and expansion of tourism) and climate warming pose serious threat to these ecosystems (Kueffer *et al.* 2013).

In particular, development of roads in mountain areas leads to an important anthropogenic impact on global mountain ecosystems by causing reoccurring disturbances, changing species compositions, fragmenting habitats, changing the hydrology, soil ecology and nutrient availability, altering the microclimate, and funneling anthropogenic effects into the most pristine environments (Forman & Alexander 1998; Forman *et al*. 2003; Müllerová *et al*. 2011). Along a roadside

[*]*Corresponding Author*; e-mail: pervaizahmaddar@yahoo.com; pervaizdar45@gmail.com

a)

b)

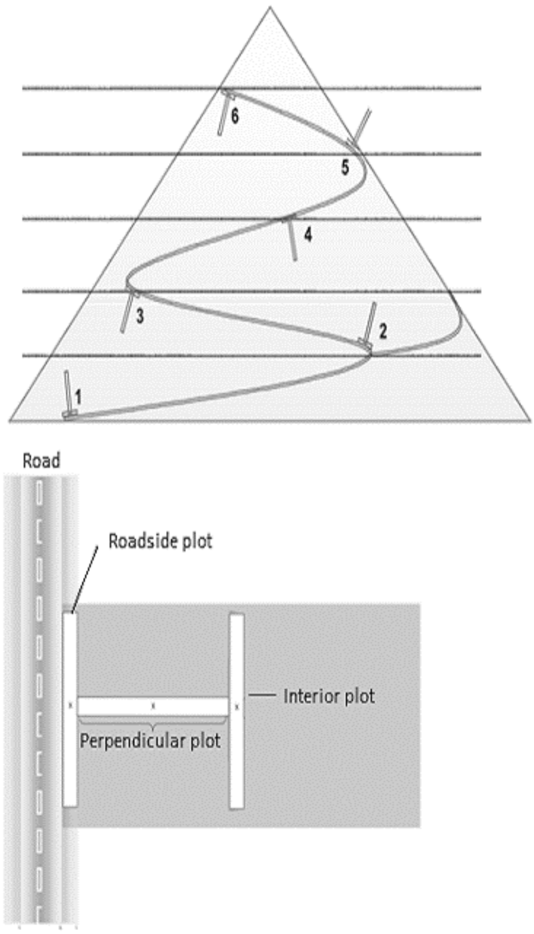


Fig. 1. a) Road transect divided into equally spaced alti-tudinal zones, and b) Three plots making a ladder step.

in mountainous regions, climatic conditions change sharply from low to high altitude, while habitat factors (e.g. vegetation characteristics, disturbance) often remain relatively constant. Mountain roadsides are also punctuated along their length by ruderal sites more disturbed than the normal verge (e.g. near settlements, commercial centres, parking areas etc.), and these may be important both as sources of propagules and for facilitating establish-ment of alien species (Godfree *et al.* 2004; Johnston & Pickering 2001; Marcus *et al.* 1998). This is posing significant threat as spread of alien species in non-native areas often has serious ecological and economic concerns (Mack *et al.* 2000; Patnaik *et al.* 2017; Pimentel *et al.* 2001). Past research on plant species ranges in mountains have seldom included the effects of roads or, if they did, only studied general patterns of species richness and composition.

Alpine ecosystems are relatively not easily accessible for humans but developmental activities like construction of roads (Dar *et al.* 2015) and other activities causing land use changes (N'dril *et al.* 2017) are likely to make these ecosystems susceptible to anthropogenic impacts by altering distribution of species and facilitating invasion by alien species. Alpine vegetation which is vulnerable to global warming (e.g., Callaghan & Jonasson 1995; Holten & Carey 1992; Körner 1995, 1999) can be used as model system for monitoring impacts of climate change as increase in temperature is likely to cause upward shift of species distribution ranges (Klanderud & Birks 2003). Given the importance of gradients of environmental stress in shaping the altitudinal distribution of both alien and native plants in mountain areas (Alpert *et al.* 2000; Godfree *et al.* 2004), studies monitoring these changes are going to be significantly important in predicting the future impacts of climate change as climate change is changing the distribution of plant species (Parmesan *et al.* 2011; Pacifici *et al.* 2015).

Although high altitude restricts the expansion of alien plant species yet the road development could channelize the upward expansion of alien plant species by facilitating their dispersal by means of vehicular movement and anthropogenic disturbances. We hypothesize that continuity of roadsides could help alien plant species overcome the altitudinal barriers.

Materials and methods

The present study was carried out in Kashmir Himalaya which is an important part of Himalayan biodiversity hotspot. Since our main focus was to investigate the role of roads along elevational gradients, we only focussed on distribution of herbs and shrubs largely because of the long life span of trees and their unlikely occurrence along roads. In order to understand distribution of native and alien plant species along an elevational gradient, two road transects were selected (One called Sinthan transect and other called Margan transect). These two road transects connect two districts (Anantnag and Kishtwar) of Jammu and Kashmir state (India) with alpine zone at the top. The lowest sampling point of a road was the point below which there was no substantial change in elevation anymore, or further sampling became impractical. The highest sampling point in the present study is the alpine area. The elevational range covered by each road was divided into 9 equally spaced elevational bands (07 in case of Margan transect), giving 10 (08 in case of Margan transect) sampling sites per road from valley bottom to mountain top (Fig. 1a). At each sampling site, three 2×50 m² rectangular plots were laid out, with one plot parallel to the road (hereafter called 'roadside plot'), second perpendicular to the centre of the first (hereafter called 'perpendicular plot') and third again parallel to the road (50 m away, hereafter called 'interior plot') forming a ladder step (Fig. 1b). This was done to evaluate the role of roads in upward movement of alien plant species along an altitudinal gradient. In all plots, occurrence (presence/ absence) of all vascular plant species was recorded.

The nativity of plant species collected from various study sites was determined from all possible sources, such as Khuroo *et al.* (2007), the specialized internet web pages (www.efloras.org; Germplasm Resources Information Network) and the recently published similar studies (Dar & Reshi 2015). Alien plant species were grouped into casual, naturalized and invasive species (on the basis of invasion status) following Richardson *et al.* (2000) and Pyšek *et al.* (2004); and annuals, biennials and perennials (on the basis of life span).

Species richness was expressed as total number of species recorded in a particular plot (and site). Average species richness per plot at each study site was calculated as:

$$Average\ species\ richness = \frac{n1 + n2 + n3}{N}$$

Where n1, n2, and n3 are total number of species in roadside, perpendicular and interior plots respectively and N is the number of plots which is 3.

We also calculated mean values of total species richness, native species richness, alien species richness and level of invasion observed at all sites.

$$Mean = \frac{n1 + n2 + n3 + \cdots}{N}$$

Where n1, n2, n3,.......... are values observed for a particular plot at different altitudes and N is the number of sites (10 in case of Sinthan transect and 8 in case of Margan transect).

Then mean values were compared using F-test by Past3 software. We then plotted total species, native species and alien species richness with altitude.

Level of invasion

Level of invasion, a measure which results from both the habitat properties and the propagule pressure (Chytrý *et al.* 2005, 2008; Hierro *et al.* 2005; Richardson & Pyšek 2006), has been used by various studies for habitat comparisons. In the present study, the level of invasion was expressed as proportion of alien to all plant species per site (now written as proportion of alien species). Level of invasion per site was calculated as:

$$Proportion\ of\ alien\ species = \frac{Number\ of\ alien\ species}{Total\ number\ of\ species}\ X\ 100$$

Floristic similarity

For estimation of floristic similarity and species turnover along altitudinal gradient, we calculated Jaccard's similarity and Jaccard's dissimilarity (1-Jaccard index) index separately for native, alien, and native + alien species. We then calculated average values of similarity and dissimarity index of all the values with same altitudinal difference (site pair comparisons with same altitudinal difference were grouped together which resulted in 9 altitudinal difference bands). Then percent dissimilarity was calculated as:

Percent dissimilarity= (1–Average Jaccard index)*100

The percent dissimilarity was then plotted against altitudinal difference along each transect.

Results

Species richness

The present study revealed the occurrence of 200 plant species (Table S1). Out of these 133 species were native and only 67 were alien. Of the 67 alien species, 37 were invasive, 28 were naturalized and 02 were casuals. These 200 species belonged to 45 families (01 pteridophyte, 01 Gymnosperm, 39 dicot and 04 monocot families) and 136 genera. The most representative families were Asteraceae (32 spp.), Lamiaceae (15 spp.), Caryophyllaceae (14 spp.), Poaceae (12 spp.), Polygonaceae (11 spp.), and Rosaceae (10 spp.).

Out of 200 species, 181 species (115 natives, 02 casuals, 28 naturalized and 36 invasive) were herbs and 19 (18 natives and 01 invasive) were shrubs/subshrubs/liana (*Juniperus walichiana* had bushy appearance and as such was included among shrubs). Besides, 51 (25 natives, 01 casuals, 07 naturalized and 18 invasive) were annual, 11 (04 natives, 01 casual, 02 naturalized and 04 invasive) were biennial and 138 were perennial species (104 natives, 19 naturalized and 15 invasive) (Table 1).

Table 1. Categorization of plant species on the basis of their life span and growth form.

Category	Native	Casual	Naturalized	Invasive	Total
Annual	25	1	7	18	51
Biennial	4	1	2	4	11
Perennial	104	-	19	15	138
Herbs	115	2	28	36	181
Shrubs/Sub–shrubs/Liana	18	-	-	1	19

Table 2. Mean values of total species richness, native species richness, alien species richness and level of invasion

Parameter	Sinthan transect						Margan transect				
	Plot	Maxi-mum	Mini-mum	Mean	F-test	*P*	Maxi-mum	Mini-mum	Mean	F-test	*P*
Total species richness	P1	30	5	21.7	0.9283	0.4133	26	12	20.87	0.2188	0.8062
	P2	27	17	21.2			31	13	22.25		
	P3	26	17	23.0			24	16	21.25		
Native species richness	P1	20	4	11.3	5.013	0.0186*	17	4	9.25	3.536	0.05715*
	P2	17	3	12.1			16	6	11.75		
	P3	21	7	14.7			21	7	13.125		
Alien species richness	P1	26	0	10.2	2.802	0.0497*	21	3	11.625	5.042	0.02242*
	P2	17	0	9.1			24	1	10.5		
	P3	19	0	8.3			17	1	8.125		
Level of invasion	P1	86.66	0	41.79	11.65	0.0005679*	84	25	51.13	28.77	0.000011*
	P2	85	0	41.08			80.64	7.69	40.55		
	P3	73.07	0	32.97			70.83	4.54	36.38		

*-values are significant (*P*=0.05).

The present study revealed that total species richness decreases with increase in altitude. Along Sinthan transect, it decreased from a total of 42 at an altitude of 1678 m to 22 at an altitude of 3749 m (alpine) and along Margan transect it decreased from 41 at altitude of 2164 m to 27 at altitude of 3645 m (alpine). This decrease was found to differ in three surveyed plots (Fig 2a). Average species richness per plot decreased from 25 to 16 along Sinthan transect and from 26 to 17 along Margan transect (Table 2).

Plots showed differences with respect to total number of species, number of native and alien plant species. In particular mean values of alien species richness, level of invasion were significantly different between plots (Table 3) there by indicating that roads significantly affect distribution of native and alien plant species. A graph of total species richness *vs* altitude for perpendicular plot produced a hump-shaped pattern with a maximum at mid-elevations while others produced a monocline decrease pattern. In addition it was observed that the proportion of perennial species per plot increased with the increase in altitude thereby indicating environmental filtering of perennial life span along the altitudinal gradient (Table 3).

In general, native species richness increased with increase in altitude (Fig. 2b). The graph for roadside plot (in case of both transects) and perpendicular plot (in case of Sinthan transect) showed a mid altitude peak. On the other hand alien species richness decreased with the increase in altitude (Fig. 2c).

Level of invasion

Present study reveals that at all sites level of invasion was highest in roadside plots and lowest in the interior plots. Along Sinthan transect, total level of invasion expressed as proportion of alien to all plant species decreased from 83.33 to 0 while it decreased from 86.66 to 0, 85 to 0 and 73 to 0 in roadside, perpendicular and interior plots respectively (Fig. 2d). Along Margan transect total level of invasion expressed as proportion of alien to all plant species decreased from 70.73 to 11.11 while it decreased from 84 to 16.66, 80 to 7.69 and 70 to 4.54 in roadside, perpendicular and interior plots, respectively (Fig. 2d).

Table 3. Species richness in plots at different altitudes.

Transect	Altitude (m)	Total	Proportion of perennial species	P1	P2	P3	Average species richness
Sinthan Transect	1678	42	45.23	30	20	26	25.33
	1965	40	56.09	24	21	26	23.66
	2163	40	62.50	24	22	24	23.33
	2461	37	64.86	24	24	26	24.66
	2631	35	71.42	25	27	25	25.66
	2861	34	70.58	25	24	25	24.66
	3135	33	72.72	26	20	25	23.66
	3351	29	75.86	18	20	20	19.33
	3561	23	73.91	5	17	16	12.66
	3749	22	90.47	16	17	17	16.66
Margan Transect	2164	41	51.21	25	31	24	26.66
	2276	40	62.50	25	31	24	26.66
	2593	38	68.42	23	19	24	22.00
	3024	34	64.70	26	30	22	26.00
	3236	32	81.25	26	18	16	20.00
	3420	28	71.42	12	20	22	18.00
	3542	27	92.59	12	16	16	14.66
	3645	27	81.48	18	13	22	17.66

Altitudinal decay of floristic similarity

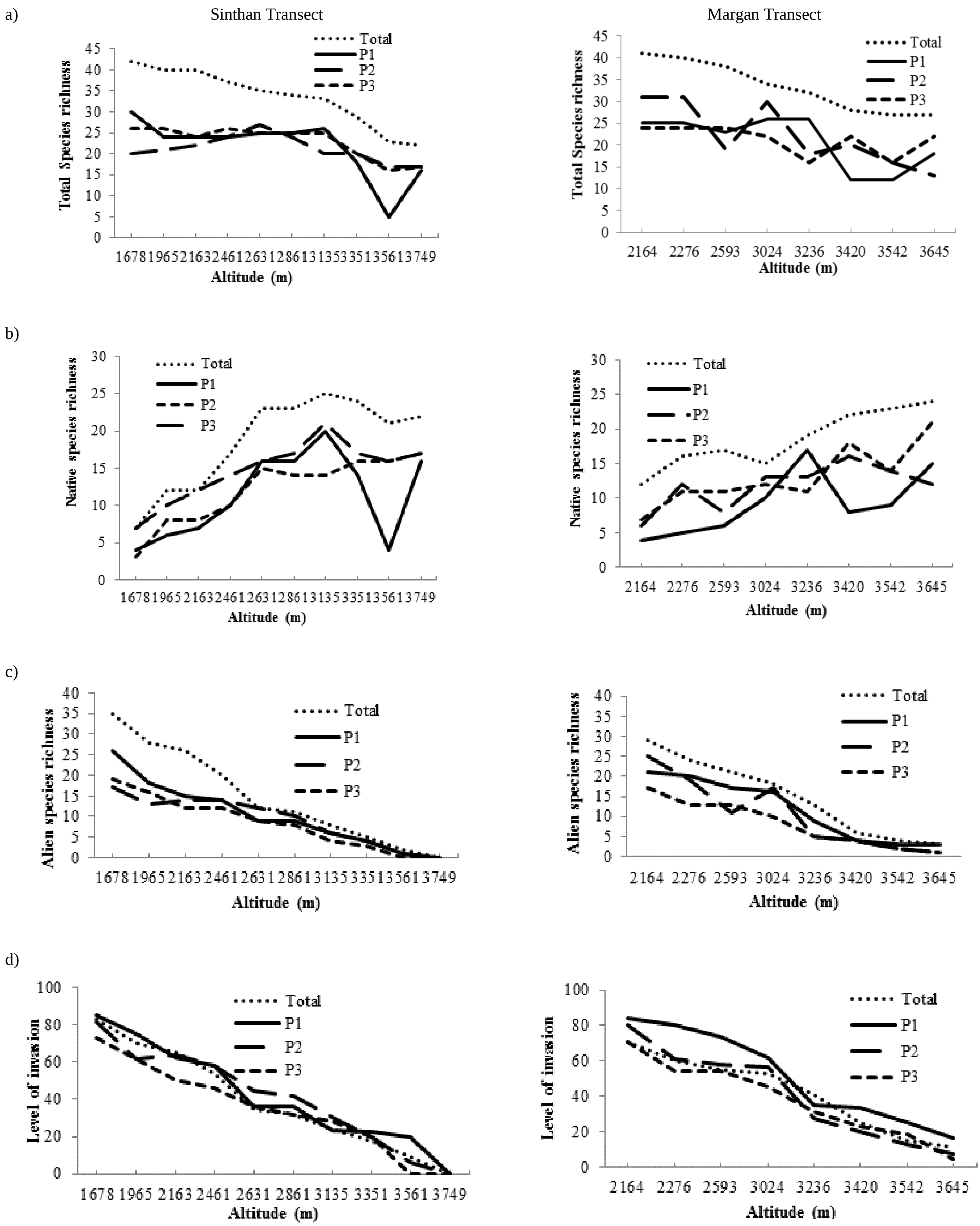
Present study also reveals that greater the altitudinal difference between sites greater is the dissimilarity (i.e. less similarity) as percent dissimilarity increased with increased altitudinal difference between sites thus indicating significant vegetation turnover along elevational gradient (Fig. 2e,f,g). In addition this altitudinal decay in similarity was found to differ depending upon the type of plot being taken into consideration. In general, mean value of percent dissimilarity for a particular altitudinal band was lowest for roadside plot in comparison to perpendicular and interior plots. It indicates that roadside plots, which are characterized by highest levels of invasion, are more similar than other two plots which is consistent with the corridor role of roads.

Discussion

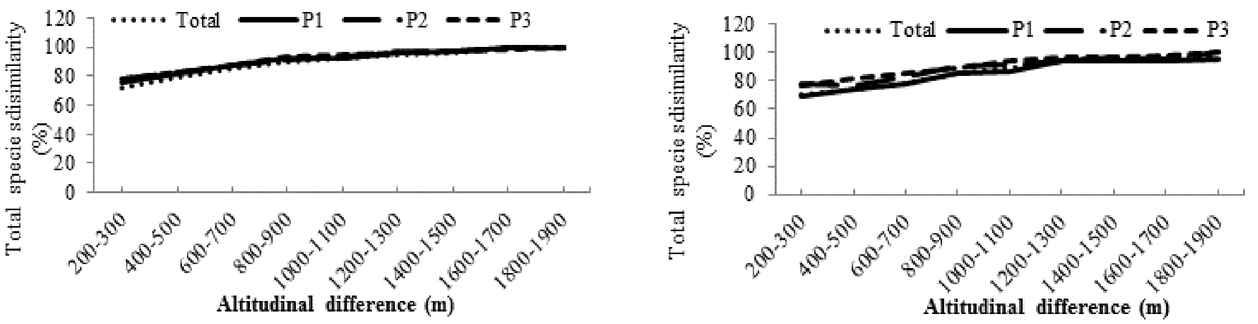
The present study is an attempt to understand the role of roads in upward expansion of alien plant species along elevational gradient in mountain areas. Past investigations in mountain areas have reported three general trends of altitudianal variations in species richness (Rahbek 1995, 1997) which include a linear decrease with altitude or producing a hump-shaped pattern with a maximum at mid-elevations, or it remains constant from the lowlands to mid–elevations then declining strongly further up. We have observed that different plots show different patterns with some plots producing a hump shaped curve and others showing a linear decline. Although previous studies have reported different species richness patterns for different road transects (Rahbek 2005), present study reveals that different plots (differing in their position with respect to main road) show different richness patterns. This is largely because of the effect of the road with road associated factors (disturbance, propagule pressure etc) varying with distance from the road (Dar *et al.* 2015). Thus roads can significantly alter the distribution patterns of plants in mountain areas.

Research in mountain areas has also revealed that factors like short growing season and ecophysical factors (low temperature and low ecosystem productivity) at high altitudes contribute to altitudinal decline in species richness (Körner 1998). In addition, discontinuity in pathways of immigration at higher altitudes leads to less migration of species from lowlands to uplands thereby resulting in less number of species occupying high altitude (Colwell & Lees 2000; Gerytnes & Vetaas 2002).

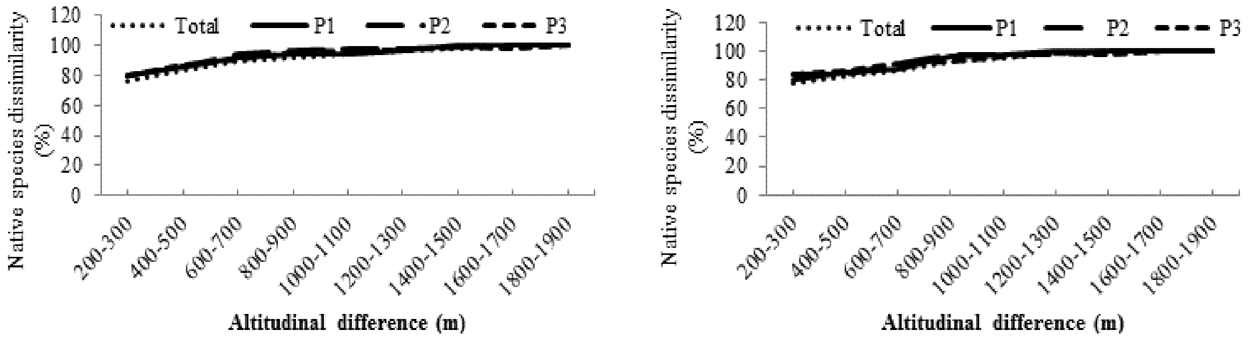
The observed hump shaped diversity pattern in native species richness might be attributed to


a)
Sinthan Transect
Margan Transect
Total
P1
P2
P3
Total Species richness
Altitude (m)
1678 1965 2163 2461 2631 2861 3135 3351 3561 3749
2164 2276 2593 3024 3236 3420 3542 3645
b)
Native species richness
c)
Alien species richness
d)
Level of invasion

e)



f)



g)

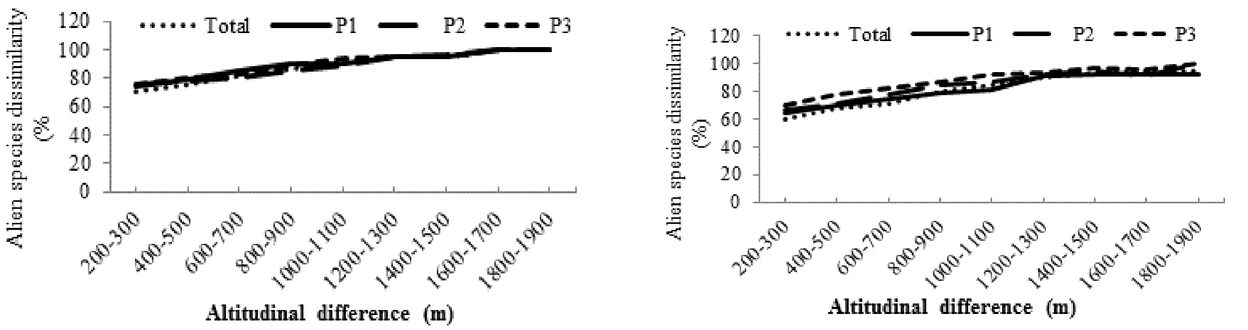


Fig. 2 (a-g): Altitudinal variation in (a) Total species richness, (b) alien species richness, (c) native species richness, (d) level of invasion, (e) total species dissimilarity (%), (f) native species dissimilarity (%), (g) alien species dissimilarity (%) along Sinthan and Margan transect [Legends: Total- aggregate of all three plots of a ladder step i.e. aggregate of P1, P2 and P3), P1- plot parallel to the road (roadside plot), P2- plot perpendicular to the road (perpendicular plot) and P3- interior parallel plot 50 m away from P1 (interior plot). For better understanding refer to Fig. 1b].

optimal climate conditions (e.g. precipitation and temperature) at the middle elevations (McCain 2007) and mid-domain effect within a bounded elevational domain (Kharkwal *et al.* 2005; Vetaas & Gerytnes 2002; Wang *et al.* 2007; Zhao *et al.* 2005) that results from the overlap of species ranges at ecotones of species adapted to different parts of the gradient (Oommen & Shanker 2005). The hump shaped pattern has also been reported by other studies in Himalayan area (Rawat 2011).

We have reported a gradual decline in alien species richness with alpine areas either uninvaded or invaded to a very low extent. Same pattern has been reported by many other studies (Alexander *et* *al*. 2011; Barni *et al*. 2012; Seipel *et al*. 2011) and majority of the studies have advocated directional filtering (Alexander *et al*. 2011; Averett *et al*. 2016) as possible explanation for describing the pattern. Since majority of alien species are introduced in lowland areas around human habitation, subsequent unidirectional expansion of alien species from anthropogenic sources at low elevations and progressive ecological filtering from low elevations to high elevations (Alexander *et al*. 2016) cause decline in their richness - a phenomenon described as directional filtering (Alexander *et al*. 2011; Averett *et al*. 2016). In addition not all alien species are preadapted to survive in extreme conditions at higher altitudes which lead to their failure in colonizing high altitude areas (Alexandar *et al*. 2016). Besides, only alien plants with broad climatic tolerances capable of growing across a wide elevational range have been reported to be reaching higher altitudes (Alexander *et al*. 2011; Becker *et al*. 2005; Marini *et al*. 2013). We have also observed progressive filtering of perennial life span as proportion of perennial plants increased with altitude. Harsh climate conditions like very low temperature of high altitude (alpine) areas favours perennial life span (Evette *et al*. 2009; Klimeš *et al*. 1997; Klimešová *et al*. 2010; Körner 1999).

Level of invasion

In comparison to natural habitats, roadsides are often characterized by very high proportion of alien species on account of factors like high disturbance (Johnston & Johnston 2004), high dispersal due to vehicular movement (Von der Lippe & Kowarik 2007; Von der Lippe *et al*. 2013), high propagule pressure (Lembrechts *et al*. 2014; Pickering & Mount 2010; Von der Lippe & Kowarik 2007) which promote establishment and colonization by alien plant species. The present study reveals that in comparison to perpendicular and interior plots (which are relatively less disturbed and parts of natural habitats particularly at higher altitudes), roadsides are characterized by highest levels of invasion at all altitudinal zones. Species which were found in alpine areas were exclusively associated with roadsides. It indicates that roads can potentially serve as conduits for the dispersal of alien species (Christen & Matlack 2006; Johnston & Johnston 2004; Parendes & Jones 2000; Tyser & Worley 1992) despite ecological filtering along altitudinal gradients. It assumes great significance in view of the fact that alien roadside species more easily invade alpine than lowland plant communities in a subarctic mountain ecosystem (Lembrechts *et al*. 2014) which pose serious threat to alpine ecosystems of the area.

Altitudinal decay of floristic similarity

The floristic similarity between plots decreased with the increase in altitudinal difference. Similar results were reported by Zhang *et al*. (2016). Decrease in total floristic similarity and native floristic similarity produced similar results for all the three plots. But decrease in alien species similarity differed between plots. Due to their linear structure and associated facilitation of seed dispersal by vehicular movement (Tikka *et al*. 2001), roads homogenize the regional plant communities and act as corridors for the spread of alien taxa, providing a major conduit for plant invasion (Christen & Matlack 2006; Forman & Alexander 1998; Harrison *et al*. 2002; Tikka *et al*. 2001). In comparsion to other natural habitats, roadsides have been reported to be more homogenous (Dar *et al*. 2015) largely due to their linear structure and higher levels of invasion.

Conclusion

Studies like this could provide baseline information from which we can measure future effects of climate change and anthropogenic changes on vegetation in mountain areas. The observed pattern of associations between species distribution and elevation bands is likely to help in understanding the possible effects of climate change as climate change is expected to change species distributions with species shifting towards higher altitudes. Despite being relatively uninvaded the alpine ecosystems of the region are likely to face serious consequences on account of unplanned socioeconomic developmental activities in the area facilitating spread of alien species.

Acknowledgement

We thank Dr. A. R. Naqshi for his help with identification of plant specimens. We also thank anonymous reviewer for his valuable suggestions.

References

Alexander, J. M., C. Kueffer, C. C. Daehler, P. J. Edwards, A. Pauchard, T. Seipel, MIREN consortium. 2011. Assembly of nonnative floras along elevational gradients explained by directional ecological filtering.

Proceedings of National Academy of Sciences, USA **108**: 656–661.

Alexander, J. M., J. J. Lembrechts, L. A. Cavieres, C. Daehler, S. Haider, C. Kueffer, G. Liu *et al*. 2016. Plant invasions into mountains and alpine ecosystems: current status and future challenges. *Alpine Botany* **126**: 89–103.

Alpert, P., E. Bone, C. Holzapfel. 2000. Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution & Systematics* **3**: 52–66.

Averett, J. P., B. McCune, C. G. Parks, B. J. Naylor, T. DelCurto & R. Mata-González. 2016. Non-Native Plant Invasion along Elevation and Canopy Closure Gradients in a Middle Rocky Mountain Ecosystem. *PLoS ONE* **11**: e0147826.

Barni, E., G. Bacaro, S. Falzolai, F. Spanna & C. Siniscalco. 2012. Establishing climatic constraints shaping the distribution of alien plant species along the elevation gradient in the Alps. *Plant Ecol.* **213**: 757–767.

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

Brown, J. 2001. Mammals on mountainsides: elevational patterns of diversity. *Global Ecology and Biogeography* **10**: 101–109.

Callaghan, T. V. & S. Jonasson. 1995: Implications for changes in Arctic plant biodiversity from environmental manipulation experiments. pp. 151–166. *In*: F. S. III Chapin & C. Körner (ed.), *Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences*, Eco-logical Studies 113, Berlin, Heidelberg: Springer.

Christen, D. & G. Matlack. 2006. The role of roadsites in plantinvasions: a demographic approach. *Conservation Biology* **20**: 385–391.

Chytrý, M., P. Pyšek, L. Tichy, I. Knollová & J. Danihelka. 2005. Invasions by alien plants in the Czech Republic: a quantitative assessment across habitats. *Preslia* **77**: 339–354.

Chytrý, M., V. Jarosík, P. Pyšek, O. Hájek, O. Knollová, L. Tichy & J. Danihelka. 2008. Separating habitat invasibility by alien plants from the actual level of invasion. *Ecology* **89**: 1541–1553.

Colwell, R. K. & D. C. Lees. 2000. The mid -domain effect: geometric constraints on the geography of species richness. *Trends in Ecology and Evolution* **15**: 70–76.

Dar, P. A. & Z. A. Reshi. 2015. Do alien plant invasions cause biotic homogenization of terrestrial ecosystems in the Kashmir Valley, India? *Tropical Ecology* **56**: 111–123.

Dar, P. A., Z. A. Reshi & M. A. Shah. 2015. Roads act as corridors for the spread of alien plant species in the mountainous regions: A case study of Kashmir Valley, India'. *Tropical Ecology* **56**: 183–190.

Evette, A., A. Bédécarrats & G. Bornette. 2009. Environmental constraints influence clonal traits of herbaceous plant communities in an Alpine Massif. *Folia Geobot* **44**: 95–108.

Forman, R. T. T. & L. E. Alexander 1998. Roads and their major ecological effects. *Annual Reviews in Ecology Systematics* **29**: 207–231.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine & T. C. Winter. 2003. *Road Ecology; Science and Solutions*. Island Press, Covelo, CA.

Gerytnes, J. A. & O. R. Vetaas. 2002. Species richness and altitude: a comparison between simulation modes and interpolated plant species richness along the Himalayan altitudinal gradient, Nepal. *American Naturalist* **159**: 294–304.

Godfree, R., B. Lepschi, D. Mallison. 2004. Ecological filtering of exotic plants in an Australian sub-alpine environment. *Journal of Vegetation Science* **15**: 227–236.

Harrison, S., C. Hohn & S. Ratay. 2002. Distribution of exotic plants along roads in a peninsular nature reserve. *Biological Invasions* **4**: 425–430.

Hierro, J. L., J. L. Maron & R. M. Callaway. 2005. A biogeographical approach to plant invasions: the importance of studying exotics in their introduced and native range. *Journal of Ecology* **93**: 5–15.

Holten, J. I. & P. D. Carey. 1992. *Responses of Climate Change on Natural Terrestrial Ecosystems in Norway*. NINA forskningsrapport 029, Trondheim.

Johnston F. M. & S. W. Johnston. 2004. Impacts of road disturbance on soil properties and on exotic plant occurrence in subalpine areas of the Australian Alps. *Arctic Antanetic and Alpine Research* **36**: 201–207.

Johnston, F. M. & C. M. Pickering. 2001. Alien plants in the Australian Alps. *Mountain Research and Development* **21**: 284–291.

Kharkwal, G., P. Mehrotra, Y. S. Rawat & Y. P. S. Pangtey. 2005. Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science* **89**: 873–878.

Khuroo, A. A., I. Rashid, Z. Reshi, G. H. Dar & B. A. Wafai. 2007. The alien flora of Kashmir Himalaya. *Biological Invasions* **9**: 269–292.

Klanderud, K. & H. J. B. Birks. 2003. Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. *The Holocene* **13**: 1–6.

Klimes, L., J. Klimesová, R. Hendriks & J. Van Groenendal. 1997. Clonal plant architecture: a comparative analysis of form and function. pp. 1–29. *In*: H. De Kroon & J. Van Groenendal (eds) *The Ecology and Evolution of Clonal Plants*. Leiden, Backhujs Publishers.

Klimešová J., J. Doležal, M. Dvorský, F. de Bello & L. Klimeš. 2010. Clonal Growth Forms in Eastern Ladakh, Western Himalayas: Classification and Habitat Preferences. *Folia Geobotanica* DOI 10.1007/s 12224-010-9076-3.

Körner C. 1998. A re-assessment of high elevation treeline positions and their explanation. *Oecologia* **115**: 445–459.

Körner, C. 1995. Impact of atmospheric changes on alpine vegetation: the ecophysiological perspective. pp. 13–120. *In*: A. Guisan, J. I. Holten, R. Spichiger & Tessier, L., (ed.). *Potential Ecological Impacts of Climate Change in the Alps and Fennoscandian Mountains, Genève. Ed. Conserv. Jard. Bot.*

Körner, C. 1999. *Alpine Plant Life*. Springer Verlag, Berlin.

Körner, C. 2003. *Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems,* 2nd edn. Springer, Heidelberg.

Körner, C. 2007. The use of 'altitude' in ecological research. *Trends in Ecology and Evolution* **22**: 569–574.

Kueffer, C., K. McDougall, J. Alexander, C. Daehler, P. Edwards, S. Haider, A. Milbau, C. Parks, A. Pauchard & Z. A. Reshi. 2013. Plant invasions into mountain protected areas: assessment, prevention and control at multiple spatial scales. pp. 89–113. *In*: L. C. Foxcroft, D. M. Richardson, Pyšek P. & P. Genovesi (eds.) *Alien Plant Invasions in Protected Areas: A Global Assessment*. Springer, Berlin.

Lembrechts, J. J., A. Milbau & I. Nijs. 2014. Alien roadside Species More Easily Invade Alpine than lowland plant communities in a subarctic mountain ecosystem. *PLoS ONE* **9**: e89664.

Lomolino, M. V. 2001. Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* **10**: 3–13.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H. Clout, M., & F. A. Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications* **10**: 689–710.

Marcus, W. A., G. Milner & B. Maxwell. 1998. Spotted knapweed distribution in stock camps and trails of the Selway-Bitterroot Wilderness. *Great Basin Nat.* **58**: 156–166.

Marini L., A. Bertolli, E. Bona, G. Federici, F. Martini, F. Prosser & R. Bommarco. 2013. Beta-diversity patterns elucidate mechanisms of alien plant invasion in mountains. *Global Ecology Biogeography* **22**: 450–460.

McCain, C. M. 2007. Could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and Biogeography* **16**: 1–13.

McDougall, K. L., A. A. Khuroo, L. L. Loope, C. G. Parks, A. Pauchard, Z. A. Reshi, I. Rushworth & C. Kueffer. 2011. Plant invasions in mountains: global lessons for better management. *Mountain Research Development* **31**: 380–387.

Müllerová, J., M. Vítková & O. Vítek. 2011. The impacts of road and walking trails upon adjacent vegetation: Effects of road building materials on species composition in a nutrient poor environment. *Science of the Total Environ* **409**: 3839–3849.

N'driL, J. K., S. D. Zon, J. E. Tondoh & J. Lagerlöf. 2017. Changes in mite richness and diversity along a gradient of land-use intensity from mid-west Ivory Coast. *Tropical Ecology* **58**: 497–506.

Oommen M. A. & K. Shankar 2005. Elevational species richness patterns emerge from multiple local mechanisms in Himalayan woody plants. *Ecology* **86**: 3039–3047.

Pacifici, M., W. B. Foden, P. Visconti, J. E. M. Watson, S. H. M. Butchart, K. M. Kovacs, B. R. Scheffers, *et al.* 2015. Assessing species vulnerability to climate change. *Nature Climate Change* **5**: 215–224.

Parendes, L. A. & J. A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H. J. Andrews Experimental Forest, Oregon. *Conservation Biology* **14**: 64–75.

Parmesan, C., C. Duarte, E. Poloczanska, A. J. Richardson & M. C. Singer. 2011. Overstretching attribution. *Nature Climate Change* **1**: 2–4.

Patnaik, P., A. Tasneem & S. A. Abbasi. 2017. Prosopis (*Prosopis juliflora*): blessing and bane. *Tropical Ecology* **58**: 455–483.

Pauchard A., C. Kueffer, H. Dietz, C. Daehler, J. Alexander, P. Edwards, J. Arévalo, *et al.* 2009. Ain't no mountain high enough: plant invasions reaching new elevations. *Frontiers in Ecology and Environment* **7**: 479–486.

Pickering, C. M. & A. Mount. 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**: 239–256.

Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, E. C. O'Connell, *et al.* 2001. Economic and environmental threats of alien plant, animal and microbe invasions. *Agriculture, Ecosystems and Environment* **84**: 1–20.

Pyšek P., D. M. Richardson, M. Rejmánek, G. L. Webster,

M. Williamson & J. Kirschner. 2004. Alien plants in checklists and flora: towards better communication between taxonomists and ecologists. *Taxon* **53**: 131–143.

Rahbek, C. 1995. The elevation al gradient of species richness: a uniform pattern? *Ecography* **18**: 200–205.

Rahbek, C. 1997. The relationship among area, elevation and regional species richness in neotropical birds. *American Naturalist* **149**: 875–902.

Rahbek, C. 2005. The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology Letters* **8**: 224–239.

Rawat, D. S. 2011. Elevational reduction of plant species diversity in high altitudes of Garhwal Himalaya, India. *Current Science* **100**: 833–836.

Richardson D. M. & P. Pyšek. 2006. Plant invasions: merging the concepts of species invasiveness and community invasibility. *Progress in Physical Geography* **30**: 409–431.

Richardson, D. M., P. Pyšek, M. Rejmánek, M. G. Barbour, F. D. Penetta & C. J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* **6**: 93–107.

Seipel, T., C. Kueffer, L. J. Rew, C. Daehler, A. Pauchard, B. Naylor, J. M. Alexander, *et al.* 2011. Processes at multiple scales affect richness and similarity of non-native plant species in mountains around the world. *Global Ecology and Biogeography* **21**: 236–246.

Tikka, P. M., H. Hogmander & P. S. Koski. 2001. Road and railway verges serve as dispersal corridors for grassland plants. *Landscape Ecology* **16**: 659–666.

Tyser R. W. & C. A. Worley. 1992. Alien flora in grasslands adjacent to road andtrail corridors in Glacier National Park, Montana (USA). *Conservation Biology* **6**: 253–262.

Vetaas O. R. & J. A. Grytnes. 2002. Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology & Biogeography* **11**: 291–301.

von der Lippe M. & I. Kowarik. 2007. Long-distance dispersal of plants by vehicles as a driver of plant invasions. *Conservation Biology* **21**: 986–996.

von der Lippe, M., J. M. Bullock, I. Kowarik, T. Knopp, M. Wichmann. 2013. Human-mediated dispersal of seeds by the airflow of vehicles. *PLoS ONE* **8**: e52733.

Wang, Z., Z. Tang & J. Fang. 2007. Altitudinal patterns of seed plant richness in the Gaoligong Mountains, south-east Tibet, China. *Diversity & Distributions* **13**: 845–854.

Zhang W., D. Huang, R. Wang, J. Liu, N. Du. 2016. Altitudinal patterns of species diversity and phylogenetic diversity across temperate mountain forests of Northern China. *PLoS ONE* **11**: e0159995. doi:10.1371/journal.pone.0159995.

Zhao, C. M., W. L. Chen, Z. Q. Tian & Z. Q. Xie. 2005. Altitudinal pattern of plant species diversity in Shennongjia Mountains, central China. *Journal of Integrative Plant Biology* **47**: 1431–1449.

(Received on 07.03.2018 and accepted after revisions, on 28.03.2018)

Supporting Information

Additional supporting information may be found in the online version of this article.

Table S1. Altitudinal distribution of native and alien plant species.