

Research

# Distribution of vascular plants in a subalpine-nival gradient of Central Himalaya: current patterns and predictions for future warming climate

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## Abstract

Following the standard method of Global Research Initiative in Alpine Environments (GLORIA), we performed a systematic investigation of vascular plant species distribution along a subalpine to nival gradient in the Central Himalaya. Our study aims to identify the richness and distribution patterns of vascular plant species and biogeographic groups under current climatic conditions and make predictions for their distribution under warmer conditions anticipated by the Intergovernmental Panel on Climate Change (IPCC). Species richness decreased along an increasing elevation gradient. Aspect also influenced richness levels along the study gradient. Biogeographically, a majority of taxa were Himalayan endemics, followed by species with pan-Himalayan distribution. A complete turnover of indicator species along the elevation gradient was observed due to distinct phytoclimates. Twenty three percent of the plant species recorded in the present study showed a narrow elevation amplitude (<1250 masl) and are projected to be most sensitive to rising global surface temperatures. Taxa with restricted geographical distribution and narrow elevation amplitude must adapt through range shift to compensate for expected future increases in temperature. However, limited habitat availability may hinder the ability of high alpine species to migrate upward in elevation.

**Key-words:** Species distribution, life forms, chorotypes, climate change, range shift.

## Introduction

The alpine-nival life zone exclusively encompasses vegetation above tree line and below permanent snow line where life is constrained by physical components of the environment, mainly low temperature and hence low energy, high solar radiation, strong wind, and short growth period (Körner 2003; Nagy and Grabherr 2009). Despite environmental stresses, most of the alpine-nival

regions are biodiversity hotspots inhabited by a substantial number of rare and endemic taxa (Salick and Byg 2007; Salick *et al.* 2014) important from economic, ecological and evolutionary perspectives in addition to their conservation significance.

Gradients in temperature, water availability, light and soil nutrients all vary with elevation and are important to shaping plant distribution (Körner 2003; Jonas *et al.* 2008). Decreasing temperature and precipitation with increasing elevation results in the success of species with life forms better adapted to cold and dryness (Klfmes 2003; Vittoz *et al.* 2010; Grau *et al.*

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2012). Besides these environmental variables, topographic variables, aspect and slope, influence the amount of radiation received in a particular mountain area and considerably affect plant species distribution and diversity at the local scale (O'Brien 1998; McCune 2007).

The recurrence of fluctuating climatic conditions during the Quaternary has greatly affected the migration and adaptation of flora in mountain regions and subsequently influenced the distribution of taxa and the speciation rate, thereby influencing the extent of endemism (Mani 1978; Tribsch and Schönswetter 2003; Yoshida 2006). The Himalaya and neighboring mountain ranges are considered one of the most active regions in the world for the speciation of seed plants during the Quaternary (Yoshida 2006). As a result, this region supports high flowering plant diversity and endemism. One current estimate suggests that out of an estimated 10,000 species of plants in the Himalaya, about 3,160 are endemic (Conservation International 2012) and endemic species richness in the Himalaya is greater than reported in the European alpine environment (Salick *et al.* 2014).

Endemic species richness in the Himalaya is expected to be especially high at high elevation zones, particularly between the subalpine and upper alpine belt (Shrestha and Joshi 1996; Vetaas and Grytnes 2002; Ghimire 2005). In contrast, the total species richness along this gradient declines monotonically with the rise in elevation (Lomolino 2001; Körner 2003; Vittoz *et al.* 2010). Most of the endemic species so far reported from Nepal have a very narrow range size and show high habitat specificity (Shrestha and Joshi 1996; Ghimire 2005; Rajbhandari and Adhikari 2009).

Most global environmental issues including climate change are expected to have greater impact on the biodiversity at higher elevations. The study of current taxa distribution patterns along an elevation gradient provides baseline knowledge for predicting future distributions and for evaluating the relative impacts of environmental changes over time. It is already an established fact that high altitude regions favor species with narrow ranges of distribution. Studying the impacts of climate change on such species has wider implications for species and habitat conservation strategies in the

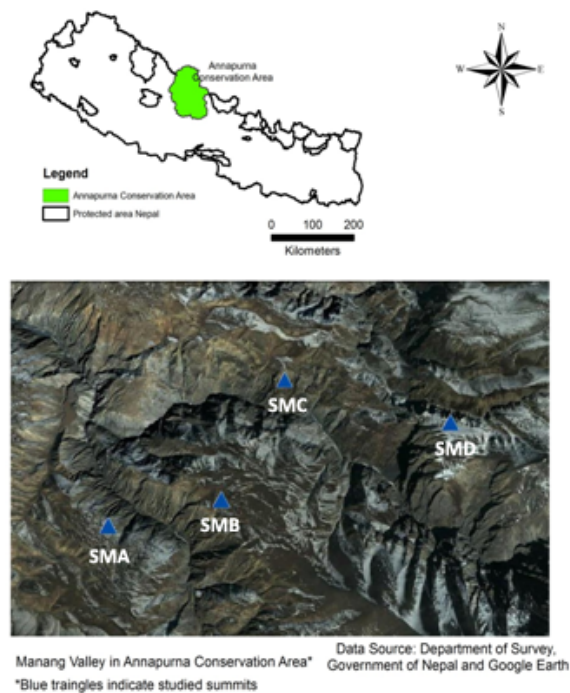
Himalaya. Long-term ecological monitoring on high altitude taxa will serve this need.

Following the method of the Global Observation Research Initiative in Alpine Environments (GLORIA), this study aims to assess species distribution patterns under current climatic conditions along a subalpine-nival gradient in Central Nepal and make predictions for vascular plant distribution under warmer climatic conditions anticipated by the Intergovernmental Panel on Climate Change (IPCC). Specifically, we assess the biogeographic (chorotypic) and elevation patterns of distribution of vascular plant species on mountain summits at various elevations, identify indicator species along ecological zones (ecotones) represented by mountain summits, and evaluate future distribution of vascular plant species in response to their exposure to more warmer climatic conditions. The globally standardized GLORIA protocol (Grabherr *et al.* 2001; Pauli *et al.* 2004) has been utilized in high altitude regions around the world. Completing long-term ecological monitoring in Central Nepal will link the observed impacts of climate change on vascular plant species unique to this region to wider Himalayan and global datasets and provide baseline information useful in interpreting the impacts of anticipated climatic change on species distribution patterns.

## Materials and Methods

### STUDY AREA

The study area is located in north-eastern part of Nyeshang valley in Manang district within Annapurna Conservation Area (ACA), Nepal (Figure 1, Table 1). Manang district lies in the partial rain shadow zone surrounded by Annapurna (>7500 masl), Lamjung (6932 masl) and Manaslu (8163 masl) mountain series. Thus the area is characterized by low annual precipitation (<400 mm) compared to the other mountainous areas of Nepal. Analysis of 30 years of temperature and precipitation data at two nearby meteorological stations, Chame and Jomsom stations, revealed the annual mean maximum temperature of 16.73°C and 17.61°C, annual mean



**Figure 1.** Study sites in Nyeshang valley, Manang include 4 summits: SMA = subalpine-lower alpine (4150 m); SMB = lower alpine-middle alpine (4575 m), SMC = middle alpine-upper alpine (4835 m), SMD = upper alpine-subnival (5005 m).

minimum temperature of 4.8°C and 5.48°C, and annual mean precipitation of 948.73 mm and 269.37 mm, respectively.

#### VEGETATION SAMPLING AND DATA COLLECTION

We followed standardized methods for GLORIA (Grabherr *et al.* 2001; Pauli *et al.* 2004; Figure 2) to

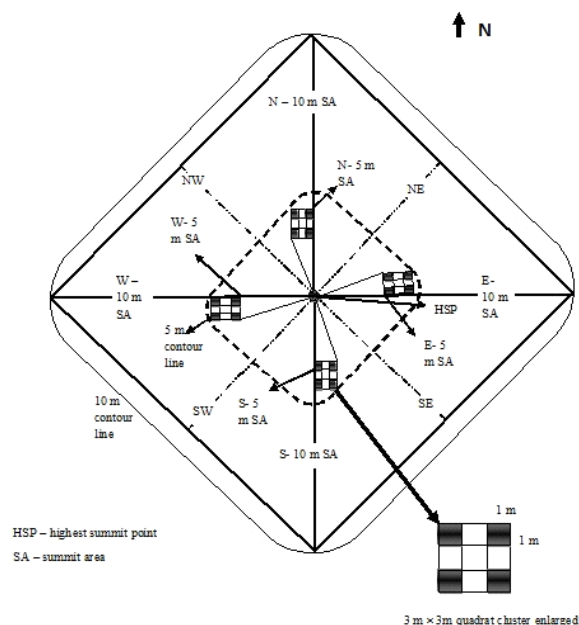
establish long-term research plots in Nyeshang valley, Manang. Permanent plots are also part of a larger Himalayan climate change and biodiversity study (Salick *et al.* 2014).

Four summits were selected along an elevation gradient between tree line and permanent snowline representing four ecotones: subalpine-lower alpine, lower alpine-middle alpine, middle alpine-upper alpine, and upper alpine-subnival (Figure 1, Table 1). In each summit, vegetation sampling was completed at three spatial scales: (i) 1 m x 1 m quadrats, (ii) quadrat-clusters (consisting of four 1 m x 1 m quadrats), and (iii) large summit area sections (SAS) (Figure 2). Each summit was divided into eight SAS: (i) four upper SAS representing four cardinal directions (N, S, E and W) from the highest summit point (HSP, top of the summit) down 5 m in vertical elevation, and (ii) four lower SAS representing four cardinal directions from the 5 m corner point of upper SAS further down 5 m in vertical elevation. At each cardinal direction and 5 m vertical elevation from the HSP, one 3 m x 3 m grid (quadrat-cluster) was positioned (thus totaling four such grids at four cardinal directions per summit). Each grid was divided into nine 1 m x 1 m quadrats, out of which four quadrats at each corner of the grid were selected for vegetation sampling. Altogether, sixteen 1 m x 1 m quadrats were sampled in each summit.

Presence of species was recorded in each SAS. Combining the species presence from all eight SAS gave total summit flora. In each of the sixteen 1 m x 1 m quadrats, species cover (%) of each vascular plant, and

**Table 1.** Geographical location and dominant plant species of four different summits studied.

Summit	Vegetation zone	Latitude	Longitude	Major vegetation
SMA (4150 m asl)	Subalpine – lower alpine ecotone	28°67.418'	84°04.060'	<i>Cicerbita macrorhiza</i> var. <i>saxatilis</i> , <i>Galium megacytarion</i> , <i>Juniperus squamata</i> , <i>Polygonatum cirrhifolium</i>
SMB (4575 m asl)	Lower alpine – middle alpine ecotone	28°67.631'	84°05.206'	<i>Anaphalis royleana</i> , <i>Lonicera obovata</i> , <i>Potentilla argyrophylla</i> var. <i>atrosanguinea</i> , <i>Sibbaldia parviflora</i> , <i>Viola biflora</i>
SMC (4835 m asl)	Middle alpine – upper alpine ecotone	28°68.767'	84°05.807'	<i>Bistorta macrophylla</i> , <i>Cortia depressa</i> , <i>Cremanthodium nepalense</i> , <i>Gentiana algida</i> var. <i>przewalskii</i> , <i>Kobresia pygmaea</i> , <i>Lomatogonium himalayense</i> , <i>Nardostachys grandiflora</i> , <i>Rhododendron anthopogon</i> ,
SMD (5005 m asl)	Upper alpine-subnival ecotone	28°68.296'	84°07.482'	<i>Eriophyton wallichii</i> , <i>Potentilla fruticosa</i> , <i>Saussurea leontodontoides</i> , <i>Saxifraga andersonii</i>



**Figure 2.** Sampling design (after Pauli *et al.* 2004).

top cover (%) of surface types (vascular plant, lichen, bryophyte, scree, bare ground, and litter cover) were recorded based on visual observation. Each corner quadrat was divided into 100 cells of 0.1 m x 0.1 m using a wooden grid frame for frequency count. Presence/absence of vascular plant was recorded in each grid cell.

#### PLANT LIFE FORM CLASSIFICATION

Plant species were classified as one of the five principle life forms described by Raunkiaer (1934), *viz.* chamaephytes (CHP), cryptophytes (CRP), hemicryptophytes (HCP), phanerophytes (PHP) and therophytes (THP).

#### DISTRIBUTION PATTERNS

Elevation and biogeographic (chorotypic) patterns of distribution of plant species recorded in each summit was based on the updated version of Annotated Checklist of Flowering Plants of Nepal (Press *et al.* 2002) and Flora of China (Zheng-Yi and Raven 1996-2003) available online, and Flora of Mustang (Ohba *et al.* 2008). Based on the biogeographical range of distribution, the following categories were made: (i) *Himalayan endemics (HE)*: those species which are endemic to the Himalaya

(spreading over 5 countries-India, Nepal, Bhutan, China (Tibet) and Pakistan; the Himalaya are bordered on the north by the Tibetan Plateau, south by the Indo-Gangetic Plain, northwest by the Karakoram and Hindu Kush ranges, and east by the Indian state of Arunachal Pradesh); (ii) *pan-Himalayan distribution (PE)*: species whose distribution crosses the boundary of Himalayan range, but restricted to the areas lying adjacent to the Himalaya (including Himalaya as above); and (iii) *Broad range of distribution (BE)*: species having wider range of distribution crossing the territory of pan-Himalaya.

#### DATA ANALYSIS

Species richness ( $\alpha$ -diversity) is the principle measure of diversity considered in this study. It was obtained at the level of 1 m x 1 m quadrat and quadrat-cluster. Total number of species from all SAS and quadrats per summit is defined as  $\gamma$ -diversity (Whittaker 1972). The difference in mean species richness among summits was compared through one-way ANOVA. Two-way ANOVA was performed to see the effect of summit and aspect (at main compass directions) on species richness at quadrat level.

For each species recorded in the summits, lower and upper elevation distribution limits were obtained based on the empirical data and literature. The difference between these two limits gave the elevation amplitude or vertical range for each species. Plant species recorded in each summit were grouped into five categories of elevation distribution ( $\leq 500$ ,  $>500-1000$ ,  $>1000-1500$ ,  $>1500-2000$  and  $>2000$  masl).

Indicator species analysis (ISA) was used to evaluate species associations with groups of sample units in a particular summit. This method produces indicator values for each species in a group ranging from 0 (no indication) to 100 (perfect indication), which were then tested for statistical significance using a Monte Carlo test (McCune & Mefford 1999).

#### POSSIBLE IMPACT OF CLIMATE CHANGE ON SPECIES DISTRIBUTION

We followed global emission scenarios provided by IPCC to assess the possible impacts of global surface temperature rise on species distribution (Table 2). IPCC

emission scenarios are grouped into four families (A1, A2, B1 and B2; Table 2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting green house gas (GHG) emissions (IPCC 2007).

Here we used B1 (lowest prediction) and A1F1 (highest prediction) scenarios for the projection of likely impacts on the species distribution. Using these IPCC emission scenarios, we calculated the range of elevation in which there is possible impact of increased temperature on species distribution based on local adiabatic lapse rate. The adiabatic lapse rate of temperature is the rate of decrease in air temperature with increasing elevation, which is used to explain the potential shift of vegetation in elevation gradient due to climate change (Van de Ven 2007; Medina *et al.* 2011). We have taken 0.53°C as the standard value for local adiabatic lapse rate per 100 m rise in elevation in Nepal Himalaya (Bhattarai *et al.* 2004). Those elevation ranges for individual species, which fall on the likely impact range of increased temperature, were grouped in different vulnerability categories. Species with lower elevation amplitude were treated as more vulnerable than those with higher amplitude.

## Results

### SPECIES RICHNESS PATTERN

Altogether, 176 species of vascular plant, belonging to 96 genera and 49 families, were recorded in the present

**Table 2.** Projected global surface warming at the end of 21st century (from IPCC 2007). Data shown are temperature change (°C at 2090-2099).

Case	Best estimate	Likely range
Constant year 2000 concentrations	0.6	0.3 – 0.9
B1 scenario	1.8	1.1 – 2.9
A1T scenario	2.4	1.4 – 3.8
B2 scenario	2.4	1.4 – 3.8
A1B scenario	2.8	1.7 – 4.4
A2 scenario	3.4	2.0 – 5.4
A1F1 scenario	4.0	2.4 – 6.4

study (Supplementary Material 1). Asteraceae with 28 genera was the largest family, and *Potentilla* (Rosaceae) with 10 species was the largest genus. The landscape-level diversity ( $\gamma$ -diversity, total 176 from all summits) decreased in summits representing different ecotones from lower to higher elevations (Table 3). Although the two lower-elevation summits of subalpine-lower alpine (SMA) and lower alpine-middle alpine (SMB) ecotones did not vary much in total species occurrence, a sharp decline in total number of species was observed from middle alpine-upper alpine (SMC) to upper alpine-subnival (SMD) ecotones (the two higher-elevation summits) (Table 3).

A similar trend was observed for richness of species at the level of quadrat-cluster (Table 3). One-way ANOVA and Tukey's range test showed that the value of species richness at the quadrat-cluster level was significantly higher in two lower-elevation summits than in the

**Table 3.** Species diversity measures at different spatial scales in summits along elevation gradient.

Diversity measures	Summits at different ecotones*				Overall	F	P
	SMA	SMB	SMC	SMD			
$\gamma$ -diversity at summit level	103	102	65	41	176		
$\alpha$ -diversity at quadrat-cluster level	32.25±3.30 <sup>a</sup>	26.75±1.31 <sup>ab</sup>	23.50±0.64 <sup>b</sup>	16.00±1.73 <sup>c</sup>	25.20±1.70	13.37	0.01
$\alpha$ -diversity at quadrat level	14.19±1.03 <sup>a</sup>	13.94±0.94 <sup>a</sup>	15.19±0.48 <sup>a</sup>	8.00±1.01 <sup>b</sup>	13.15±0.55	12.06	<0.001

\*SMA = subalpine-lower alpine (4150 m); SMB = lower alpine-middle alpine (4575 m), SMC = middle alpine-upper alpine (4835 m), SMD = upper alpine-subnival (5005 m). The different superscript letters in each category of diversity measures represent significant difference (at  $p < 0.05$  level) based on one-way-ANOVA and Tukey's range test.

summits at higher elevations (Table 3). Contrary to these findings, species richness at the quadrat level did not reflect a sharp trend, except the value was significantly low for summit at highest elevation (SMD, Table 3). Tukey's range test showed that the three lower-elevation summits had almost similar value of species richness at quadrat level.

Two-way ANOVA clearly showed no consistent trend in species richness among summits for four compass directions (Table 4). However, the significant interaction term between aspect and summit indicated that the effect of aspect was different in different summits (Table 4). The two lower-elevation summits (SMA and SMB) comprised greater number of species at quadrat level on shady northern slopes, whereas the two high-elevation summits (SMC and SMD) showed greater number of species on exposed (generally western) slopes (data not shown).

#### BIOGEOGRAPHICAL PATTERN OF DISTRIBUTION

Biogeographical (chorotype) classification was only available for 170 species identified up to species level. The alpine-nival zone of the study area was dominated by Himalayan endemics (Table 5), which represented 58.3% of total species recorded in the four summits. The second largest group was species with pan-Himalayan distribution (28.8%), followed by species with broad range of geographical distribution (12.9%).

#### ELEVATION PATTERN OF DISTRIBUTION

The study area was dominated by species with broad elevation ranges (Figure 3). Among the total ( $n = 170$ ), 34.1% species ( $n = 58$ ) had an elevation range  $>2000$  m, and 1.2% ( $n = 2$ ) had a range  $<500$  m (Figure 3). In general,

**Table 4.** Two-way ANOVA showing the effect of summit and aspect (at main compass directions) on species richness at the quadrat level. Species richness values were log<sub>10</sub> transformed before analysis.

Source	Sum of Square	df	Mean Square	F	P
Intercept	68.439	1	68.439	4345.090	<0.0001
Summit	0.695	3	0.232	14.699	<0.0001
Aspect	0.101	3	0.034	2.138	0.109
Summit * aspect	0.424	8	0.053	3.361	0.004
Error	0.709	45	0.016		
Total	72.939	60			

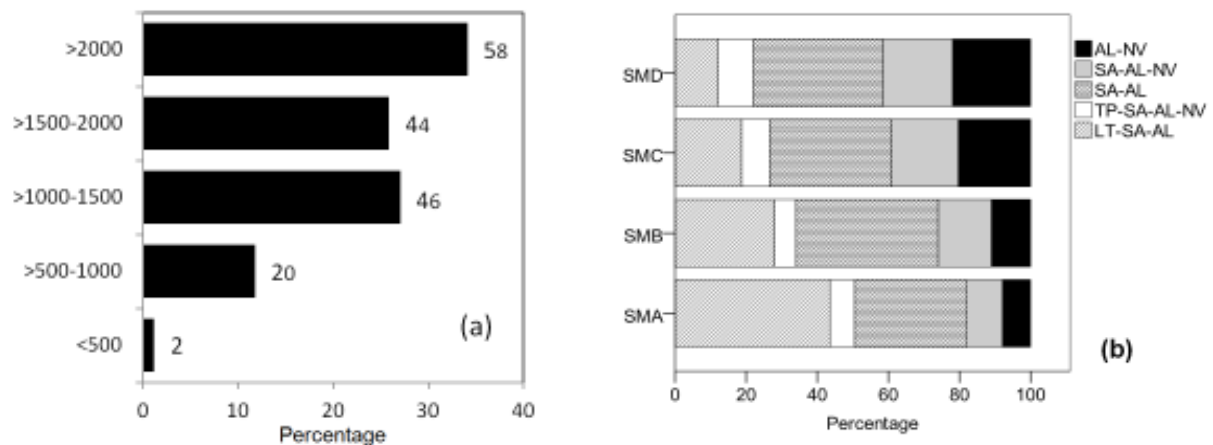
the lower-elevation summit (SMA) comprised greater proportions of species with a wide range of vertical distribution (species with lower temperate to alpine distribution with elevation range  $>2000$  m), the proportion of which decreased with increasing elevations. The high-elevation summits (SMC and SMD) were generally represented by species with narrow elevation range ( $<1500$  m). Higher proportions of Himalayan endemic species exhibited a narrow elevation range, followed by species with a pan-Himalayan distribution (Figure 4). Species with broad geographical distribution generally had a wide elevation amplitude ( $>2000$  m) (Figure 4).

In the present study, 44 vascular plant species showed higher upper elevation limit ( $\geq 100$  m) than reported previously. The majority of such species were shrubs and forbs, like *Artemisia subdigitata* (previous record of 3000 m vs. 4575 m recorded in the present study), *Cortia depressa* (4900 vs. 5005 m), *Epilobium brevifolium* (4000 vs. 4575 m), *Heracleum sublineare* (3850 vs. 4150 m), *Pleurospermum apiolens* (4700 vs.

**Table 5.** Number of species (percentage in parentheses) classified under three biogeographical domains (chorotypes) in summits representing different ecotones along elevation gradient.

Chorotypes	Summits at different ecotones*				Overall
	SMA	SMB	SMC	SMD	
Himalayan endemic (HE)	57 (56.4)	58 (58.0)	35 (54.7)	24 (58.5)	99 (58.3)
pan-Himalayan (PH)	28 (27.7)	30 (30.0)	19 (29.7)	11 (26.8)	49 (28.8)
Broad range of distribution (BR)	16 (15.7)	12 (12.0)	10 (15.6)	6 (14.7)	22 (12.9)

\*description of summits at different ecotones is given in Table 1 & 3.



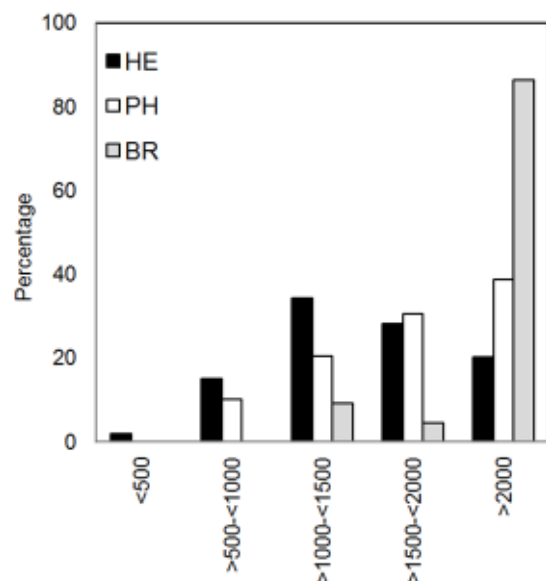
**Figure 3.** Elevation range of species: (a) elevation range for all species calculated as the difference between lower and upper elevation limits, (b) elevation range for species in four summits studied. In (a) value on the top of the bar represents number of species in each elevation range. Abbreviations in (b): AL-NV = alpine-nival; SA-AL-NV = subalpine-alpine-nival; SA-AL = subalpine-alpine; TP-SA-AL-NV = temperate-subalpine-alpine-nival; LT-SA-AL = lower temperate-subalpine-alpine.

5005 m), *Potentilla exigua* (4500 vs. 5005 m), *Salix calyculata* (4500 vs. 4835 m) and *Sedum ewersii* (4500 vs. 5005 m). Among graminoids *Agrostis pilosula* (4600 vs. 4838 m), *Bromus himalaicus* (3700 vs. 4150 m), *Elymus nutans* (4600 vs. 5005 m), *Festuca polycolea* (4600 vs. 5005 m), *Poa annua* (3500 vs. 4150 m) and *Kobresia williamsii* (4000 vs. 4835 m) also showed increased upper elevation limit than reported previously.

#### INDICATOR SPECIES TO THE MOUNTAIN SUMMITS

The indicator species analysis revealed that the species indicator to the study summits were mostly herbaceous taxa with biogeographical distribution restricted to the Himalayan region (50% of total indicator species), followed by species with pan-Himalayan distribution (33%). Only 17% of taxa identified as indicators were broad range species. Himalayan endemics and pan-Himalayan range species identified as indicators had almost equal share in all the study summits, except SMB where large proportion of indicators were those having broad distribution range (Figure 5a).

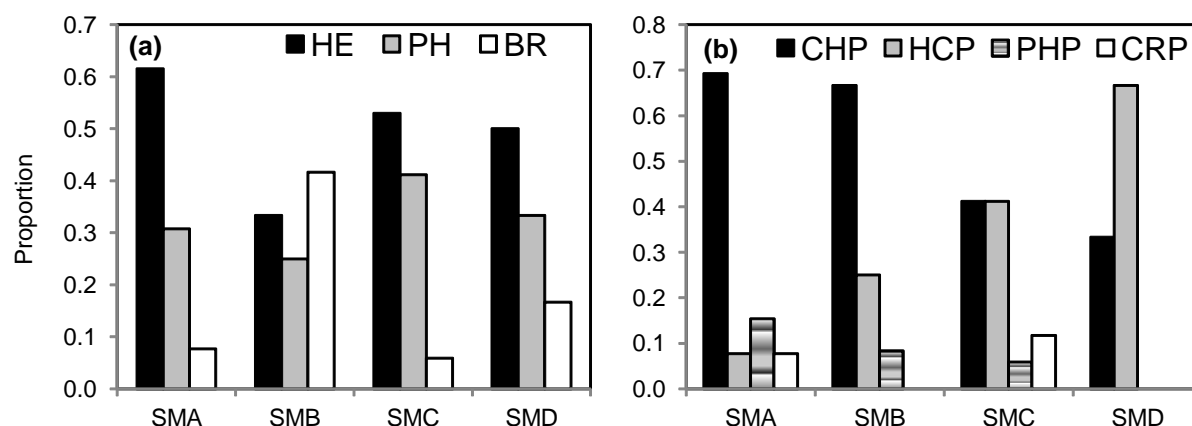
Majority of indicators (54%) were chamaephytes, followed by hemicryptophytes (31%), phanerophytes (8%) and cryptophytes (6%). But, majority of indicators at higher elevations were hemicryptophytes and that of lower elevations were chamaephytes (Figure 5b).



**Figure 4.** Elevation range of species categorized into different chorotypes (HE-Himalayan endemic, PH-pan-Himalayan, BR-broad geographical distribution).

#### POSSIBLE IMPACTS OF CLIMATE CHANGE ON SPECIES DISTRIBUTION

The analysis revealed that, under different emission scenarios (low, intermediate and high), 40 plant species were identified as vulnerable and expected to adapt through range shift to compensate for warming or develop specific traits for adaptation on the current



**Figure 5.** Proportion of indicator species in different summits according to (a) chorotype (HE-Himalayan endemic, PH-pan-Himalayan, BR-broad geographical distribution), and (b) life form categories (CHP-chamaephytes, CRP-cryptophytes, HCP-hemicryptophytes, PHP-phanerophytes, and THP-therophytes). Description of summits is given in Table 1.

habitat (Table 6, 7). The predicted vulnerable plant species belonged to 17 vascular plant families. Most of them ( $n = 8$ ) belonged to Asteraceae, followed by Gentianaceae ( $n = 5$ ), Apiaceae ( $n = 4$ ), Crassulaceae ( $n = 3$ ) and Rosaceae ( $n = 3$ ) (Table 7).

Of the 170 species analyzed, 1.76 % ( $n = 3$ ) were regarded as most vulnerable, as they fall on the likely impact range within B1 scenario (the lowest emission prediction made by IPCC) (Table 6, 7). They were all chamaephytes and Himalaya endemics. Similarly, 22.94% species ( $n = 39$ ) having their elevation range within the likely impact range for A1F1 scenario (the highest emission prediction made by IPCC), were treated as vulnerable (Table 6, 7). Out of which 1.18% species ( $n = 2$ ) were found to be highly vulnerable (vulnerability rank I), 6.47% species ( $n = 11$ ) moderately vulnerable (vulnerability rank II), and 15.29% species ( $n = 26$ ) less vulnerable (vulnerability rank III) (Table 7). Among the vulnerable species, 56.41% species ( $n = 22$ ) were chamaephytes and 28.20% species ( $n = 11$ ) were hemicryptophytes. Cryptophytes and Phanerophytes each comprised 7.69% species ( $n = 3$ ) (Table 7). Similarly, 79.49% species ( $n = 31$ ) were Himalaya endemics and 20.51% species ( $n = 8$ ) were having pan-Himalayan distribution (Table 7).

**Table 6.** Predicted impact of climate change on different altitudinal ranges.

Emission scenario	Rate of average warming <sup>3</sup> (°C)	Likely impacted elevation range (m)	Number of species
B1 <sup>1</sup>	Low	1.1	208
	Intermediate	2.0	378
	High	2.9	548
A1F1 <sup>2</sup>	Low	2.4	453
	Intermediate	4.4	830
	High	6.4	1208

<sup>1</sup>IPCC emission scenario describing a world of very rapid economic growth, a global population that peaks in mid century and rapid introduction of new and efficient technologies (IPCC 2007). <sup>2</sup>IPCC emission scenario describing a fossil intensive world with the population same as in B1 scenario (IPCC 2007). <sup>3</sup>Predicted average surface warming scenario given by IPCC 2007.

## Discussion

A general trend of decreasing vascular plant species richness along the subalpine-nival gradient at different scales of measurement is observed in the present study. A similar trend in species richness has been reported



**Table 7.** Plant species having altitudinal amplitude within the likely impact range of projected average global surface warming.

Name of plant species	Family	Chorotype <sup>2</sup>	Altitudinal amplitude (m)	Vulnerability rank <sup>3</sup>
<b>B1 scenario</b>				
<i>Taraxacum pseudostenoceras</i>	Asteraceae	HE	175	I
<i>Bupleurum himalayense</i>	Apiaceae	HE	400	III
<i>Heracleum sublineare</i>	Apiaceae	HE	550	III
<b>A1F1 scenario</b>				
<i>Taraxacum pseudostenoceras</i>	Asteraceae	HE	175	I
<i>Bupleurum himalayense</i>	Apiaceae	HE	400	I
<i>Heracleum sublineare</i>	Apiaceae	HE	550	II
<i>Potentilla caliginosa</i>	Rosaceae	HE	600	II
<i>Astragalus oplites</i>	Fabaceae	PH	650	II
<i>Bromus himalaicus</i>	Poaceae	HE	650	II
<i>Haplosphaera himalayensis</i>	Apiaceae	HE	675	II
<i>Gentiana stellariifolia</i>	Gentianaceae	HE	735	II
<i>Aconitum naviculare</i> var. <i>leiocarpum</i>	Ranunculaceae	HE	790	II
<i>Gentiana algida</i> var. <i>przewalskii</i>	Gentianaceae	HE	800	II
<i>Rhodiola crenulata</i>	Crassulaceae	PH	800	II
<i>Saussurea leontodontoides</i>	Asteraceae	PH	800	II
<i>Stellaria congestiflora</i>	Caryophyllaceae	HE	805	II
<i>Anaphalis cavei</i>	Asteraceae	HE	900	III
<i>Swertia multicaulis</i>	Gentianaceae	HE	900	III
<i>Gentiana himalayensis</i>	Gentianaceae	HE	900	III
<i>Polygonatum cirrhifolium</i>	Liliaceae	PH	900	III
<i>Potentilla forrestii</i>	Rosaceae	HE	905	III
<i>Veronica cephaloides</i>	Scrophulariaceae	HE	975	III
<i>Pedicularis cheilanthifolia</i>	Orobanchaceae	PH	1000	III
<i>Silene nigrescens</i>	Caryophyllaceae	HE	1005	III
<i>Saussurea polystichoides</i>	Asteraceae	HE	1005	III
<i>Lonicera obovata</i>	Caprifoliaceae	HE	1075	III
<i>Astragalus himalayanus</i>	Fabaceae	HE	1075	III
<i>Sedum gagei</i>	Crassulaceae	HE	1100	III
<i>Swertia cuneata</i>	Gentianaceae	HE	1100	III
<i>Kobresia uncinoides</i>	Cyperaceae	HE	1100	III
<i>Pleurospermum album</i>	Apiaceae	HE	1105	III
<i>Rhodiola hemalensis</i>	Crassulaceae	PH	1135	III
<i>Polygonum tubulosum</i>	Liliaceae	HE	1150	III
<i>Cicerbita macrorhiza</i> var. <i>saxatilis</i>	Asteraceae	HE	1200	III
<i>Thalictrum alpinum</i> var. <i>minutissimum</i>	Ranunculaceae	HE	1200	III
<i>Lonicera minutifolia</i>	Caprifoliaceae	HE	1200	III
<i>Soroseris hookeriana</i>	Asteraceae	PH	1200	III
<i>Rhododendron nivale</i>	Ericaceae	PH	1200	III
<i>Cremanthodium purpureifolium</i>	Asteraceae	HE	1205	III
<i>Potentilla exigua</i>	Rosaceae	HE	1205	III
<i>Primula capitata</i>	Primulaceae	HE	1205	III
<i>Salix lindleyana</i>	Salicaceae	HE	1205	III

<sup>2</sup>HE = Himalaya endemic, PH = Pan Himalayan distribution, BR = Broad range of distribution.

<sup>3</sup>I = highly vulnerable, II = moderately vulnerable, III = less vulnerable.

along an alpine to nival gradient in the Swiss Alps (Erschbamer *et al.* 2010; Vittoz *et al.* 2010). A linear decrease in species richness after reaching its peak at mid elevations has also been shown by previous studies conducted in the Himalaya and other mountain ranges (Grytness and Vetaas 2002; Carpenter 2005; Ghimire *et al.* 2006; Bruun *et al.* 2006). Both broad- and local-scale environmental factors have contributions on species richness and distribution patterns along an elevation gradient. Elevation itself represents a complex combination of numerous other environmental variables, including temperature, precipitation, potential evapo-transpiration, and edaphic factors including soil texture and substrate stability (Klímes 2003).

On the broader scale, there are many hypotheses on decreasing species richness at higher elevation, for example, water energy dynamics (O'Brien 1998), species area relationship and ecotone effect (Rahbek 1995; Lomolino 2001), and mid-domain effect (Grytnes and Vetaas 2002). The species-area relationship hypothesis expects the number of species to increase with an increase in area (Rahbek 1995; Lomolino 2001). Generally, available area along the subalpine-nival gradient decreases linearly with increasing elevations. Species composition in different summits along the subalpine to nival gradient may have been affected differently by this decline in area because the latter is directly related to the species pool of surrounding mountain land mass. In the upper part of the elevation gradient, decreased land area surrounding the mountain summits greatly affects the existing species pool, which is further constrained by mountain barrier limiting potential immigrants to enter into the summit (cf. Lomolino 2001).

At the local-scale, the observed trend of decreasing species richness with increasing elevation along the alpine-nival gradient signifies the important role of elevation, aspect, radiation and substrate types to shape species richness and distribution patterns. The decreasing species richness towards high-elevation can be attributed to a number of micro- and meso-scale environmental factors affecting the mountain summits. Most importantly, it can be attributed to lower moisture content and relatively lower temperature (low energy) at higher elevations (O'Brien 1998), reduced growing

season, ecophysiological constraints, deep snow cover and intense solar radiation (Körner 2000).

While the proportions of Himalayan endemics and species with pan-Himalayan distribution were higher at the high-elevation summits of the study area, they generally had narrow elevation ranges. In contrast, the proportion of species with broad geographic distributions and a wide elevation range was higher at lower elevation summits. These results signify that the distribution of species with a wide elevation range is restricted to lower-elevation summits, while narrow range species are concentrated on upper-elevation summits. A similar trend has been documented on other alpine areas of the globe, e.g., in Sierra de Cartagena, south-eastern Spain (Ferrer-castán and Vetaas 2003) and in Swiss inner Alps (Vittoz *et al.* 2010). The comparatively lower elevation amplitudes of Himalayan endemics signify their narrow range size and habitat specificity (Ferrer-castán and Vetaas 2003). Such range restricted species are more vulnerable to rapid climate change (Salick *et al.* 2009). Most of the climate change studies on high elevation zones of the globe have shown the loss of diversity and extinction path of endemic species because these may be outcompeted by faster growing, more aggressive lower elevation species extending their range to higher elevations and/or their loss due to increased pressure for limited resources (Salick *et al.* 2014; Erschbamer *et al.* 2010).

Different summits under investigation showed different indicator species in the present study. A complete turnover of indicator species along the sampled elevation gradient is an indication of distinct phytoclimates (Grau *et al.* 2012). Indicator species analysis further indicates the importance of endemic species in shaping the alpine-nival vegetation of the study area as most of the indicators of local vegetation were Himalayan endemics. This pattern of species indicators to mountain summits representing broader Himalayan gradients (also including present study site) was also reported (Salick *et al.* 2014). Warming Himalayan temperatures and concurrent changes in precipitation (IPCC 2007) have increased the pressure for the upward migration of habitat specific alpine species. Opportunistic, lower elevational species with broader amplitudes may push

the high elevation Himalayan endemic species with more compressed elevational amplitudes towards upward migration (Telwala *et al.* 2013). At a time when there is absence of suitable habitat reaching up to the permanent snow line (around 5000 m), these species are left nowhere to go and thus are of great concern in conservation.

According to IPCC, the Himalaya will experience predicted temperature rise of 5–6°C and precipitation increase by 20–30% at the end of 21<sup>st</sup> century (IPCC 2007), which is higher than the global average (0.6–4.0°C). Thus species ranges, which depend on temperature and precipitation, are expected to change considerably (Salick *et al.* 2009; Salick *et al.* 2014). The historical temperature trend for the Himalayan region strongly supports this view. For example, annual warming of 0.06°C (Shrestha *et al.* 1999) has been reported for Nepal Himalaya. Similarly, according to Sing and Smith (2009), the average temperature in Nepal is rising by an average of 0.41°C per decade. Talking about Indian subcontinent as a whole, an annual mean surface air temperature is projected to rise by 1.7 to 2.0°C during 2030s (Singh *et al.* 2011). These projections are quite similar to the projections made by IPCC, *i.e.* a higher warming trend than global average.

Although this study is limited by the lack of long-term data for predicting potential impact of climate change in real sense, the analysis of current distribution patterns and examination of the biological traits of taxa of the alpine-nival ecosystem provides baseline evidence from which we can make predictions for future distribution patterns influenced by climate change. Our estimates suggest that under an expected 1.1<sup>o</sup>–6.4<sup>o</sup>C rise on surface temperature by the end of 21<sup>st</sup> century (IPCC 2007; A1F1 & B1 emission scenario), 22.94% of species documented in this study exist within an elevational range that is within the likely impact range of projected global temperature rise and are expected to be highly vulnerable to extinction. Such species must adapt to the existing climate by upslope migration to compensate with increased temperature. Most of such species are Himalayan endemics, followed by species with pan-Himalayan distribution. The comparatively narrow elevational amplitude of Himalaya endemics is the main

cause making them more vulnerable to future climate change.

In the present study, 44 species (26%) of vascular plant showed increased upper elevation limit ( $\geq 100$  m) than reported previously. Although the difference in upper elevation limit of vascular plants may reflect the lack of proper scientific documentation in the past, the possibilities of upward shift of species due to earlier climate change events cannot be ruled out. There will be a possibility for invasion of unpalatable weed species in the alpine-nival ecosystem in response to warming. However, a thorough study is needed to overcome the misleading inference related to insufficiency of collection/documentation and climate change impact.

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