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

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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 immune 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
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 establishment 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:

\[ \text{Average species richness} = \frac{n_1 + n_2 + n_3}{N} \]

Where \( n_1 \), \( n_2 \), and \( n_3 \) 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.

\[ \text{Mean} = \frac{n_1 + n_2 + n_3 + \ldots}{N} \]

Where \( n_1 \), \( n_2 \), \( n_3 \),............ 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:

\[ \text{Proportion of alien species} = \frac{\text{Number of alien species}}{\text{Total number of species}} \times 100 \]

**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 dissimilarity 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:

\[ \text{Percent dissimilarity} = (1 - \text{Average Jaccard index}) \times 100 \]

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.

<table>
<thead>
<tr>
<th>Category</th>
<th>Native</th>
<th>Casual</th>
<th>Naturalized</th>
<th>Invasive</th>
<th>Total</th>
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<td>1</td>
<td>7</td>
<td>18</td>
<td>51</td>
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<tr>
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<td>1</td>
<td>2</td>
<td>4</td>
<td>11</td>
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<td>115</td>
<td>2</td>
<td>28</td>
<td>36</td>
<td>181</td>
</tr>
<tr>
<td>Shrub/Sub-shrub</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>19</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sinthan transect</th>
<th>Margan transect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plot</td>
<td>Maxi</td>
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<tr>
<td>Total species</td>
<td>P1 30</td>
<td>5</td>
</tr>
<tr>
<td>species</td>
<td>P2 27</td>
<td>17</td>
</tr>
<tr>
<td>richness</td>
<td>P3 26</td>
<td>17</td>
</tr>
<tr>
<td>Native species</td>
<td>P1 20</td>
<td>4</td>
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<tr>
<td>species</td>
<td>P2 17</td>
<td>3</td>
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<tr>
<td>richness</td>
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<td>7</td>
</tr>
<tr>
<td>Alien species</td>
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<tr>
<td>species</td>
<td>P2 17</td>
<td>0</td>
</tr>
<tr>
<td>richness</td>
<td>P3 19</td>
<td>0</td>
</tr>
<tr>
<td>Level of invasion</td>
<td>P1 86.66</td>
<td>0</td>
</tr>
<tr>
<td>invasion</td>
<td>P2 85</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>P3 73.07</td>
<td>0</td>
</tr>
</tbody>
</table>

* - 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.

<table>
<thead>
<tr>
<th>Transect</th>
<th>Altitude (m)</th>
<th>Total</th>
<th>Proportion of perennial species</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>Average species richness</th>
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<tr>
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<td>22</td>
<td>17.66</td>
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</table>

**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 altitudinal 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
ALTITUDINAL DISTRIBUTION OF PLANTS

a) Sinthan Transect

b) Margan Transect

c) Alien species richness

d) Level of invasion
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 comparison 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.

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References

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**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.