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Plant species diversity and rarity patterns along altitude range covering treeline ecotone in Uttarakhand: conservation implications

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Abstract: The study documents plant diversity within a forested high altitude zone (2000–3500 m asl) of Uttarakhand wherein 1471 plant species (106 trees, 233 shrubs and 1132 herbs) occur. The lowest belt, 2000–2500 m exhibited the highest diversity (815 spp.; 55.4%). A sharp decline in tree and shrub species representation was apparent with increasing altitude (low altitude: 88.7% and 66.5%; high altitude: 15.1% and 27.4%, respectively), while herb species representation did not vary (50.0–47.6%). Species to genera ratio (S/G) for entire altitude zone was 1.63 for trees, 1.97 for shrubs and 2.21 for herbs. S/G changed with elevation, but the patterns varied across growth forms. Of the total, 387 (26.3%) species were recorded from the study transects which included 52.5% (203 spp.) Himalayan natives. Rarity analysis of these natives has highlighted conservation priorities at local to regional scale. Attributes of vegetation have been described across systematically sampled 100 m altitude bands in five transects covering treeline ecotone. Altitudinal patterns varied across the transects, except for seedlings, which tended to decrease with altitude regardless of the transect. The study strongly reflects heterogeneity in patterns across altitude transects and life forms. We have used β diversity and species turn-over to shed light on local and regional conservation implications.

Key words: β diversity, conservation, life forms, rarity analysis, species richness.

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Introduction

Several studies have established that altitude plays role in regulating species richness patterns (Grytnes 2003; Kessler 2000). Therefore, altitude gradient is being increasingly recognized to offer many characteristics that make it more suitable for uncovering the underlying cause(s) of spatial variation in diversity (Sanders & Rahbek 2012). Consequently, in recent decades, there has been a noticeable increase in biodiversity research along altitude gradients in mountains (Guo *et al.* 2013; Tang *et al.* 2014).

The projected worldwide changes in vegetation distribution under the global climate change scenarios, and rapid upward shifts in vegetation boundaries in mountain ecosystems have been reported in several studies (e.g., Kapfer & Grytnes 2012; Kelly & Goulden 2008; Li *et al.* 2015; Lenoir *et al.* 2008). A multi-site and multi-partner study on European mountains indicates the species accumulation near mountain summits because of climate warming (Steinbaure *et al.* 2018). Such studies have gained greater attention to understand ecological and evolutionary responses of species to recent climate changes and consequent extinction risks at different spatial scales (Foden *et al.* 2007; Parmesan 2006; Pauli *et al.* 2006).

The Himalayan mountains, which have been globally recognized as biodiversity hotspots, provide altitude range that represents the widest bioclimatic gradient in the world (Grytnes & Vetaas 2002). Evidences suggest that Himalayas are warming at much higher rate than global average (Singh *et al.*

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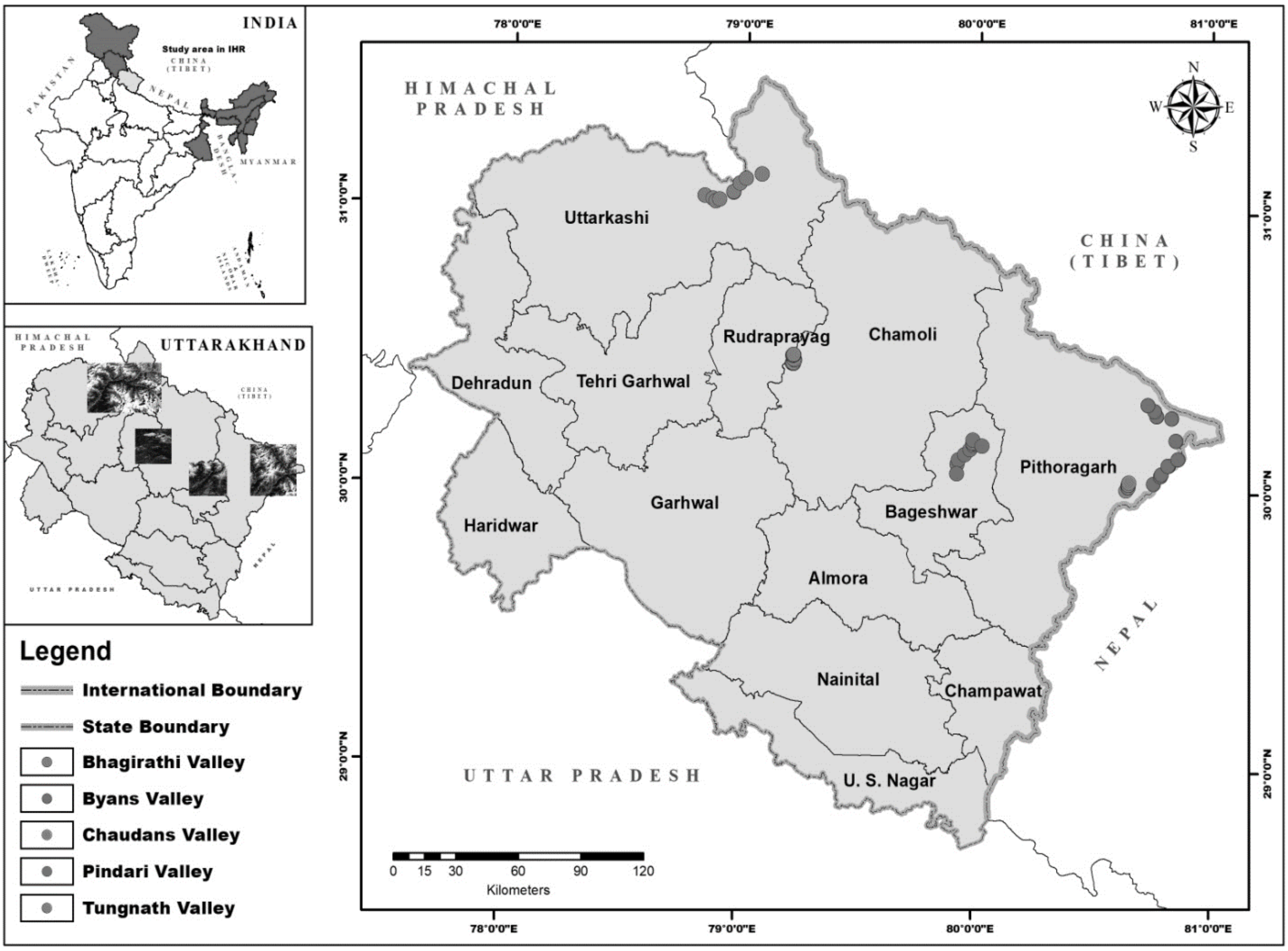

All boundaries are tentative and only for dipiction, for actual boundaries Survey of India needs to be consulted.

Fig. 1. Study area and location of the five studied altitude transects.

2010, 2011; Shrestha *et al.* 2012) and the extent of temperature rise is more in higher altitudes (You *et al.* 2017). This rapid warming in the Himalayas is predicted to increase upper limit of plants distribution, vegetation cover and abundance of species that get adapted to warmer climate. All these features have made the Himalayas interesting candidate for biodiversity studies along altitude gradients. However, because of the remoteness and difficult terrain in high altitude areas not many studies have been carried out on species composition and diversity of tree line areas of Himalayas. Only recently, a few investigations have been undertaken in Nepal Himalaya (Bhattarai & Vetaas 2006; Grau *et al*. 2007; Grytnes & Vetaas 2002; Vetaas & Grytnes 2002). In Indian Himalayas, Singh *et al.* (1994) reviewed patterns of leaf characteristics, forest structure, tree species diversity, biomass, and productivity across an altitude gradient of 3300 m in Kumaun part of west Himalaya. Some other studies have also provided insight on altitude patterns of forest vegetation form this region (Rawal & Pangtey 1994; Rawal *et al*. 1994). Oommen & Shankar (2005) used altitude gradient for comparing woody plant species distribution across local to landscape level in west Himalaya. In the eastern Indian Himalaya, Behera & Kushwaha (2006) and Acharya *et al.* (2011) have provided information about altitudinal patterns of tree species distribution. However, the comprehensive understanding on diversity distribution across plant life forms and spatial heterogeneity is still lacking. More importantly, the diversity patterns in higher altitude areas, which are more sensitive to climate change impacts, are poorly known.

This paper describes and discusses patterns of changes in species diversity in different life forms (herbs, shrubs and trees) along the altitude gradients in higher Himalaya that encompass treeline ecotones. This study, for the first time in west Himalaya, has considered multiple altitude transects for providing evidence based answers to the following questions: (i) how do the species diversity patterns along an altitude gradient in various life forms vary? (ii) what influences rare/occasional species have on diversity patterns? (iii) do the compositional patterns in treeline ecotones differ considerably across the region?, and (iv) do the existing patterns of diversity have conservation implications under changing climate?

Material and methods

Study area

This study was conducted in Uttarakhand (28°43' N 31°27' N and 77°34' to 81°02' E), west Himalaya. Representative altitude transects, covering forested area in high altitude zone (i.e., 2000–3500 m asl), were identified for intensive investigation (Fig. 1). The dissected topography and great variations in climatic conditions along altitude range are characteristic features of the area. While identifying the intensive study sites, the focus was kept on representing most of the broad geological and geo-morphological formations and climatic regimes (i.e., monsoonal and non-monsoonal). In this context, the study area broadly covers two distinct geological provinces, both falling under monsoonal regimes. The southern narrow altitude belt (approx. 2000–2400 m) belongs to lesser Himalayan domain. This chain suddenly rises to greatly elevated peaks of the greater Himalaya towards north. The greater Himalayan belt exhibits extremely rugged topography and is characterised by glacial features like lateral and medial moraines (Chandra 1986). This area occurs under the Indian monsoon regime. In non-monsoonal regime, the extreme north of study area, parallel to the Great Himalayan range, lies in an arid mountainous tract often known as cold desert that is constituted of the sediments of the Tethyan sea bed. The altitude on an average remains above 3000 m asl. This area is away from the Indian monsoon, and referred to as rain shadow of the main Himalayan region (Kumar *et al.* 2017).

Baseline on floristic diversity

A base line of potentially occurring plant species, across three life forms (i.e., trees, shrubs, and herbs) within the altitude range 2000–3500 in study area was prepared after review of published information, mainly the regional floras and other publications (i.e., Gaur 1999; Naithani 1984; Osmaston 1927; Rai *et al.* 2017). The broad distributional trends of plants in each life form were analyzed across three altitude zones, (2000–2500, 2500–3000, and 3000–3500 m asl). The information was also used to assess patterns of species to genera and species to family ratio for different life forms and altitude zones.

Vegetation assessment

Three representative altitude transects in monsoonal regimes (i.e., Pindari, Tungnath and Bhagirathi) and two in non-monsoonal regimes (i.e., Byans and Nelang) were investigated between 2013–2017 for generalizing compositional patterns of vegetation for target region. Among these, three altitude transects in monsoonal regime have been used to describe the altitude patterns of species diversity. Besides altitude, as apparent from evidences, these transect also represent three broad levels of anthropogenic disturbances (i.e., low disturbance-Pindari transect, medium disturbance- Bhagirathi transect, and high disturbance-Tungnath transect).

The study transects were investigated by systematically dividing the transect into 100 m altitude bands. Within each altitude band, forest vegetation was investigated using random sampling method. This approach represents a stratified random sampling. Evidently, in this approach most of the variations in vegetation are captured as the samples are distributed throughout the area (Reshi *et al.* 2017). However, since the transects in non-monsoonal sites (all above 3000 m asl) did not have continuous forest vegetation, sampling did not follow systematic 100 m bands, rather plots were laid depending on availability of forest vegetation.

In each altitude band, three plots (50 × 50 m) were marked randomly. For enumerating the vegetation, within each plot, ten quadrats (10 × 10 m) for trees and saplings, 20 (5 × 5 m) for shrubs and seedlings and 40 (1 × 1 m) for herbs were laid randomly. In case of tree species, individuals measuring > 10 cm diameter (diameter at breast height-dbh; 130 cm above ground level) were considered as trees (adults), individuals between > 3–10 cm diameter as saplings and individuals < 3 cm diameter as seedlings. For generating demographic profiles, the adult individuals were categorized following 10 cm diameter classes as, C: 10–20; D: 20–30; E: 30–40; F: 40–50;

Table 1. Defining rarity and conservation priority classes at different spatial scales (based on Rawal & Dhar 1997). Rarity increases from 1 to 8; conservation priority: I highest and IV lowest. Attributes are coded as: WGR-wide geographical range; RGR- restricted geographical range; BEA-Broad Ecological Amplitude; NEA-Narrow Ecological Amplitude; LA-Locally Abundant; LS-Locally Scarce.

Rarity	Attributes	Level of conservation priority	
		Himalaya	Study Area
1	WGR+BEA+LA	IV	IV
2	WGR+BEA+LS	IV	III
3	WGR+NEA+LA	III	II
4	WGR+NEA+LS	III	I
5	RGR+BEA+LA	II	IV
6	RGR+BEA+LS	II	III
7	RGR+NEA+LA	I	II
8	RGR+NEA+LS	I	I

G: 50–60; H: 60–70; I: 70–80; J: 80–90; K: 90–100; L: >100 cm or more diameter. Quadrat data was pooled by plots to estimate density, frequency, total basal area (TBA) and their relative values following the standard phytosociological approaches (Dhar *et al.* 1997; Gairola 2005; Mueller-Dombois & Ellenberg 1974). Importance Value Index (IVI) was calculated following Curtis (1959). Species richness is simply the number of species per unit area (Pielou 1975; Whittaker 1975).

Considering that beta diversity (β) is an important emergent property, which describes the change in species content from one site or sample to another, it was measured using the Whittaker (1960) formula as given in Mena & Vazquez-Dominguez (2005): $\beta = (s/\alpha) - 1$; where α is the mean number of species per altitude belt, and 's' is the total number of species recorded across the study system (i.e., altitude transect). As a measure of change in species composition, pair-wise comparison of the presence absence data was made as turnover measure across altitude belts following Wilson & Shmida (1984). The turnover was calculated with the following formula: $\beta = b + c/2a+b+c$; where 'a' is the total number of species shared by the two adjacent altitude belts, 'b' is the number of species exclusive in the higher belt and 'c' is the number of species exclusive in lower belt (Koleff *et al.* 2003).

To numerically model the distribution of species in different life forms (i.e., trees, shrubs, herbs) along the altitude gradient in different transacts, quadratic models were fitted between altitude and species distributions. Selection of the quadratic model was made based on the performance. Model performances were primarily evaluated by computing statistically significant ($P < 0.05$) r^2 values. Moreover, to assess distribution of sample means from observations and model simulations, analysis of variance (ANOVA) was carried out, particularly, estimated F value of each model was compared with critical F-value. The result section highlights those models for which a significantly high r^2 value was noted at $P < 0.05$. Subsequently, results from ANOVA for these models were elaborated.

Rarity patterns

Among the species assessed along the altitude transects, the Himalayan natives were considered as species of special interest and identified following Dhar & Samant (1993). Species with spatial range restriction in the Himalaya (i.e. Indian Himalaya, Nepal, Bhutan, Pakistan Himalaya) were considered as Himalayan endemics and the ones with range extension slightly beyond the Himalaya were referred to as 'near endemics' (Dhar & Samant 1993; Rawal & Dhar 1997). All such species were analyzed for their rarity ranking as measure of sensitivity towards endangerment. The rarity analysis approach of Rabinowitz *et al.* (1986) was used with modifications as suggested in Rawal & Dhar (1997). Three broad ecological attributes (i.e., Geographical Range- GR; Ecological Amplitude- EA; Local Abundance- LA) were considered for defining rarity class of a particular species. Further classification of GR as wide (WGR) and restricted (RGR); EA as broad (BEA) and narrow (NEA) and LA as locally abundant (LA) and locally scarce (LS) was based on Rawal & Dhar (1997). Based on the possible combinations of these attributes, total of eight classes of rarity were possible. The status of species was further described at regional (Himalaya) and local (study area) spatial scales to elucidate the conservation priorities (Table 1).

Results

Floristic diversity pool

Within the investigated altitude range (i.e., 2000–3500 m) in west Himalaya a total of 1471 plant species [106 (7.2%) trees, 233 (15.8%) shrubs and 1132 (77.0%) herbs] occur. When species distribution is seen in relation to three 500 m altitude zones (i.e.,

Table 2. Floristic diversity pool (Species- S, Genera- G, Family- F) in high altitude forest zone (2000–3500 m) of Uttarakhand.

	Trees					Shrubs					Herbs				
Altitude	S	G	F	S/G	S/F	S	G	F	S/G	S/F	S	G	F	S/G	S/F
2000–2500	93	61	35	1.52	2.66	155	97	44	1.6	3.52	567	359	88	1.57	6.44
2500–3000	45	32	21	1.40	2.14	108	69	35	1.57	3.09	529	296	75	1.79	7.05
3000–3500	16	15	11	1.10	1.45	64	31	16	2.06	4.00	539	245	62	2.20	8.69
Total	106	65	37	1.63	2.86	233	118	49	1.97	4.76	1132	511	100	2.21	11.32

Table 3. Compositional attributes of forests in three altitude transects of Uttarakhand.

Transect	Density Range (individuals ha^{-1})					TBA Range (m^2ha^{-1})
	Tree (×10)	Sapling (×10)	Seedling (×10)	Shrubs (×100)	Herbs (×1000)	
Pindari	21–80	10–41	67–950	43.5–999.0	35.2–984.0	14.8–116.9
Tungnath	11–90	00–52	2–228	4.6–57.6	44.5–351.3	3.9–99.1
Bhagirathi	54–112	14–220	20–1272	7.6–21.4	67.0–132.0	10.3–111.2

2000–2500 m lower zone, 2500–3000 middle zone and 3000–3500 m higher zone) following patterns emerge: (i) the lower altitude zone exhibited maximum floristic diversity (815 spp.; 55.4%) and the higher zone the minimum (619 spp.; 42.1%), (ii) a sharp decline in tree species number occurred from lower (93 spp.; 88.7%) to higher zone (16 spp.; 15.1%), (iii) for shrubs, the decline was less dramatic, from 66.5–27.4%, and (iv) the herb species representation remained more or less similar (50.0–47.6%) across the three altitude zones (Table 2).

While considering diversity distribution of higher level of taxa (i.e., genera and family), more rapid decline with altitude is apparent as compared to the species (Table 2). The species to genera ratio (S/G) for the entire landscape was calculated as 1.63 for trees, 1.97 for shrubs and 2.21 for herbs. However, across the three altitude zones, the S/G values declined from lower to higher zone for trees, but increased for both shrubs and herbs (Table 2). Similar trends were found for species to family (S/F) ratio (Table 2).

Analysis of rarity

While considering plant species representation, the study transects covered considerably large proportion of reported plant diversity pool in forested high altitude zone of Uttrakhand (i.e., herbs 270 spp., 23.9%; shrubs 63, 27.0%; trees 54, 50.9%). Most of these species (203, 52.5%) are Himalayan natives; of which 39.1% species are near endemics to Himalaya. Nativity across life forms ranges was 47.4% for herbs, 59.3% for trees and 68.2% for shrubs.

Frequency of native species in the eight categories of rarity across life forms is presented (Fig. 2). Altogether, most of the species (158, 77.8%) exhibited wide geographical distribution (rarity class 1–4) and more than half of these (91, 57.6%) have broad ecological amplitude (rarity class 1–2) an attribute of commonness. Forty-five species (22.2%) exhibited restricted geographic distribution (rarity class 5–8). Of these, 23 (51.1%) had narrow ecological amplitude (rarity class, 7–8), suggesting high sensitivity.

Analysis revealed that 120 taxa (59.1%) are locally abundant (rarity class 1,3,5,7) and 81 (67.5%) species of these had broad ecological amplitude, a feature contributing to commonness of taxa at local level (rarity class 1,5). Fifty-five taxa (27.1%) were locally scarce and with narrow ecological amplitude (rarity class 4, 8), hence are at high risk of becoming endangered locally. A few examples across life forms include: trees- *Acer caesium, Pyrus lanata, Syringa emodi*, *Ulmus wallichiana;* shrubs-*Berberis jaeschkeana, Rhododendron lepidotum, Thamnoclamus spathiflora;* and herbs-*Cypripedium cordigerum, C. elegans, Habenaria edgeworthii, Malaxis acuminata, Nardostachys grandiflora, Rheum tibeticum,* etc.

Forest vegetation composition

Broad range of compositional attributes of forests in three altitude transects indicate that their tree density and total tree basal area (TBA) ranges are comparable (Table 3). However, shrub and herb densities were distinctly higher for

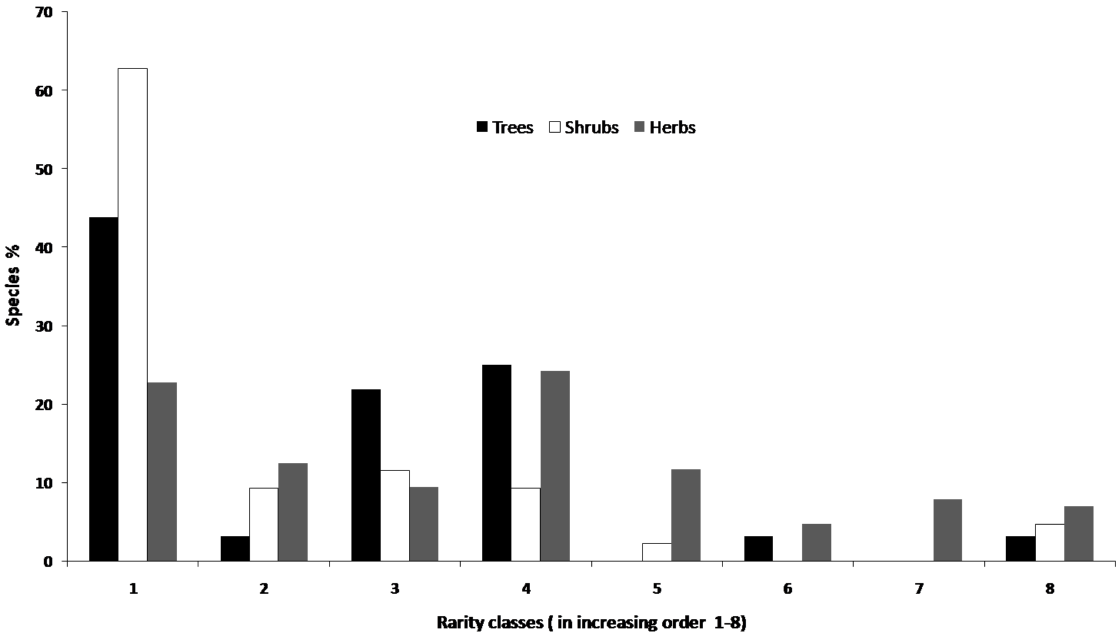

Fig. 2. Rarity distribution of Himalayan native species across life forms in studied altitude transects (level of rarity increases from 1–8).

Pindari transect. Both sapling and seedling densities were generally low but for Bhagirathi transect (Table 3).

Patterns of density distribution across altitude range were modelled for different transects. For different size classes, i.e., trees, saplings and seedlings, density distribution along altitude gradient did not follow uniform patterns (Fig. 3). Along the altitude gradient tree density either peaked around 2500 m or decreased monotonically. Sapling density varied widely along the altitude gradient. Interestingly seedling density tended to decline with altitude in all three transects (Fig. 3).

As for shrub density in relation to altitude, the three transects differed from one another. It tended to increase with altitude in Tungnath, continuously decreased with altitude in Bhagirathi and showed a mid altitude peak in Pindari. Herb density, in general, was relatively stable across the altitude transects (Fig. 4).

The Total tree basal area showed a hump shaped curve in Tungnath and Pindari, with peak around 2600 m and 2400 m, respectively. In Bhagirathi it tended to increase monotonically with altitude up to 2800–3000 m (Fig. 5).

Species richness patterns

The species richness ranged from: (i) 5–15 (Pindari), 1–7 (Tungnath) and 2–10 (Bhagirathi) for trees (100 m^2 area); (ii) 3–13 (Pindari); 2–9 (Tungnath) and 1–5 (Bhagirathi) for shrubs (25 m^2 area); and (iii) 18–53 (Pindari); 5–48 (Tungnath) and 4–11 (Bhagirathi) for herbs (1 m^2 area). Thus, for all life forms Pindari was the richest, possibly because of the lowest human disturbance.

The tree species richness along altitude gradient followed a hump shaped curve with peak in the lower half of the altitude range- around 2500 m in Tungnath and Bhagirathi, and 2700 m in Pindari (Fig. 6). In Tungnath, shrub species richness increased with altitude but it tended to decrease with altitude in other two sites. In Tungnath herbs also showed positive correlation with altitude, but in other transects the tendency was to form mid altitude peak (Pindari) or plateau (Bhagirathi).

In brief, in Tungnath tree species richness decreased sharply and shrub and herb species richness increased with altitude. In the rest, the tendency was to form mid altitude plateau.

Beta diversity and species turnover

The values of β diversity calculated for different transects for each life form (Table 4) indicated wide variations across life forms and transects. Beta diversity contributed significantly to the altitude transect level species richness of Pindari for herb and shrubs, but little for trees (Table 4). In Tungnath tree

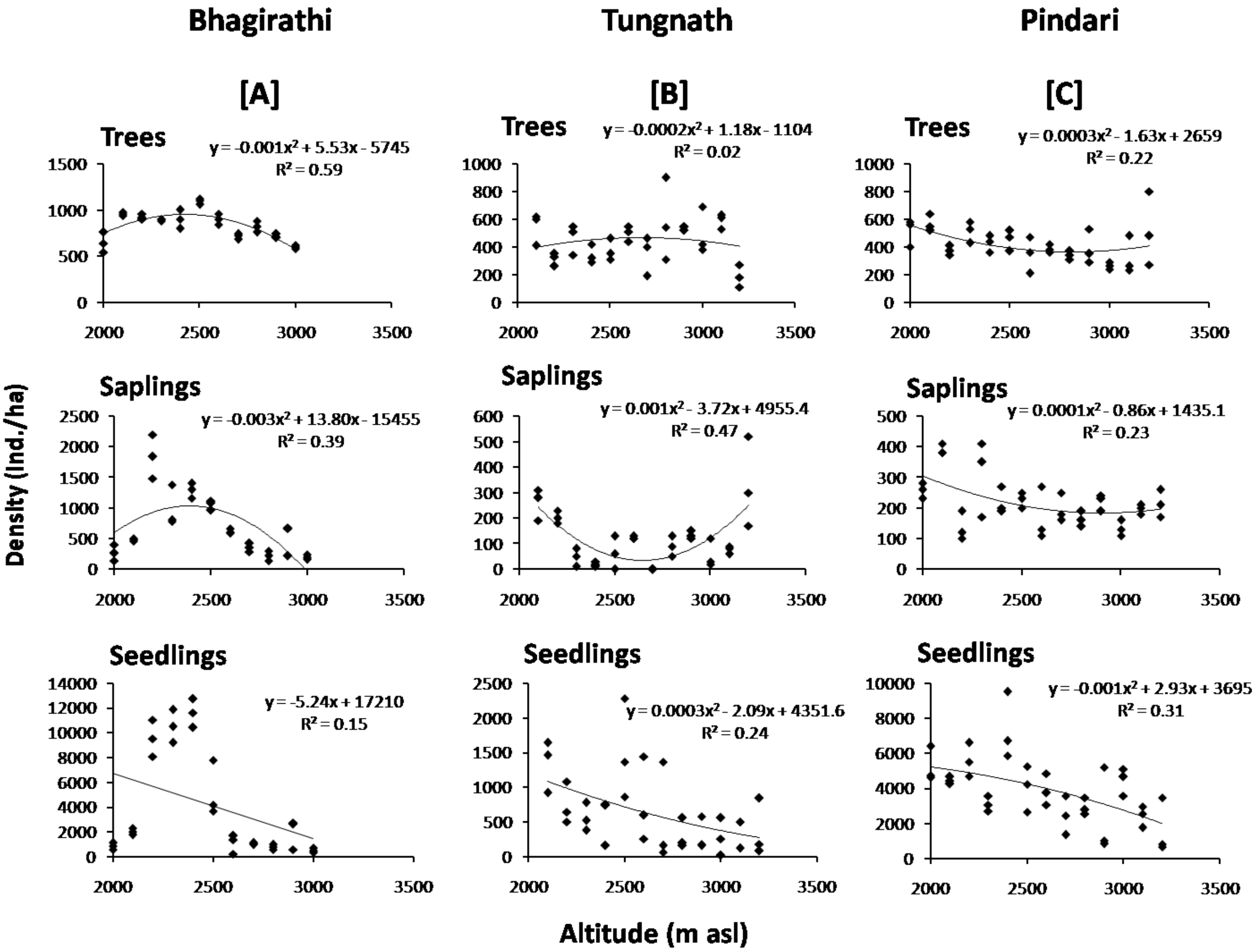

Fig. 3. Density distribution in trees, saplings and seedlings along three altitude transects: A-Bhagirathi, B- Tungnath, C-Pindari.

Table 4. Beta diversity variations across life forms and transects.

Life forms	β diversity in different transects		
	Tungnath	Bhagirathi	Pindari
Trees	5.1	3.4	2.3
Shrubs	3.1	1.8	3.3
Herbs	1.8	2.7	5.1

species change rapidly, but herbs changed slowly.

Towards understanding the species compositional heterogeneity across pairs of altitude bands in different transects, the species turnover was calculated and depicted (Fig.7). The patterns are not uniform for transects and life forms.

Composition at treeline ecotone

Considering that treeline in the study area broadly varies from 2800–4200 m (see RS based study in this volume), the studied plots falling within this altitude range were analysed separately for monsoonal and non-monsoonal sites (Table 5).

The ecotone exhibits greater richness of tree species (1–8 species per plot) and dominant/co-dominant types (i.e., *Quercus semecarpifolia, Abies pindrow, Betula utilis, Rhododendron arboreum, R. campanulatum, Taxus wallichiana, Acer accuminatum* and *Cedrus deodara)* in monsoonal sites as compared to non-monsoonal sites (1–3 spp. per plot; dominants *Pinus wallichiana, Betula utilis, Abies spectabilis, Juniperus semiglobosa).*

Discussion

Floristic diversity and representativeness

Of the known total floristic diversity pool of Uttarakhand (Uniyal *et al.* 2007), the forested high altitude zone (2000–3500 m asl) that we studied

Table 5. Forest compositional attributes at treeline ecotone of Uttarakhand.

Sites	Density h^{-1} in tree life forms			TBA ($m^2 h^{-1}$)	Shrub density (h^{-1})	Species Richness				Dominant species (IVI)
	Trees	Sap-lings	Seed-lings			Trees	Sap-lings	Seed-lings	Shrubs	
Monsoonal Sites										
(i) Chaudans Site										
2900	680	400	18400	43.7	2140	8	5	6	6	*Quercus semecarpifolia* (125); *Abies pindrow* (69)
3100	520	320	1400	25.2	2700	6	2	3	4	*Q. semecarpifolia* (142); *Taxus wallichiana* (91)
3300	810	240	2400	67.7	1160	6	1	2	2	*Q. semecarpifolia* (228); *A. pindrow* (22)
3500	710	270	1200	35.1	680	1	1	1	1	*Q. semecarpifolia* (300)
(ii) Pindari Site										
2900	530	280	5200	48.1	5000	8	6	5	7	*Q. semecarpifolia* (117); *Rhododendron Campanulatum* (48)
3100	480	210	1750	28.1	4350	8	8	5	7	*Betula utilis* (113); *A. pindrow* (56)
3300	270	260	3450	7.2	1615	6	6	8	8	*Betula utilis* (172); *R. campanulatum* (42)
(iii) Bhagirathi Site										
2900	690	180	480	48.8	950	3	3	3	2	*Cedrus deodara* (231); *A. pindrow* (47)
3100	600	200	420	57.7	920	2	2	2	2	*C. deodara* (256); *B. utilis* (44)
(iv) Tungnath Site										
2900	540	133	122	46.7	2847	3	3	4	8	*Q. semecarpifolia* (199); *Acer accuminatum* (52)
3100	590	77	373	74.5	4380	3	3	3	10	*Q. semecarpifolia* (222); *R. arboreum* (50)
3300	186	330	367	5.40	2847	2	3	2	12	*R. campanulatum* (264); *Q. semecarpifolia* (35)
Non Monsoonal Sites										
(v) Byans Site										
3000	280	190	1780	9.5	1720	3	3	3	8	*A. spectabilis* (160); *Pinus wallichiana* (66)
3200	350	180	1120	23.9	2260	2	2	2	6	*A. spectabilis* (242); *P. wallichiana* (58)
3600	150	330	1400	2.5	1440	2	2	2	5	*B. utilis* (170); *P. wallichiana* (130)
4000	140	500	420	5.6	1100	1	1	1	6	*B. utilis* (300)
(vi) Nelang Site										
3100	370	0	0	3.4	2100	2	0	0	5	*P. wallichiana* (274) *J. semiglobosa* (26)
3300	530	0	0	4.5	1100	1	0	0	5	*J. semiglobosa* (300)
3500	100	0	0	2.7	1500	1	0	0	6	*J. semiglobosa* (300)

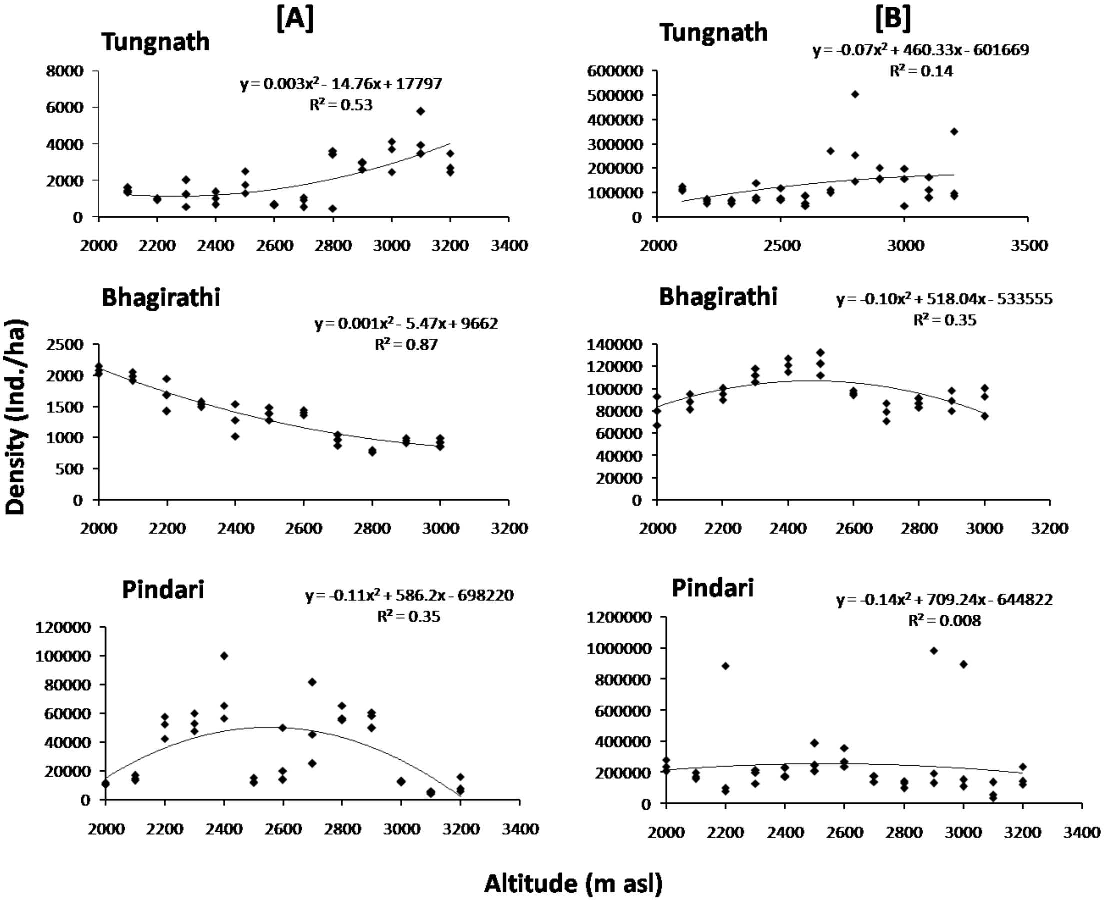

Fig. 4. Density distribution of shrubs (A) and herbs (B) along altitude transects.

accounts for 31.2% species, 45.6% genera and 83.2% families. Species level representativeness for diverse life forms ranges from 30.1% herbs, 33.3% trees to 47.9% shrubs. Even while comparing with the reported plant diversity of Himalaya (Rana & Rawat 2017), the study zone represents 14.0% species, 31.5% genera, and 59.6% family diversity of Himalaya. Therefore, from conservation perspective, any effort made to protect this altitude zone would contribute for conservation of a significant proportion of Himalayan plant biodiversity. Also, this altitude belt is left with some of the old growth forest stands, which are particularly rich in bird and some other living groups.

Recognizing that the S/G ratio have been frequently used to describe the biogeographic patterns and taxonomic structure of clades and biotas (Krug *et al.* 2008), we interpret the patterns of S/G at local scale in the light of the hypothesis that describes spatial variations of S/G as part of evolutionary dynamics wherein these ratios are related to speciation or diversification rates (Floeter *et al.* 2004). The altitudinal decrease of S/G in case of trees in study area would imply their phylogenetic over dispersion towards highest altitudes. On the contrary, the increasing S/G ratio of shrubs and herbs towards higher altitudes implies phylogenetic clumping meaning that diversification within the genera is more intense.

Rarity distribution and conservation priorities

Occurrence of 52.5% native elements of which a high proportion (39.1%) is of near endemic species in studied transects in itself reflects 'extent of rarity' (Dhar & Samant 1993; Krukerberg & Rabinowitz 1985; Rawal & Dhar 1997).

Considering the attributes of rarity, we suggest various priority classes for conservation initiatives. For instance, of the recorded native plants 22.2% taxa with restricted geographical distribution reflect higher susceptibility to endangerment at Himalayan level. This susceptibility at regional scale goes further high with narrowing of ecological

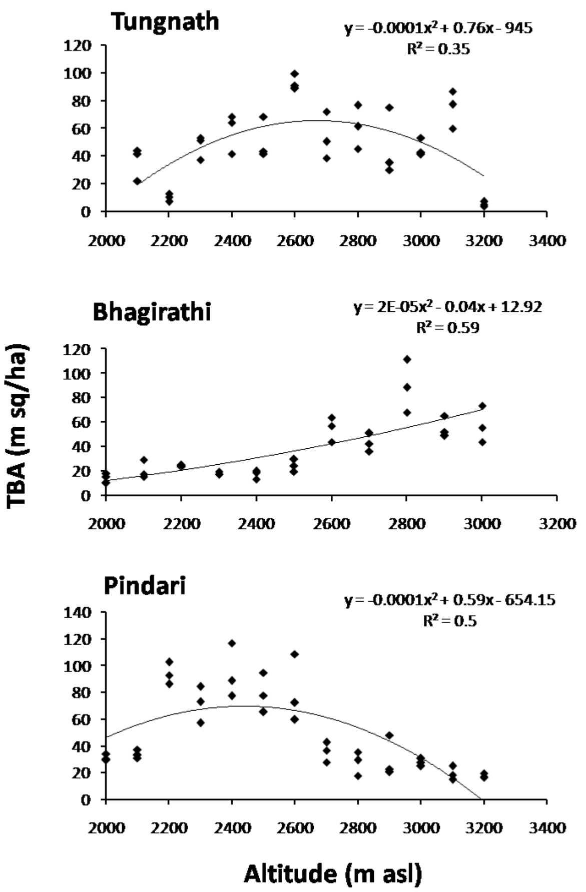

Fig. 5. Distribution of total basal area (TBA) for trees across three altitude transects in Uttarakhand.

amplitude (11.3 of native taxa). At the local level, 55 taxa with recorded low abundance and narrow ecological amplitude deserve greater attention (Rawal & Dhar 1997). However, nine species of herbs (*Andorosaces armentosa, Carex obscura, Goodeyera biflora, Habenaria edgeworthii, Lactuca lessertiana, Maharanga emodi, Primula elliptica, P. reidii, Rheum tibeticum*), two species of shrubs (*Berberis jaeschkeana, Thamnocalamus spathiflora*) and 1 species of tree (*Ulmus wallichiana*), with restricted global distribution, narrow ecological amplitude and scarce local population (rarity class 8), exhibit sensitivity both at local to regional scale, are suggested as most critical and top ranking priority taxa.

While considering the life forms, at local scale, relatively high proportion of native herbs (31.3%) and trees (28.1%) are currently threatened due to their restricted altitude range (ecological amplitude) and reduced local abundance. We argue other additional factors, such as anthropogenic disturbance, will add to their sensitivity of being eliminated at local level. However, before generalizing for entire region, there is a need to analyse these trends of rarity on a larger datasets. For instance, at least for the entire altitude transects (sub-tropical to alpine) in Uttarakhand.

Conservation imperatives of species richness and beta diversity

Towards conservation of biodiversity across spatial scales, there is a need to understand and recognize (i) the value of locally collected data sets along with the regional diversity dynamics, and (ii) the variations in mechanisms that maintain biodiversity at local to regional scale (Chesson & Kuang 2008; Socolar *et al.* 2016; Terborgh 2012).

In the above context, among various expressions of diversity, species richness has remained a major focus of biogeographical researches (Acharya *et al.* 2011; Kessler 2000; Oommen & Shankar 2005).

Considering that the total species number recorded in three study transects represented over 26.3% of species reported from entire high altitude forested zone of Uttarakhand, and this proportion of representativeness even goes higher for woody life forms (shrubs 27%, trees 50.9%), it is safe to generalize the patterns of distribution drawn from these transects for entire altitude zone (2000–3500 m) in Uttarakahnd, west Himalaya.

Our study strongly reflects that patterns of species richness distribution along altitude gradient are not uniform for transects and life forms. The tree species richness tends to form a hump-shaped relationship with altitude. Such relationships are typically reported for species richness in different parts of Himalaya (i.e., Sikkim Himalaya- Acharya *et al.* 2011; Nepal- Grytens & Vetaas 2002; west Himalaya- Oommen & Shanker 2005). However, we argue, since the present study confines only to the upper half (2000–3500 m) of entire altitude transect, which can go down to <500 m altitude, there exists a strong possibility for another tree species richness peak in lower half of the altitude transect (i.e., between <500–2000 m). This possibility can be tested through evidences generated in lower half of altitude transects. In present case, the altitude bands between 2300–2500 m support the highest tree species richness. The diversity in patterns of shrub and herbaceous life forms along altitude gradient implies increasing the role of other site-specific factors. For instance, Tungnath transect (disturbance intensive species poor) suggests increasing richness of shrubs and herbs with altitude. Whereas for Pindari transect

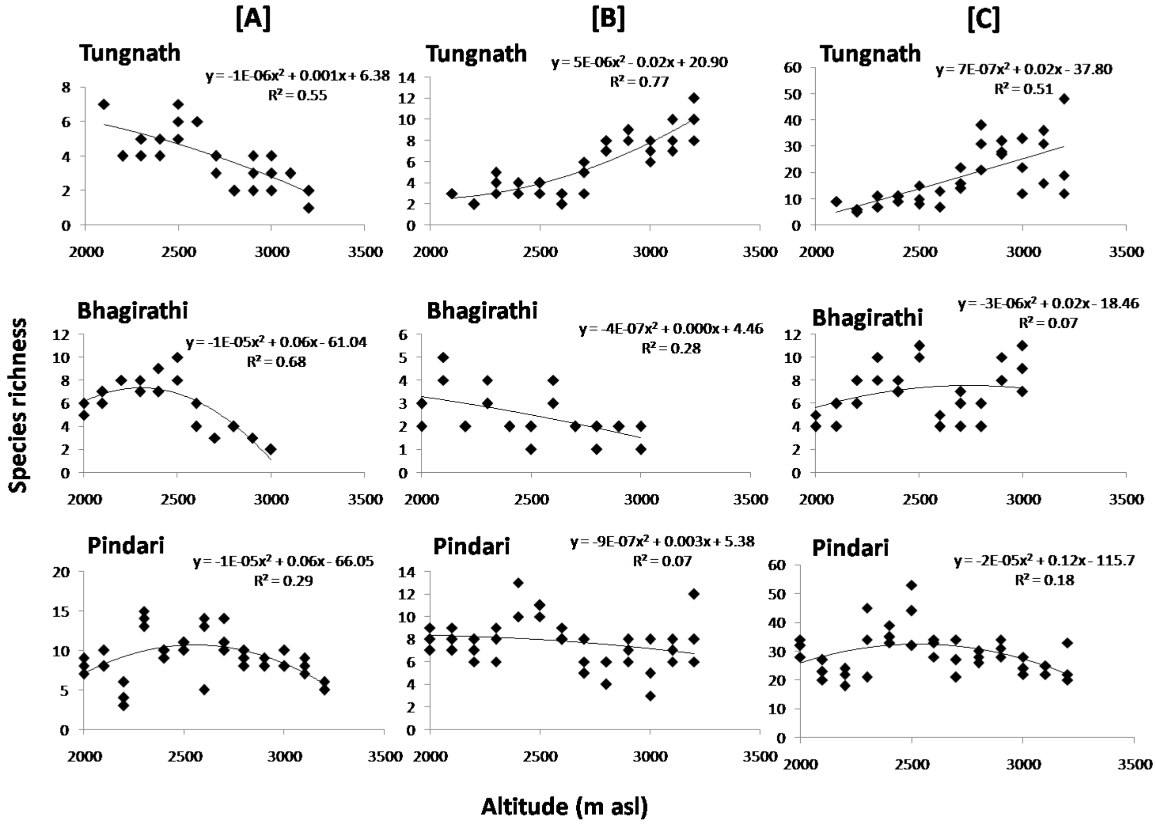

Fig. 6. Species richness distribution in different life forms (A- trees, B- shrubs, C- herbs) along altitude transects.

(least disturbed and species rich), decline in species richness with altitude is noticed. Since the species richness (Socolar *et al.* 2016) and ecological disturbances are hypothesized to alter community assembly process that ultimately influences variations in composition (i.e., ß diversity), we further build our arguments, specifically pertaining to conservation, on ß diversity assessments.

Recognizing that the patterns of ß diversity differ considerably across transects and life forms, we argue the level of disturbance plays differential role in its determination across life forms. While relatively high level of disturbance and poor species pool (i.e., Tungnath and Bhagirathi) leads to greater ß diversity in trees, it reflects reverse trend for herbs. The shrubs remain somewhere in between. Our study suggests, relatively pristine sites with high species packaging (i.e., Pindari) remain more homogenous in case of tree species distribution (low ß diversity) but become highly heterogeneous for herbs (high ß diversity). It appears such pristine sites provide more scope for occurrence of rare/occasional herbaceous species along altitude range, which contributes for higher heterogeneity of species composition. It is reported that the rare species usually constitute a heterogeneous pool of occasional plants of low persistence and low fidelity of association with specific community (Grime 1998). This role of rare/occasional species irrespective of their overall abundance and their fidelity of association with specific community types is further described. However, considering the evidence-based arguments that species differ widely in their capacity to track shifting climate envelops, depending mostly on their capacity of dispersal (Pearson 2006), indicates possible dominance of more dispersive taxa in future (Socolar *et al.* 2016). Also, climate driven declines in specialist taxa is expected leading to increased homogenization of communities in both natural and anthropogenic landscapes (Socolar *et al.* 2016; Urban 2015). This calls for attention with relation to patterns of ß diversity under changing climate, particularly in relatively pristine sites in the region (e.g., Pindari transect) where proportion of rare/occasional herbaceous species is high.

Studies have indicated that the pair-wise dissimilarities can be used to identify key spatial or environmental gradients where turn-over occurs, and such analysis before and after disturbance could pinpoint the environmental gradients along

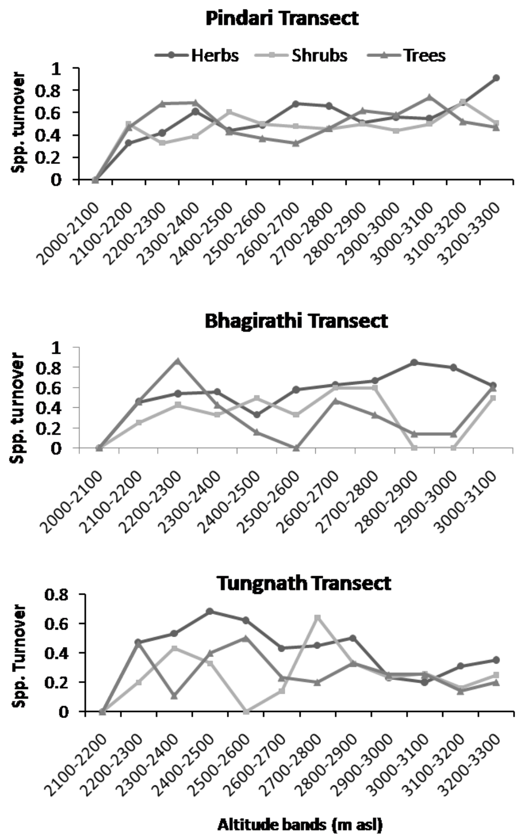

Fig. 7. Species turnover rate along altitude range of studied transects.

which beta diversity has been lost, thereby directing the preservation or restoration of key feature (Socolar *et al.* 2016).

Altitude relationship of compositional features

In the Himalayan region, strong relationship of compositional features, such as density and total basal area, with altitude are often exhibited (Dhar *et al.* 1997; Singh *et al.* 1994). However, studies have not considered multiple transects and multiple life forms to describe the patterns. In this context, present study, provides first of its kind data sets to discuss patterns drawn based on three comparable altitude transects. Barring anthropogenically disturbed altitude transect (i.e. Tungnath), the density and altitude exhibit significant quadratic relationship for different growth stages of trees in relatively less disturbed transects [Pindari: trees- $F = 5.935$, $P < 0.01$; saplings- $F = 8.149$, $P < 0.01$; seedlings- $F = 16.265$, $P < 0.01$ and Bhagirathi: trees- $F = 4.78$, $P < 0.05$; saplings- $F = 5.515$, $P < 0.05$; seedlings- $F = 5.595$, $P < 0.05$], and this model is well acceptable with $F > F_{crit}$. This suggests altitude relationships of density in case of tree species, irrespective of growth stage (tree, sapling, seedling), which gets modified by disturbance (e.g., Tungnath).

With the rejection of null hypothesis ($F > F_{crit.}$), modelled TBA distribution is acceptable in case of less disturbed sites (Pindari: $F = 11.95$, $P < 0.01$; and Bhagirathi: $F = 42.830$, $P < 0.01$). However, relationships are not uniform. The Pindari transect with sharp decline of TBA at upper elevation end differs from Bhagirathi transect where TBA continues to be high up to 3000 m. This phenomenon can be partially explained due to sharp changes in topographic and climatic feature of the Bhagirathi transect, which abruptly gives way to non-monsoonal Nelang transect beyond 3000–3100 m altitude band. At this altitude band of the Bhagirathi transect full grown *Cedrus deodara* forests dominate resulting in high TBA.

Non-significant altitude relationships for herbs ($F < F_{crit}$) across transects would imply that the herb density distribution is independent of altitude position. This calls for finding the other environmental factor(s), which govern density of herbs in the region.

Composition at treeline ecotone

Compositional features of vegetation at treeline ecotones in the Himalaya are relatively less explored. Most of our understanding comes from studies available for Tibetan Plateau. It is reported that the coniferous species in sub-alpine belt of southern part of the Tibetan Plateau (i.e., Hengduan mountain range) and southern slopes of Himalaya are highly diverse (16 species of *Abies*, *Picea*, six species of *Larix* and 11 species of *Junipers*). Of these 14 species of *Abies*, five species each of *Picea* and *Juniperus*, and four of *Larix* reach climatic forest limit to form timberline. In addition sclerophyllous *Quercus* and deciduous broad-leaved *Betula* also form timberline species in Tibetan plateau. *Juniperus indica, J. recurva, Abies spectabilis, A. densa, A. pindrow,* and *B. utilis* are reported to form timberline on southern slopes of the Himalaya (Rawal & Pangtey 1994; Schweinfurth 1957). Most of these reports have, however, subjectively described the vegetation at timberline zone. As compared to these reports, this study provides evidences from very systematically analysed data sets to establish that (i) the monsoonal treeline ecotones are most often rich in tree diversity with considerable variation in dominant and co-dominants across sites/plots; (ii) the non-monsoonal treeline ecotones remain poor in tree species richness and exhibit less variation of dominant/co-dominant types; and (iii) the compositional attributes (density, TBA, etc.) in monsoonal sites are relatively closer to those of the rest of the lower transect. This would imply that the vegetation composition in treeline ecotones in monsoonal and non-monsoonal sites in the region differ considerably. Also, the composition of treeline ecotone in this part of Himalaya varies significantly from other reported compositions in treeline/timberline ecotones elsewhere in Himalaya.

Conclusions

The study concludes the following: (i) the forested high altitude (2000–3500 m asl) zone of Uttarakhand represents a significant proportion of provincial (west Himalaya) and regional (Himalaya) plant diversity pool; (ii) the broad patterns of floristic diversity distribution vary across altitude zones and life forms; (iii) of the total plants recorded from study transects 52.5% are Himalayan natives, and rarity analysis of these natives reveals 22.2% taxa with restricted geographical distribution reflect higher susceptibility to endangerment at regional scale, whereas 27.9% taxa with narrow ecological amplitude and scarce local abundance deserve conservation support at local level; (iv) the species richness and β diversity patterns are sensitive to human disturbances and climate change; (v) the altitude patterns of vegetation vary considerably across sites (i.e. altitude transects) thereby suggesting stronger influence of micro level factors.

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