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Patterns of alien plant species richness across gradients of altitude: analyses from the Himalayan state of Himachal Pradesh

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Abstract: The spread of alien plant species in bio-rich mountains calls for documenting their distribution across altitudes. The present study, therefore, analysed altitudinal distribution of alien species richness in the Himalayan state of Himachal Pradesh and tested the null hypothesis that- alien species richness in Himalaya is independent of altitude. For this, information on alien species was collated from published literature. As the zone above 5000 m is mostly snow-covered and devoid of major vegetation in the Himalaya, the altitudinal range from 300–5000 m was divided into bands of 100 m each. If a species was reported occurring from 300 to 600 m, then it's presence was counted in the 300–400 m, 400–500 m, and 500–600 m bands. All the species occurring in these individual 100 m bands were tabulated. For comparisons of alien species richness along altitude, five altitudinal groups were identified (>1000, 1000–2000, 2000–3000, 3000–4000 and 4000–5000). Their richness across and between these group was statistically compared using R. Alien species richness was maximum in the 1000–1100 m band, and significantly varied along the altitudinal gradient. Life form analyses revealed the absence of alien climbers above 2500 m. Alien species distribution patterns are in contrast to the native species distribution whose maximum richness is reported at mid-altitudes (2000–2500 m). This may be because most of the alien species are tropical in origin and have been introduced at lower altitudes. Interestingly, alike the native species, members of Asteraceae, Fabaceae, and Poaceae dominated the alien flora along the entire altitudinal gradient.

Key words: Elevation, Himalaya, invasion, mountains, species richness.

Introduction

Gradient analysis of species and their distribution not only provide input to ecology and environment but also guide their conservation and management programmes (Grytnes 2003; Rahbek 2005). Across mountains, altitude is an important gradient that governs patterns of species distribution and richness (Grytnes & Vetaas 2002; Sanders & Rahbek 2012). Most of the studies on species distribution in the mountains have focussed on native species, and have documented a mid-altitude (2000–2500 m) species richness peak (Bhattarai & Vetaas 2003, Bhattarai *et al.* 2004, Bhattarai & Vetaas 2006; Giorgis *et al.* 2011; Gryntes 2003; Rahbek 2005). While, on the other hand, many studies have noted an increase in the richness of alien species (non-native species that have been intentionally or accidentally introduced outside their range) in mountains (Dietz *et al.* 2006; Lembrechts *et al.* 2014; Marini *et al.* 2013; McDougall *et al.* 2011a). Few studies have prepared checklist of alien floras (Bhatt *et al.* 2012; Nagar *et al.* 2004; Negi & Hajra 2007; Reddy *et al.* 2008; Sekar 2012), analysed their floristics, nativity, and categorized them into various alien categories (Jaryan *et al.* 2013; Khuroo *et al.* 2007; Khuroo *et al.* 2009). Patterns of alien species distribution along roadsides have also been attempted (Kosaka *et al.* 2010; Pickering & Hill 2007; Sharma & Raghubanshi

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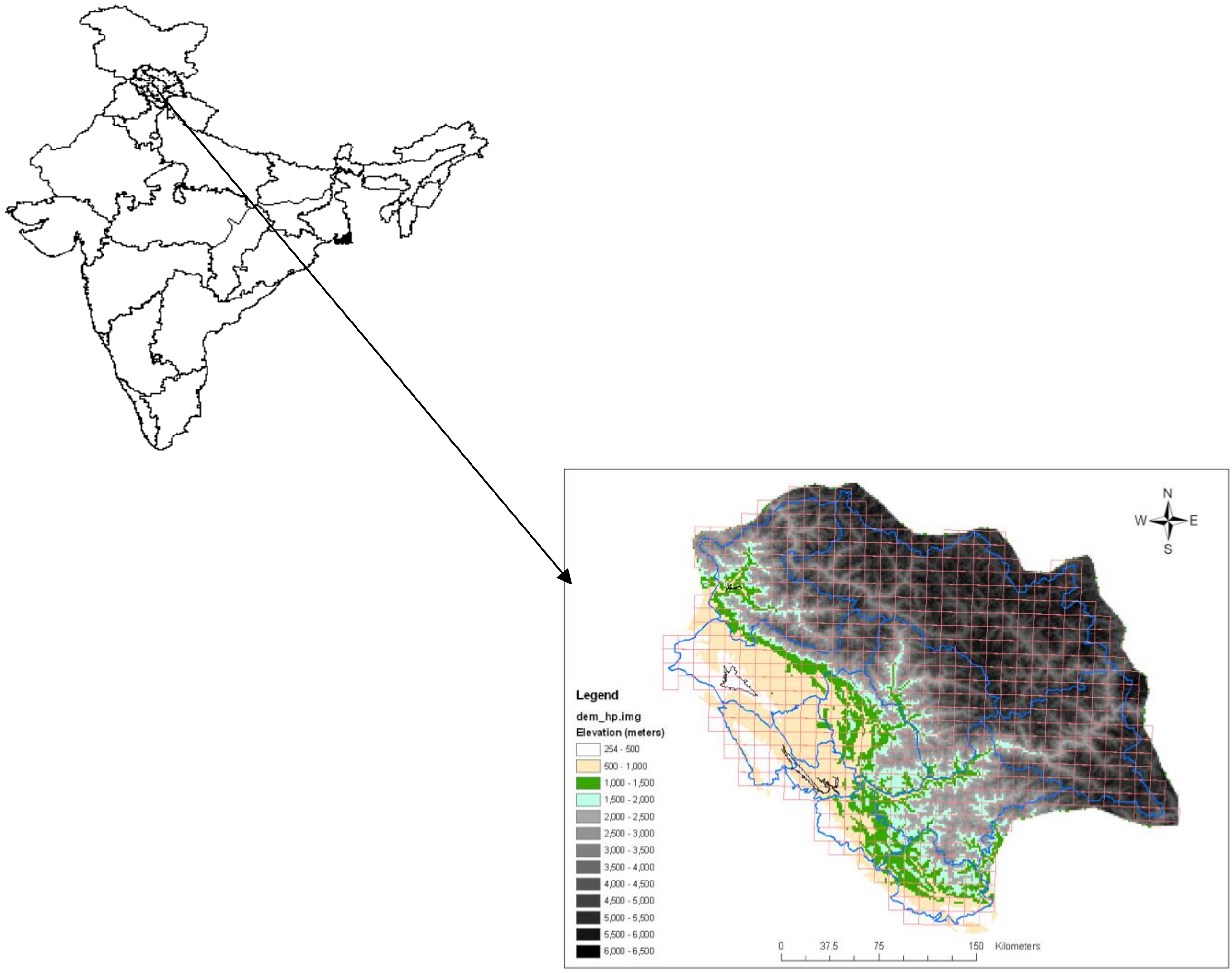

Fig. 1. Location of Himachal Pradesh and its elevation map

2009) while others have discussed the distribution of woody alien species across altitude (Haider *et al.* 2011; Khuroo *et al.* 2011). McDougall *et al.* (2011b) has compared alien species composition in different mountain ranges whereas a comparative account of native and invasive species distribution in Nepal Himalaya has been presented by Bhattarai *et al.* (2014). Patnaik *et al.* (2017) have recently discussed the implications of an invasive species spread in the tropical and sub-tropical regions of India.

Recognizing that rich mountain biodiversity (Mittermeier *et al.* 2005; Myers *et al.* 2000) is critical for livelihood (Körner 2004; Xu *et al.* 2009) and that alien species detrimentally effect biodiversity (Pimentel *et al.* 2005; Wilcove *et al.* 1998), studies targeting altitudinal distribution patterns of alien species in the mountains such as the Himalaya have been advocated (Becker *et al.* 2005; Haider *et al.* 2011). Thus, the key questions that we attempt to answer are: (1) does alien species richness change with altitude in the Himalaya, and (2) at which altitudinal range their richness is maximum. The null hypothesis that we propose is: alien species distribution in Himalaya is independent of altitude. Consequently, the objectives framed for the study include identifying: 1) the altitudinal bands that harbours maximum alien species, 2) the floristic composition across altitude, and 3) species with wide and narrow altitudinal amplitude.

Materials and methods

Study area

The present study was carried out in Himachal Pradesh (HP), one of the biologically rich states of Himalaya. It occupies 55673 sq. km area that lies between 28° to 33°N and 75° to 79°E with altitudes ranging from ~300 to ~7000 m (Fig. 1). At lower altitudes (~500 m), during summers, the maximum temperature ranges between 38 to 42 °C while the minimum temperature varies from 24 to 28 °C. During winters, the maximum temperature ranges between 17 to 20 °C and the minimum temperature from 4 to 6 °C. On the other hand, at high altitude regions such as Spiti (~4000 m), the maximum temperature during summers varies from 25 to 28 °C and the minimum from 8 to 10 °C. In winters, the maximum temperature in the region varies from −8 to −5 °C and the minimum temperature from −28 to −25 °C. Large variations in rainfall have also been reported from the state. While annual rainfall in Dhauladhar mountain range is ~2500 mm, the cold desert regions of the state receive 500 mm annual rainfall (Balokhra 2002). Overall, the average maximum temperature of the state is ~27 °C while the minimum is ~5.6 °C**.** The documented average annual rainfall of the state is ~1200 mm (Govt. of Himachal Pradesh 2016). Based on the development and physico-chemical properties, nine soil types have been reported from the state (Verma & Tripathi 1982). The state supports ~3500 plant species (Chowdhery & Wadhwa 1984; Uniyal & Singh 2014) that includes alien plant species.

Data collection

A total of ~500 alien plant species have been reported from HP (Jaryan *et al.* 2013). Information on these species was obtained by screening available literature and secondary information. Information on life form characteristics and altitudinal distribution range of these species was recorded from- Flora of HP an analysis (Chowdhery & Wadhwa 1984), Flora of Chamba district (Singh & Sharma 2006), Flora of Sirmaur (Kaur & Mishra 2004), Flora of Kullu (Dhaliwal & Sharma 1999), Flora Similensis (Collet 1902), and Flora ofthe Great Himalayan National Park (Singh & Rawat 2000). Information was also sourced from publications of neighbouring west Himalayan states (Dhar & Kachroo 1998; Gaur 1999; Khuroo *et al.* 2007; Negi & Hajra 2007; Osmaston 1994; Sekar 2012) and that of the nearby Himalayan countries namely China, Nepal, and Pakistan (www.eFloras.org). Flowers of the Himalaya (Polunin *et al.* 2006) and Concise Flowers of the Himalaya (Stainton 2005) were also consulted to have as much information as possible on these alien species.

Data Analyses

Patterns of alien species richness across altitude is based on analyses of 425 species that does not include commonly cultivated crops such as *Allium cepa*, *Allium sativum*, *Hordeum vulgare*, *Raphanus sativus*, *Solanum tuberosum*, and *Triticum aestivum* (Table S1). These 425 species have been categorized into different life forms (herb, shrub, tree, and climber) and analysed for their altitudinal distribution. Alien status of the species is also presented following categorization used by Jaryan *et al.* (2013) and Pyšek *et al.* (2004). Alien species that do not form self-sustaining populations and rely on repeated introductions for their persistence are known are casual (Ca). Alien species that sustain more than one life cycle and do not invade ecosystems are known are naturalized (Nt). Naturalized alien species that produce reproductive offspring in very large numbers and thus can spread over a large area are referred as Invasive (In). Alien species that are grown or planted are referred to as cultivated (Cl). Further, Ca/Nt refers to those casual alien species for which the current evidence limits their categorization into naturalized but these species have the potential to become naturalized in the near future. Nt/In refers to those naturalized alien species for which the current data limits them to be recognized as invasive but have the potential to become invasive (Table S1). As the zone above 5000 m is mostly snow-covered and devoid of major vegetation in the Himalaya, it was excluded from analyses. At the same time, starting from low to high altitude, the altitudinal range from 300–5000 m was divided into bands of 100 m each. 300–400 m represented one band, 400–500 m represented another, and so on till 5000 m. If a species was reported to be occurring from 300 to 600 m, then it's presence was counted in the bands 300–400 m, 400–500 m, and 500–600 m. All the species occurring in these individual 100 m bands were tabulated and counted. This was done to identify the altitudinal band with highest alien species richness.

Statistical analyses

For comparison of alien species richness along the 300–5000 m gradient, the entire altitudinal range was divided into five altitudinal groups (>1000, 1000–2000, 2000–3000, 3000–4000 and 4000–5000). Alien species richness across and between the above five altitudinal groups was compared using ANOVA. Cumulative species

Table 1. Alien species richness across the altitudinal gradient.

Altitudinal Range	Herb	Shrub	Climber	Tree	Total
300–400	152	20	6	27	205
400–500	152	19	6	27	204
500–600	151	19	6	27	203
600–700	215	28	11	29	283
700–800	219	28	11	29	287
800–900	227	28	11	35	301
900–1000	231	28	11	34	304
1000–1100	242	26	11	38	317
1100–1200	241	25	11	39	316
1200–1300	239	25	10	39	313
1300–1400	235	26	10	39	310
1400–1500	231	25	10	39	305
1500–1600	199	18	4	33	254
1600–1700	193	18	4	32	247
1700–1800	190	18	3	33	244
1800–1900	184	17	4	29	234
1900–2000	181	17	4	29	231
2000–2100	162	17	2	24	205
2100–2200	161	17	1	22	201
2200–2300	148	17	1	21	187
2300–2400	146	16	1	21	184
2400-2500	142	15	1	18	176
2500–2600	117	10	nd	14	141
2600–2700	117	9	nd	14	140
2700–2800	77	7	nd	10	94
2800–2900	69	7	nd	6	82
2900–3000	66	7	nd	5	78
3000–3100	40	2	nd	4	46
3100–3200	40	1	nd	3	44
3200–3300	35	1	nd	3	39
3300–3400	35	1	nd	1	37
3400–3500	35	1	nd	1	37
3500–3600	20	1	nd	1	22
3600–3700	17	1	nd	1	19
3700–3800	14	1	nd	1	16
3800–3900	12	1	nd	1	14
3900–4000	12	1	nd	1	14
4000–4100	6	1	nd	nd	7
4100–4200	5	1	nd	nd	6
4200–4300	5	1	nd	nd	6
4300–4400	2	1	nd	nd	3
4400–4500	2	1	nd	nd	3
4500–4600	1	1	nd	nd	2
4600–4700	1	1	nd	nd	2
4700–4800	1	1	nd	nd	2
4800–4900	nd	1	nd	nd	1

nd = not detected.

richness has also been analysed. All statistical analyses have been done using the statistical software package R (R Development Core Team 2012).

Results

Alien species were found distributed all along the altitudinal gradient i.e. from 300 m to 4900 m. The maximum richness of alien species (317) was observed in the 1000–1100 m altitudinal band. After this, a gradual decline in their richness was observed. It declined to 254 in the 1500–1600 m band and was below 50 in the 3000–3100 m band. Only one alien, *Caragana versicolor*, occurred in 4800–4900 m band (Table 1). Below this, upto 4800 m *Thalictrum minus* also occurred. Distribution of 36 plant species that include *Trapa natans*, *Celosia argentea*, *Corchorus tridens*, *Hibiscus cannabinus*, *Urena lobata*, *Acacia farnesiana* and *Indigofera astragalina* was found restricted below 1000 m. At the same time, 120 species such as *Achillea millefolium, Artemisia vestita, Gnaphalium polycaulon* and *Poa pratensis* occurred only above 1000 m. Twenty-nine alien species that include *Thalictrum minus, Agrostis canina* and *Vulpia myuros* did not occur below 2000 m. Species such as *Ageratum conyzoides*, *Taraxacum officinale*, *Verbascum thapsus*, *Oxalis corniculata*, *Juncus bufonius* and *Tridax procumbens* covered a wide altitudinal gradient (Table S1).

Of the total alien species, maximum are herbs (n=323), followed by trees (n=49), shrubs (n=40), and climbers (n=13). Alike total alien species, richness of alien herbs was also highest in the 1000–1100 m altitudinal band (n=242). The richness of alien tree species reached its peak in the 1100–1200 m band (n=39) and was stable until the 1400–1500 m band. After this, a decline in their richness was observed (Fig. 2). However, the richness of alien climber species peaked in the 600–700 m band (n=11) and was maintained until 1100–1200 m band. Though distribution of alien shrubs also peaked in the 600–700 m altitudinal band (n=28) and was maintained until the 900–1000 m altitudinal band (Table 1), unlike the climbers, they were also present in the high altitudes. Alien climbers were not recorded to occur above 2500 m. Thus, alien species richness significantly varied across altitude. This was true for all life forms (Table 2). Low altitude regions had a significantly higher number of alien species as compared to high altitude regions. Amongst the five altitudinal

Table 2. Comparison of alien species richness along altitude (one-way ANOVA table).

Variation of variable	*df*	SS	F	*P*
Species richness	1,44	512330	203.23	<0.001
Climber	2,19	182.2	11.20	<0.001
Tree species richness	1,44	7891.3	169.71	<0.001
Shrub species richness	1,44	3908.9	218.66	<0.001
Herb species richness	1,44	293522	196.8	<0.001
Between Altitudinal groups	4,41	572863	116.5	<0.001

(Altitude used as a factor and species richness as a response variable).

Table 3. Comparison of species richness amongst the five altitudinal groups.

Between Groups	Mean differences	Lower bound	Upper bound	Adjusted *P*-value
<1000 & 1000–2000	21.81	−27.47	71.10	0.714
<1000 & 2000–3000	−106.48	−155.77	−57.19	<0.001
<1000 & 3000–4000	−226.48	−275.77	−177.19	<0.001
<1000 & 4000–5000	−251.73	−302.13	−201.32	<0.001
1000–2000 & 2000–3000	−128.30	−173.02	−83.57	<0.001
1000–2000 & 3000–4000	−248.30	−293.02	−203.57	<0.001
1000–2000 & 4000–5000	−273.54	−319.49	−227.59	<0.001
2000–3000 & 3000–4000	−120.00	−164.72	−75.27	<0.001
2000–3000 & 4000–5000	−145.24	−191.19	−99.29	<0.001
3000–4000 & 4000–5000	−25.24	−71.19	20.70	0.526

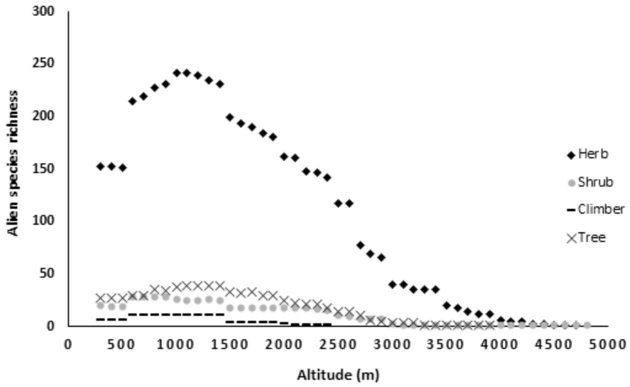

Fig. 2. Alien species richness along altitude.

groups, significant variations in alien species richness were observed (Table 3). This is also reflected in the cumulative alien species richness graph that shows an increase up to 2000 m after which it is more or less stable (Fig. 3). Thus, altitudinal distribution pattern of alien species richness is quite evident, and our null hypothesis that alien species distribution in Himalaya is independent of altitude stands rejected.

With respect to families, for majority of the altitudinal gradient, Asteraceae had higher alien species richness as compared to other families. However, between 3000 to 3500 m members of Poaceae dominated the alien flora. Amaranthaceae, Brassicaceae, Convolvulaceae and Fabaceae are the other alien species-rich families that occurred along the majority of the gradient. Above 4300 m Fabaceae was the dominant family (Table S1).

Discussion

It is evident that distribution and richness of alien species in the Himalaya changes with altitude as is the case with native species. However, as opposed to native plant species whose richness peaks around 2000–2500 m (Bhattarai *et al.* 2004; Giorgis *et al.* 2011; Grytnes & Vetaas 2002;), alien species richness was found to be maximum at lower altitudes (1000–1200 m) (Table 1). This is also indicated in the cumulative alien species richness graph that almost forms a plateau after 2000 m thereby indicating the minimal addition of unique alien species after this altitude (Fig. 3). This could be attributed to the fact that generally alien species have been introduced by humans at lower altitudes (Alexander *et al.* 2016). Most of the alien species occurring in HP are from South America and are of tropical origin (Jaryan *et al.* 2013). It has been stated that species that successfully colonize the

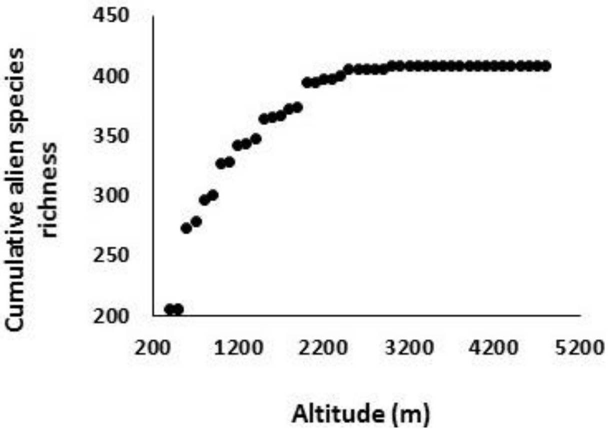

Fig. 3. Cumulative alien species richness along altitude.

low altitude regions have a chance to spread upwards (Alexander *et al.* 2011).

Negative correlation between alien species richness and altitude have also been reported along a roadside altitudinal gradient of 280–1290 m in Chile (Pauchard & Alaback 2004). In South Africa (Kalwij *et al.* 2008) and Australia (Mallen-Cooper & Pickering 2008; McDougall *et al.* 2005), linear decline in species richness with elevation have been reported while in the Canary island (Arevalo *et al.* 2005) and Mascareigne Archipelago (Tassin & Riviere 2003) hump-shaped patterns have been reported. Arevalo *et al.* (2005) found the highest number of alien species at intermediate altitudes while studying their distribution along a 0–2000 m altitudinal gradient. However, in Nepal, invasive and native species richness was observed peaking in the same elevation range (Bhattarai *et al.* 2014). In Arunachal Pradesh, maximum alien species were found in the low altitude tropical forests, followed by sub-tropical, and high altitude temperate forests (Kosaka *et al.* 2010).

Thus, generally, low altitude regions of Himalaya have relatively higher alien species richness that decreases with increasing altitude. In contrast, maximum native species richness is at mid altitudes where species common to both the lower and higher altitude are present. Here, native species richness has been found to be positively co-related with temperature, mean annual rainfall, moisture index and actual evapo-transpiration (Acharya *et al.* 2011). Interestingly, native plant species such as *Picrorhiza kurroa*, *Aconitum heterophyllum*, *Nardostachys jatamansi*, etc. that occur at high altitudes have narrow ecological amplitude and are adapted to low temperature conditions. On the contrary, alien species such as *Rumex nepalensis*, *Taraxacum officinale*, *Trifolium repens*, etc. that occur at higher altitudes have a wider altitudinal distribution and they are found at low altitudes also. It lends support to the view that these species are basically generalist and have been introduced at low altitudes (Alexander *et al.* 2016). They seem to have crossed the environmental barriers and successfully adapted to high altitude conditions. While *Taraxacum officinale* was the only species found going upto 3000 m in Arunachal Pradesh (Kosaka *et al.* 2010), the present study reports occurrence of *Zephyranthes citrina*, *Adonis aestivalis*, *Thalictrum minus,* etc. above 4000 m. It has been reported that harsh climatic conditions, minimal human disturbance, and lower propagule pressure at high altitudes progressively filters out alien species and hence their richness at higher altitudes is low (Alexander *et al.* 2011). In addition to the above, environmental heterogeneity and time of introduction of alien species also plays an important role in determining their spread. The early an alien species has been introduced, the higher is the possibility of its spread (Becker *et al.* 2005). In the Canary Islands, archaeophytes having a history of more than 500 years of introduction were found to be widely distributed as compared to neophytes (Haider *et al.* 2011). Analyses of such temporal patterns of alien species introduction and their spread are also desired from the Himalaya. In addition to deliberate introductions, trans-boundary trade and migration are some of the other reasons behind upcoming of alien plant species in the Himalayan region (Khuroo *et al.* 2007). The silk route and high altitude passes in the Himalaya may have favoured their establishment at higher altitudes. During the past few years, new roads have been added in HP with a considerable amount of them being in the high altitudes (http://himachalpr.gov.in). This surely is going to promote their spread as developmental activities in the form of road construction have been suggested to favour establishment of alien species (Pickering & Hill 2007).

As expected, owing to traits variations, species richness of different life forms peaked in different altitudinal bands. While woody species were common at lower altitudes, herbaceous life form dominated the relatively higher altitudes. The harsh climatic conditions at higher altitudes limit arboreal growth (Körner 2003; Xu *et al.* 2017). It has been reported that across elevation functional traits such as plant height, leaf area, seed mass, time to maturity, nutrient allocation, etc. vary more in alien species when compared to native species (Bustamante *et al.* 2018). Alien species therefore exhibit greater adaptive plasticity than natives across altitude (Datta *et al.* 2017; Moran *et al.* 2017). Traits such as low seed mass and short time to maturity will be favoured by environmental changes and will facilitate spread of alien species (Hellmann *et al.* 2008). Also, owing to increasing temperatures, it is expected that low temperature constraints on alien species will be reduced thereby favouring their growth in upper elevation bands or ranges. Thus, while the study provides information on alien species richness across an altitudinal gradient, it also provides inputs regarding spatial spread of species along altitude. This becomes important for documenting future spread of alien species.

Overall, along the entire altitudinal gradient, the dominance of alien species belonging to Asteraceae, Poaceae and Fabaceae are evident. Asteraceae followed by Fabaceae have also been reported to be the dominant alien rich families in a road side elevation transect in Arunachal Pradesh (Kosaka *et al.* 2010). These three families have the highest species richness in the world, Himalaya and Himachal Pradesh (Rao 1994). Therefore, the dominance of alien species belonging to these families seems justified.

Conclusions

The study concludes that distribution pattern of alien species richness changes along the altitudinal gradient. The maximum richness of alien species is at lower altitudes, which is significantly different from higher and middle altitudes. These patterns of alien species distribution are in contrast to the native species distribution whose maximum richness is at mid-altitudes. In the changing climatic conditions, where-in changes in species distributional range and optima have been documented, how alien species will respond is worth investigating.

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Supporting Information

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

Table S1. Characteristics of alien species occurring in HP.