

Distribution of Vascular Plants and Variation in Plant Functional Traits along a Subalpine-Alpine Gradient in Manang, Central Nepal

A Dissertation Submitted for the Partial Fulfillment of the Requirements for the Master's Degree in Botany, Central Department of Botany



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RECOMMENDATION

It is hereby recommended that **Pratikshya Chalise**, M.Sc. Botany final semester student from ‘Plant Systematics and Biodiversity Conservation Unit’ at Tribhuvan University, Institute of Science and Technology, Kirtipur, Kathmandu has carried out the research work entitled “**Distribution of Vascular Plants and Variation in Plant Functional Traits along a Subalpine-Alpine Gradient in Manang, Central Nepal**” under my supervision. The entire work is based on the field work performed by her and brings out some useful findings in the field of biodiversity and biogeography.

As per my knowledge, this work has not been submitted for any other academic degree. I, therefore recommend this dissertation to be accepted for the partial fulfillment of the requirement of Master’s Degree in Botany at the Institute of Science and Technology, Tribhuvan University.

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LETTER OF APPROVAL

The M.Sc. dissertation entitled "Distribution of Vascular Plants and Variation in Plant Functional Traits along a Subalpine-Alpine Gradient in Manang, Central Nepal" submitted by Pratikshya Chalise has been accepted for the partial fulfillment of her Master's Degree in Botany (Plant Systematics and Biodiversity Conservation).

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DECLARATION OF ORIGINALITY

I, the undersigned author, of this work, declare that this dissertation is my own work, and has not been submitted, in any form, either in whole or in part, for a degree at any other institution. All the views and opinions expressed herein remain the sole responsibility of the author and do not necessarily represent those of the other institute.

Information derived from the other sources has been acknowledged in the text and a list of references has been given. Every reasonable effort has been made to gain permission and acknowledge the owner of copyright materials.



Pratikshya Chalise

15th March, 2017

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Pratikshya Chalise

ABBREVIATIONS AND ACRONYMS

ACA	Annapurna Conservation Area
Anno. Check. Fl. Pl. Nepal	Annotated Checklist of Flowering Plants of Nepal.
asl	above sea level
CA	conservation area
CCA	canonical correspondence analysis
CDB	Central Department of Botany
DCA	detrended correspondence analysis
DNPWC	Department of National Parks and Wildlife Conservation
DPR	Department of Plant Resources
FDMC	fruit dry matter content
Fl. Bhutan	Flora of Bhutan
Fl. China	Flora of China
Fl. Himalaya	Flowers of Himalaya
GLM	generalized linear model
GLORIA	Global Observation Research Initiative in Alpine Environments
K	Royal Botanical Garden, Kew Herbarium
KATH	National Herbarium and Plant Laboratories, Godawari
LDMC	leaf dry matter content
LT	leaf thickness
MCA	Manaslu Conservation Area
MO	Missouri Botanical Garden Herbarium
PADIR	potential annual direct incident radiation
PFTs	plant functional traits
SI	plant size
SLA	specific leaf area
TI	University Museum, University of Tokyo
TUCH	Tribhuvan University Central Herbarium
VDC	Village Development Committee

ABSTRACT

A systematic investigation of vascular plant species distribution along a subalpine-alpine gradient of Central Himalaya, Manang, Nepal along an elevation gradient ranging from 3700 m to 4600 m asl was carried out. Study aimed at identifying the diversity and distribution patterns of vascular plants, including different life forms and biogeographic groups along the gradient; and conceptualizing the inter- and intraspecific variation in plant functional traits (PFTs) with elevation.

The species richness exhibited a hump-shaped pattern with elevation with maximum richness between 4200 to 4500 m asl, with major influence of shrub canopy, radiation, disturbance, and substrate types. Species composition varied between and within the elevation band in different canopy types, including shrub shelter and open canopy. Life form analysis revealed that the study area was characterized by harsh climate with majority of taxa belonging to chamaephyte and hemicryptophyte. However, substrate type played a very important role in determining the presence of particular life form along the gradient. Biogeographically, majority of taxa were Himalayan endemics followed by the species with pan-Himalayan distribution. The proportion of Himalayan endemics increased with increasing elevation. The species indicator to the study site were mostly herbaceous taxa with biogeographical distribution restricted to the Himalaya, indicating the importance of endemics in shaping the alpine vegetation of the study area. A complete turnover of indicator species along elevation gradient was observed due to distinct phytoclimate.

The presence of distinct phytoclimate resulted in inter- and intraspecific variation in different PFTs along the elevation gradient. For the analysis of PFTs, *Rhododendron lepidotum*, *Cotoneaster microphyllus*, *Dactylorhiza hatagirea*, *Cypripedium himalaicum*, and *Rhodiola bupleuroides* were considered. The analysis of PFTs showed that different plant species respond differently in terms of their PFTs with increasing elevation and the variation in PFTs is species specific and trait specific. The mountain ecosystems are sensitive to climate therefore the underlying ecological processes influencing the PFTs may change dramatically under climate change. Therefore, the study of variation in PFTs along a natural gradient like elevation is an effective method to understand how a species or, the community as a whole change with a variety of environmental conditions and how they respond to climate change.

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CHAPTER 1: INTRODUCTION

1.1 Background

In mountainous areas, life is constrained by physical components of the environment, such as low temperature, low energy, high solar radiation, strong wind, and short growing periods (Vetaas and Grytnes 2002; Körner 2003). This increasing climatic harshness coincides with a consistent reduction in land area with increasing elevation (Körner 2003). Decreasing temperature and precipitation with increasing elevation tends to favour the species of different life forms with better adaptation to cold and dryness, determining the pool of potential species able to withstand the increasing harsh environmental conditions at high elevations (Klimes 2003; Grau *et al.* 2012). All the factors are supposed to govern the distribution of taxa and the speciation rate, and thus influence the species composition and richness in the mountain ecosystem. Thus, species distribution pattern along the elevation and latitudinal gradient can be explained by various factors, such as climate (Telwala *et al.* 2013), productivity (Bhattarai and Vetaas 2003), isolation (Lomolino 2001), habitat diversity and anthropogenic disturbance (Chawla *et al.* 2008). Since, elevation itself is correlated with different environmental variables (Austin 1980), decline in area with increasing elevation can alter the species composition as well as richness.

The climatic factors that vary with elevation include temperature, potential-evapotranspiration, length of growing season, humidity, air pressure, availability of soil nutrients, ultraviolet radiation, rainfall which have a direct influence on the distribution of species along the gradient (Bhattarai and Veetas 2003). Of these environmental factors affecting species richness, factors such as topography, rainfall, temperature (Salick *et al.* 2009), available spatial area, and increased isolation greatly alter species distribution pattern along elevation (Brown and Lomolino 1998). Plants growing at extreme altitudes are adapted to multiple stresses and some species are even restricted to the extreme conditions of subnival zone (Dvorský 2014). Despite of these environmental stresses, high elevations support high biodiversity, therefore, mountains are the hotspots of biodiversity (Körner *et al.* 2016) and are inhabited by substantial number of rare and endemic species (Körner 2003).

The Himalayan elevation gradient is the longest bioclimatic gradient in the world extending from about 60m to as high as 8848 m, within 120- 200 km, south-to north transect (Bhattarai *et al.* 2004). Majority of studies have shown pronounced variations in species richness along the elevation gradient in the Himalaya (Veetas and Grytness 2002; Bhattarai and Vetaas 2003, 2004; Bhattarai *et al.* 2004). Generally, species richness tends to decrease with increasing elevation (Stevens 1992; Rahbek 1995; Brown and Lomolino 1998; Bhattarai and Vetaas 2004; Vittoz *et al.* 2010; Joshi 2011). But several studies have shown a unimodal pattern of species richness in the Himalaya (Vetaas and Grytnes 2002; Grytnes and Vetaas 2002; Bhattarai and Vetaas 2003; Panthi *et al.* 2007; Wang *et al.* 2007; Baniya *et al.* 2010; McCain and Grytnes 2010; Grau *et al.* 2012; Rokaya *et al.* 2012; Bhattarai *et al.* 2014). However, very few studies have shown an increasing species richness with elevation (Salick *et al.* 2004, Camarero *et al.* 2006, Kromer *et al.* 2013) and the possible cause of this increased species richness towards higher elevation is due to upslope migration of species from lower elevation (Pauli *et al.* 2012).

A significant increase in the plant species richness in the mountain summits was reported from the European Alps (Pauli *et al.* 2007, 2012) and Swiss Alps (Holzinger *et al.* 2008) particularly in the alpine environment. Species richness in the alpine environment increased almost by 11.8% in the European Alps (Pauli *et al.* 2007). Prolonged temperature increase gradually remove the local environmental boundaries, allowing a warming-induced range shift of alpine plant species towards higher altitudes due to which the species richness is expected to increase in the high alpine and nival belt (Vanneste *et al.* 2016). Rapidly changing climate might favor the species that can extend their ranges quickly or, that can tolerate a wide range of climatic conditions (Duke 2003, in Global Biodiversity and Climate Change). Thus, alpine region is rich in terms of biodiversity and the most suitable alpine habitat in the Himalaya lies below 5000 m asl, above which soil is scarce and scree habitats dominate (Salick *et al.* 2014).

Species level association and richness along the environmental gradients are well documented at local scales but there is limited information about community level patterns like change in species richness in relation to the canopy. Remote sensing using airborne lidar, in a Neotropical forest of Panama exhibited that canopy height,

elevation and terrain curvature are important variables governing the variation in plant species richness at local scale (Wolf *et al.* 2012). With increasing latitude particularly outside tropics, the overstorey canopies absorb greater proportion of incident solar radiation resulting in reduced species richness of the understory strata (Specht and Specht 1993). Decreased species richness in canopy might be due to reduction in incoming solar radiation (Isermann *et al.* 2005), which directly influences the rate of photosynthesis. Since, alpine region is characterized by dwarf shrubs, canopy is an important parameter governing species richness. The prevalence of dwarf shrubs towards alpine-nival region is highly correlated with elevation, therefore, studies have incorporated change in the pattern of species richness with elevation rather than canopy types.

The most diversified elevation zone on earth in terms of species richness is between 1500- 2500 m, and the maximum number of endemics are concentrated between 3800- 4200 m (Veetas and Grytnes 2002). Diversity of endemic species in Himalaya is expected to be high at high elevation zones due to isolation (MacArthur and Wilson 1967; Shrestha and Joshi 1996, cited in Rajbhandari *et al.* 2016), particularly between subalpine and upper alpine belt (Vetaas and Grytnes 2002; Dhar 2002; GoN, 2009). Most of the endemic species, so far reported from Nepal, have very narrow range of distribution (Vetaas and Grytnes 2002; Rajbhandari and Adhikari 2009; Rajbhandari and Dhungana 2010, 2011; Rajbhandari *et al.* 2016) and show high habitat specificity (Ghimire 2005). Rare and endemic species are particularly susceptible to climate change due to their limited geographic range of distribution (Salick *et al.* 2009). As the diversity of such range restricted species is high at high elevations, vegetation of high mountain areas can be used as a sensitive ecological indicator for climate change (Pauli *et al.* 2003).

Plant rarity and endemism both are correlated with different vegetative as well as reproductive traits of the plants. Particularly in harsh environment, functional traits such as life form spectrum becomes more important. In response to severe environmental condition, plant develops adaptation that enable the protection of newly developing buds and spread the risk of bud mortality by multiplying those buds through clonal growth (Klimes[~] 2003). Thus, out of large number of eco-morphological traits in plants, life form spectrum is one of the most important

functional trait of plants widely used in vegetation ecology. Raunkiaer (1934) developed a simple life form system, which was completely based on the height of perennating buds in relation to the soil surface. Perennating tissue refers to the embryonic (meristematic tissue) that remains inactive during a winter or, dry season and then resumes growth with return of a favourable season (Cornelissen *et al.* 2003). This system became widely accepted and applied in comparative vegetation studies, and is particularly useful in environments with pronounced climatic seasonality, especially where winter frost and summer drought strongly affect seasonal plant growth and development (Klimes 2003). The basic life form categories include phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes (Raunkiaer 1934).

One of the major gradients along which life form varies is the elevation (Klimes 2003). Diversity of life forms usually decreases with increasing elevation and one or two life forms remain at extreme elevations (Pavón *et al.* 2000; Klimes 2003). Cessation of individual life form and prevalence of hemicryptophytes at the highest elevation have been reported from several mountains in the Himalayas (Klimes 2003; Joshi 2011; Dvorský *et al.* 2015). The life form spectra can be predicted for particular climate properties, for any continent, biogeographic region or elevation (Raunkiaer 1934). Therefore, Raunkiaer life forms are useful categories with a great predictive power, potentially applicable in any environment colonized by plants but particularly useful in regions with seasonal climate (Klimes 2003). Majority of the basic elements of life history of plants are strongly affected or even largely determined by the life form.

Apart from the study of plant life forms, variation in plant functional traits can also play an important role in this regard. Trait is any morphological, physiological or phenological feature measurable at the individual level, from the cell to the whole-organism level, without reference to the environment or any other level of organization; whereas any trait which impacts fitness indirectly via its effects on growth, reproduction and survival is a functional trait (Violle *et al.* 2007). The changes in plant functional traits along the environmental gradient can be applicable for critically understanding the assembly of communities and their response to global and local environmental drivers (Pescador *et al.* 2015). Knowing the pattern of plant

fitness and phenotypic expression change along environmental gradients is essential for understanding the response of plant communities to the global drivers of change (HilleRisLambers *et al.* 2012). These changes reflect the effects of species composition, species abundance and intra-specific trait variability (Pescador *et al.* 2015) and also help to understand the population dynamics and the mechanisms affecting ecosystem functioning (Tilman *et al.* 1997), such as diversity of herbivores (Crutsinger *et al.* 2006), interspecific interactions and resource partitioning within local communities. A study from Sagarmatha National park and its Buffer zone, eastern Nepal revealed that both quantitative as well as qualitative traits show a great deal of variation along different environmental gradients including elevation and land-use types (Shah 2013). However, elevation is an important gradient along which the plant functional traits vary (Körner 2007, Zhong *et al.* 2014).

Sides (2011) suggested both inter- and intraspecific changes in specific leaf area (SLA) with elevation and further stated that SLA may either increase or decrease with elevation depending upon the species studied. Recent studies have shown decreasing individual size and increasing leaf thickness in some species with elevation (Pescador *et al.* 2015). Generally, fast-growing species with a resource-acquisitive life strategy tend to have short-lived leaves, while slow-growing, conservative species invest more resources into thick, durable leaves (Sides 2011). SLA is a good positive correlate of potential relative growth rate or mass-based maximum photosynthetic rate, and lower values of SLA indicate relatively high investment in 'leaf defences' and 'long leaf life-span' (Cornelissen *et al.* 2003) through extra structural strength and sometimes through allocation to tannins, phenols or other defensive compounds (Westoby 1998). Leaves with high leaf dry matter content (LDMC) tend to be tough and are therefore assumed to be more resistant towards herbivory, wind, hail, etc. compared to the leaves with low LDMC (Cornelissen *et al.* 2003). Leaf mass area (LMA) and leaf Nitrogen content vary with mean annual temperature along elevational gradient (Read *et al.* 2014). The leaf morphological and physiological traits change with changes in environmental conditions, particularly in response to abiotic factors such as soil nutrients (McDonald *et al.* 2003), soil moisture (Alaei *et al.* 2013), air temperature (Cordell *et al.* 1998), atmospheric CO₂ concentrations (Franks *et al.* 2013) and solar radiation (Long *et al.* 2011).

Variation occurs not only in terms of vegetative traits but also in reproductive traits. Studies have shown that highland species tend to invest more resources towards floral structures compared to lowland species (Fabbro and Körner 2004) but reproductive yield is higher towards lower elevation (Guo *et al.* 2010). Plants tend to increase the lifespan as well as size of flowers and alter corolla dimensions towards higher elevation in order to enhance pollination by insects towards alpine regions (Fabbro and Körner 2004, Herrera 2005). However, in stressful conditions, reduced corolla dimensions and decreased flower mass may be more advantageous (Herrera 2005) and during scarcity of resources, plants tend to conserve the size of flower rather than producing large number of flowers (Cresswell *et al.* 2001). Elevation is one of the most important factor governing the seed production per fruit. Therefore, plant size tends to become smaller with greater number of seeds per fruit towards higher elevation (Guo *et al.* 2010). Although, seed number goes on increasing, but seed size tends to decrease with elevation (Guo *et al.* 2010)

These environmental responses are both trait and resource specific, and represent evolved characteristics that vary among genotypes, populations and species (Sultan 2000). However, the interspecific variation in these traits can be attributed to genotypic differences (Sultan 2000), phenotypic plasticity (Herrera 2005) or, stochastic differences between individuals. Phenotypic plasticity is considered one of the major means by which plants can cope with the variability in environmental factors (Gratani 2014). Whatever be the cause of variation, species that express a higher degree of functional trait variation can compete more effectively within as well as across the plant communities. Leaves can be considered as a microcopy of plants, and the variations in leaf morphology can reflect the plants' capacity to acquire, use and conserve resources (Xu *et al.* 2009). Therefore, comparing the functional traits across natural gradients is an effective way to understand what factors dictate the pattern of individual species or the community change across a variety of conditions, and how they respond to climate change.

Alpine regions are characterized by the presence of two opposing gradients; cold temperature and summer drought (Pescador *et al.* 2015), thus, the coexisting plant species in the summits should adapt themselves in such a way that they can co-exist and overcome resource competition. Here, climate-related variables are the most

important factors in shaping the distributional ranges of alpine and subalpine plant species (Fangyuan *et al.* 2016). Alpine-nival ecosystems are particularly more vulnerable to climate change than other areas because the main climatic factors, viz temperature and precipitation, shaping alpine-nival plant life, are directly influenced by global warming (Salick *et al.* 2007). Spatial variation in plant traits along elevational gradients may exhibit parallel trends associated with ongoing and projected anthropogenic climate warming (Dunne *et al.* 2004), which is predicted to affect the functional trait composition of plant communities (Suding *et al.* 2008). Therefore, the coexisting plant species tend to develop specific functional traits that enable them to cope up with the changing environment in response to climate change. Physiological changes driven by both genetic divergence and phenotypic plasticity may contribute to the overall response of plant communities to the selective agents of climate change (Bellard *et al.* 2012), because these changes determine the ability of plants to pass through existing environmental filters. Some species are more competitive and can express a higher degree of functional trait variation to adapt in the changing environment, and thus get selected during environmental filtering but those species which cannot adapt themselves with the changing environment are gradually replaced by the competitive ones. In this regard, study towards documenting subalpine-alpine plant diversity and their current distribution pattern among the life forms and chorological spectrum, together with the variation in plant functional traits will provide ample support in collecting the base-line data on climate change research.

1.2 Rationale of Study

Manang district lies at the transition between eastern and western Himalaya, thus both eastern and western Himalayan floristic elements are found. Geographically, Bhimthang lies between two major conservation areas Annapurna Conservation Area and Manaslu Conservation Area, but is not included in any of these two. This area seems to be highly neglected such that Bhimthang and the Gyasumdo valley itself is relatively less explored botanically. The area encompasses a unique glaciated landscape in the very shore of the Bhimthan glacier, thus the flora of this region shares unique spatial distribution pattern due to heterogeneous landscape. However,

till date no any detail works related to floral diversity have been carried out in this area.

On the other hand, this heterogeneous landscape creates a distinct phytoclimate within the elevational gradient, which in turn alters the plant functional traits to a large extent. However, very few studies have been carried out regarding the PFTs in Nepal and those incorporating the variation of PFTs along the elevation are very rare (Shah 2013, Rana and Ghimire 2017). Thus, PFTs represent a promising aspect of research in Nepal which can provide a lot of information related to the vegetation patterns and species's specific response towards the environment. Hence, present research work was undertaken to enumerate and document the vascular plants and to assess their diversity and distribution patterns, and the variation of PFTs along the elevation gradient covering two different moraines of the Bhimthan glacier.

1.3 Objectives

This study is aimed at assessing species distribution pattern along a subalpine-alpine gradient of Bhimthang, Manang, Central Nepal. Here, the broad objective of this study is to determine the floristic composition and richness of vascular plants in relation to elevation gradient in Bhimthang, Manang whereas the specific objectives of this study include;

- a. To assess the composition and pattern of distribution of vascular plant species in different canopy types along the elevation gradient.
- b. To assess the composition and pattern of distribution of vascular plant species grouped into different categories according to endemism and life forms along the elevation gradient.
- c. To study inter and intra-specific variation in plant functional traits along the elevation gradient.

1.4 Research Questions

To fulfill the above objectives, some research questions were developed.

- Q.1 Does the vascular plant diversity change with change in elevation gradient in different canopy types?

Q.2 What will be the diversity of narrow range species, having narrow habitat amplitude at higher elevations?

Q.3 Do the plant functional traits vary with change in elevation?

1.5 Limitations of the Study

The study was carried out in a subalpine– alpine gradient of Manang. Due to topographical constraints the study was limited to southern aspect only. Since, a short gradient which covers subalpine-alpine ecotone as well as lower and mid alpine region, starting from 3700 to 4600 m asl has been taken in this study, it cannot explain the actual pattern of species richness in alpine. Adverse weather conditions and timing of the field visits were the other limiting factors for this study.

The plant functional traits covered as many traits as possible for the analyses in order to get a better picture of the variation along the elevational gradients. It was carried out in five selected species only because including almost all the species present in the study area would be more time-consuming. However, analyzing all the feasible traits in those five species is again time-consuming and worthless because almost all the traits may not be informative. Hence, only eight functional traits were selected for the present study. Not all of the traits were considered in all the selected plant species. For example, plant size was measured only for shrubs and not for herbaceous plants. Similarly, reproductive output was measured only in four out of five species.

CHAPTER 2: MATERIALS AND METHODS

2.1 Study Area

2.1.1 Location

Gyasumdo valley (lower Manang), occupies about 40% of the total territory of Manang district, and lies between 28° 27' to 28° 46.35' N latitude and 84° 10.44' to 84° 30' E longitude and extends in the north to Tibet and in the south to Lamjung district and covers a wide range of elevation from 1,600 m asl (Tal) to over 8,163 m asl (Mt. Manaslu) (Shrestha et. al 1995). It is a glacially formed U-shaped valley traversed by the Dudh khola and surrounded by high mountains. The Dudh khola emerges from the Bhimthang glacier and flows down from north to south and merges with the Marsyangdi River near Thoche village. Gyasumdo valley consists of four different VDCs, namely Chame, Bagarchhap, Thoche and Dharapani.

The study area is located in north-eastern part of Gyasumdo valley in Manang district between the boundary of Annapurna Conservation Area (ACA), Nepal and Manaslu Conservation Area (MCA), Nepal. The subalpine- alpine zone, north-east of Gyasumdo valley, the actual sampling location, lies adjacent to the Bhimthan glacier, which is formed by the union of three glaciers; Ponker glacier, Salpudada glacier and Kechakyu Khola glacier. The sampling site incorporates two different moraines of the large Bhimthan glacier; the lower elevation bands comprise of the relatively younger lateral moraine of the glacier while the higher elevation bands comprise of the relatively older, stable Ponker Hill towards terminal moraine of the Bhimthan glacier.

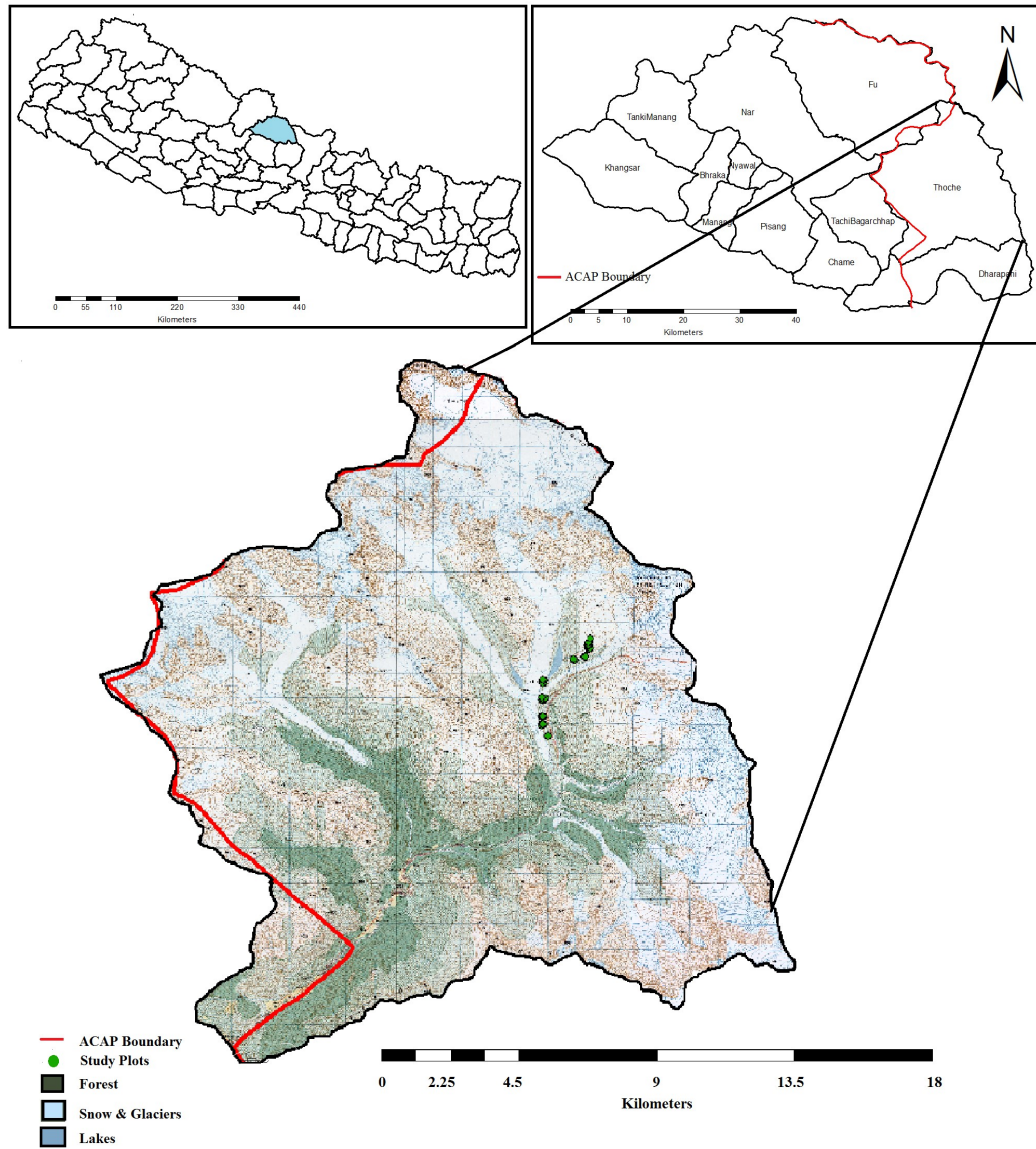


Fig. 1: Map of the study area showing Manang district and the sampling sites in Bhimthang covering a wide elevation range across the lateral moraine and terminal moraine of Bhimthan glacier.

a.



b.



Fig. 2: Some photographs of study area including: **a.** temporary settlement in Bhimthang along the lateral moraine of Bhimthang glacier, and **b.** southern aspect of Ponker Hill from Phedi.

2.1.2 Climate

In Manang, the humid air current of monsoon from south is shielded by the mountain ranges of Annapurna (>7500 m asl), Lamjung (6932 m asl) and Manaslu (8163 m asl)

so the effect of monsoon is greatly reduced (Pohle 1990). Monsoon enters from south-east, resulting a decreasing moisture from east to west in Manang valley, thus, the south-facing slopes are significantly drier and warmer than those facing north (Baniya *et al.* 2009). Depending upon the rainfall extent, Manang is categorized into Upper and Lower Manang. Lower Manang consists of single large valley, the Gyasumdo valley and covers four VDCs Chame, Dharapani, Thoche and Bagarchhap. The present study was carried out in Thoche VDC.

As the Gyasumdo valley lies on the southeastern part of the district, it receives higher precipitation compared to the other valleys of the district. The nearest meteorological station, Chame in Manang district (lat.: 28° 33', long.: 84° 14', elevation: 2680 m asl) was selected as meteorological reference point for the description of the climate of the area because both Chame and Bhimthang lie within Gyasumdo valley and share similar climatic pattern. The annual mean maximum and minimum temperature are 16.84°C and 4.70°C respectively whereas the average annual precipitation is 972.08 mm.

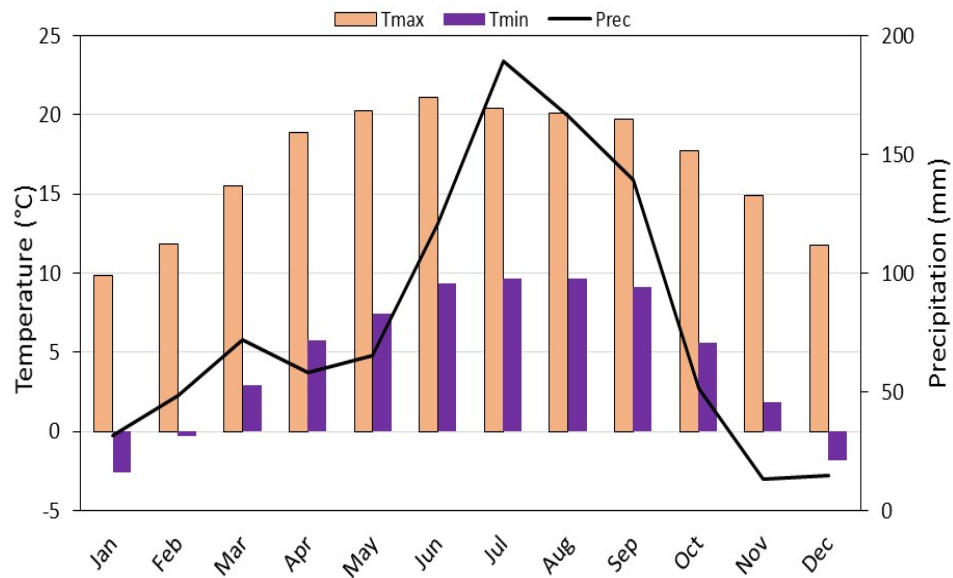


Fig. 3: Ombrothermic graph representing the monthly average maximum (**Tmax**) and minimum (**Tmin**) temperature and precipitation (**Prec**) trend of Chame meteorological reference point (as per the climatic data of 1980- 2012). (Data Source: Department of Hydrology and Meteorology, Government of Nepal).

2.1.3 Vegetation and phytogeography

Geographically, Manang district lies in the arid zone northward of the massif Himalayas, thus the vegetation of the study area is quite similar to that of Tibetan Plateau (Chaudhary 1998). However, in Gyasumdo Valley (1600- 3600 m asl), there is still a relatively rich subtropical vegetation, predominant with dense oak (*Quercus* spp.) and *Rhododendron* forests in the lower belt and conifers (*Pinus wallichiana*, *Picea smithiana*, *Taxus wallichiana*, *Tsuga dumosa* and *Abies spectabilis*) in the upper belt (Shrestha *et al.* 1995).

Forest vegetation is restricted to valley bottoms at low elevation (<3800 m asl). The dominant tree species in such forests are *Abies spectabilis*, *Taxus wallichiana*, *Tsuga dumosa* and *Pinus wallichiana* with scattered trees of *Betula utilis* and *Acer pectinatum* in south facing slopes together with some patches of *Rhododendron* forests under open canopy. However, along the riverine course of Dudhkhola, *Taxus wallichiana* formed dominant canopy trees (Shrestha *et al.* 1995). As we move higher (>3800 m asl) is exclusively represented by alpine meadows interrupted by shrub patches of *Rhododendron lepidotum*, *Cotoneaster microphyllus*, *Lonicera spinosa*, *Salix lindleyana*, *Gaultheria tricophylla* and *Potentilla fruticosa* in southern slopes. However, on shady northern slopes, the vegetation consists of dwarf thickets of *Rhododendron anthopogon*, *Salix calyculata*, *S. lindleyana* and *Rheum australe*.

The alpine meadows, mainly on exposed slopes, are dominated by *Anaphalis royleana*, *Bistorta vivipara*, *Selinum wallichianum*, *Cortia depressa*, *Gentiana depressa*, *Kobresia pygmaea*, *Saxifraga parnassifolia*, *Potentilla argyrophylla*, *Lilium nanum*, *Sibaldia cuneata*, *Cyananthus lobatus*, *Aster asteroids*, *Erigeron multiradiatus*, *Taraxacum eriopodum*, *Dactylorhiza hatagirea*, *Cypripedium himalaicum*, *Leontopodium stracheyi*, *Primula capitata* and *Pedicularis* spp.

2.1.4 Socio-economy and culture

The total population of Manang district, according to 2011 census, is 6,538 with 3,661 males and 2,877 females (CBS 2011a). Chame VDC has the highest population of 1,129, whereas Thoche, with only two permanent settlements Thoche and Tilche has 102 households and a minimum population of 382 with 177 males and 205 females

(CBS 2011b). Approximately, two-third of the total inhabitants are Gurungs, however, members of Tibetan ethnic origin have also taken up residence in this valley since long ago. Generally, they are called “Gyasumdopas” or “Lamas” as their language, lifestyle, food habit, custom and culture resemble to those of Tibetans Lamas (Shrestha *et al.* 1995). However, the original inhabitants are the Gurungs. Local economy is based on tourism, traditional agriculture, animal husbandry, trade of wild vegetables and medicinal herbs and business. Since Thoche VDC serves as the major trekking route to the Larke Pass (5160 m asl), majority of the people are involved in hotel business. The highest (3710 m asl) temporary settlement exists near to our sampling site in Bhimthang at ca. 3700 m asl, where almost all the people are involved in hotel business.

2.2 Study Design

2.2.1 Field sampling and data collection

Three field visits were carried out from October, 2015 to August, 2016. The first visit was carried out during October- November, 2015 to access the topographical features and vegetation of the study area. A preliminary survey was carried out from 4000 to 4600 m asl in every 200 m elevation interval in both North and South. However, a perfect north was inaccessible due to the location of study area within glaciated landscape. Based on the sites that were surveyed, it was found that species richness was higher in south compared to north. Therefore, a comparatively large gradient starting from 3700 to 4600 m asl in southern aspect was taken and sample plots were laid in every 100 m elevation interval during August 2016. Sampling was carried out by following standard method (Pauli *et al.* 2015).

During the preliminary survey, 3x3m plots were laid down at every 200 m elevation interval along the 4000 to 4600 m elevation range. The plot were subsequently divided into nine quadrats each of 1x1m. Out of those nine quadrats, only the four corner quadrats were considered for vegetation sampling (**Fig. 4a**). The plots were replicated for five times such that 20 quadrats each with 1x1m area were studied in each elevation belt with a total of 80 quadrats in each aspect. Hence, the total number of quadrats studied in both aspects became 160 during the preliminary survey.

In the second visit, sampling was carried out covering wide elevation range (3700 to 4600 m asl) in every 100 m elevation interval but only in southern aspect. In this case, each of the 3x3m plots were subsequently divided into nine 1x1m quadrats, out of which four corner quadrats and one central quadrat were considered for vegetation sampling (**Fig. 4b**). Thus, in each plot, the vegetation of five quadrats were studied. The plots were replicated for six times, three in each, open and closed canopy types, such that 30 quadrats each with 1x1m area were studied in each belt. Hence, a total of 300 quadrats were studied during this period.

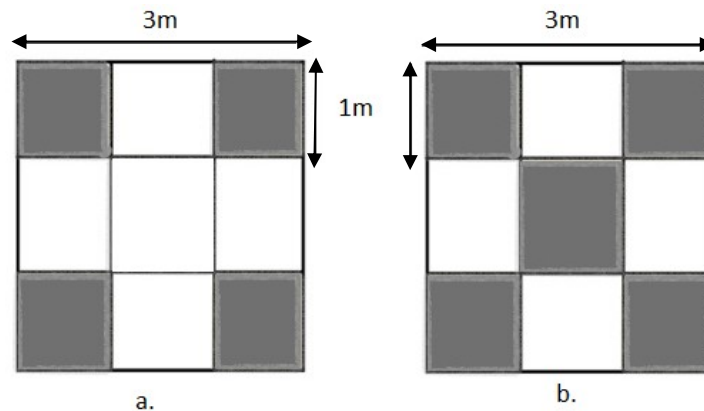


Fig. 4: Diagrammatic representation of the 3x3m plots divided into nine 1x1m quadrats of which the shaded ones were studied (**a.** sampling design during the preliminary survey, and **b.** sampling design during the final survey).

Vascular plants present in each quadrat were recorded along with the individual species cover percentage. Habitat parameters including the vegetation types such as vascular plants cover (%), shrub cover (%), herbs cover (%), graminoids cover (%), lichen cover (%), bryophytes cover (%) and major surface cover types such as rock and scree cover (%), and bare ground cover (%) were recorded. Disturbance was measured as a categorical value starting from 0 to 4, where 0 represented 'no disturbance', 1 represented 'very little disturbance', 2 represented 'moderate level of disturbance', 3 represented 'high level of disturbance' and 4 represented 'very high level of disturbance'. Topographical features such as latitude, longitude, and altitude were recorded for each 3x3m plot (using GPS); whereas slope (using clinometer) and aspect (using compass) were recorded for each 1x1m quadrat. The aspect was folded

about the north-south line (rescaling 0-360° to 0-180°, such that NE= NW) using the following formula (McCune and Keon 2002).

$$\text{Folded aspect} = 180 - |\text{Aspect} - 180|$$

The value of latitude, slope and folded aspect were combined to calculate potential annual direct incident radiation (PADIR, MJ cm⁻²yr⁻¹), using the formula given by McCune and Keon (2002). PADIR gives a relative value of how much solar radiation a particular sight receives.

$$\begin{aligned} \text{PADIR} = & -1.236 + (1.35 \times \text{COS}(\text{latitude in radian}) \times \text{COS}(\text{slope in radian})) - \\ & 1.376 \times \text{COS}(\text{folded aspect}) \times \text{SIN}(\text{slope in radian}) \times \text{SIN}(\text{latitude in radian}) - \\ & 0.331 \times \text{SIN}(\text{latitude in radian}) \times \text{SIN}(\text{slope in radian}) + (0.375 \times \text{SIN}(\text{folded} \\ & \text{aspect}) \times \text{SIN}(\text{slope in radian})) \end{aligned}$$

2.2.2 Voucher specimen collection and maintenance

Voucher specimens (at least 2 sets) of each species of the vascular plants on the state of either flowering or, fruiting or both were collected from the study area. Identification of those voucher specimens was carried out by following standard literature (Grieson and Long 1983- 2000; Noltie 1994- 2000; Ohba *et al.* 2008; Polunin and Stainton 1984; Stainton 1988; Press *et al.* 2000; Zheng-Yi and Raven 1996-2003; Fraser-Jenkins 2015), expert consultation, visit to the herbaria (TUCH and KATH) and by comparing with the high resolution herbarium images of TI, K and MO. Nomenclature follows e-version of the Annotated Checklist of Flowering Plants of Nepal (efloras.org 2016) and The Plant List (www.theplantlist.org). The herbarium specimens prepared are deposited in KATH and TUCH.

2.2.3 Plant life form classification

Life form is the ultimate manifestation of sum of all the adaptations undergone by a plant to the climate of the surrounding (Raunkier 1934). Plant life forms were identified based on the Raunkiaer's life form classification system (Raunkiaer 1934) where plant species were classified into five principle life forms i.e, Phanerophytes (PHP), Chamaephytes (CHP), Hemicryptophytes (HCP), Cryptophytes (CRP) and Therophytes (THP) (**Fig. 5**).

- ❖ **Phanerophytes** (PHP) are species in which the perennating buds are present in the air. This category of plants may lose their leaves during unfavorable season but the apical buds are protected by bud-scales (Raunkiaer 1934). This life form mostly includes woody trees and shrubs. Based on the size, they are further categorized into four different types: **a.** Megaphanerophytes, **b.** Mesophanerophytes, **c.** Microphanerophytes and **d.** Nanophanerophytes.
- ❖ **Chamaephytes** (CHP) are species in which perennating buds are present in air but do not exceed 25 cm above ground. According to the shoot behavior four categories are recognized: **a.** active chamaephytes, **b.** passive chamaephytes, **c.** suffruticose chamaephytes and **d.** cushion chamaephytes.
- ❖ **Hemicryptophytes** (HCP) are the species in which the perennating buds are present in upper crust of the soil just below the surface of ground. It includes three different forms of plants: **a.** non-rosette (proto-hemicryptophytes: plants which lack basal leaves), **b.** sub-rosette forms (plants which possess both basal and stem leaves), **c.** rosette forms (plants which possess all or nearly all leaves in a compact basal rosette).
- ❖ **Cryptophytes** (CRP) are the plant species in which perennating buds are found beneath the substratum that may be either terrestrial or subjacent soil surface. It includes **a.** geophytes (plants with bulbs, corms, rhizomes, tubers and root tubers), **b.** hydrophytes (those plants in which perennating buds are submerged under water), and **c.** helophytes (marsh plants in which perennating buds are present in the soil surface beneath water).
- ❖ **Therophytes** (THP) are annual plant species that remain dormant throughout the unfavorable season in the form of seeds. They are mostly found in disturbed vegetation.

The occurrence of different life forms along elevation gradient explains their ability to adapt with the varied climatic conditions (Klimes~ 2003). General trend shows that phanerophytes and therophytes are dominant functional traits at low elevations and are gradually replaced by hemicryptophytes and chamaephytes at the higher elevations (Raunkiaer 1934).

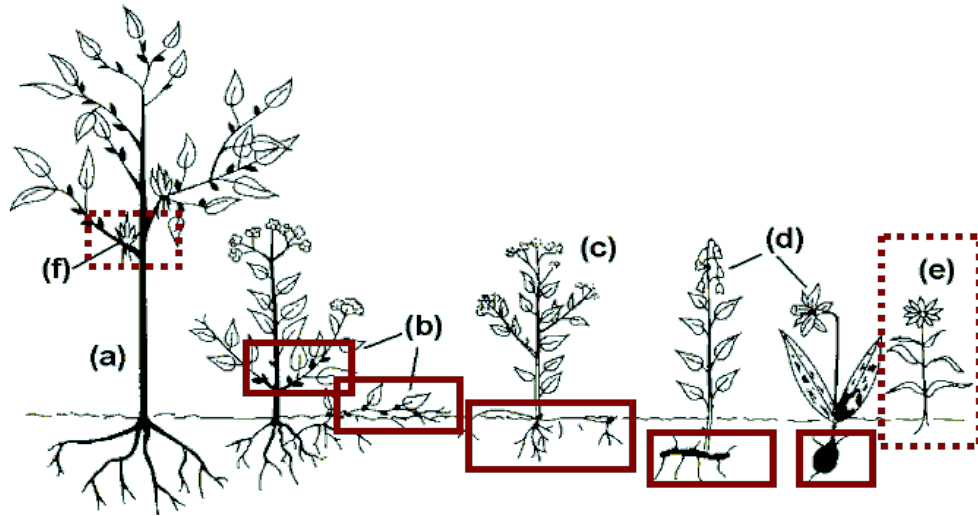


Fig 5. Diagrammatic representation of different life forms adopted from the classification of Raunkier (1934): **a.** phanerophyte, **b.** chamaephyte, **c.** hemicytophyte, **d.** cryptophyte, **e.** therophyte, and **f.** an epiphyte growing on a phanerophyte. (Source: hosho.ees.hokudai.ac.jp/~tsuyu/top/dct/lf.html)

2.2.4 Distribution patterns

The distribution pattern of the plant species was based on the electronic versions of Annotated Checklist of Flowering Plants of Nepal (Press *et al.* 2000) and Flora of China (Zheng-Yi and Raven 1996-2003). Plant species were assigned, based on the biogeographical affinity into three chorotypes (Joshi 2011). Chorotypes constitute biogeographic units that can be applied as a conceptual tool to improve insight into distribution patterns (Olivero *et al.* 2011).

- ❖ **Himalayan endemics (HE)** include those species which are endemic to the Himalaya. Here, the term Himalaya represents a wide area extending from eastern border of Afghanistan to western border of Myanmar, including Tibetan Autonomous Region of China (Xizang) and some parts of W. China (Sichuan and Yunnan).
- ❖ **Pan-Himalayan distribution (PE)** comprise those species whose distribution crosses the boundary of Himalayan range, but is restricted to the areas lying adjacent to the Himalaya (Gansu, Hebei, Ningxia, Qinghai, Shaanxi, Xinjiang,

E. China, S. China, Jilin, Heilongjiang, Liaoning, and Tajikistan including the Himalaya as above).

- ❖ **Broad range of distribution (BE)** includes those species which have wider range of distribution crossing the territory of pan-Himalaya.

The occurrence of different chorotypes along the elevation gradients reflects that proportion of endemics increases with increasing elevation particularly in the mountainous areas. In the alpine-nival zone of the Himalaya, endemics are dominant which is followed by the species with pan-Himalayan distribution (Joshi 2011).

2.2.5 Plant functional trait study

For the study of variation in plant functional traits five different species were selected: *Rhododendron lepidotum*, *Cotoneaster microphyllus*, *Dactylorhiza hatagirea*, *Cypripedium himalaicum*, and *Rhodiola bupleuroides*. During the selection of these plant species, two things were kept into consideration. The first thing was the distribution of the individual species over a wide elevation range in the study area. Diversed groups of plants were taken as far as possible, which covers two species of orchids, two species of shrubs, and one species of succulent plant. Samples were collected from entire sampling range in the study area covering a wide elevation from 3700 to 4600 m asl. However, for *Cypripedium himalaicum*, the elevation range extends between 3900 to 4500 m asl.

For all these species selected, plant height, stem girth and canopy diameter (only for *Rhododendron lepidotum* and *Cotoneaster microphyllus*, as these were the dominant shrubs forming canopy along the elevation) were measured in the field. The total number of flowers and/or fruits present in the sampling individuals were counted. From each sampling individual, leaves and fruit samples were collected and their fresh weight was measured. For leaves, the maximum length and width were also measured. Replicate samples of each species were collected from five individuals at each elevation bands.

Samples were brought to the laboratory, oven dried for 72 hours at 60°C and their dry weight was taken (Pescador *et al.* 2015). In case of leaves, the collected samples were pressed in newspaper and brought to the laboratory, rehydrated at room temperature

for 12 hours. Then, those rehydrated leaves were placed in between blotting paper to absorb the excess water and scanned using Canon LIDE 120 scanner. Finally, the area of leaves were calculated using ImageJ (Schneider *et al.* 2012).

2.2.6 Data analysis

2.2.6.1 Species composition pattern: Multivariate analyses

Ordination was carried out in order to understand the relationship between the species and environment. Detrended correspondence analysis (DCA), a method of indirect gradient analysis which ordines both species and sample units under study simultaneously (McCune and Grace 2002), was carried as the preliminary multivariate analysis. It is used to study the distribution of sample units and species in environmental space, thus a distribution pattern is obtained in the form of DCA Ordination diagram. The first DCA axis is correlated with β -diversity and gives a measure of Species turnover (Hill and Gauch 1980). Higher the value of Gradient Length of DCA axis-I, higher will be the β -diversity and hence the species turnover. From the DCA ordination, a gradient length of 4.465 SD units was obtained which indicates a higher β -diversity and a complete turnover of the species along the gradient. Since, the length of gradient is longer (>2.5), canonical correspondence analysis (CCA) becomes appropriate to explain the species-environment relationship.

CCA is a direct gradient analysis (ter Braak 1986) used to access the relationship between the species and environment. In the present study, CCA was carried out to understand the relationship between different environmental parameters such as elevation, slope, radiation, major substrate types including surface cover and vegetation type. These parameters were tested for their significance in governing the species distribution pattern, using Monte Carlo Permutation test with 9999 permutations at significance level $p < 0.05$. The plant life forms were also assessed together with environmental variables in CCA so as to understand the relationship with the environmental variables. CANOCO version 4.5 (ter Braak 2002) was used to perform DCA and CCA ordinations. The relationships between environmental variables were tested using Spearman-rank correlation. On the other hand, to understand the effect of shrub canopy upon species richness, Multiresponse

permutation procedure (MRPP) was carried out between species presence/absence data from different canopy types at each elevation bands. MRPP was carried out in RStudio version 0.99.1172 (RStudio Team 2015).

2.2.6.2 Species diversity measures

Species richness (α -diversity) is the principle measure of diversity considered in this study. It is defined as the number of species per unit area. Species richness was obtained at the level of 1×1m quadrat, 3x3m plot and along ten different elevation bands. Together species richness was also analysed in north and south along an elevation range of 4000 to 4600 m asl. All the data were first checked for the normality using Shapiro-Wilk normality test. The relationship between species richness and elevation as well as along different canopy types, at different spatial scales were assessed using generalized linear model (GLM). Species richness was treated as response variable and regressed against different environmental variables such as elevation, canopy cover, rock and scree cover, bryophytes cover, lichen cover, disturbance and litter depth. The relationship between species richness and multiple environmental variables was also assessed through multiple regression using generalized linear model (GLM). A poisson error distribution was used due to count nature of response variable. Together, a Quasi Poisson error distribution with F-test was used to handle the over dispersion of the deviance (Crawley 2007). The significance of each model was tested against null model as well as with each other up to second order polynomials. Forward selection of model was done and the model with higher F-value was selected for the model fitting and graphical representation. However, in case of multiple regression significance of each model was tested against null model and only first order polynomial was considered. RStudio version 0.99.1172 (RStudio Team 2015) was used for the regression analysis.

Spearman rank correlation coefficients were obtained to assess the relationships between environmental variables under investigation. The disturbance factors such as grazing, trampling, fire, and harvesting were combined through dimension reduction technique into two major types (disturbance imposed by animals and disturbance imposed by human), using principal component analysis (PCA) in IBM SPSS 20.0. The differences in frequency and cover of individual species in different canopy types

along the two major moraines was analyzed using Man-Whitney U test in IBM SPSS 20.0. The life form data were skewed and non-normality persisted even after transformation, therefore these were treated through non-parametric tests (usually Kruskal Wallis test for K independent samples). The distribution pattern of different life forms and endemism along the elevation gradient was analysed using GLM.

2.2.6.3 Indicator species analysis

Indicator species analysis (ISA) is a method of numerical classification applicable to large set of qualitative and quantitative data that provides a simple, intuitive solution to the problem of evaluating species associated with groups of sample units (Dufrene and Legendre 1997). Indicator species are often determined using an analysis of the relationship between the species occurrence or abundance values from a set of sites and the classification of the same sites into site groups (habitat types, community types, disturbance states, etc.) (DeCáceres 2013). Indicator species are biological indicators of groups of sites representing habitat types or combinations of habitat types (DeCáceres *et al.* 2010). Since, the study area comprised of two major moraines, ISA was carried out for each species based on its response to environmental variables in order to obtain a relationship between species and each site group (each of those moraines) in the form indicator value indices (IndVal). Finally, the statistical significance of this relationship was tested using a Monte Carlo permutation test with 9999 permutations. Indicator species analysis was carried out in RStudio version 0.99.1172 (RStudio Team 2015) by using “multipatt” function in a package called “indicspecies” (DeCáceres 2013).

2.2.6.4 Plant functional traits analysis

The major traits considered for this study were plant height, plant size, stem girth, specific leaf area (SLA), leaf dry matter content (LDMC), leaf thickness (LT), reproductive output (no. of fruits), and fruit dry matter content (FDMC).

2.2.6.4.1 Plant height

Plant height is the shortest distance between the upper boundary of the main photosynthetic tissues of an individual and the ground level (Cornelissen *et al.* 2003).

Plant height is one of the most important functional traits, which is a major determinant of plants' ability to compete and survive in the given community. Plant height for individual species was measured in centimeters (cm).

2.2.6.4.2 Plant size

Plant size (SI) was measured only for shrubs as they were the major determinants of the closed canopy type along elevation. It was measured in cm² using canopy area projection method, adjusting an ellipsoid shape, using the formula (Pescador *et al.* 2015):

$$SI = \pi \frac{D}{2} * \frac{d}{2}$$

where, 'D' is the largest diameter and 'd' is the smallest perpendicular to the largest one.

The largest diameter (D) and three perpendiculars to D were measured in the field (i.e. d₁, d₂ and d₃, such that d= (d₁ + d₂ + d₃)/3).

2.2.6.4.3 Stem girth

Stem girth (in *Rhododendron lepidotum*, *Cotoneaster microphyllus* and *Rhodiola bupleuroides*) was measured at 1 cm above the ground level in each studied species. In *Dactylorhiza hatagirea* and *Cypripedium himalaicum*, stem girth was measured 1cm above the ground excluding the lowermost withered leaf in each individual. The stem girth was measured in centimeters.

2.2.6.4.4 Specific leaf area

Specific leaf area (SLA) is defined as the ratio of fresh leaf area to dry leaf weight (Pescador *et al.* 2015), measured in cm²g⁻¹. SLA is a growth and resource acquisition indicator, a good correlate of the potential relative growth rate of the plant (Cornelissen *et al.* 2003, Körner 2003). SLA was calculated by using the formula (Pescador *et al.* 2015, Cornelissen *et al.* 2003):

$$SLA = \frac{\text{Area of leaf}}{\text{Dry weight of leaf}}$$

2.2.6.4.5 Leaf dry matter content

Leaf dry matter content (LDMC) is defined as the ratio of dry leaf weight to the fresh leaf weight (Pescador *et al.* 2015), measured in gg^{-1} . LDMC is a growth and resource acquisition indicator and gives an indication of the leaf water content corresponding to the leaf content in mesophyll, the photosynthetic tissue (Cornelissen *et al.* 2003). LDMC was calculated by using the formula (Pescador *et al.* 2015, Cornelissen *et al.* 2003):

$$\text{LDMC} = \frac{\text{Dry weight of leaf}}{\text{Fresh weight of leaf}}$$

2.2.6.4.6 Leaf thickness

Leaf thickness (LT) is a major functional trait in plants that deals with the degree of abiotic stress that plants need to tackle. Plants develop a different degree of thickness of their leaves depending upon the existing environmental conditions and the nature of plant itself. LT is related to resource acquisition and is measured in mm. LT is highly correlated with SLA and LDMC thus, LT was calculated by using the formula (Vile *et al.* 2005):

$$\text{LT} = \frac{1}{\text{Specific Leaf Area} * \text{Leaf Dry Matter Content}}$$

2.2.6.4.7 Reproductive output

As the field visit was carried out during late July to early August, majority of the species were in fruiting stage in the study area. Therefore, reproductive output was measured in terms of number of fruits per individual. The number of fruits present per individual were counted manually in order to determine the reproductive output. However, in *Cypripedium himalaicum*, reproductive output was not considered because the individuals along the elevation exhibited only one fruit per individual.

2.2.6.4.8 Fruit dry matter content

Fruit dry matter content (FDMC) is defined as the ratio of dry weight of fruit to the fresh weight of fruit, measured in gg^{-1} . It gives a measure of how much resource the plant had invested into fruits. FDMC was calculated by using the formula:

$$\text{FDMC} = \frac{\text{Dry weight of fruit}}{\text{Fresh weight of fruit}}$$

Variation of different functional traits with elevation for all the five selected species was carried out using generalized linear model in Rstudio version 0.99.1172 (RStudio Team 2015).

CHAPTER 3: RESULTS

3.1 Local- scale Distribution Pattern: along Major Environmental Gradients

The environmental variables (mean \pm SE) recorded in quadrats along the elevation gradient is given in Appendix 4. The result showed that the different elevation bands vary in terms of radiation, disturbance and other habitat parameters like surface cover types and vegetation composition, which is shown by cover percentage of major substrate types (Appendix 4). The correlation between different environmental variables is given in Appendix 5. Animal disturbance, herb cover, graminoids cover, and species richness were positively correlated with elevation whereas shrub canopy, human disturbance, bryophytes cover, lichen cover, litter cover, rock and scree cover, bare ground, and vascular plants cover were negatively correlated with elevation. Bryophytes cover, lichen cover, litter cover and vascular plants cover were positively correlated with shrub canopy whereas animal disturbance, herb cover, graminoids cover, species richness were negatively correlated with shrub canopy. Habitats at lower elevation, particularly along the lateral moraine, were characterized by poor soil with higher proportion of rock and scree cover. The major substrate types including rock and scree cover ($F= 11.592, p= 0.0007531$) decreased with elevation (**Fig. 6b**). The lower elevation bands along the lateral moraine had greater proportion of shrubs, lichen and bryophytes compared to higher elevation bands along the terminal moraine. The vegetation parameters such as shrub cover ($F= 82.385, p<0.0001$) (**Fig. 6a**), bryophyte cover ($F= 51.653, p<0.0001$) (**Fig. 6c**), lichen cover ($F= 82.997, p<0.0001$) (**Fig. 6d**), and litter cover ($F= 25.918, p<0.0001$) (**Fig. 6e**), significantly decreased with increasing elevation.

The CCA ordination explained the relationship between samples, species, plant life forms and environmental variables. Forward selection and Monte Carlo permutation tests revealed that elevation was the most important variable ($F= 15.832, p= 0.0001$) governing the species composition (Table 1). Disturbance due to animal was the second most significant variable ($F= 3.644, p= 0.0001$), followed by radiation ($F= 2.994, p= 0.0001$), rock and scree cover ($F= 2.466, p=0.0001$), and so on. A brief summary of the Monte Carlo permutation tests showing the relative importance of environmental variables on the species composition is presented in the Table 1.

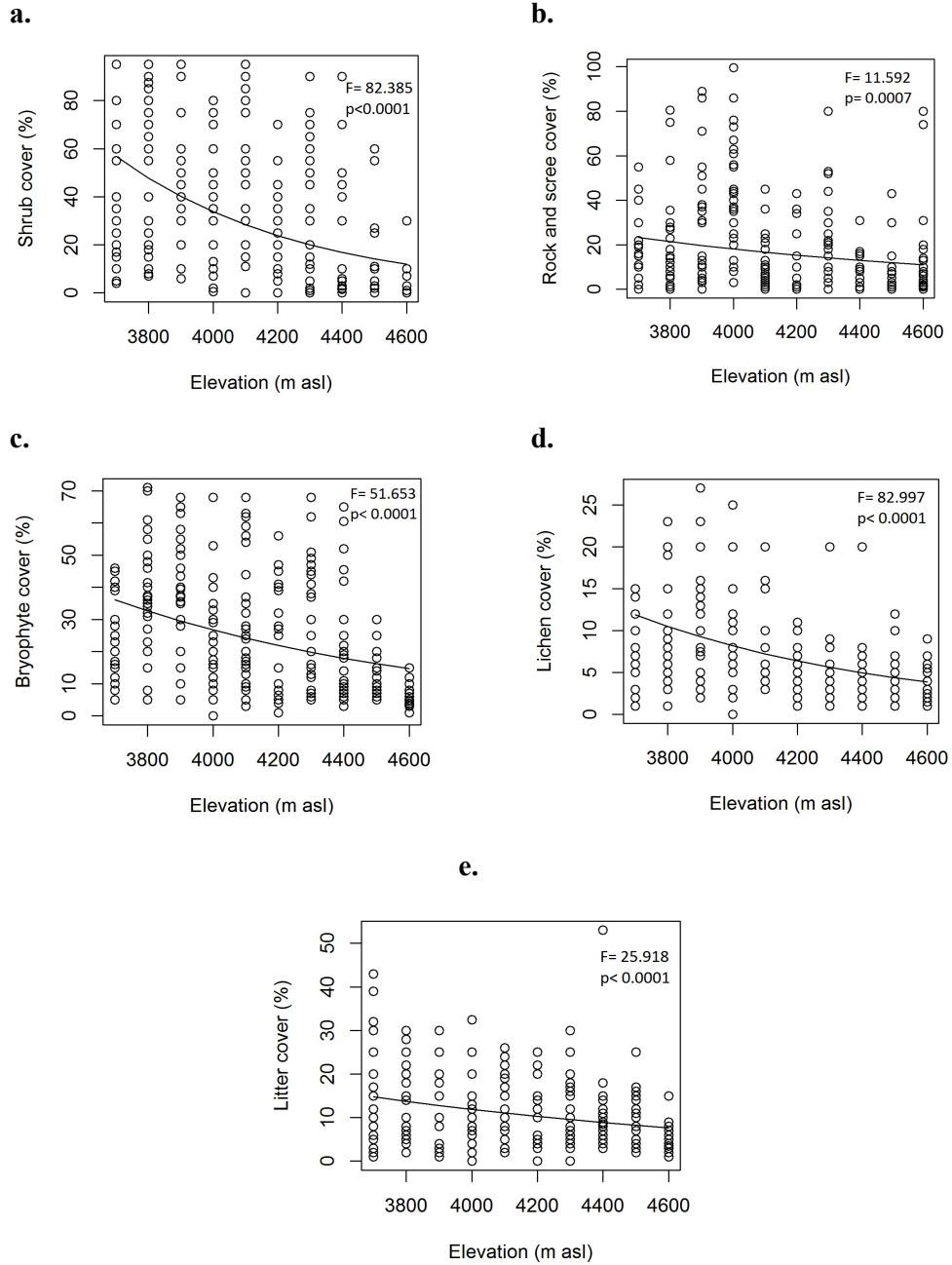


Fig. 6: Relationship between cover of major substrate types (shrubs, rock and scree, lichen, and bryophytes) with elevation: **a.** shrubs cover, **b.** rock and scree cover, **c.** bryophytes cover, **d.** lichen cover, and **e.** litter cover. Lines are fitted with GLM 1st order polynomial regression (for details see Appendix 2).

Table 1. Relative importance of environmental variables on species composition based on the CCA analysis. The statistical significance (p-value) of the variables was obtained using Monte Carlo permutation test with 9999 permutations.

Environmental variables	Abbreviation	Variance explained	<i>F</i>	<i>P</i>
Elevation (m asl)	Elv	0.453	15.823	0.0001
Disturbance imposed by animals	A.Dis	0.099	3.644	0.0001
PADIR (MJ cm ⁻² yr ⁻¹)	Rad	0.079	2.994	0.0001
Rock and scree (%)	R+S	0.065	2.466	0.0001
Disturbance imposed by human	H.Dis	0.062	2.377	0.0050
Canopy (shrub canopy %)	Cnpy	0.055	2.093	0.0001
Litter cover (%)	Lit	0.049	1.883	0.0008
Bryophytes on soil (%)	Bry	0.047	1.817	0.0002
Lichen on soil (%)	Lic	0.045	1.753	0.0009
Bare ground (%)	Bgr	0.036	1.302	0.1193

Table 2. Summary of CCA ordination (Total inertia = 8.983, sum of all canonical eigenvalues = 1.605).

Axes	:	1	2	3	4
Eigenvalues	:	0.467	0.219	0.193	0.137
Species-environment correlations	:	0.972	0.861	0.788	0.835
Cumulative percentage variance					
of species data	:	5.2	7.6	9.8	11.3
of species-environment relation	:	29.1	42.8	54.8	63.3

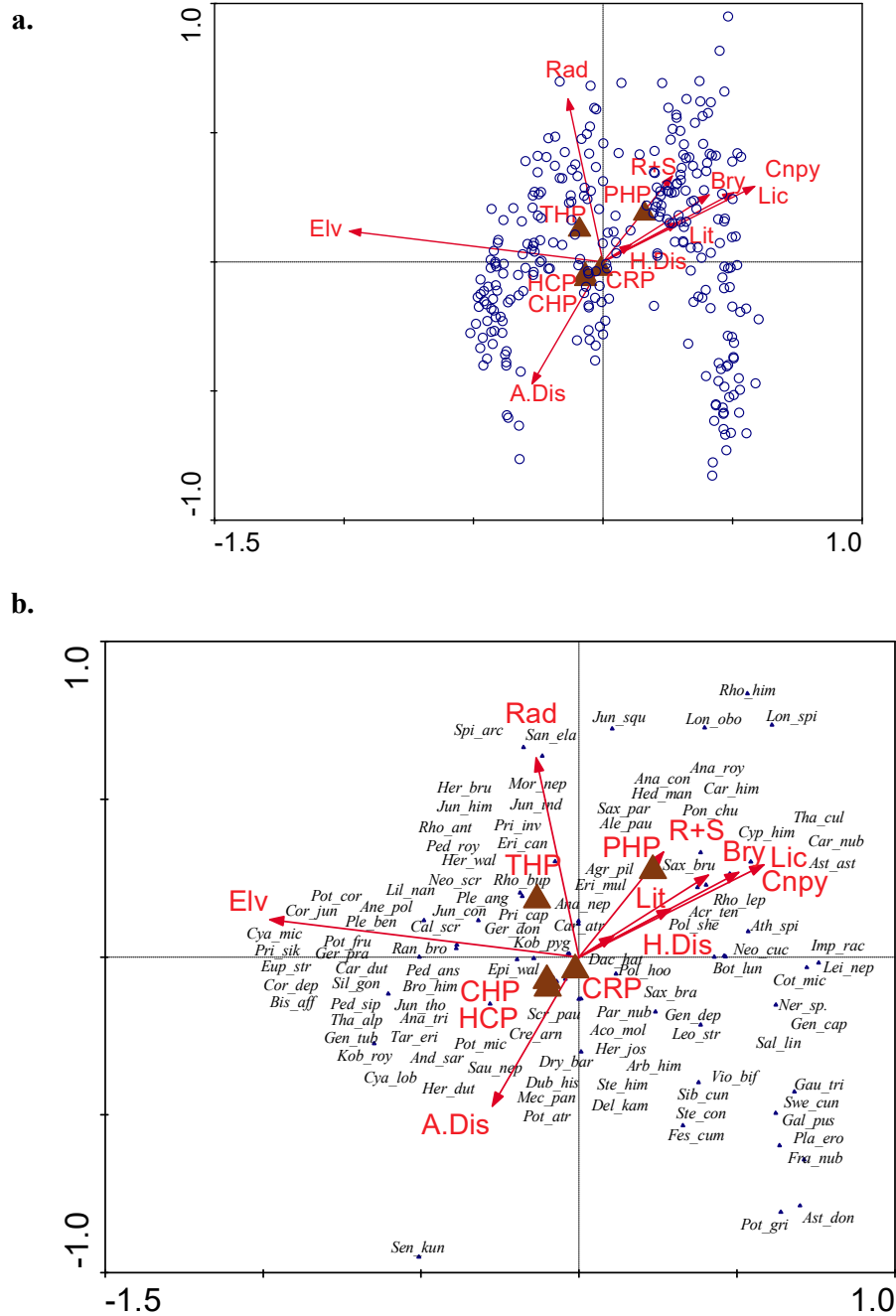


Fig. 7: CCA biplots for **a.** sample plots and environmental variables, **b.** species and environmental variables along with plant life forms (CHP- chamaephytes, HCP- hemicryptophytes, CRP- cryptophytes, PHP- phanerophytes, and THP- therophytes). Species abbreviations represent concatenated forms of first three letters of generic name and specific epithet, as presented in Appendix 1 (those for environmental variables are given in Table 1 above).

The CCA ordination diagram clearly explained that the axis I is correlated with elevation, which explains about 29% variance in the species- environment data and 5.2% variance in the species data. The CCA axis I separated samples (**Fig. 7a**) and species (**Fig. 7b**) from the lowest (positive end of CCA I) to the highest elevation (at the negative end of the axis). The DCA ordination also gave a high gradient length (4.465 SD units) for the DCA axis I, indicating a high turnover of the species composition along the gradient. The high eigenvalue for the CCA axis I (0.467) indicated effective separation of the species along the gradient (Table 2).

The second CCA axis represented a complex gradient related to various topographic and habitat variables including radiation, disturbance and substrate types such as rock and scree cover, lichen cover, bryophytes cover and litter cover. This axis explained 2.4 % variance in the species data along with the topography, disturbance and surface cover types. Although, the eigenvalue of the CCA axis II is comparatively lower (0.219), but it explains a remarkable separation of the species forming different types of vegetation; one type of vegetation along the rocky substrate with high bryophytes (Bry), lichens (Lic) and litter cover (Lit) supporting substantial dominance of the phanerophytes along the rock crevices, and the other type of vegetation along the open scrubland with high solar radiation (Rad) along the positive end of CCA II (**Fig. 7a**). However, the negative end of the CCA axis II was highly correlated with disturbance imposed by animals (A.Dis) forming a different association of the species (**Fig. 7a**).

The species like *Dactylorhiza hatagirea* (Dac_hat), *Polygonatum hookeri* (Pol_hoo), *Epilobium wallichianum* (Epi_wal), *Carex atrata* (Car_atr), *Kobresia pygmaea* (Kob_pyg) and *Geranium donianum* (Ger_don) seemed to be evenly distributed along the gradients (**Fig. 7b**). However, species like *Aletris pauciflora* (Ale_pau), *Hedysarum manaslense* (Hed_man), *Anaphalis contorta* (Ana_con), *Anaphalis royleana* (Ana_roy) and *Ponerorchis chusua* (Pon_chu) tended to be distributed along the rocks; whereas species like *Cypripedium himalaicum* (Cyp_him), *Thalictrum cultratum* (Tha_cul), *Rhododendron lepidotum* (Rho_lep), *Athyrium spinulosum* (Ath_spi), *Acronema tenerum* (Acr_ten), *Polystichum shensiense* (Pol_she), *Saxifraga brunonis* (Sax_bru), *Aster asteroides* (Ast_ast) and *Carex nubigena* (Car_nub) tended to be distributed along the bryophytes and lichen-rich

substrates (**Fig. 7b**). Similarly, species like *Sanicula elata* (San_ela), *Spiraea arcuata* (Spi_arc), *Juniperus indica* (Jun_ind), *Juncus himalensis* (Jun_him), *Morina nepalensis* (Mor_nep), *Rhododendron anthopogon* (Rho_ant), *Heracleum brunonis* (Her_bru) and *Primula involucrata* (Pri_inv) showed strong affinity towards exposed southern slopes with greater sunlight (Rad) (**Fig. 7b**). Species like *Corydalis juncea* (Cor_jun), *Cyananthus microphyllus* (Cya_mic), *Primula sikkimensis* (Pri_sik), *Cortia depressa* (Cor_dep), *Bupleurum longicaule* (Bup_lon), *Bistorta affinis* (Bis_aff) and *Geranium pratense* (Ger_pra) showed strong affinity and luxuriant growth towards the higher elevation (Elv) (**Fig. 7b**). On the other hand, species like *Saussurea nepalensis* (Sau_nep), *Dubayea hispida* (Dub_his), *Meconopsis paniculata* (Mec_pan), *Potentilla atosanguinea var. argyrophylla* (Pot_atr), *Senecio kunthianus* (Sen_kun), *Herminium duthiei* (Her_dut) and *Carex filicina* (Car_fil) showed strong affinity towards the area with greater disturbance due to animals (A.Dis) (**Fig. 7b**).

Chamaephytes, hemicryptophytes, and cryptophytes were nearly equally distributed along the gradient but phanerophytes showed strong affinity towards rocky substrates with higher proportion of lichens and bryophytes. Similarly, therophytes also exhibited positive tendency towards solar radiation.

3.2 Species Diversity Pattern

3.2.1 Total diversity and distribution

Total 129 species of vascular plants, belonging to 85 genera and 41 families, were recorded in the plots. Asteraceae, with 10 genera and 14 species, was the largest family followed by Apiaceae (7 genera, 10 species), Orchidaceae (6 genera, 7 species), Rosaceae (5 genera, 9 species) and Cyperaceae (2 genera, 8 species). *Carex* (Cyperaceae) and *Potentilla* (Rosaceae) with 5 species each were the largest genera followed by *Anaphalis* (Asteraceae) and *Pedicularis* (Orobanchaceae) each with 4 species (for details see Appendix 1). Typical eastern Himalayan elements such as *Heracleum walichii*, *Codonopsis thalictrifolia*, *Bromus himalaicus* and some characteristic western Himalayan elements such as *Rhododendron anthopogon* were recorded during this study. Some of the characteristic taxa endemic to Nepal, such as *Hedysarum manaslense*, *Carex himalaica*, *Pedicularis anserantha*, etc were also recorded. Some potentially high valued medicinal plants such as *Dactylorhiza*

hatagirea, *Neopicrorhiza scrophulariiflora*, *Nardostachys grandiflora*, *Rheum australe*, *Lilium nanum*, etc were also recorded in and around the studied plots.

The measures of species diversity (as per the data of August 2016) did not show any sharp trend with elevation, but the values were higher between 4200 to 4500 m asl (Appendix 3). The corresponding values of mean species richness at different spatial scales along the elevation and canopy types is given in Appendix 3. However, the pattern of species richness with elevation studied using GLM revealed that the overall species richness at 3x3m plot level exhibited a hump-shaped pattern with a peak between 4300 to 4400 m asl ($F= 9.39$, $p= 0.0003$) (**Fig. 8a**). The species richness in both open and closed canopy types showed similar trend with elevation, with a peak at 4500 and 4400 m asl in open ($F= 4.88$, $p= 0.016$) and closed canopy respectively ($F= 4.14$, $p= 0.028$) (**Fig. 9a, b**). Similarly, species richness at 1x1m quadrat level from 4000 to 4600 m asl (as per the data of October 2015) showed hump-shaped pattern with elevation with maximum richness at ca. 4200 m asl ($F= 45.55$, $p<0.0001$) (**Fig. 8b**). Species richness was greater in south compared to north (**Fig. 8c**).

Since, the lowermost elevation band, i.e. 3700 m asl was very close to human settlement, it was highly disturbed and thus outliers were obtained in the values of species richness at this elevation belt. Thus, it was excluded while studying the pattern of species richness along the elevation gradient.

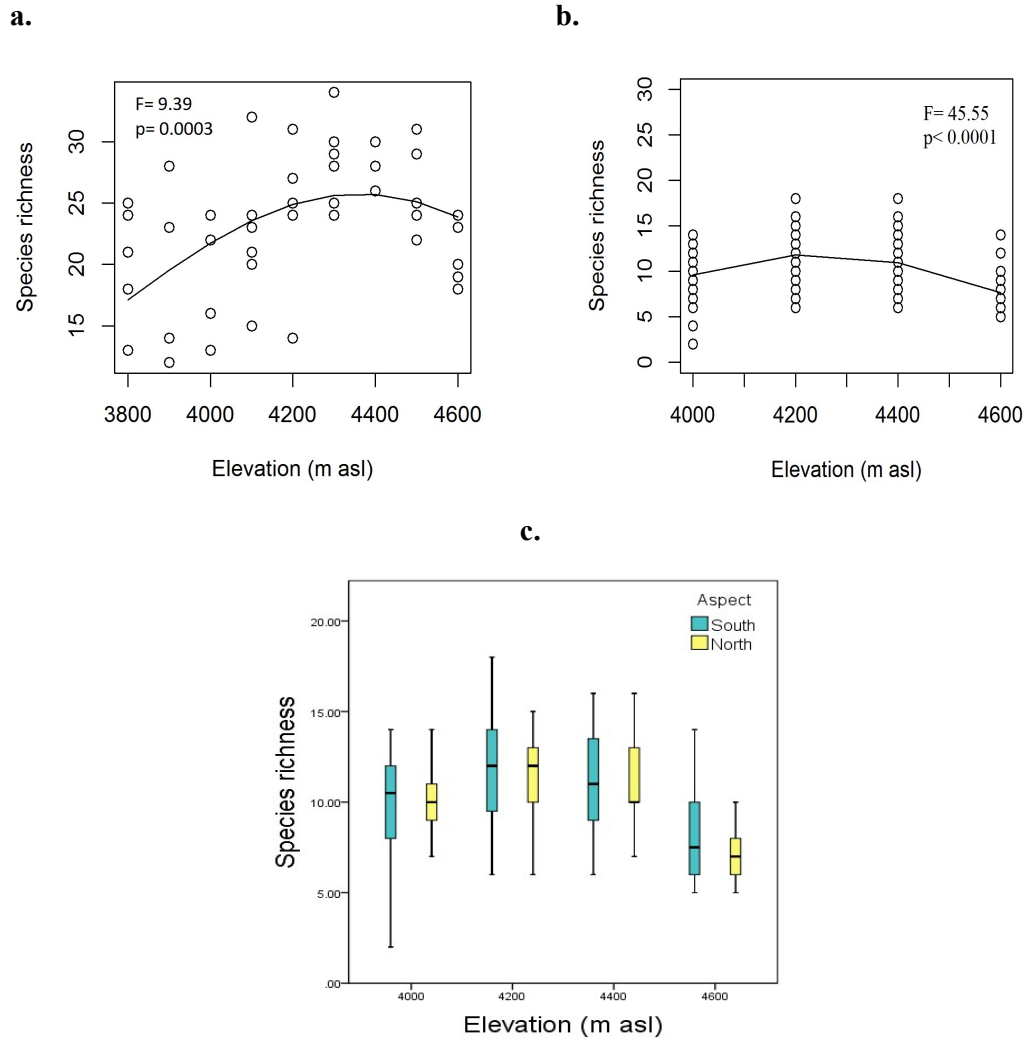


Fig. 8: Pattern of species richness with elevation **a.** overall species richness at 3x3m plot level combining the plots from both open and closed canopy, **b.** overall species richness combining the plots from both north and south, and **c.** mean species richness in north and south. Lines are fitted according to GLM 2nd order polynomial regression (a, b) (for details see Appendix 2). Diagrams were prepared based on the data of August 2016 (a) and October 2015 (b, c).

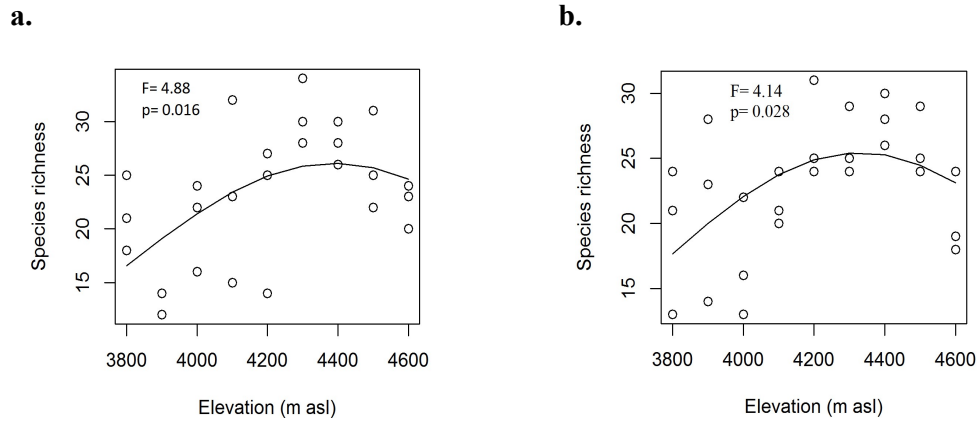


Fig. 9: Pattern of species richness with elevation at 3x3m plot level: **a.** in open canopy, and **b.** in closed canopy. Lines are drawn according to GLM 2nd order polynomial regression (a, b) (for details see Appendix 2).

3.2.2 Species richness and habitat variables

Species richness was considered as a response variable and regressed against the major habitat parameters, like surface cover types, radiation, disturbance and major vegetation types using multiple regression assuming generalized linear model (Appendix 2). Elevation and shrub canopy were the most important variables along which the species richness varied. Since elevation was the most important variables correlated with several other environmental variables, followed by shrub canopy, almost all the variables were tested for their individual as well as combined effect with elevation and shrub canopy. Rock and scree cover, disturbance imposed by animals, bryophytes cover, herbs cover, graminoids cover, vascular plants cover affected the species richness singly as well as in combination with the major environmental variables like elevation and canopy at both the spatial scales (Appendix 2). On the other hand, radiation, disturbance due to human, litter cover and bareground cover did not show significant effects on species richness individually, but in combination with elevation and shrub canopy, these variables significantly affected the species richness (Appendix 2).

Species richness significantly decreased with increase in rock and scree cover ($F=71.562, p<0.001$) (**Fig. 10a**), canopy of shrub ($F=47.64, p<0.001$) (**Fig. 10b**), lichen cover ($F=44.821, p<0.001$) (**Fig. 10c**), and bryophytes cover ($F=23.131, p<0.001$) (**Fig. 10d**). On the other hand, species richness was found higher towards the area

with intermediate animal disturbance ($F= 16.398$, $p<0.0001$) (**Fig. 10e**). However, species richness did not show any significant relationship with litter cover ($F= 0.209$, $p= 0.8115$) (**Fig. 10f**).

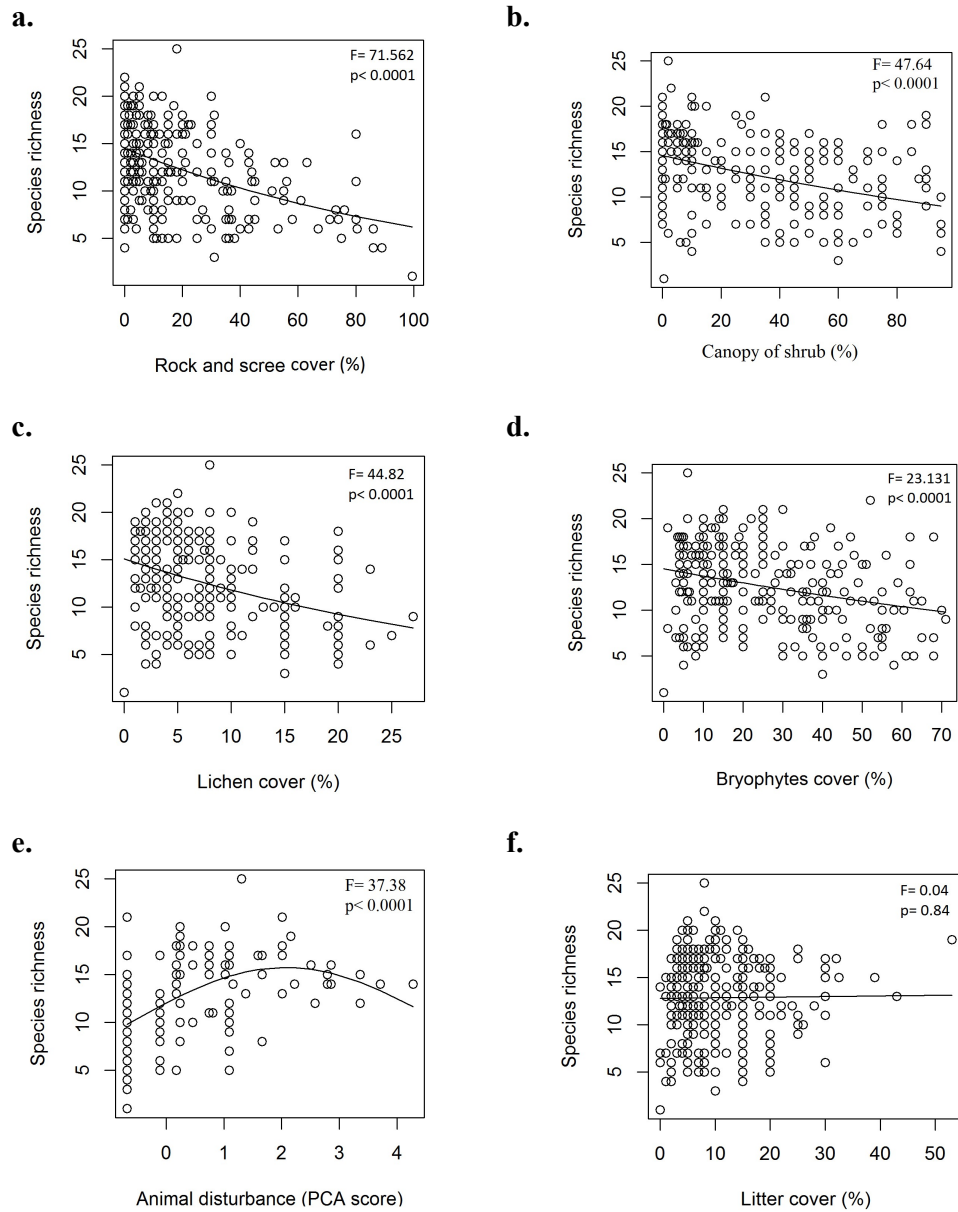


Fig. 10: Variation of species richness with major cover types at 1x1m quadrat level: **a.** with rock and scree cover, **b.** with canopy of shrub, **c.** with lichen on soil, **d.** with bryophytes on soil, **e.** with disturbance imposed by animals, and **f.** with litter cover. The lines are fitted according to GLM 1st (a, b, c, d, f) and 2nd order polynomial regressions (e) (for details see Appendix 2).

3.2.3 Plant life form diversity

Life form classification was limited to 127 species which were identified up to species level (see Appendix 1). The diversity of species categorized into different life forms at landscape level showed that the habitat was predominantly dominated by chamaephytes. The chamaephytes represented 45.74% of the total species recorded in this study. The second largest group was hemicryptophytes (27.90%), followed by cryptophytes (17.05%), phanerophytes (6.98%) and therophytes (2.33%) (**Fig. 11**). The dominance of chamaephytes and hemicryptophytes along the elevation gradient indicates the prevalence of harsh xerophytic climate. Chamaephytes were the dominant vegetation in the exposed southern slopes of Ponker Hill (above 4200 m asl), however, on the rocky scrubland (3700- 4100 m asl), the proportion of hemicryptophytes was comparatively higher. The chamaephytes went on increasing with altitude whereas the hemicryptophytes decreased with altitude.

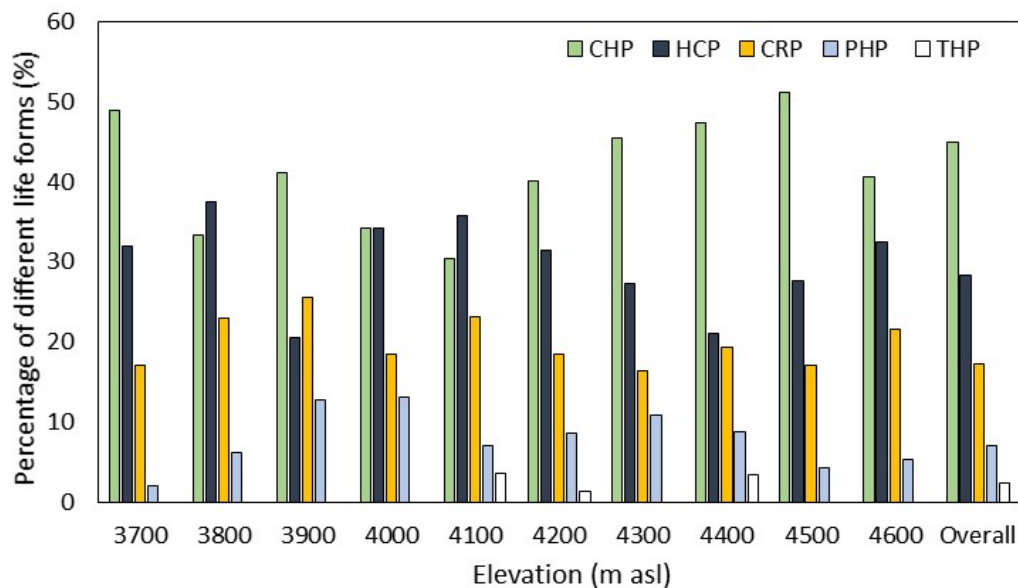


Fig. 11: Percentage of plant life form diversity along elevation gradient at landscape level, where CHP, HCP, CRP, PHP and THP represent chamaephytes, hemicryptophytes, cryptophytes, phanerophytes and therophytes, respectively. The life forms are represented in terms of percentage of each life forms in respective elevation bands.

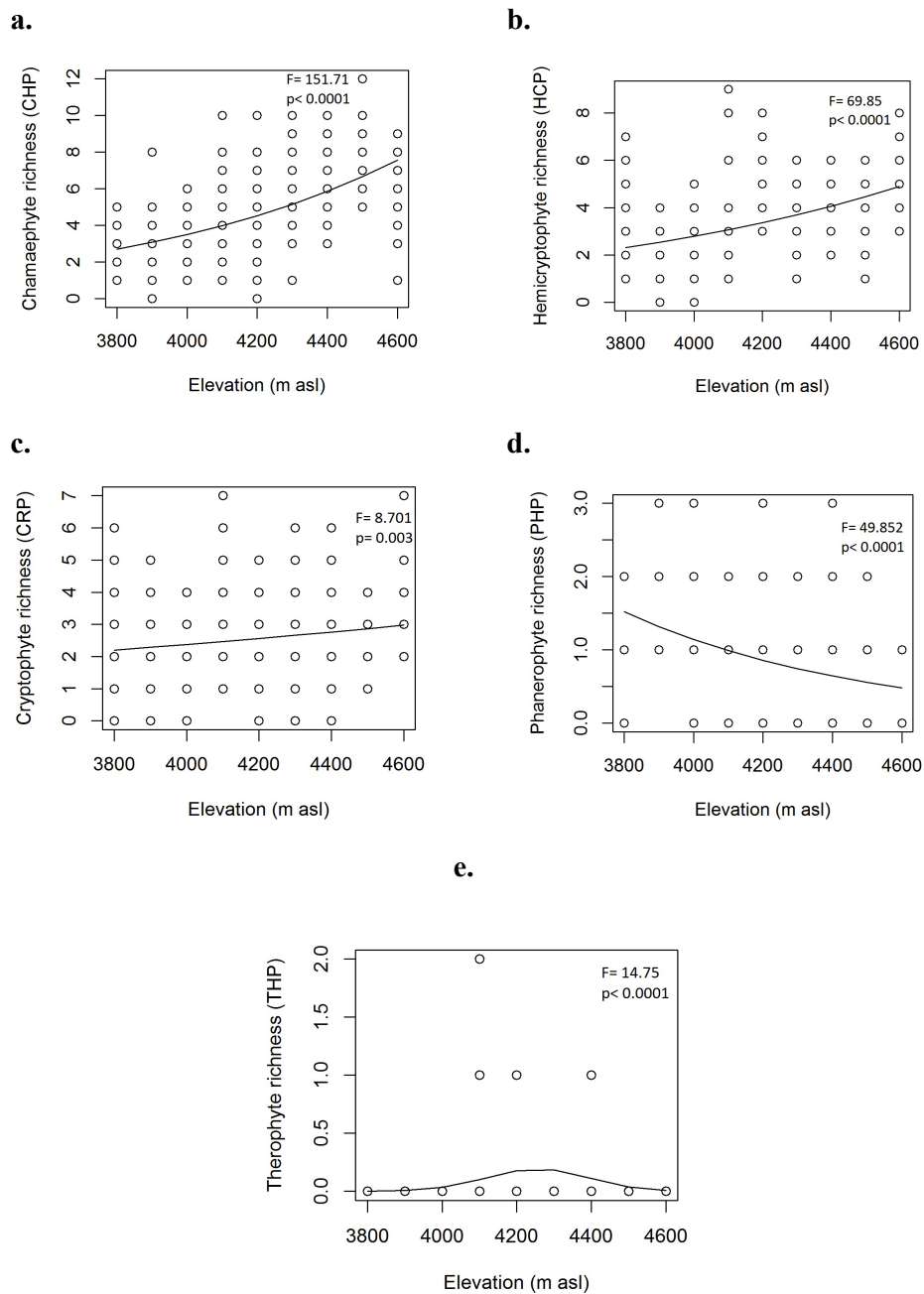


Fig. 12: Variation of individual life forms with elevation, measured at 1x1m quadrat level: **a.** chamaephytes, **b.** hemicryptophytes, **c.** cryptophytes, **d.** phanerophytes and **e.** therophytes. Lines are fitted according to GLM 1st (a, b, c, d) and 2nd order polynomial regression (e) (for details see Appendix 2).

Chamaephytes form the dominant life form type at almost all spatial scales of measurement; 1x1m quadrat level (4.95 ± 0.15), 3x3m plot level (9.28 ± 0.46) and landscape level (59), followed by hemicryptophytes (3.48 ± 0.10 at 1x1m quadrat level,

6.00±0.30 at 3x3m plot level, and 36 at landscape level) (Appendix 6). The life form diversity at landscape level is presented diagrammatically in **Fig. 11**. However, the values of life form diversity (Mean±SE) at different 3x3m plot level and 1x1m quadrat level is given in the Appendix 6. It shows that chamaephyte is the dominant life form type at both these spatial scales, followed by hemicryptophytes.

Richness of chamaephytes ($F= 151.71, p<0.0001$) and hemicryptophytes ($F= 69.85, p<0.0001$) significantly increased with elevation (**Fig. 12a, b**). Cryptophyte richness also exhibited a slight increase with elevation ($F= 8.701, p= 0.003$) (**Fig. 12c**). However, phanerophyte richness was higher among the rocks towards lateral moraine at lower elevation and significantly decreased with elevation ($F= 49.85, p<0.0001$) towards the terminal moraine (**Fig. 12d**). Therophytes, on the other hand, were present only beyond the mid elevation thus, exhibited a hump-shaped pattern with elevation ($F= 14.75, p<0.0001$) (**Fig. 12e**).

3.2.4 Biogeographical pattern

Biogeographical (chorotype) classification was limited to 127 species which were identified up to species level (see Appendix 1). The study area was dominated by Himalayan endemics (49.61%), followed by the species with pan-Himalayan distribution (34.11%). The proportion of Himalayan endemics increased with elevation (**Fig. 13**). Species with pan-Himalayan distribution showed competition with the Himalayan endemics at lower elevation but they gradually decreased towards the higher elevation (**Fig. 13**). However, the broad ranged species did not show any sharp trend with elevation (**Fig. 13**). The chorotype diversity at 1x1m quadrat level and 3x3m plot level also revealed that majority of taxa were Himalayan endemics, followed by the species with pan-Himalayan distribution (Appendix 7).

The richness of Himalayan endemics ($F= 48.291, p<0.0001$), pan-Himalayan species ($F= 52.43, p<0.0001$) increased significantly with increasing elevation at 1x1m quadrat level (**Fig. 14a, b**).

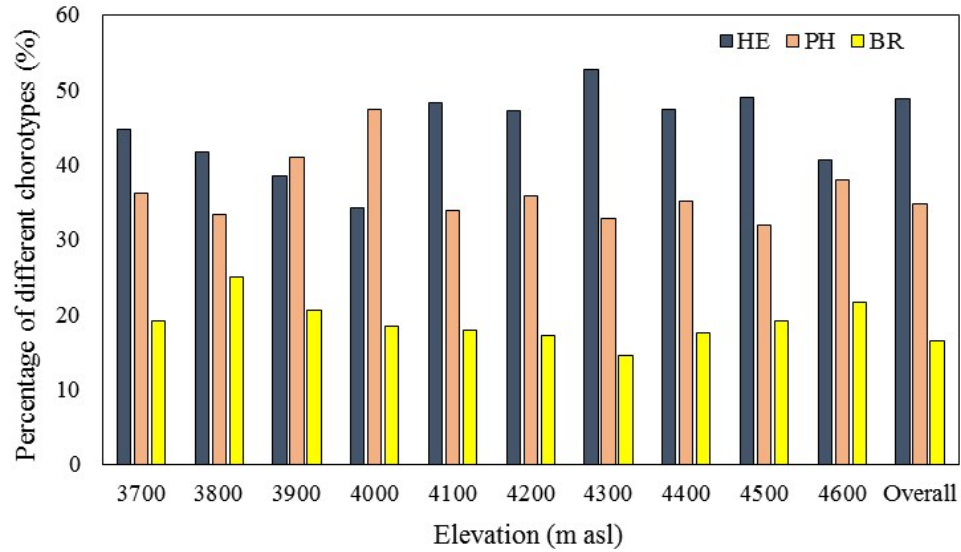


Fig. 13: Biogeographical pattern (chorotype) with elevation at landscape level, where HE represent Himalayan endemics, PH and BR represent the species with pan-Himalayan and broad distribution range respectively.

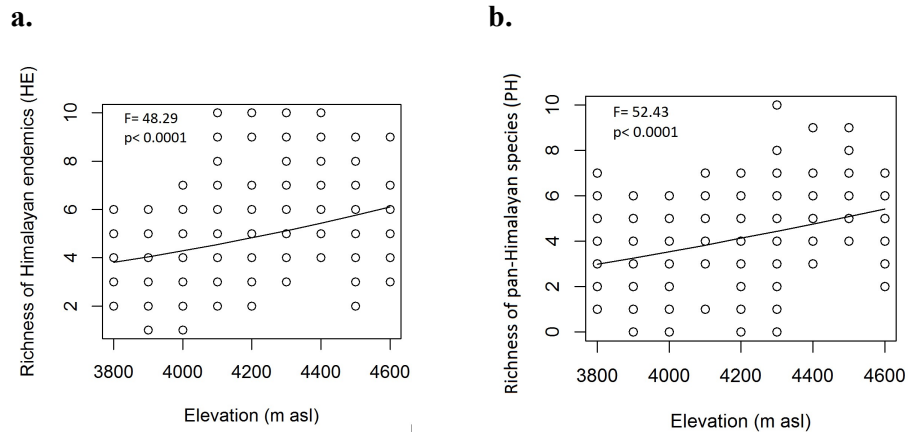


Fig. 14: Variation in richness of plant species classified into different chorotypes along the elevation gradient at 1x1m quadrat level: **a.** Himalayan endemics, and **b.** pan-Himalayan species. Lines are fitted according to GLM 1st order polynomial regression (for details see Appendix 2).

3.2.5 Indicator species analysis

The indicator species analysis showed that the species indicator to the study area were herbaceous taxa with biogeographical distribution restricted to the Himalaya (51.56% of total indicator species), followed by the species with pan-Himalayan distribution

(28.13%) (**Fig. 15a**). This reflects the importance of endemics in shaping the alpine vegetation. The rest of the taxa identified as indicator species were the species with broad range of distribution (i.e, 12.5%). Himalayan endemics identified as indicator species were greater towards the terminal moraine (n= 24) compared to lateral moraine of Bhimthan glacier (n= 12). Here, the terminal moraine comprises of exposed southern slopes including grassland and scrubland of Ponker Hill; whereas the lateral moraine comprises rocky scrubland on the way from Bhimthang to Ponker Lake. Majority of the indicator species were chamaephytes (45.31%), followed by hemicryptophytes (34.38%), cryptophytes (10.94%), and phanerophytes (6.25%) (**Fig. 15b**). A list of indicator species in the two different moraines is given in Appendix 8. *Rhododendron lepidotum* (72.55), *Cotoneaster microphyllus* (64.14), *Salix lindleyana* (52), *Gaultheria trichophylla* (26) and *Festuca cuminsii* (22.82) were the species with highest indicator values in lateral moraine whereas *Geranium pratense* (76), *Bistorta vivipara* (67.3), *Cortia depressa* (46.67), *Euphorbia stracheyi* (44.67) and *Swertia nervosa* (42.42) were the species with highest indicator values in terminal moraine.

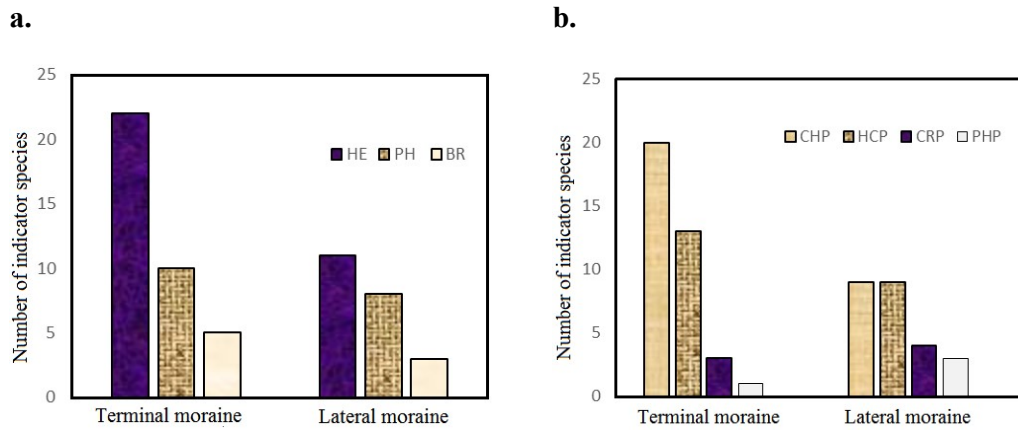


Fig. 15: Number of indicator species in the lateral and terminal moraine of Bhimthan glacier, according to **a.** biogeographical affinity, and **b.** life forms.

Indicator species analysis was also carried out to identify the taxa indicator to the different canopy types imposed by shrub cover. A list of indicator species in the different canopy types is given in Table 3. Majority of the indicator species were chamaephytes with pan-Himalayan distribution. Regarding chorotype, almost all the species in open canopy types comprised of the species with pan-Himalayan

distribution whereas that in closed canopy types included the Himalayan endemics and the species with pan-Himalayan distribution.

On the other hand, regarding the life forms, chamaephytes were the dominant life form in closed canopy type whereas that in open canopy type comprised of hemicryptophytes, therophytes and cryptophytes. *Parnassia nubicola* (8.64), *Eritrichium canum* (8.33) and *Bistorta affinis* (6.667) were the indicator species in open canopy whereas *Nervilia* sp. (11.755), *Anaphalis royleana* (5.33) and *Androsace globifera* (4.67) were the species with highest indicator values in open and closed canopy types.

Table 3. List of indicator species of different canopy types.

Name of species	Life forms	Chorotypes	Indicator value	p-value
Open canopy				
<i>Parnassia nubicola</i> Wall. ex Royle	HCP	PH	8.64	0.038
<i>Eritrichium canum</i> (Benth.) Kitam.	THP	PH	8.333	0.006
<i>Bistorta affinis</i> (D. Don) Greene	CRP	PH	6.667	0.002
Closed canopy				
<i>Nervilia</i> sp.	-	-	11.755	0.005
<i>Anaphalis royleana</i> DC.	CHP	PH	5.333	0.007
<i>Androsace globifera</i> Duby	CHP	HE	4.667	0.015

3.3 Species Composition and Abundance: along the Canopy Types

3.3.1 Species composition

The results of MRPP along the elevation gradient in two different canopy types, open and closed is given in Table 5. The results showed that there was a significant difference in the species composition between the two canopy types along the elevation gradient. Furthermore, positive values of 'A' indicates that there was a high within-group similarity in terms of composition in both the canopy types.

Table 5. Variation in species composition along the elevation gradient. Comparison was made between two major canopy types (open and closed) based on the multiresponse permutation procedure, involving Euclidean distance, followed by 9999 permutations.

Level of measurements along the elevation gradient between open and closed canopy types	Observed delta	Expected delta	A	p-value
3700 m asl: open vs. closed	3.331	3.518	0.05328	<0.0001
3800 m asl: open vs. closed	3.014	3.117	0.03312	<0.0001
3900 m asl: open vs. closed	3.029	3.164	0.04259	<0.0001
4000 m asl: open vs. closed	3.19	3.255	0.02003	0.0085
4100 m asl: open vs. closed	3.598	3.768	0.04523	<0.0001
4200 m asl: open vs. closed	4.159	4.248	0.02075	0.0224
4300 m asl: open vs. closed	4.159	4.248	0.02075	0.0213
4400 m asl: open vs. closed	4.051	4.208	0.03718	<0.0001
4500 m asl: open vs. closed	3.473	3.726	0.06788	<0.0001
4600 m asl: open vs. closed	3.179	3.276	0.02958	0.0177
Overall: open vs. closed	4.317	4.331	0.003163	<0.0001

3.3.2 Species abundance

Together, the frequency and cover of individual species in both open and closed canopy types varied along the two different moraines. Percentage cover of *Cotoneaster microphyllus* ($p= 0.008$), *Anaphalis nepalensis* ($p= 0.019$) and *Epilobium wallichianum* ($p= 0.011$) significantly differed between open and closed canopy types along the lateral moraine but none of the recorded species showed significant difference in terms of cover along the terminal moraine (Appendix 9). Here, *Cotoneaster microphyllus* (2853.33 vs 1084) showed greater cover in closed canopy type whereas *Anaphalis nepalensis* (48.53 vs 12.67) and *Epilobium wallichianum* (44.8 vs 0.27) showed higher cover in open canopy (Appendix 9). Furthermore, the frequency of individual species varied between open and closed canopy types along the two moraines but the result was not statistically significant.

In terms of frequency, *Polygonatum hookeri* (Pol_hoo), *Kobresia pygmaea* (Kob_pyg), *Saxifraga parnassifolia* (Sax_par), *Bistorta vivipara* (Bis_viv), and *Rhododendron lepidotum* (Rho_lep) were the dominant species in closed canopy type; whereas *Bistorta vivipara* (Bis_viv), *Rhododendron lepidotum* (Rho_lep), *Polygonatum hookeri* (Pol_hoo), *Dactylorhiza hatagirea* (Dac_hat), and *Saxifraga parnassifolia* (Sax_par) were the dominant species in open canopy types. However, in terms of cover percentage, *Rhododendron lepidotum* (Rho_lep), *Cotoneaster microphyllus* (Cot_mic), *Bistorta vivipara* (Bis_viv), *Salix lindleyana* (Sal_lin), and *Juniperus indica* (Jun_ind) were the dominant species in closed canopy type; whereas *Rhododendron lepidotum* (Rho_lep), *Cotoneaster microphyllus* (Cot_mic), *Bistorta vivipara* (Bis_viv), *Salix lindleyana* (Sal_lin), and *Kobresia pygmaea* (Kob_pyg) were the dominant species in open canopy type.

3.4 Plant Functional Traits Variation

The mean values of each functional traits are given in Appendix 10.

3.4.1 Plant height

Plant height in majority of the species *Cotoneaster microphyllus* ($F= 5.80, p= 0.019$), *Rhododendron lepidotum* ($F= 19.74, p<0.0001$), *Cypripedium himalaicum* ($F= 15.34, p= 0.0004$) and *Rhodiola bupleuroides* ($F= 16.51, p= 0.0001$) decreased with increasing elevation (**Fig. 16 a-d**). However, in *Dactylorhiza hatagirea* plant height increased with increase in elevation up to certain elevation (i.e. 4200 m asl) and then decreased with further increase in elevation beyond 4200 m asl ($F= 11.23, p= 0.0001$) (**Fig. 16e**).

3.4.2 Plant size

Plant size (SI) in *Rhododendron lepidotum* decreased with increasing elevation ($F= 11.524, p= 0.0013$) (**Fig. 17a**). However, *Cotoneaster microphyllus* showed a unimodal trend with elevation, where the plant size increased upto 4100 m asl and then decreased with further increase in elevation but the result was not statistically significant ($F= 0.7525, p= 0.476$) (**Fig. 17b**).

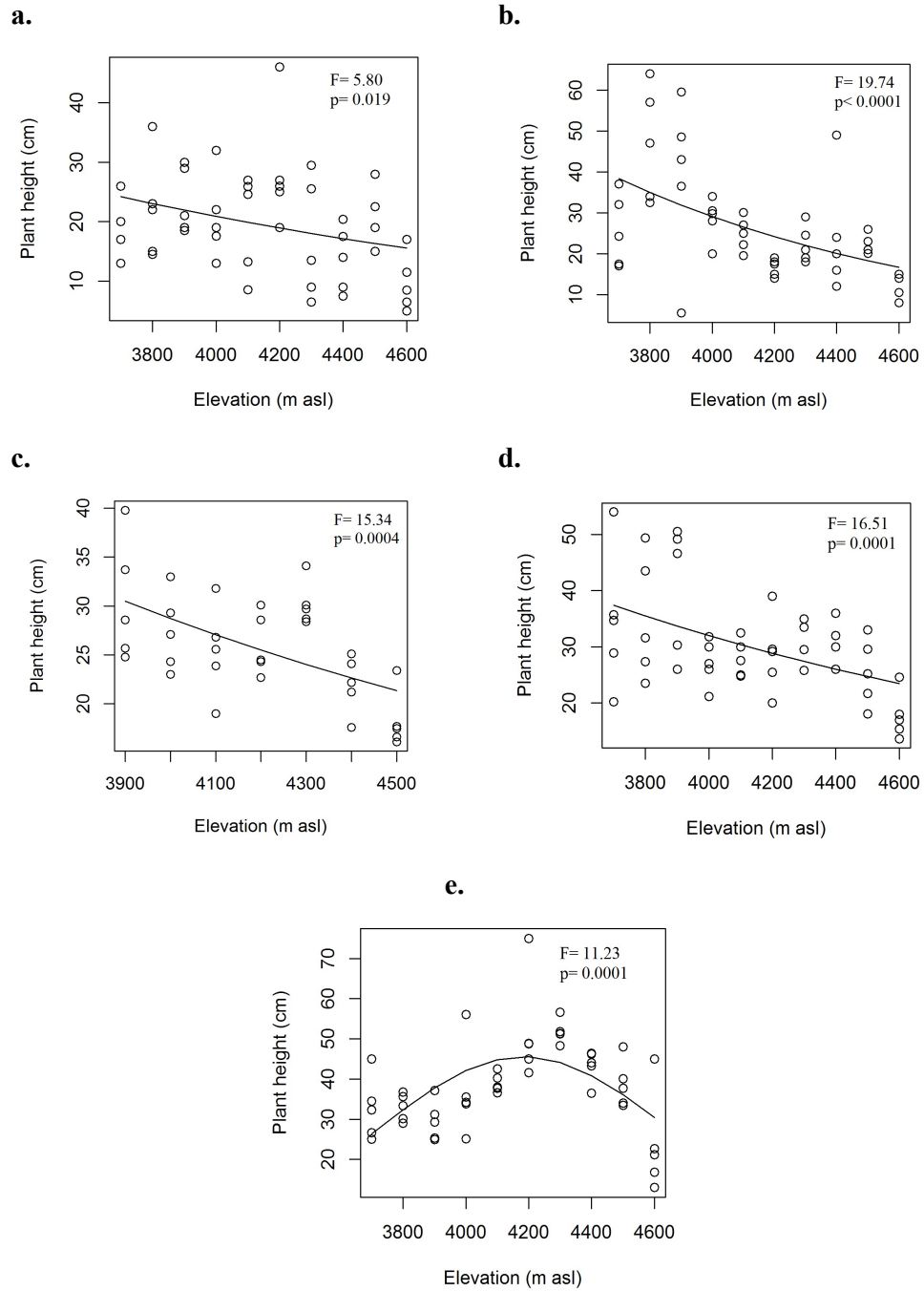


Fig. 16: Variation in plant height along the elevation gradient in: **a.** *Cotoneaster microphyllus*, **b.** *Rhododendron lepidotum*, **c.** *Cypripedium himalaicum*, **d.** *Rhodiola bupleuroides*, and **e.** *Dactylorhiza hatagirea*. Lines are fitted with GLM 1st (a, b, c, d) and 2nd order polynomial regression (e) (for details see Appendix 11).

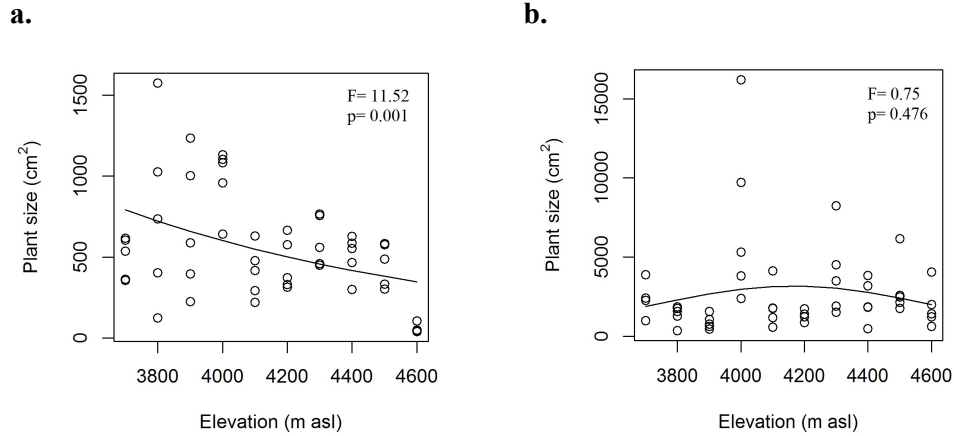


Fig. 17: Variation in plant size along elevation gradient: **a.** *Rhododendron lepidotum*, and **b.** *Cotoneaster microphyllus*. Lines are fitted according to GLM 1st (a) and 2nd order polynomial regression (b) (for details see Appendix 11).

3.4.3 Stem girth

The stem girth increased linearly with elevation in *Cypripedium himalaicum* ($F= 5.28$, $p= 0.028$) (**Fig. 18a**). However, in *Cotoneaster microphyllus* ($F= 4.44$, $p= 0.017$) and *Dactylorhiza hatagirea* ($F= 11.23$, $p= 0.0001$), stem girth increased with elevation upto certain threshold elevation and then decreased with further increase in elevation (**Fig. 18b, c**). The threshold elevation was 4100 m asl in *Cotoneaster microphyllus* and 4200 m asl in *Dactylorhiza hatagirea*. Contrary to this, stem girth significantly decreased with elevation in *Rhododendron lepidotum* ($F= 13.16$, $p= 0.0006$) (**Fig. 18d**). Similarly, stem girth in *Rhodiola bupleuroides* also decreased with elevation but the result was not statistically significant ($F= 0.6618$, $p= 0.5207$) (**Fig. 18e**).

3.4.4 Specific leaf area

The specific leaf area (SLA) responded differently in different species along the elevation gradient. SLA significantly increased with increasing elevation in *Cotoneaster microphyllus* ($F= 211.32$, $p<0.0001$) (**Fig. 19a**), *Dactylorhiza hatagirea* ($F= 21.48$, $p<0.0001$) (**Fig. 19b**) and *Cypripedium himalaicum* ($F= 36.47$, $p<0.0001$) (**Fig. 19c**). Contrary to this, SLA significantly decreased with increasing elevation in *Rhododendron lepidotum* ($F= 21.84$, $p<0.0001$) (**Fig. 19d**) and *Rhodiola bupleuroides* ($F= 30.21$, $p<0.0001$) (**Fig. 19e**).

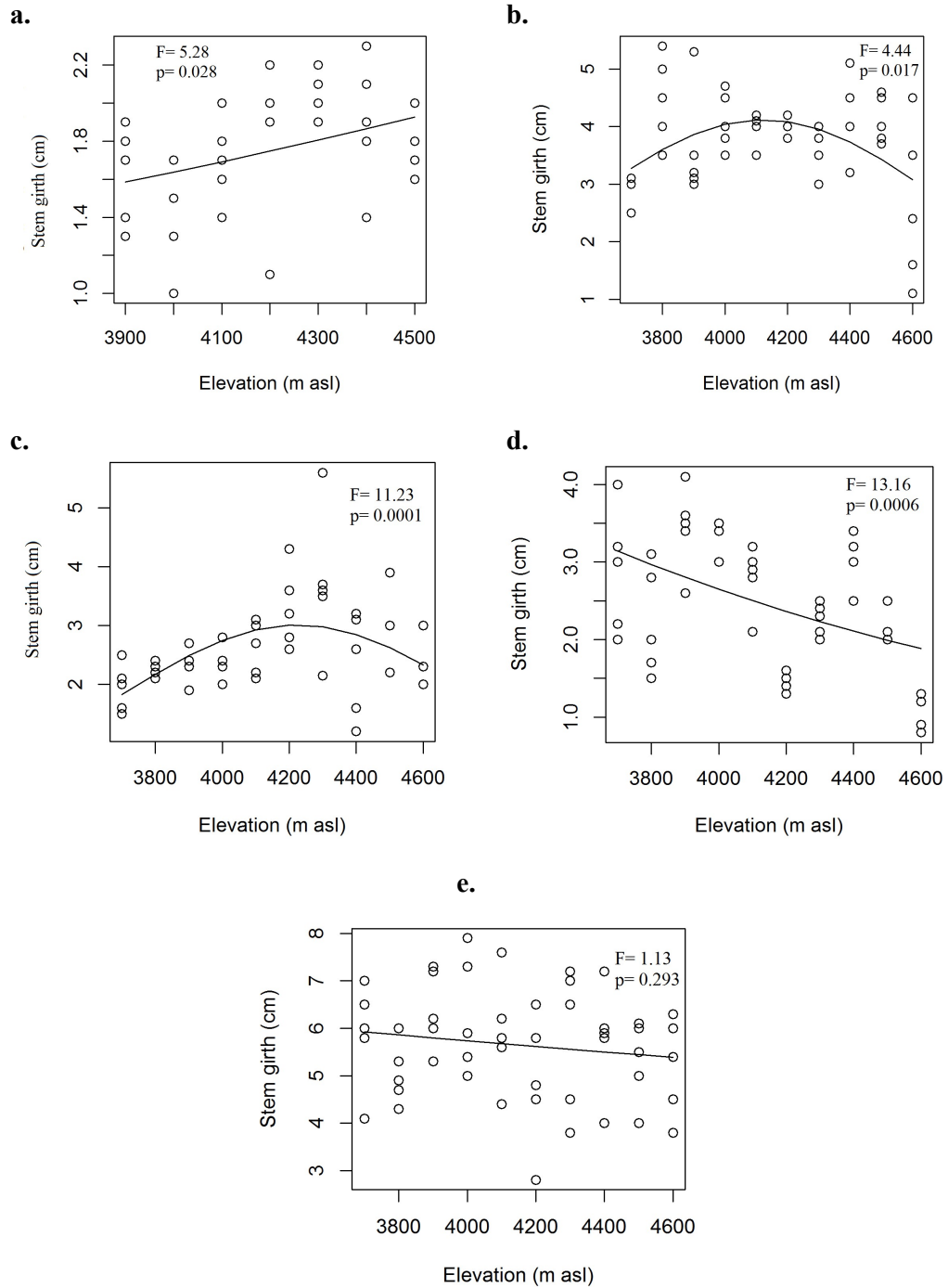


Fig. 18: Variation in stem girth along elevation gradient in: **a.** *Cypripedium himalaicum*, **b.** *Cotoneaster microphyllus*, **c.** *Dactylorhiza hatagirea*, **d.** *Rhododendron lepidotum*, and **e.** *Rhodiola bupleuroides*. Lines are fitted with GLM 1st (a, d, e) and 2nd order polynomial regression (b, c) (for details see Appendix 11).

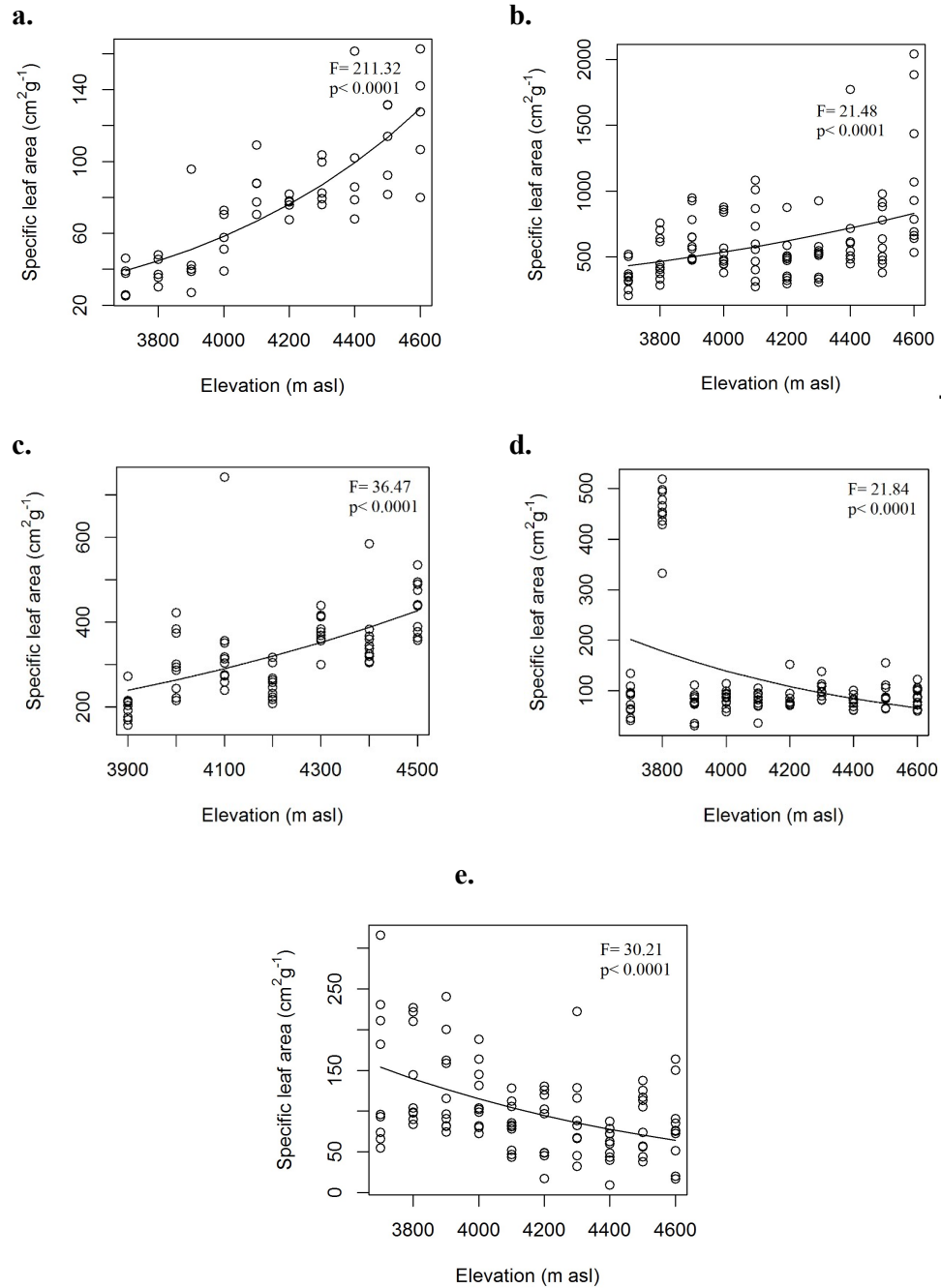


Fig. 19: Variation in specific leaf area along elevation gradient in different species studied: **a.** *Cotoneaster microphyllus*, **b.** *Dactylorhiza hatagirea*, **c.** *Cypripedium himalaicum*, **d.** *Rhododendron lepidotum* and **e.** *Rhodiola bupleuroides*. Lines are fitted with GLM 1st order polynomial regression (for details see Appendix 11).

3.4.5 Leaf dry matter content

The leaf dry matter content (LDMC) responded differently in different species along the elevation gradient. LDMC significantly decreased with increasing elevation in *Cotoneaster microphyllus* ($F= 61.68, p<0.0001$) (**Fig. 20a**), *Dactylorhiza hatagirea* ($F= 10.96, p= 0.001$) (**Fig. 20b**) and *Cypripedium himalaicum* ($F= 22.26, p<0.0001$) (**Fig. 20c**). However, in *Rhododendron lepidotum*, LDMC significantly increased with increasing elevation ($F= 12.84, p= 0.0005$) (**Fig. 20d**). On the other hand, in *Rhodiola bupleuroides*, LDMC increased with elevation upto certain threshold and then decreased after further increase in elevation ($F= 5.406, p= 0.006$) (**Fig. 20e**).

3.4.6 Leaf thickness

In *Cotoneaster microphyllus* ($F= 51.93, p<0.0001$), *Dactylorhiza hatagirea* ($F= 5.35, p= 0.023$), and *Cypripedium himalaicum* ($F= 10.88, p= 0.001$), leaf thickness decreased with increasing elevation (**Fig. 21a-c**), whereas in *Rhodiola bupleuroides* leaf thickness significantly increased with increasing elevation ($F= 11.28, p= 0.001$) (**Fig. 21d**). However, in *Rhododendron lepidotum* leaf thickness increased upto 4000 m asl and decreased beyond 4000 m asl but the result was not statistically significant ($F= 1.73, p= 0.182$) (**Fig. 21e**).

3.4.7 Reproductive output

Reproductive output increased significantly with increasing elevation in *Cotoneaster microphyllus* ($F= 57.12, p<0.0001$) (**Fig. 22a**) but decreased with increasing elevation in *Rhododendron lepidotum* ($F= 5.17, p= 0.027$) (**Fig. 22b**) and *Rhodiola bupleuroides* ($F= 4.37, p= 0.041$) (**Fig. 22c**). However, in *Dactylorhiza hatagirea* reproductive output increased with increasing elevation upto certain threshold (ca. 4300 m asl) and then decreased with further increase in elevation ($F= 4.07, p= 0.023$) (**Fig. 22d**).

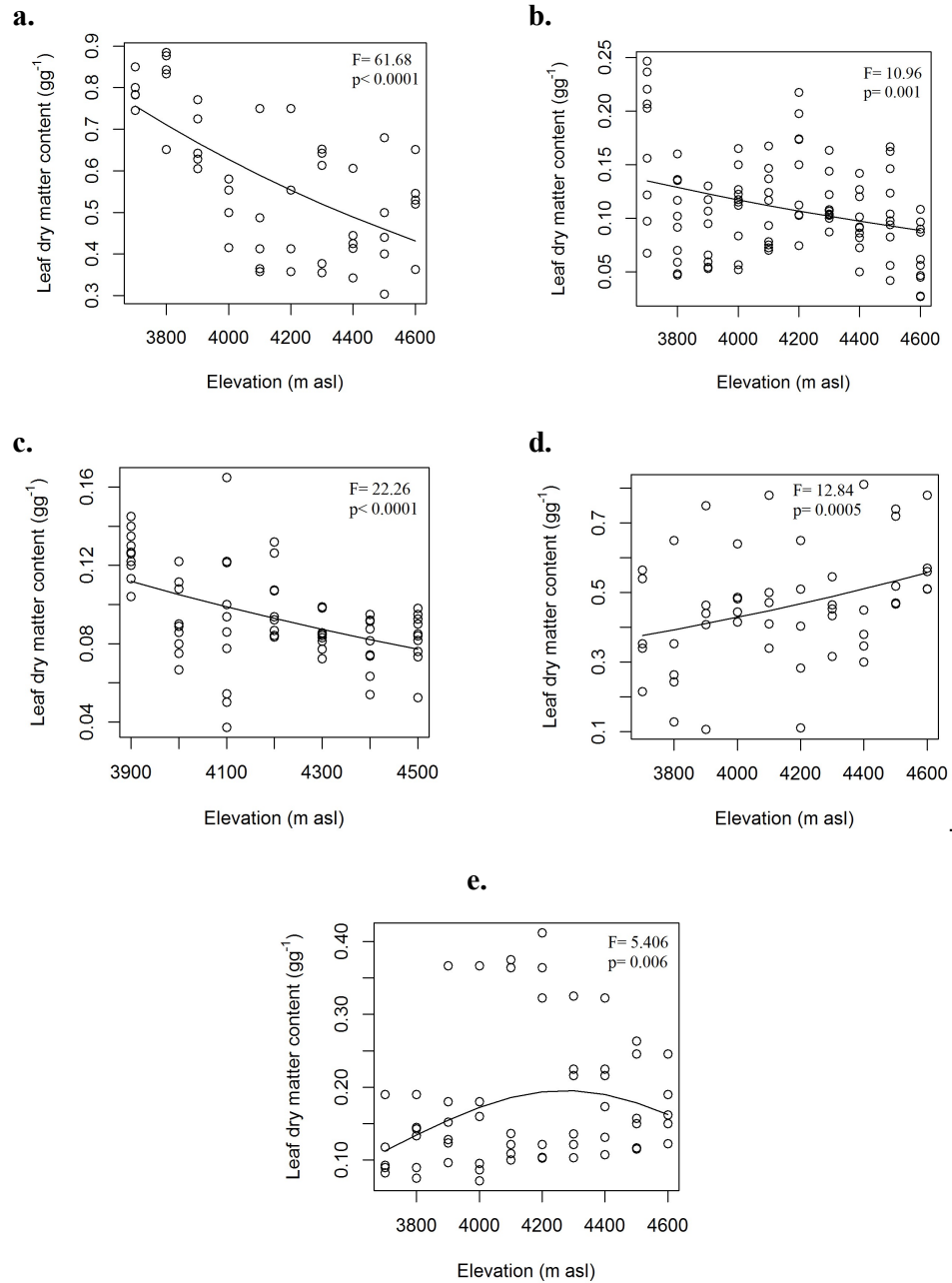


Fig. 20: Variation in leaf dry matter content along elevation gradient in different species studied: **a.** *Cotoneaster microphyllus*, **b.** *Dactylorhiza hatagirea*, **c.** *Cypripedium himalaicum*, **d.** *Rhododendron lepidotum*, and **e.** *Rhodiola bupleuroides*. Lines are fitted with GLM 1st (a, b, c, d) and 2nd order polynomial regression (e) (for details see Appendix 11).

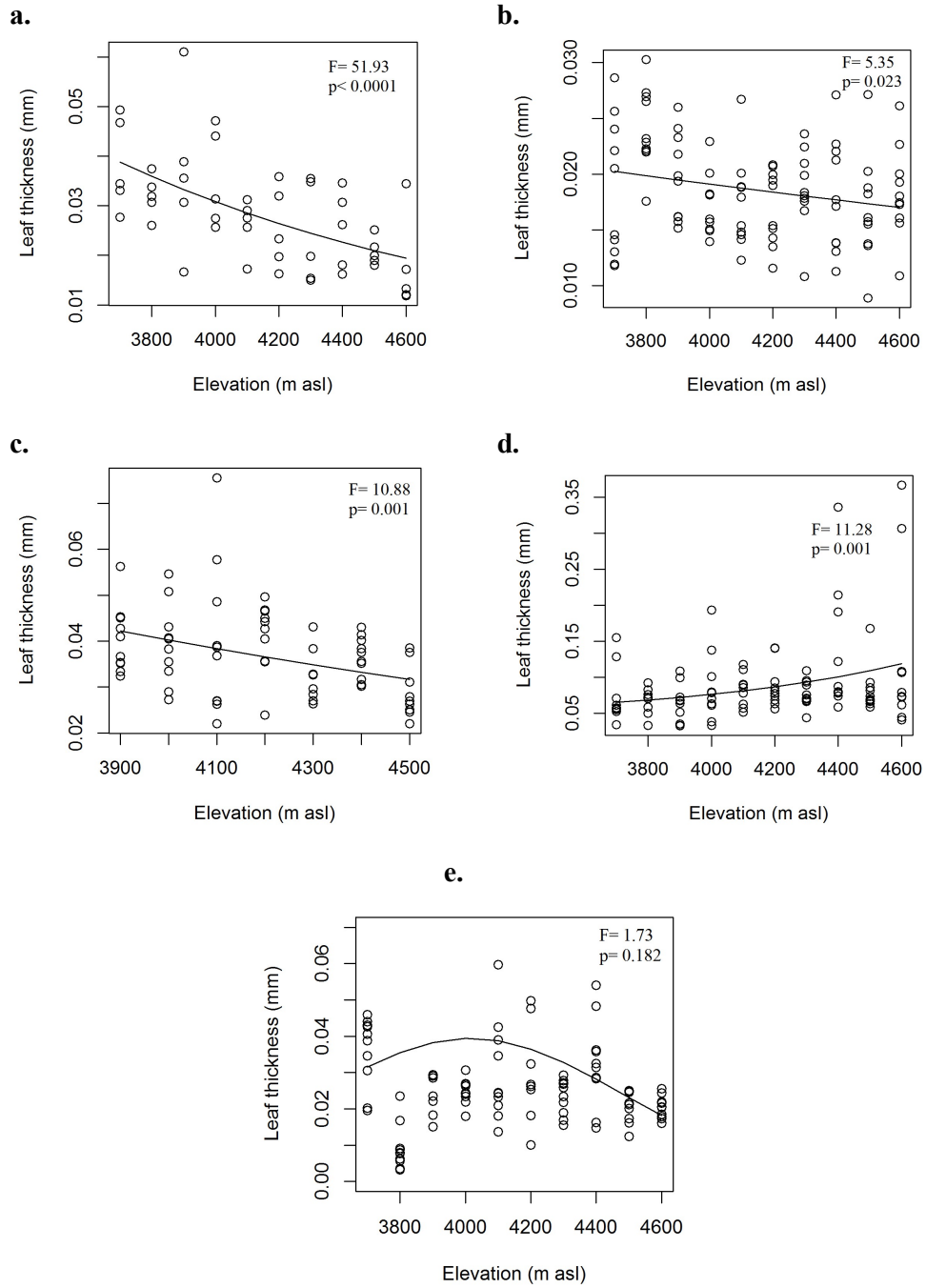


Fig. 21: Variation in leaf thickness along elevation gradient in different species studied: **a.** *Cotoneaster microphyllus*, **b.** *Dactylorhiza hatagirea*, **c.** *Cypripedium himalaicum* **d.** *Rhodiola bupleuroides* and **e.** *Rhododendron lepidotum*. Lines are fitted with GLM 1st (a, b, c, d) and 2nd order polynomial regression (e) (for details see Appendix 11).

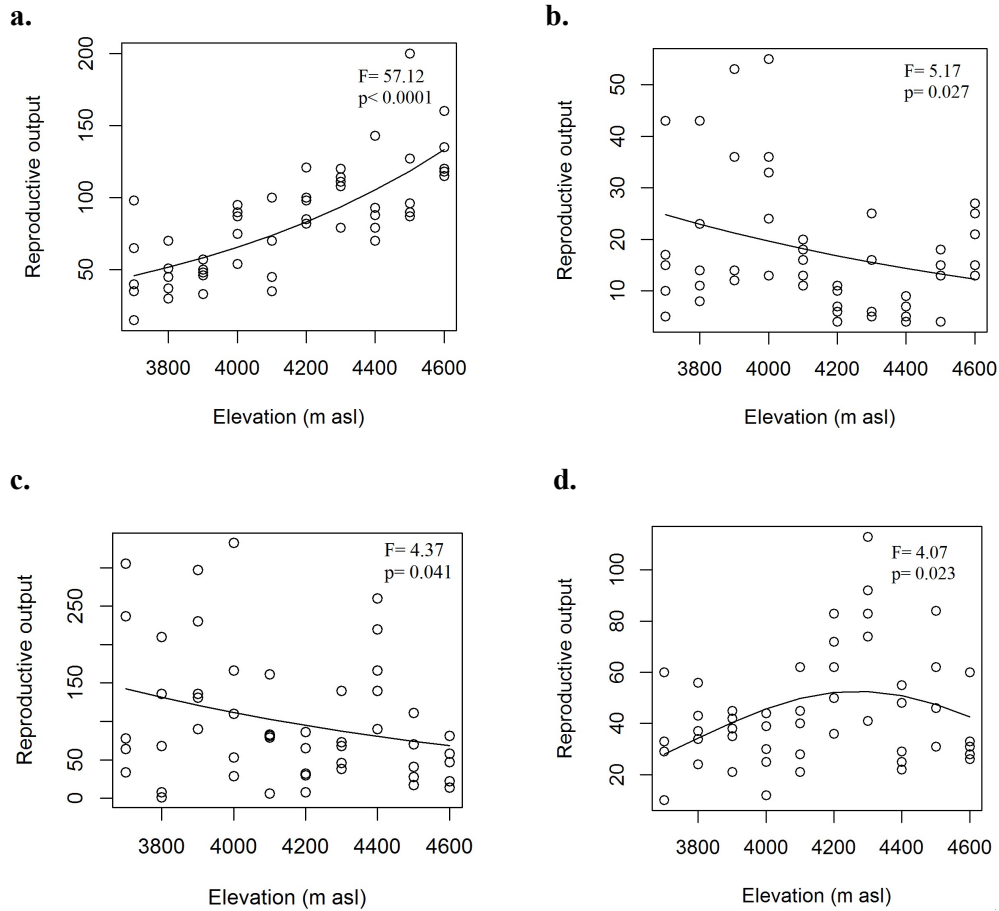


Fig. 22: Variation in reproductive output along elevation gradient in different species studied: **a.** *Cotoneaster microphyllus*, **b.** *Rhododendron lepidotum*, **c.** *Rhodiola bupleuroides*, and **d.** *Dactylorhiza hatagirea*. Lines are fitted according to GLM 1st (a, b, c) and 2nd order polynomial regression (d) (for details see Appendix 11).

3.4.8 Fruit dry matter content

Fruit dry matter content increased significantly with increasing elevation in *Cotoneaster microphyllus* ($F = 23.47$, $p < 0.0001$) (**Fig. 23a**) but decreased with increasing elevation in *Dactylorhiza hatagirea* ($F = 12.47$, $p = 0.0009$) (**Fig. 23b**). In *Rhododendron lepidotum*, fruit dry matter content first increased and then decreased after reaching certain limit of elevation ($F = 4.36$, $p = 0.018$) (**Fig. 23c**). Similarly, *Rhodiola bupleuroides* ($F = 2.05$, $p = 0.158$) (**Fig. 23d**) and *Cypripedium himalaicum* ($F = 0.316$, $p = 0.577$) (**Fig. 23e**) also exhibited linear decreasing trend with increasing elevation but the result was not significant statistically.

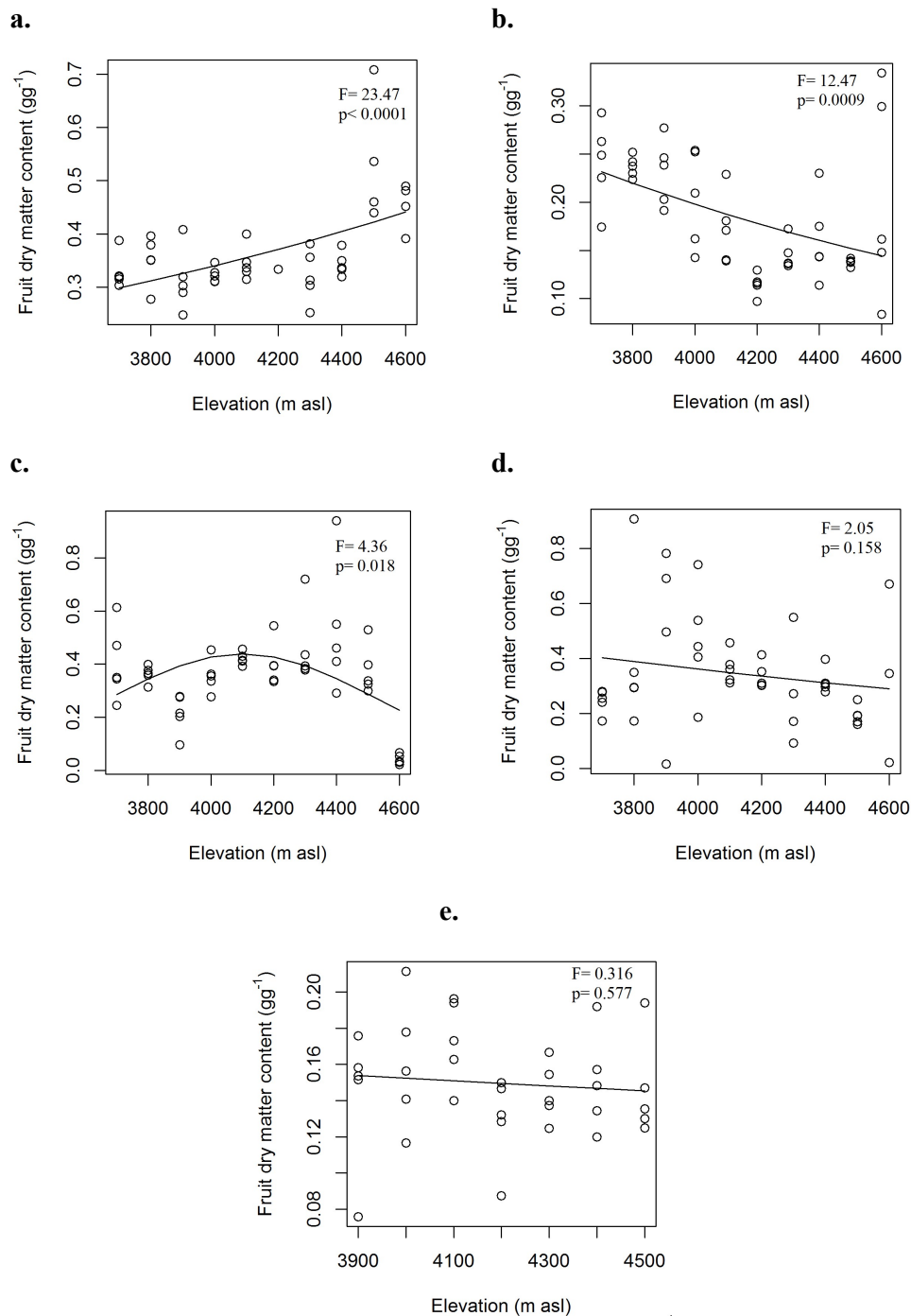


Fig. 23: Variation in fruit dry matter content along elevation gradient in different species studied: **a.** *Cotoneaster microphyllus*, **b.** *Dactylorhiza hatagirea*, **c.** *Rhododendron lepidotum*, **d.** *Rhodiola bupleuroides*, and **e.** *Cypripedium himalaicum*. Lines are fitted according to GLM 1st order (for details see Appendix 11).

CHAPTER 4: DISCUSSION

4.1 Species Diversity and Distribution

Although the sampling site falls along the moraines of the large Bhimthan glacier, it supports a huge biodiversity with many unique species. Altogether 129 species of vascular plants, belonging to 85 genera and 41 families, were recorded in the plots. Botanically, Bhimthang as well as Manang itself is a transition zone between western and eastern Himalaya with the complex topography and varied ecosystem sources. Typical eastern Himalayan elements, such as *Heracleum walichii*, *Codonopsis thalictrifolia*, *Bromus himalaicus*, *Aristolochia griffithii*, *Heracleum walichii*, *Prinsepia utilis*, *Codonopsis thalictrifolia*, *Bromus himalaicus*, *Paris polyphylla* and some characteristic western Himalayan elements such as *Rhododendron anthopogon*, *Abies spectabilis*, *Picea smithiana*, *Viburnum cotinifolium*, *Rhododendron arboreum*, *Rhododendron campanulatum*, *Rhododendron barbatum*, *Rhododendron anthopogon*, *Sarcococca saligna* were recorded during this study (as compared with Takhtajan 1977). Some of the characteristic taxa endemic to Nepal such as *Hedysarum manaslense*, *Berberis mucrifolia* (Central Nepal), *Carex himalaica* (Eastern Nepal), and *Pedicularis anserantha* (Western Nepal) were also recorded during this study (as outlined in Rajbhandari *et al.* 2016). This indicates that Bhimthang serves as a meeting place of both western and eastern Himalayan floristic elements as well as characteristic taxa endemic to eastern and western Nepal. On the other hand, some potentially high valued medicinal plants such as *Dactylorhiza hatagirea*, *Neopicrorhiza scrophulariflora*, *Nardostachys grandiflora*, *Paris polyphylla*, *Bergenia ciliata*, *Taxus wallichiana*, *Swertia chirayita*, *Rheum australe* and *Lilium nanum* were also recorded during present study. Presence of such medicinal plants indicates that Bhimthang harbors substantially higher number of high-valued medicinal plants since time immemorial. Ponker Hill, a large part of the sampling site along the terminal moraine is regarded as one of the hotspot for medicinal plants (Shrestha *et al.* 1995).

A general hump-shaped pattern of species diversity along the subalpine-alpine gradient has been obtained along different spatial scales of measurement (landscape level and 3x3 plot level). Similar trend of species diversity was obtained in both open

and closed canopy types. However, on having a look at the individual values of species richness at the three different scales, highest species richness was obtained between 4200 to 4500 m asl in the present study. Similar diversity trend was observed in the alpine-nivale gradient of Menri Mountains in the Eastern Himalayas, with highest diversity between 4200 to 4500 m asl (Salick *et al.* 2004). This substantial increase in the number of species in the high mountain summits could be due to the upward migration of the species from lower elevations (Holzinger *et al.* 2008, Pauli *et al.* 2012). A linearly increasing pattern of species richness with elevation across the tree-line ecotone was observed in Central Pyrenees (Camarero *et al.* 2006). Similar trend of increasing species richness with a peak at the interval of 4000 to 4500 m asl and then decreasing onwards with further increase in elevation was observed in Ladakh, India (Kala *et al.* 2002). A wide group of plants including epiphytes, orchids and piperoids also exhibited a substantial increase in species richness with increasing elevation (Kromer *et al.* 2013). Similar pattern of species richness along the elevation gradient was obtained for lichens (Baniya *et al.* 2012). Klimes[~] (2003) also reported maximum species richness between 4500 to 4750 m asl from high altitude plains of eastern Ladakh.

The increased species richness towards higher elevation compared to lower one, might have been influenced by the substrate type also. Lower elevation in the study area is dominated by a rocky scrubland lying on the lateral moraine of glacier, which is very close to the settlement area and forms a major part of the walking trail towards Larke pass and Ponker Lake. Therefore, high anthropogenic disturbance and rocky substrate on the lateral moraine, towards lower elevation support fewer number of species compared to moderately disturbed, open south facing slopes of Ponker Hill on the terminal moraine towards higher elevation.

A relatively smaller gradient from 3700 to 4600 m asl was considered for the present study, which exhibits a hump-shaped pattern with elevation with a pleatau between 4300 to 4500 m asl. Here, the study was limited to lower alpine region and some portions of middle alpine region but the upper alpine region could not be included because the maximum elevation limit for the study site was ca. 4650 m asl. Thus, it cannot necessarily explain the actual pattern of species richness in alpine. If some

levation bands of upper alpine region could also be incorporated, the actual pattern of species richness in alpine could have been reflected.

Multiresponse permutation procedure revealed that species composition varied along the elevation as well as between canopy types. This is possibly due to micro-environmental heterogeneity created by the shrub canopy (Rodríguez-Echeverría, and Pérez-Fernández 2003) due to which species composition, presence frequency and diversity differed not only between different elevation bands, but also within the same elevation band in different canopy types. Furthermore, frequency and cover percentage of the individual species also varied between open and closed canopy types along the lateral and terminal moraines. Generally, greater light penetration results into increased species richness in open canopy, whereas facilitative interactions can increase seedling abundance and species richness in closed canopy (Maarten *et al.* 2012) but only upto certain limit. Highly exposed open slopes result into a decrease in species richness due to extremely dry xeric conditions. Similarly, dense canopy can result into decreased species richness due to excessive competition and very little light penetration.

Elevation was the most important environmental variables governing species diversity and distribution (Salick *et al.* 2004), followed by the shrub canopy (Wolf *et al.* 2012). Several environmental variables singly and/or in combination with elevation affected species richness which shows that majority of environmental variables are correlated with elevation (Austin 1980). Species richness was found to be governed by the habitat parameters such as substrate cover types, radiation and disturbance, which were in turn governed by the elevation and shrub canopy. Species richness increased with increase in herb cover and decreased with shrub cover and rock and scree cover. Increasing species richness with herb cover might be due to increase in soil microbial activity and nutrient cycling (Yin K. *et al.* 2016); whereas decrease in species richness with shrub cover and rock and scree cover might be due to decline in relative radiance beneath the shrubs (Isermann *et al.* 2005) and increase in proportion of barren land and decrease in available moisture and nutrients among the rocks (Bhattarai *et al.* 2014). Furthermore, species richness increased with increase in graminoids and vascular plants upto certain limit and decreased with further increase, this might be due to intraspecific competition “self-thinning” (Westoby 1984). Species richness was

higher at intermediate level of animal disturbance, which is in accordance with the 'Intermediate Disturbance hypothesis' (Connell 1978).

Regarding the distribution of plant life forms, the subalpine-alpine gradient of the study area was dominated by chamaephytes. Similar results were obtained from alpine meadows of Kedarnath, Garhwal Himalaya, India (Pharswan and Mehta 2013) and Upper Manang, Nepal (Joshi 2011). The dominance of chamaephytes along the elevation gradient is possibly due to their ability to adapt under wide range of habitats; including rocky slopes, understory in shrub canopy as well as in exposed open slopes (Grau *et al.* 2012). Chamaephytes were followed by hemicryptophytes. The dominance of chamaephytes and hemicryptophytes along the subalpine-alpine gradient indicates potentially harsh and cold xerophytic climate of the high mountain region (Khan *et al.* 2013). Chamaephytes form the dominant life form in open grassland and scrubland towards higher elevation which covers the terminal moraine of Bhimthan glacier; whereas hemicryptophytes showed relatively higher dominance towards the rocky scrubland along the lateral moraine compared to terminal moraine. Thus, the dominance of particular life form was determined by the substrate type rather than elevation alone. Several studies have shown that vegetation changes gradually from moist-cool temperate phanerophytic and chamaephytic elements to dry-cold subalpine and alpine herbaceous hemi-cryptophytic and cryptophytic vegetation in the upper elevations (Khan *et al.* 2013). In the present study, hemicryptophytes exhibited strong correlation with rocky substrates with high cover of lichen, reflecting greater tendency to occupy harsh climate even along the unstable substrates (Raunkiaer 1934) showing a high habitat specificity compared to the other life forms. Cryptophytes exhibited a slight increase with elevation; whereas phanerophytes decreased on moving upslope. However, therophytes were under-represented in most of the elevation bands during this study (Joshi 2011).

Regarding the chorotype classification, the study area was dominated by Himalayan endemics, followed by the species with pan-Himalayan distribution. Similar results were obtained from upper Manang region, Nepal (Joshi 2011). The proportion of Himalayan endemic species increased towards higher elevations (Veetas and Grytnes 2002) and so did the species with pan-Himalayan distribution. In general, species with narrow geographical ranges go on increasing with elevation; whereas the species with

broad geographical distribution ranges tend to decrease with elevation (Vittoz *et al.* 2010). Therefore, it is assumed that the species with broad geographical distribution dominate the lower elevation and tend to decrease towards higher elevation. But, in this study the proportion of species with broad geographical range did not reflect any sharp trend with elevation, instead they were fairly well represented even towards higher elevation. This might be possibly due to the upslope migration of some habitat generalist opportunistic species from the lower elevation to higher elevation, resulting in greater proportion of broad ranged species than expected (Pauli *et al.* 2012). The lowland dwarf shrubs and species with wide altitudinal and ecological range showed the greatest increase in abundance and altitudinal advances while the high-altitude species have disappeared from their lower-elevation sites and increased their abundance at the highest altitudes (Klanderud and Birks 2003) resulting in greater proportion of endemics at higher elevation. This might be due to increased competition at lower elevation, where habitat generalists have invaded resulting into a decreased abundance of the less competitive species and a concentration of high-altitude species on the highest ridges (Klanderud and Birks 2003).

Indicator species analysis of two major moraines of Bhimthan glacier showed the presence of totally different indicator species in these two different sites. Such a complete turnover of the indicator species indicates the presence of distinct phytoclimate along the two moraines (Grau *et al.* 2012). Regarding the life forms of indicator species, majority of the indicator species were chamaephytes followed by hemicryptophytes (Joshi 2011). Majority of the species, indicator to these sites, were the herbaceous taxa whose biogeographical distribution is restricted to the Himalaya followed by the species with pan-Himalayan distribution. Similar trend regarding the dominance of Himalayan endemics along subalpine-nival gradient was reported from upper Manang, Nepal (Joshi 2011). There were very few indicator species which exhibit a broad range of distribution. This reflects the importance of endemics in shaping the subalpine- alpine vegetation of the study area.

4.2 Plant Functional Traits

Plant functional traits analysis revealed that different species show inter- and intraspecific differences in response to resource limitation and/or environmental stress

factors (Gratani 2014). This variability within and between individuals and populations is likely widespread due to plastic responses to highly localized abiotic and biotic interactions (Hulshof and Swenson 2010; Hulshof *et al.* 2013). Trait values vary within species, but this variability depended on both traits and species, suggesting that the behavior of individuals or populations of a species is not fixed and might differ depending on the environmental conditions (Albert *et al.* 2010). Plant height showed a linear decrease with elevation in four out of five species studied; *Rhododendron lepidotum*, *Cypripedium himalaicum*, *Cotoneaster microphyllus* and *Rhodiola bupleuroides*. Several studies have shown decreasing plant height with elevation (Kofidis and Bosabalidis 2008, Shi *et al.* 2008, Rana and Ghimire 2017). Noshiro and Suzuki (2010) reported that plant height in *Rhododendron* species in Nepalese Himalaya decreases with elevation. The decrease in plant height with elevation might be due to reduced water availability at higher elevation, the ‘hydraulic limitation hypothesis’ (Ryan *et al.* 2006), competition for light in vertical structure (Falster and Westoby 2003) and reduced availability of the soil nutrients. On the other hand, this decreasing plant height might also be an adaptation and response of the plants towards grazing herbivores (Cornelissen *et al.* 2003). However, in case of *Dactylorhiza hatagirea*, plant height increases with elevation up to certain limit and then declines with further rise in elevation. This increased plant height around 4200 m asl might have been influenced by the greater availability of light and nutrients in stable substrate of Ponker Hill, along the terminal moraine. Since it is a short-lived perennial, the species might invest the available resources to enhance photosynthetic output by increasing the photosynthetic area, which might be achieved by increasing plant height, number of leaves and the area of leaves. However, at higher elevation (i.e, beyond 4200 m asl), plants cannot invest more towards increasing the number of leaves because the resources get more and more scarce with increasing elevation so they tend to increase the area of leaves instead of number, resulting into a hump-shaped pattern of plant height that peaks around 4200 m asl. The increased SLA with elevation also support this view.

On the other hand, plant size (SI) decreased monotonically with elevation in *Rhododendron lepidotum* which is in accordance with the ‘growth limitation hypothesis’ (Shi *et al.* 2008). In alpine region, plants become thermally constrained by their own life form, because of the close thermal coupling of their shoots to the

atmosphere and through self-shading of their root zone (Körner 1998, Körner 2005). Thus, plants tend to protect themselves from self-shading by reducing their size.

Similarly, the stem girth was found to be decreasing with elevation in *Rhododendron lepidotum*. Similar trend of decreasing stem girth in *Rhododendron* spp. with elevation was reported by Shi *et al.* (2008) from eastern Himalayas. This decrease in stem girth might be due to increasing level of water stress (Hedayati *et al.* 2013) towards higher elevation. However, in case of *Cypripedium himalaicum* stem girth increased with elevation, since it is a herbaceous plant, decreasing the plant height and increasing stem girth with elevation might be a key adaptational feature of the plant to avoid the stresses caused by wind (Nagashima and Hikosaka 2011). Similarly, in case of *Cotoneaster microphyllus* and *Dactylorhiza hatagirea*, stem girth was found to be maximum towards the mid elevation, this might also be an adaptational feature of the plant to provide mechanical support to the larger sized (in *Cotoneaster microphyllus*) and taller individuals (in *Dactylorhiza hatagirea*) towards mid elevation and also provide protection against wind stress (Nagashima and Hikosaka 2011).

Specific leaf area (SLA) was one of the most important functional traits which showed different patterns in different species. SLA increased with elevation in *Cotoneaster microphyllus*, *Dactylorhiza hatagirea* and *Cypripedium himalaicum*. This might be because high SLA values are correlated with shorter life-span, such that plant receives greater photosynthetic return for every unit mass that the plant invests in leaf (Cornelissen *et al.* 2003), but the leaf dies quickly (Sides 2011). Thus, it is advantageous for plants to have higher SLA values at the higher elevations where the length of growing season is much shorter (Sides 2011). Contrary to this, a monotonous decrease in SLA with increasing elevation was reported in *Rhododendron lepidotum* and *Rhodiola bupleuroides*. This monotonous decrease in SLA with elevation is possibly because of decrease in air temperature with elevation (Long *et al.* 2011). Early season perennials like *Rhododendron lepidotum* have higher SLA values at lower elevation and this value of SLA decreases with elevation. This is because, these species are dominantly found in rocky habitat where snow melts earlier, and these plants emerge earlier and flower earlier (Keller *et al.* 2005), immediately after the receding snowpack; thus they have a longer growing season and

hence, they tend to develop long-lived, thick, and durable leaves by maintaining a lower value for SLA (Sides 2011). However, in case of *Rhodiola bupleuroides*, decrease in SLA with elevation is due to the increase in solar irradiance with elevation (Long *et al.* 2011) due to which this particular plant tends to decrease the area of leaf and increase the thickness of leaves in order to ensure protection to the underlying photosynthetic tissues and to reduce the loss of water from leaves.

Leaf dry matter content (LDMC) also exhibited striking difference with elevation in different species. LDMC represents plants' ability to use particular environmental resource and how much material is used to build up leaves (Zhong *et al.* 2006). Furthermore, it is negatively correlated with potential relative growth rate and positively with leaf life span (Cornelissen *et al.* 2003). The LDMC values decreased with elevation in *Dactylorhiza hatagirea*, *Cotoneaster microphyllus*, and *Cypripedium himalaicum*. Similar trend of decreasing LDMC with elevation was reported by Shah (2013) from Sagarmatha National park and its buffer zone. This decline in the LDMC might be due to shorter life-span of leaves in these species (Cornelissen *et al.* 2003) on one hand and resource scarcity in the surrounding on the other hand, due to which plant tends to invest more towards reproduction instead of vegetative development (Fabbro and Körner 2004). However, a linear rise in LDMC with elevation was found in *Rhododendron lepidotum*. This might be due to higher investment of energy and resources by the plant towards increasing stomatal frequency to overcome the effect of reduced partial pressure with elevation (Körner 2003), and towards chlorophyll synthesis in order to enhance the photosynthetic output. On the other hand, the increasing LDMC in the beginning as in *Rhodiola bupleuroides* might have been influenced by the increasing solar radiation (Long *et al.* 2011), however, it goes on decreasing after certain threshold possibly due to scarce nutrients and water.

Leaf thickness (LT) shows two opposite patterns with elevation. *Rhodiola bupleuroides* showed a monotonous increase in leaf thickness with elevation resulting in thicker leaves at higher elevation. At higher elevations, high solar irradiance (Long *et al.* 2011) and water scarcity are the two major abiotic stresses for the entire flora. For succulent plants, leaf thickness and rate of water loss are the key regulating factors (Monteiro *et al.* 2016). Therefore, it becomes crucial for this species to protect the underlying photosynthetic tissues of leaves from damage and to prevent the loss of

water during transpiration. This can be accompanied by thickening the leaves in *Rhodiola bupleuroides*. On the other hand, decreasing leaf thickness in *Cypripedium himalaicum*, *Dactylorhiza hatagirea*, and *Cotoneaster microphyllus* is due to the presence of harsh environmental condition and extremely reduced nutrient availability, due to which plants tend to have short-lived, thin leaves which enables them towards greater photosynthetic output per unit mass invested (Sides 2011).

Reproductive traits were measured in terms of reproductive output and fruit dry matter content. In *Cotoneaster microphyllus*, reproductive output (here, number of fruits per individual) goes on increasing with elevation. This might be because of decreased browsing intensity and increased light availability that governs the production of berries (Sjoblom 2015), along the elevation gradient. In case of *Dactylorhiza hatagirea*, reproductive output is maximum towards the mid elevation compared to lower and higher elevation. Since, plant height is one of the important factor governing the overall fecundity of plants (Cornelissen *et al.* 2003), taller individuals of *Dactylorhiza hatagirea* towards mid elevation exhibit greater reproductive output compared to lower and higher elevations. Furthermore, taller individuals exhibit greater ability to compete for light and also high resource use efficiency compared to the shorter ones, resulting into an increased number of fruits. However in *Rhododendron lepidotum* and *Rhodiola bupleuroides* reproductive output decreased with increasing elevation. Similar trends of decreasing reproductive output with elevation were obtained in *Physalis peruviana* from Boyacá region of Colombia (Fischer *et al.* 2007) and *Meconopsis napaulensis* from Langtang National Park, Nepal (Rana and Ghimire 2017). This might be because of increasing climatic harshness which results in reduced nutrient and water availability that in turn affects the photosynthetic output as well as reproduction.

The fruit dry matter content increased with elevation in *Cotoneaster microphyllus*. This might be because towards higher elevation, due to the presence of extremely harsh climate, the plant tends to invest more resources towards reproductive development (Fabbro and Körner 2004). It may be achieved either by increasing the number of fruits and seeds or, by protecting the existing fruits and seeds through thickening of the walls of fruits. However, in *Dactylorhiza hatagirea* fruit dry matter content was found higher towards lower elevation and decreased with elevation.

Similar results were obtained in *Physalis peruviana* from Boyacá region of Colombia and higher values of fruit dry matter at lower elevation is probably due to higher sink strength or a more efficient translocation of photosynthates as compared with the higher elevation (Fischer *et al.* 2007); where fruit diameter and dry matter content both were found higher towards lower elevation. However, in *Rhododendron lepidotum* fruit dry matter content first increases and then decreases with elevation. Since, it prefers to grow in rocky habitat where snow melts earlier, it can take advantage of the moisture obtained from the melting of snow and thus flowers earlier (Keller *et al.* 2005). Since they flower earlier, comparatively greater proportion of the available resources will be allocated towards fruits. Therefore, the fruit dry matter content goes on increasing in such rocky habitat but on reaching higher up moisture availability becomes the limiting factor such that fruit dry matter goes on decreasing resulting into a hump-shaped pattern of fruit dry matter content in this study.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study came up with a basic idea about the diversity and distribution of vascular plants, and the variation in plant functional traits along the subalpine-alpine gradient of Bhimthang, Manang, Central Himalayas. The vascular plant diversity showed a hump shaped pattern with elevation with highest diversity between 4200 to 4500 m asl. Similar trends of species richness was found in both open and closed canopy types along the elevation gradient. Species richness was greater in exposed southern slopes compared to shady northern slopes. The measures of species diversity varied not only in canopy types between different elevation bands but also along different canopy types within each elevation bands. Environmental factors such as elevation, radiation, substrate types (moist nutrient rich substrate vs. dry, nutrient poor rocks) played an important role in shaping the species distribution. Elevation itself was a complex variable along which several other variables covary, followed by shrub canopy. Here, graminoids, herbs, and shrub cover played a crucial role in shaping the current distribution pattern. Species diversity tends to increase with increase in graminoids and herbs cover, towards the higher elevation along the terminal moraine. On the other hand, higher shrub and rock cover towards the lower elevation along the lateral moraine does not support high diversity compared to that of terminal moraine towards higher elevation. Radiation is also an important variable governing the species distribution, which tend to form a different association of species on the exposed southern slopes towards mid to higher elevation.

Majority of the taxa recorded in the present study are Himalayan endemics, followed by the species with pan-Himalayan distribution. The analysis of indicator species shows that majority of the taxa indicator to the study area are herbaceous having their distribution restricted to the Himalaya. This reflects the importance of endemics in shaping the alpine vegetation. The proportion of these narrow ranged species increases with increase in elevation. Chamaephyte is the dominant life form in the study area followed by hemicryptophytes. The dominance of chamaephytes and hemicryptophytes along the gradient indicates the presence of potentially harsh xerophytic climate. However, the analysis of individual life forms revealed that

hemicryptophytes were dominant towards the rocky lateral moraine and chamaephytes were dominant towards the terminal moraine of the Bhimthan glacier. This indicates that substrate cover plays a significant role in determining the vegetation of an area, rather than elevation alone. On the other hand, the CCA ordination shows a complete turnover in the species composition along the altitudinal gradient which indicates the presence of distinct phytoclimate.

The presence of distinct phytoclimate causes inter- as well as intra-specific variation in different plant functional traits in order to adapt with the harsh environmental condition along the elevation gradient. The analysis of plant functional traits shows that different plant species respond differently in terms of their functional traits with increasing elevation. However, this variation in PFTs is both species specific and trait specific. The mountain ecosystems are highly sensitive towards climate change therefore the underlying ecological processes influencing the plant functional traits may change dramatically under climate change. Therefore, the study of variation of plant functional traits along a natural gradient like elevation is an effective method to understand how a species or, the community as a whole change with a variety of environmental conditions and how they respond to climate change.

5.2 Recommendation

- ❖ This study was carried out in a relatively smaller gradient, 3700- 4600 m asl, covering subalpine-alpine ecotone and lower alpine regions but could not incorporate sufficient elevation bands of upper alpine region, thus the actual trend of species richness in alpine region could not be reflected. Therefore, studies incorporating larger gradients extending through the entire alpine region is recommended, such that actual pattern of species richness in alpine could be reflected.
- ❖ Plant functional trait analysis revealed that there is inter- and intraspecific variation in plant functional traits along the elevation gradient. They show strong correlation with the environmental variables particularly with elevation. Therefore, incorporation of such functional traits in long-term ecological studies can help to understand plants' specific response towards climate change.

- ❖ A large portion of the sampling site lies within the moraine of glacier, therefore, the area encompasses unique landscape. There is a greater possibility of recording unique plant species therefore, extensive botanical exploration to the area is recommended.
- ❖ The complex topography and heterogeneous landscape creates isolation and thus can result into substantial number of rare and endemic species. Therefore, incorporation of the area into Annapurna Conservation Area might be helpful for the conservation, sustainable management and long-term persistence of the biodiversity.
- ❖ It was apparent that succession has already started and some early successional species have successfully established themselves in some parts of the Kechyakyu Khola glacier. Therefore, succession and vegetation transformation in this glaciated landscape in the due course of time, could be an interesting ecological study.

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APPENDICES

APPENDIX 1: A list of species recorded in plot, assigned into respective life forms, chorotype and elevation range.

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
1	<i>Aconogonum molle</i> var. <i>frondosum</i> (D. Don) H. Hara	Aco_mol	Polygonaceae	CHP	HE	2100-4000	4200-4215	2115
2	<i>Acronema tenerum</i> (DC.) Edgew.	Acr_ten	Apiaceae	CHP	PH	2800- 4000	3800	1200
3	<i>Agrostis pilosula</i> Trinius	Agro_pil	Poaceae	HCP	BR	3600-4600	3700-4605	1005
4	<i>Aletris pauciflora</i> (Klotzsch) Hand.-Mazz.	Ale_pau	Nartheciaceae	CRP	PH	1500-4900	3800-4490	3400
5	<i>Anaphalis contorta</i> (D. Don) Hook. f.	Ana_con	Asteraceae	CHP	PH	1700-3500	3900-4005	2705
6	<i>Anaphalis nepalensis</i> (Spreng.) Hand.-Mazz	Ana_nep	Asteraceae	CHP	PH	2400-4500	3600-4605	2205
7	<i>Anaphalis royleana</i> DC.	Ana_roy	Asteraceae	CHP	PH	1200-4200	3700-4100	3000
8	<i>Anaphalis triplinervis</i> (Sims) C. B. Clarke	Ana_tri	Asteraceae	HCP	BR	2300-5500	2500-4600	3200
9	<i>Androsace globifera</i> Duby	And_glo	Primulaceae	CHP	HE	3200-4700	4400-4510	1310
10	<i>Androsace sarmentosa</i> Wall.	And_sar	Primulaceae	CHP	HE	2500-4500	3700-4520	2020
11	<i>Anemone polyanthes</i> D. Don	Ane_pol	Ranunculaceae	CHP	HE	3000-4400	4200-4350	1400
12	<i>Arabidopsis himalaica</i> (Edgew.) O.E.Schulz	Arb_him	Brassicaceae	THP	PH	3000-3800	4100	1100
13	<i>Aster asteroides</i> (DC.) Kuntze	Ast_ast	Asteraceae	HCP	PH	3200-4900	3900-4100	1700
14	<i>Astragalus donianus</i> DC.	Ast_don	Fabaceae	CHP	HE	2900-4500	3700-3970	1600
15	<i>Athyrium spinulosum</i> (Maximowicz) Milde	Ath_spi	Athyriaceae	CRP	HE	800-3000	3910	3110
16	<i>Bistorta affinis</i> (D. Don) Greene	Bis_aff	Polygonaceae	CRP	PH	3500-4800	4000-4600	1300
17	<i>Bistorta vivipara</i> (L.) Gray	Bis_viv	Polygonaceae	CRP	BR	3300-5000	3700-4610	1700
18	<i>Botrychium lunaria</i> (L.) Sw.	Bot_lun	Ophioglossaceae	CRP	PH	1300-4000	3650-4305	3005
19	<i>Bromus himalaicus</i> Stapf apud Hook. f.	Bro_him	Poaceae	HCP	HE	3000-3700	4150-4400	1400

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
20	<i>Bupleurum longicaule</i> Wall. ex DC.	Bup_lon	Apiaceae	CHP	PH	1000-4900	3600-4600	3600
21	<i>Calamagrostis scabrescens</i> Griseb.	Cal_scr	Poaceae	HCP	HE	2590-4000	3700-4500	1910
22	<i>Carex atrata</i> L.	Car_atr	Cyperaceae	HCP	BR	3500-4400	3690-4515	1015
23	<i>Carex duthiei</i> C.B.Clarke	Car_dut	Cyperaceae	HCP	HE	2700-3600	3700-4608	1908
24	<i>Carex filicina</i> Nees	Car_fil	Cyperaceae	HCP	BR	2000-4400	3700-4300	2400
25	<i>Carex himalaica</i> T. Koyama	Car_him	Cyperaceae	HCP	HE	1200-4200	3700-4100	3000
26	<i>Carex nubigena</i> D. Don	Car_nub	Cyperaceae	HCP	BR	1500-4000	3700-4105	2550
27	<i>Cortia depressa</i> (D. Don) C. Norman	Cor_dep	Apiaceae	HCP	HE	3600-4900	3790-4605	1300
28	<i>Corydalis juncea</i> Wall.	Cor_jun	Papaveraceae	CHP	HE	2500-5100	4500	2000
29	<i>Cotoneaster microphyllus</i> Wall. ex Lindl.	Cot_mic	Rosaceae	CHP	HE	2000-5400	2100-4580	3400
30	<i>Cremanthodium arnicoides</i> (DC. ex Royle) R. Good	Cre_am	Asteraceae	CHP	HE	3100-4900	3700-4600	1800
31	<i>Cyananthus lobatus</i> Wall. ex Benth.	Cya_lob	Campanulaceae	CHP	HE	2800-4700	3700-4600	1900
32	<i>Cyananthus microphyllus</i> Edgew.	Cya_mic	Campanulaceae	CHP	HE	2900-4800	4300-4600	1900
33	<i>Cypripedium himalaicum</i> Rolfe apud Hemsl.	Cyp_him	Orchidaceae	CRP	HE	3000-4800	3905-4520	1800
34	<i>Dactylorhiza hatagirea</i> (D. Don) Soo	Dac_hat	Orchidaceae	CRP	PH	600-4100	3650-4615	4015
35	<i>Delphinium kamaonense</i> Huth	Del_kam	Ranunculaceae	CRP	PH	2500-4500	3300-4250	2000
36	<i>Dryopteris barbigera</i> (T. Moore ex Hooker) Kuntze	Dry_bar	Dryopteridaceae	HCP	HE	3600-4700	4100-4210	1100
37	<i>Dubyaea hispida</i> DC.	Dub_his	Asteraceae	CHP	HE	2700-4500	3750-4300	1800
38	<i>Elsholtzia strobilifera</i> (Benth.) Benth.	Els_str	Labiatae	THP	BR	1900-4800	4360-4405	2900
39	<i>Epilobium wallichianum</i> Hausskn.	Epi_wal	Onagraceae	CHP	PH	1800-4100	2800-4600	2800
40	<i>Erigeron multiradiatus</i> (Lindl. ex DC.) C. B. Clarke	Eri_mul	Asteraceae	CHP	BR	2300-4600	3400-4500	2300

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
41	<i>Eritrichium canum</i> (Benth.) Kitam.	Eri_can	Boraginaceae	THP	PH	2700-5600	3800-4400	2900
42	<i>Euphorbia stracheyi</i> Boiss.	Eup_str	Euphorbiaceae	HCP	PH	1000-5000	4160-4605	4000
43	<i>Euphrasia himalayica</i> Wettst	Eup_him	Scrophulariaceae	CHP	PH	3200-4200	3700-4600	1400
44	<i>Festuca cuminsii</i> Stapf	Fes_cum	Poaceae	HCP	HE	3500-4300	3700-4255	800
45	<i>Fragaria nubicola</i> Lindl. ex Lacaita	Fra_nub	Rosaceae	CHP	PH	1600-4000	3700	2400
46	<i>Galium pusillosetosum</i> H. Hara	Gal_pus	Rubiaceae	CHP	PH	2100-3900	3700-4300	220
47	<i>Gaultheria trichophylla</i> Royle	Gau_tri	Ericaceae	CHP	PH	2700-4700	3700-3900	2000
48	<i>Gentiana capitata</i> Buch.-Ham. ex D. Don	Gen_cap	Gentianaceae	HCP	HE	2800-4200	3700-4300	1500
49	<i>Gentiana depressa</i> D. Don	Gen_dep	Gentianaceae	HCP	HE	2900-4500	3700-4350	1600
50	<i>Gentiana tubiflora</i> (G. Don) Griseb.	Gen_tub	Gentianaceae	HCP	HE	4000-5700	3800-4600	1700
51	<i>Gentianella azurea</i> (Bunge) Holub	Gen_azu	Gentianaceae	CHP	BR	2200-4900	4600	2700
52	<i>Geranium donianum</i> Sweet	Ger_don	Geraniaceae	CHP	PH	2500-4800	3700-4400	2300
53	<i>Geranium pratense</i> L.	Ger_pra	Geraniaceae	CHP	BR	1400-4000	4200-4600	3200
54	<i>Hedysarum manaslense</i> (Kitam.) H. Ohashi	Hed_man	Fabaceae	CHP	HE	4100-4200	36700-4100	530
55	<i>Heracleum brunonis</i> (DC.) C. B. Clarke	Her_bru	Apiaceae	CHP	HE	3300-4600	4300-4400	1300
56	<i>Heracleum nepalense</i> D. Don	Her_nep	Apiaceae	CHP	HE	1800-4000	4200-4400	2600
57	<i>Heracleum wallichii</i> DC.	Her_wal	Apiaceae	CHP	HE	3600-4100	3900-4115	515
58	<i>Herminium duthiei</i> Hook. f.	Her_dut	Orchidaceae	CRP	HE	2900-4600	3350-4605	1700
59	<i>Herminium josephii</i> Rechb. f.	Her_jos	Orchidaceae	CRP	HE	1900-4100	3450-4600	2700
60	<i>Impatiens racemosa</i> DC.	Imp_rac	Balsaminaceae	CHP	HE	1200-3900	3800	2700

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
61	<i>Iris goniocarpa</i> Baker	Iri_gon	Iridaceae	CRP	PH	3000-4400	4200	1400
62	<i>Juncus concinnus</i> D. Don	Jun_con	Juncaceae	CRP	PH	1500-5200	3100-4450	3700
63	<i>Juncus himalensis</i> Klotzsch	Jun_him	Juncaceae	CRP	PH	2400-5200	3800-4400	2800
64	<i>Juncus thomsonii</i> Buchenau	Jun_tho	Juncaceae	CRP	BR	2700-5200	2900-4600	2500
65	<i>Juniperus indica</i> Bertol.	Jun_ind	Cupressaceae	PHP	PH	2600-5100	3400-4530	2500
66	<i>Juniperus squamata</i> Buch.-Ham. ex D. Don	Jun_squ	Cupressaceae	PHP	PH	1600-4500	3650-4400	2900
67	<i>Kobresia nepalensis</i> (Nees) Kuk.	Kob_nep	Cyperaceae	HCP	HE	2900-5700	4000-4500	2800
68	<i>Kobresia pygmaea</i> (C. B. Clarke) C. B. Clarke	Kob_pyg	Cyperaceae	HCP	PH	1100-5600	3700-4600	4500
69	<i>Kobresia royleana</i> (Nees) Boeck.	Kob_roy	Cyperaceae	HCP	PH	700-5200	4300-4600	4500
70	<i>Leibnitzia nepalensis</i> (Kuntze) Kitam	Lei_nep	Asteraceae	CHP	HE	3200-4600	3600-3800	1400
71	<i>Leontopodium stracheyi</i> (Hook. f.) C. B. Clarke ex Hemsl.	Leo_str	Asteraceae	CHP	PH	2000-4700	3700-4200	2700
72	<i>Lilium nanum</i> Klotzsch	Lil_nan	Liliaceae	CRP	HE	3500-4500	3800-4500	1000
73	<i>Lonicera obovata</i> Royle ex Hook. f. and Thomson	Lon_obo	Caprifoliaceae	PHP	PH	3500-4400	3900-4200	900
74	<i>Lonicera spinosa</i> (Jacquem. ex Decne.) Walp.	Lon_spi	Caprifoliaceae	PHP	PH	1700-4600	3800-4100	2900
75	<i>Meconopsis paniculata</i> Prain	Mec_pan	Papaveraceae	CHP	HE	3000-4400	4100-4190	1400
76	<i>Morina nepalensis</i> D. Don	Mor_nep	Morinaceae	HCP	PH	3000-4500	4200-4500	1500
77	<i>Neopicrorhiza scrophulariiflora</i> (Pennell) D.Y. Hong	Neo_scr	Scrophulariaceae	CRP	PH	3500-4800	4000-4600	1300
78	<i>Neottianthe cucullata</i> (L.) Schltr.	Neo_cuc	Orchidaceae	CRP	BR	400-4500	3600-4370	4100
79	<i>Nervilia</i> sp.	Ner_sp.	Orchidaceae				3700-4100	
80	<i>Parnassia nubicola</i> Wall. ex Royle	Par_nub	Parnassiaceae	HCP	PH	2700-4200	3700-4600	1900

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
81	<i>Pedicularis anserantha</i> T. Yamaz.	Ped_ans	Orobanchaceae	CHP	HE	3600-3900	4200-4400	800
82	<i>Pedicularis rhinanthoides</i> Schrenk	Ped_rhi	Orobanchaceae	CHP	BR	2300-5000	4200	2700
83	<i>Pedicularis roylei</i> Maxim.	Ped_roy	Orobanchaceae	CHP	PH	3400-5500	4200-4300	2100
84	<i>Pedicularis siphonantha</i> D. Don	Ped_sip	Orobanchaceae	CHP	HE	3000-4600	4100-4600	1600
85	<i>Plantago erosa</i> Wall.	Pla_ero	Plantaginaceae	HCP	PH	900-4100	3700-4200	3300
86	<i>Pleurospermum apiolens</i> C. B. Clarke	Ple_api	Apiaceae	CHP	HE	3600-4700	3900-4200	1100
87	<i>Pleurospermum benthamii</i> (Wallich ex de Candolle) C. B. Clarke	Ple_ben	Apiaceae	CHP	HE	2200-4000	4200-4400	2200
88	<i>Polygonatum hookeri</i> Baker	Pol_hoo	Liliaceae	CRP	PH	2900-5000	3650-4615	2100
89	<i>Polystichum shensiense</i> Christ	Pol_she	Dryopteridaceae	CRP	HE	2600-4000	4000-4190	1590
90	<i>Ponerorchis chusua</i> (D. Don) Soo	Pon_chu	Orchidaceae	CRP	BR	500-4900	3600-4470	4400
91	<i>Potentilla atosanguinea</i> G.Lodd. ex D.Don	Pot_atr	Rosaceae	CHP	HE	3300-4600	3700-4600	1300
92	<i>Potentilla coriandrifolia</i> D. Don	Pot_cor	Rosaceae	HCP	HE	3300-5600	4200-4600	2300
93	<i>Potentilla fructicosa</i> L.	Pot_fru	Rosaceae	CHP	PH	400-5000	3900-4600	4600
94	<i>Potentilla griffithii</i> Hook. f.	Pot_gri	Rosaceae	HCP	PH	2000-4000	3800	2000
95	<i>Potentilla microphylla</i> D. Don	Pot_mic	Rosaceae	HCP	HE	3400-5200	3650-4600	1800
96	<i>Primula capitata</i> Hooker	Pri_cap	Primulaceae	CHP	HE	2700-5000	3450-4500	2300
97	<i>Primula involucrata</i> Wall. ex Duby	Pri_inv	Primulaceae	CHP	HE	2700-4800	4200-4600	2100
98	<i>Primula sikkimensis</i> Hook. f.	Pri_sik	Primulaceae	CHP	HE	2900-4800	3450-4600	1900
99	<i>Ranunculus brotherusii</i> var. <i>brotherusii</i> Freyn	Ran_bro	Ranunculaceae	CHP	PH	2100-4700	4200-4400	2600
100	<i>Rhodiola bupleuroides</i> (Wall. ex Hook. f. and Thomson) S. H. Fu	Rho_bup	Crassulaceae	CHP	HE	2000-5100	3700-4605	3100

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
101	<i>Rhodiola himalensis</i> (D. Don) S.H. Fu	Rho_him	Crassulaceae	CHP	PH	3700-4600	3900	900
102	<i>Rhododendron anthopogon</i> D. Don	Rho_ant	Ericaceae	PHP	HE	3000-5000	3750-4600	2000
103	<i>Rhododendron lepidotum</i> Wall. ex G. Don	Rho_lep	Ericaceae	PHP	HE	1700-4200	3380-4600	2900
104	<i>Salix lindleyana</i> Wall. ex Andersson	Sal_lin	Salicaceae	HCP	HE	3800-5000	3700-4100	1300
105	<i>Salix sikkimensis</i> Andersson	Sal_sik	Salicaceae	PHP	PH	3700-4500	3600-4200	900
106	<i>Sanicula elata</i> Buch.-Ham. ex D. Don	San_ela	Apiaceae	CHP	BR	800-3200	4300	3500
107	<i>Saussurea nepalensis</i> Spreng.	Sau_nep	Asteraceae	HCP	HE	3200-4900	3900-4200	1700
108	<i>Saussurea uniflora</i> Wall. ex Sch.	Sau_uni	Asteraceae	HCP	HE	3700-4800	4200	1100
109	<i>Saxifraga brachypoda</i> D. Don	Sax_bra	Saxifragaceae	CHP	HE	3000-5000	3400-4550	2000
110	<i>Saxifraga brunonis</i> Wall. ex Ser.	Sax_bru	Saxifragaceae	CHP	HE	2400-5600	2900-4200	3200
111	<i>Saxifraga parnassifolia</i> D. Don	Sax_par	Saxifragaceae	CHP	HE	1900-4900	3500-4400	3000
112	<i>Scrophularia pauciflora</i> Benth.	Scr_pau	Scrophulariaceae	CHP	HE	2500-4100	3700-4310	1810
113	<i>Sedum oreades</i> (Decne.) Raym.-Hamet	Sed_ore	Crassulaceae	CHP	HE	3000-5200	4200	2200
114	<i>Selinum wallichianum</i> (DC.) Raizada and Saxena	Sel_wal	Apiaceae	CHP	HE	2600-4800	3700-4500	1900
115	<i>Senecio kunthianus</i> Wall. ex DC.	Sen_kun	Asteraceae	CHP	HE	3600-4100	4500	900
116	<i>Sibbaldia cuneata</i> Hornem. ex Kuntze	Sib_cun	Rosaceae	CHP	BR	3400-4500	3700-4400	1100
117	<i>Silene gonosperma</i> (Rupr.) Bocquet	Sil_gon	Caryophyllaceae	CHP	BR	1600-4400	3400-4600	3000
118	<i>Spiraea arcuata</i> Hook. f.	Spi_arc	Rosaceae	PHP	HE	3000-4900	4200-4400	1900
119	<i>Stellaria congestiflora</i> H. Hara	Ste_con	Caryophyllaceae	HCP	HE	3800-4700	3700-4100	1000
120	<i>Stellaria himalayensis</i> Majumdar	Ste_him	Caryophyllaceae	HCP	HE	2600-3400	3800-4100	1500

S. N.	Name of plant species with author citation	Abbreviation in ordination	Family	Life forms	Chorotype	Distribution range (m asl)		Elevation amplitude
						Literature based	Observed	
121	<i>Swertia cuneata</i> Wall. ex D. Don	Swe_cun	Gentianaceae	CHP	HE	3600-5000	3700-4300	1400
122	<i>Swertia nervosa</i> (G. Don) C. B. Clarke	Swe_ner	Gentianaceae	CHP	PH	400-3000	3700-4600	4200
123	<i>Taraxacum eriopodum</i> DC.	Tar_eri	Asteraceae	CHP	HE	2000-4600	3700-4500	2600
124	<i>Thalictrum alpinum</i> L.	Tha_alp	Rannunculaceae	CHP	BR	2400-5300	3700-4600	2900
125	<i>Thalictrum cultratum</i> Wall.	Tha_cul	Rannunculaceae	CHP	PH	1700-4200	3700-4270	2570
126	Unknown A	Lab_lik					4100-4250	
127	Unknown B	Sax_lik					4100-4300	
128	<i>Vicia angustifolia</i> L.	Vic_ang	Fabaceae	CHP	BR	200-4000	4200-4400	3800
129	<i>Viola biflora</i> L.	Vio_bif	Violaceae	HCP	BR	2100-4500	3000-4200	2400

APPENDIX 2: Regression statistics of species richness and environmental variables, and environmental variables with elevation. GLM was run upto 2nd order polynomials.

Response variables	Model	Polynomial order	1x1m quadrat level						3x3m plot level					
			Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
Species richness vs. elevation in open canopy type	Null	0	134	244.91	-	-	-	-	26	43.859	-	-	-	-
	GLM	1	133	168.95	1	75.958	62.374	<0.0001	25	34.970	1	8.8888	6.4722	0.0175
	GLM	2	132	162.12	2	82.788	35.147	<0.0001	24	31.418	2	12.44	4.8849	0.0166
Species richness vs. elevation in closed canopy type	Null	0	134	198.83	-	-	-	-	26	30.053	-	-	-	-
	GLM	1	133	143.38	1	55.458	53.527	<0.0001	25	25.962	1	4.0915	4.1044	0.0536
	GLM	2	132	141.82	2	57.016	27.518	<0.0001	24	22.469	2	7.5843	4.1381	0.0286
Species richness vs. elevation overall	Null	0	269	444.70	-	-	-	-	53	73.919	-	-	-	-
	GLM	1	268	314.22	1	130.48	115.77	<0.0001	52	61.394	1	12.525	10.909	0.0017
	GLM	2	267	306.82	2	137.88	62.268	0.01033	51	54.382	2	19.537	9.3942	0.0003
Species richness and canopy of shrubs	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
	GLM	1	298	401.19	1	58.975	47.64	<0.0001	58	49.315	1	14.726	18.472	<0.0001
	GLM	2	297	393.7	2	66.469	27.319	<0.0001	57	47.109	2	16.931	10.796	0.0001
Species richness * elevation * shrub canopy	GLM	1	297	369.17	2	90.997	39.197	<0.0001	57	45.307	2	18.733	12.396	<0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
	GLM	1	298	375.37	1	84.796	71.562	<0.0001	58	43.989	1	20.052	27.783	<0.0001
Species richness and Rock and Scree cover	GLM	2	297	372.05	2	88.119	37.371	<0.0001	57	43.528	2	20.513	14.176	<0.0001
	GLM	1	297	325.7	2	134.46	63.996	<0.0001	57	36.155	2	27.886	22.639	<0.0001
Species richness * elevation * Rock and Scree	GLM	1	297	325.7	2	134.46	63.996	<0.0001	57	36.155	2	27.886	22.639	<0.0001
Species richness * shrub canopy * Rock and Scree	GLM	1	297	309.25	2	150.91	75.949	<0.0001	57	32.257	2	31.783	28.804	<0.0001

Response variables	Model	Polynomial order	1x1m quadrat level						3x3m plot level					
			Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
Species richness * elevation * shrub canopy * Rock and Scree	GLM	1	296	299.32	3	160.84	55.532	<0.0001	56	31.502	3	32.538	19.823	<0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness and Bryophytes on soil	GLM	1	298	429.31	1	30.851	23.131	<0.0001	58	52.803	1	11.238	13.071	0.0006
	GLM	2	297	423.85	2	36.318	13.664	<0.0001	57	52.757	2	11.284	6.438	0.003
Species richness * elevation * bryophytes	GLM	1	297	378.59	2	81.57	34.048	<0.0001	57	46.127	2	17.914	11.603	<0.0001
Species richness * shrub canopy * bryophytes	GLM	1	297	400.82	2	59.343	23.889	<0.0001	57	49.068	2	14.973	9.248	0.0003
Species richness * elevation * shrub canopy * bryophytes	GLM	1	296	369.17	3	90.997	26.044	<0.0001	56	45.134	3	18.907	8.219	0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness and Lichens on soil	GLM	1	298	404.08	1	56.087	44.821	<0.0001	58	44.321	1	19.719	27.069	<0.0001
	GLM	2	297	402.84	2	57.32	22.883	<0.0001	57	43.595	2	20.446	13.957	<0.0001
Species richness * elevation * lichens	GLM	1	297	369.08	2	91.081	39.116	<0.0001	57	42.316	2	21.725	15.28	<0.0001
Species richness * shrub canopy * lichens	GLM	1	297	378.31	2	81.857	35.143	<0.0001	57	41.393	2	22.648	16.493	<0.0001
Species richness * elevation * shrub canopy * lichens	GLM	1	296	359.78	3	100.38	29.638	<0.0001	56	40.762	3	23.278	11.222	<0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness and Litter	GLM	1	298	460.11	1	0.057657	0.0405	0.8406	58	63.78	1	0.260	0.254	0.615
	GLM	2	297	459.57	2	0.59515	0.209	0.8115	57	63.771	2	0.269	0.129	0.878
Species richness * elevation * litter	GLM	1	297	375.42	2	84.748	35.209	<0.0001	57	44.07	2	19.97	13.338	<0.0001
Species richness * shrub canopy * litter	GLM	1	297	381.71	2	78.455	32.557	<0.0001	57	43.432	2	20.609	14.053	<0.0001

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
			1x1m quadrat level						3x3m plot level					
Species richness * elevation * shrub canopy * litter	GLM	1	296	346.31	3	113.86	34.086	<0.0001	56	37.548	3	26.492	13.593	<0.0001
	Null	0	214	336.48	-	-	-	-	59	64.04	-	-	-	-
Species richness and animal disturbance	GLM	1	213	274.09	1	62.387	51.035	<0.0001	58	63.941	1	0.098	0.096	0.7571
	GLM	2	212	252.43	2	84.049	37.379	<0.0001	57	57.79	2	6.250	3.255	0.045
Species richness * elevation * animal disturbance	GLM	1	297	377.99	2	82.176	34.237	<0.0001	57	47.443	2	16.598	10.402	0.0001
Species richness * shrub canopy * animal disturbance	GLM	1	297	392.47	2	67.693	27.588	<0.0001	57	47.975	2	16.066	10.114	0.0002
Species richness * elevation * shrub canopy * animal disturbance	GLM	1	296	365.65	3	94.516	27.254	<0.0001	56	44.701	3	19.339	8.488	<0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness * Radiation	GLM	1	298	459.67	1	0.4949	0.348	0.556	58	63.941	1	0.098	0.096	0.757
	GLM	2	297	452.24	2	7.9209	2.810	0.061	57	62.456	2	1.584	0.772	0.466
Species richness * elevation * Radiation	GLM	1	297	380.66	2	79.509	32.93	<0.0001	57	48.139	2	15.902	9.8694	0.0002
Species richness * shrub canopy * Radiation	GLM	1	297	401.12	2	59.044	23.782	<0.0001	57	49.242	2	14.799	9.133	0.0004
Species richness * shrub canopy * Radiation	GLM	1	297	401.12	2	59.044	23.782	<0.0001	57	49.242	2	14.799	9.133	0.0004
Species richness * shrub canopy * Radiation	GLM	1	297	401.12	2	59.044	23.782	<0.0001	57	49.242	2	14.799	9.133	0.0004
Species richness * elevation * shrub canopy * Radiation	GLM	1	296	368.31	3	91.854	26.337	<0.0001	56	45.239	3	18.802	8.168	0.0001
Species richness * human disturbance	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
	GLM	1	298	458.96	1	1.2008	0.846	0.359	58	63.9	1	0.140	0.137	0.712

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
			1x1m quadrat level						3x3m plot level					
Species richness * human disturbance	GLM	2	297	458.69	2	1.478	0.519	0.5	57	63.829	2	0.211	0.101	0.903
Species richness * elevation * human disturbance	GLM	1	297	380.21	2	79.952	33.048	<0.0001	57	48.187	2	15.853	9.758	0.0002
Species richness * shrub canopy * human disturbance	GLM	1	297	400.04	2	60.123	24.235	<0.0001	57	49.174	2	14.867	9.176	0.0004
Species richness * elevation * shrub canopy * human disturbance	GLM	1	296	366.47	3	93.695	26.943	<0.0001	56	44.94	3	19.101	8.323	0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness * herbs	GLM	1	298	347.55	1	112.62	100.9	<0.0001	58	41.24	1	22.801	33.086	<0.0001
	GLM	2	297	297.69	2	162.48	83.373	<0.0001	57	33.378	2	30.662	27	<0.0001
Species richness * elevation * herbs	GLM	1	297	334.11	2	126.06	58.603	<0.0001	57	39.538	2	24.503	18.215	<0.0001
Species richness * shrub canopy * herbs	GLM	1	297	342.79	2	117.38	53.366	<0.0001	57	40.217	2	23.823	17.468	<0.0001
Species richness * elevation * shrub canopy * herbs	GLM	1	296	332.86	3	127.31	39.59	<0.0001	56	39.215	3	24.825	12.219	<0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness * graminoids	GLM	1	298	428.32	1	31.84	23.85	<0.0001	58	57.828	1	6.213	6.213	0.012
	GLM	2	297	387.41	2	72.75	29.62	<0.0001	57	49.655	2	14.386	8.566	0.0005
Species richness * elevation * graminoids	GLM	1	297	376.35	2	83.812	35.045	<0.0001	57	47.663	2	16.378	10.222	0.0002
Species richness * shrub canopy * graminoids	GLM	1	297	391.17	2	68.997	28.337	<0.0001	57	48.574	2	15.466	9.6618	0.0002
Species richness * elevation * shrub canopy * graminoids	GLM	1	296	365.35	3	94.816	27.355	<0.0001	56	45.02	3	19.021	8.2891	0.0001
	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
Species richness * bare ground	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
	GLM	1	298	450.26	1	9.904	7.054	0.008	58	62.357	1	1.683	1.665	0.202

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
			1x1m quadrat level						3x3m plot level					
Species richness * bare ground	GLM	2	297	444.48	2	15.686	5.601	0.004	57	62.053	2	1.987	0.967	0.386
Species richness * elevation * bare ground	GLM	1	297	365.72	2	94.446	40.214	<0.0001	57	44.912	2	19.128	12.474	<0.0001
Species richness * shrub canopy * bare ground	GLM	1	297	393.88	2	66.284	26.934	<0.0001	57	48.134	2	15.906	9.920	0.0002
Species richness * elevation * shrub canopy * bare ground	GLM	1	296	355.17	3	105	30.843	<0.0001	56	42.656	3	21.384	9.672	<0.0001
Species richness * vascular plants cover	Null	0	299	460.16	-	-	-	-	59	64.04	-	-	-	-
	GLM	1	298	447.45	1	12.716	9.153	0.003	58	62.648	1	1.392	1.379	0.245
	GLM	2	297	417.52	2	42.641	16.371	<0.0001	57	59.876	2	4.165	2.108	0.130
Species richness * elevation * vascular plants cover	GLM	1	297	356.72	2	103.44	45.46	<0.0001	57	43.924	2	20.116	13.56	<0.0001
Species richness * shrub canopy * vascular plants cover	GLM	1	297	316.02	2	144.15	71.998	<0.0001	57	35.865	2	28.175	23.256	<0.0001
Species richness * elevation * shrub canopy * vascular plants cover	GLM	1	296	294.88	3	165.28	58.437	<0.0001	56	32.88	3	31.16	18.285	<0.0001
	Null	0	269	198.08	-	-	-	-	59	57.703	-	-	-	-
Himalayan endemics and elevation	GLM	1	268	167.83	1	30.256	48.291	<0.0001	58	56.138	1	1.565	1.608	0.209
	GLM	2	267	160.86	2	37.226	31.216	<0.0001	57	55.655	2	2.048	1.037	0.360
	Null	0	269	264.86	-	-	-	-	59	30.858	-	-	-	-
Pan-Himalayan species and elevation	GLM	1	268	224.82	1	40.041	52.432	<0.0001	58	29.676	1	1.182	2.392	0.127
	GLM	2	267	224.73	2	40.129	26.197	<0.0001	57	29.676	2	1.182	1.175	0.316
	Null	0	269	276.74	-	-	-	-	59	35.993	-	-	-	-
Broad ranged species and elevation	GLM	1	268	216.40	1	60.34	85.029	<0.0001	58	30.745	1	5.248	10.31	0.002
	GLM	2	267	215.25	2	61.48	43.49	<0.0001	57	30.456	2	5.536	5.378	0.007

Response variables	Model	Polynomial order	1x1m quadrat level						3x3m plot level					
			Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
CHP and Elevation (1x1m)	Null	0	269	403.43	-	-	-	-	59	88.046	-	-	-	-
	GLM	1	268	266.12	1	137.31	151.71	<0.0001	58	75.219	1	12.827	10.68	0.001
	GLM	2	267	256.65	2	146.78	84.914	<0.0001	57	74.312	2	13.735	5.729	0.005
HCP and Elevation (1x1m)	Null	0	269	264.35	-	-	-	-	59	58.563	-	-	-	-
	GLM	1	268	210.30	1	54.045	69.847	<0.0001	58	57.095	1	1.467	1.606	0.21
	GLM	2	267	209.94	2	54.406	35.201	<0.0001	57	55.901	2	2.662	1.428	0.248
CRP and Elevation (1x1m)	Null	0	269	234.55	-	-	-	-	59	28.87	-	-	-	-
	GLM	1	268	228.01	1	6.5407	8.701	0.0035	58	28.71	1	0.159	0.328	0.568
	GLM	2	267	226.47	2	8.0839	5.3606	0.0052	57	28.319	2	0.550	0.558	0.575
PHP and Elevation (1x1m)	Null	0	269	230.07	-	-	-	-	59	52.883	-	-	-	-
	GLM	1	268	197.64	1	32.431	49.852	<0.0001	58	51.135	1	1.748	2.392	0.127
	GLM	2	267	187.29	2	42.772	33.922	<0.0001	57	43.642	2	9.241	7.716	0.001
THP and Elevation (1x1m)	Null	0	269	106.88	-	-	-	-	59	38.608	-	-	-	-
	GLM	1	268	105.97	1	0.9117	0.8865	0.3473	58	37.118	1	1.489	1.429	0.236
	GLM	2	267	87.96	2	18.92	14.754	<0.0001	57	25.863	2	12.745	11.606	<0.0001
Canopy of shrubs vs. Elevation	Null	0	299	9541.3	-	-	-	-	59	1363.13	-	-	-	-
	GLM	1	298	7507.7	1	2033.6	82.385	<0.0001	58	956.41	1	406.72	26.665	<0.0001
	GLM	2	297	6746.2	2	2795.1	59.176	<0.0001	57	804.11	2	559.02	21.378	<0.0001
Rock and Scree vs. Elevation	Null	0	299	6593.5	-	-	-	-	59	723.15	-	-	-	-
	GLM	1	298	6313.7	1	279.79	11.592	0.00075	58	667.19	1	55.957	4.932	0.031
	GLM	2	297	6123.3	2	470.15	9.6075	<0.0001	57	629.12	2	94.029	4.450	0.015

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value	Res.	Res. Dev.	DF	Deviance	F	p-value
			1x1m quadrat level						3x3m plot level					
	Null	0	299	3764.1	-	-	-	-	59	497.67	-	-	-	-
Bryophytes on soil vs. Elevation	GLM	1	298	3185.8	1	578.25	51.653	<0.0001	58	382.02	1	115.65	16.607	0.0001
	GLM	2	297	2937.4	2	826.68	41.365	<0.0001	57	332.33	2	165.34	13.909	<0.0001
	Null	0	299	1154.2	-	-	-	-	59	137.176	-	-	-	-
Lichens on soil vs. Elevation	GLM	1	298	888.1	1	266.12	82.997	<0.0001	58	83.952	1	53.224	36.303	<0.0001
	GLM	2	297	811.35	2	342.87	59.185	<0.0001	57	68.603	2	68.573	27.718	<0.0001
	Null	0	299	1670.6	-	-	-	-	59	207.55	-	-	-	-
Litter cover vs. Elevation	GLM	1	298	1530.2	1	140.38	25.918	<0.0001	58	179.48	1	28.076	9.309	0.003
	GLM	2	297	1516.4	2	154.23	14.191	<0.0001	57	176.71	2	30.846	5.064	0.009
	Null	0	159	150.16	-	-	-	-	18	5.86	-	-	-	-
Overall species richness vs. elevation in both north and southern aspects	GLM	1	158	141.08	1	9.084	10.27	0.0016	17	5.65	1	0.212	0.649	0.431
	GLM	2	157	109.71	2	31.363	45.55	<0.0001	16	3.35	2	2.507	6.085	0.0108

APPENDIX 3: Mean species richness in different canopy types along different elevation bands. The values represent Mean±SE.

Diversity measures	Different elevation bands under study (in m asl)									Overall
	3800	3900	4000	4100	4200	4300	4400	4500	4600	
Closed canopy										
Y-diversity at each elevational bands	36	38	32	35	58	44	49	42	30	113
α -diversity at 3x3m plot level	19.33±3.28	21.67±4.1	17±2.65	21.67±1.2	26.67±2.19	26±1.53	28±1.15	26±1.53	20.33±1.86	23.23±0.89
α-diversity at 1x1m quadrat level	9.93±0.94	10.6±0.99	7.33±0.85	11.2±0.71	13.87±0.76	15.2±0.68	15.27±1.04	14.8±0.68	15±0.72	12.83±0.33
Open canopy										
Y-diversity at each elevational band	38	22	35	51	52	52	48	40	34	117
α -diversity at 3x3m plot level	21.33±2.03	13.33±0.67	20.67±2.4	23.33±4.91	22±4.04	30.67±1.76	28±1.15	26±2.65	22.33±1.2	23.27±1.07
α-diversity at 1x1m quadrat level	10.4±0.84	6.33±0.58	10.73±0.77	13.33±1.33	12.33±1.01	15.2±1.23	16.6±0.52	17.07±0.49	14.6±0.87	12.95±0.36
Overall										
Y-diversity at each elevational band	50	42	40	58	74	58	60	49	38	134
α -diversity at 3x3m plot level	20.33±1.78	17.5±2.63	18.83±1.8	22.5±2.29	24.33±2.3	28.33±1.48	28±0.73	26±1.37	21.33±1.09	23.25±0.69
α-diversity at 1x1m quadrat level	10.17±0.62	8.47±0.69	9.03±0.65	12.27±0.77	13.1±0.64	15.2±0.69	15.93±0.59	15.93±0.46	14.8±0.56	12.89±0.25

APPENDIX 4: Habitat variables including the vegetation and substrate types recorded at different elevational bands from 3700 to 4600 m asl. The numerical values are the values of Mean±SE.

Elevation (m asl)	Canopy	Radiation	Rock and Scree cover	Animal disturbance	Human disturbance	Herbs cover	Graminoids cover	Bryophytes on Soil	Lichen on Soil	Litter cover	Vascular plants cover
3700	37.37±8.66	-0.1±0.01	13.47±2.88	0.21±0.17	0.07±0.18	37.3±5.59	2.53±0.44	21.83±3.46	7.3±1.14	14.2±2.16	67.17±6.12
3800	49.35±9.8	0.04±0.01	16.83±3.86	0.13±0.19	0.07±0.13	17.63±2.49	3.53±0.77	39.1±4.99	10.57±1.55	11.3±1.63	68.63±6.53
3900	46.53±5.81	0.05±0.01	24.53±4.62	-0.35±0.09	-0.17±0	7.63±0.84	0.98±0.3	37.77±3.49	12.58±1.48	15.6±1.56	58.14±6.42
4000	39.08±6.95	0.02±0.01	41.75±4.35	-0.64±0.03	-0.17±0	8.32±2.27	3.93±0.78	23.18±3.54	10.23±0.83	11.95±1.32	54.19±5.33
4100	45.2±11.79	0.01±0.01	10.4±1.99	-0.56±0.05	1.02±0.51	21.9±5.21	14.2±4.63	29.17±7.09	9.9±1.81	11.73±1.23	84.17±4.09
4200	16.9±6.65	0.04±0.01	7.57±2.14	-0.66±0.02	-0.17±0	29.2±6.21	27.77±5.17	20.42±6.14	5.07±0.62	9.17±1.17	62.48±7.41
4300	32.07±9.8	0.07±0	24.4±3.63	-0.4±0.1	-0.17±0	22.08±4.59	12.13±2.18	25.5±6.71	5.3±1.12	10.07±1.23	70.94±6.97
4400	16.25±7.15	0.05±0.01	6.57±1.38	-0.38±0.1	-0.09±0.08	45.4±8.54	10±2.28	22.33±5.64	4.13±0.68	10.58±1.65	59.98±4.27
4500	9.43±4.81	-0.05±0.02	6.53±2.14	1.11±0.25	-0.17±0	55.33±4.35	9.37±2.56	13.37±1.01	4.57±0.9	8.87±0.98	57.48±3.33
4600	1.7±0.96	0.01±0.01	12.62±3.53	0.95±0.19	-0.17±0	55.97±3.12	14.87±1.85	7.38±1	2.77±0.68	5.42±0.78	49.62±2.95

APPENDIX 5: Spearman-rank correlation between the environmental variables under study.

	Abbreviation	Elv	Cnpy	A.Dis	H.Dis	Hrb	Grs	Bry	Lic	Lit	R+S	Bgr	Vpl	SpRich
Elevation	Elv	1												
Canopy (shrub canopy)	Cnpy	-0.561**	1											
Disturbance due to animal	A.Dis	0.207**	-0.267**	1										
Disturbance due to human	H.Dis	-0.119*	0.046	0.177**	1									
Herb cover (%)	Hrb	0.490**	-0.569**	0.338**	-0.027	1								
Graminoides cover (%)	Grs	0.584**	-0.425**	0.056	0.091	0.338**	1							
Bryophytes on soil (%)	Bry	-0.431**	0.669**	-0.222**	0.050	-0.466**	-0.372**	1						
Lichen on soil (%)	Lic	-0.516**	0.463**	-0.067	0.081	-0.521**	-0.274**	0.454**	1					
Litter	Lit	-0.251**	0.464**	-0.037	0.084	-0.330**	-0.012	0.266**	0.453**	1				
Rock and Scree	R+S	-0.203**	0.027	-0.088	-0.013	-0.514**	-0.223**	-0.164**	0.122*	-0.138*	1			
Bare ground	Bgr	-0.117*	-0.057	0.242**	0.112	0.119*	-0.010	-0.032	0.064	0.049	-0.086	1		
Vascular plants Cover (%)	Vpl	-0.186**	0.523**	-0.112	0.090	-0.077	0.085	0.268**	0.195**	0.400**	-0.227**	-0.006	1	
Species richness	SpRich	0.433**	-0.410**	0.235**	0.046	0.579**	0.440**	-0.237**	-0.333**	-0.014	-0.348**	0.196**	0.115*	1

Bold entries represent statistically significant values

** and * represent statistical significance at 0.01 and 0.05 level respectively.

APPENDIX 6: Life form diversity at different spatial scales: 1x1m quadrat level, 3x3m plot level and overall landscape level. The statistical significance (p-value) and χ^2 values were obtained from Kruskal-Wallis test.

Life forms	Different Elevation bands (m asl)									Overall	χ^2	p-value
	3800	3900	4000	4100	4200	4300	4400	4500	4600			
1x1m quadrat level												
CHP	2.73±0.2	2.77±0.31	3.37±0.26	3.57±0.44	4.17±0.42	6.33±0.41	6.73±0.32	7.93±0.33	5.5±0.31	4.95±0.15	151.84	<0.0001
HCP	3.27±0.31	1.37±0.2	2.27±0.24	3.27±0.39	4.53±0.22	3.2±0.19	4.1±0.21	3.93±0.2	5.27±0.24	3.48±0.1	118.79	<0.0001
CRP	2.67±0.26	2.23±0.27	1.5±0.19	3.23±0.3	2±0.26	2.7±0.24	2.9±0.23	2.83±0.15	3.1±0.21	2.61±0.08	40.695	<0.0001
PHP	1.07±0.1	1.57±0.13	1.27±0.12	0.93±0.1	0.93±0.19	1.1±0.13	0.73±0.14	0.47±0.13	0.2±0.07	0.91±0.04	78.152	<0.0001
THP	0	0	0	0.23±0.09	0.13±0.06	0	0.3±0.09	0	0	0.07±0.02	54.186	<0.0001
3x3m plot level												
CHP	5.5±0.62	6±0.89	7.5±1.06	6.83±1.54	8.33±1.36	12.67±0.42	12.5±0.72	13.83±0.7	8.33±0.42	9.28±0.46	41.078	<0.0001
HCP	6.83±0.91	3±0.86	4.67±0.76	6.17±1.58	7.67±0.8	5.5±0.99	6.5±0.43	5.83±0.6	7.33±0.42	6±0.3	21.877	0.009
CRP	5.33±0.49	5.17±0.79	3.33±0.49	6.33±0.8	4.17±0.4	5.5±0.56	5.33±0.67	4.5±0.43	5.17±0.6	5.07±0.2	15.7	0.073
PHP	1.67±0.33	2.33±0.42	2.17±0.4	1.33±0.33	1.67±0.67	2.17±0.31	1.33±0.42	0.83±0.4	0.67±0.21	1.5±0.14	18.688	0.027
THP	0	0	0	0.5±0.34	0.33±0.21	0.17±0.17	0.67±0.21	0	0	0.17±0.05	21.392	0.011
Overall (landscape level)												
CHP	16(33.33)	16(41.03)	13(34.21)	17(30.36)	28(40)	25(45.45)	27(47.37)	24(51.06)	15(40.54)	59(45.73)	-	-
HCP	18(37.5)	8(20.51)	13(34.21)	20(35.71)	22(31.43)	15(27.27)	12(21.05)	13(27.66)	12(32.43)	36(27.90)	-	-
CRP	11(22.92)	10(25.64)	7(18.42)	13(23.21)	13(18.57)	9(16.36)	11(19.3)	8(17.02)	8(21.62)	22(17.05)	-	-
PHP	3(6.25)	5(12.82)	5(13.16)	4(7.14)	6(8.57)	6(10.91)	5(8.77)	2(4.26)	2(5.41)	9(6.97)	-	-
THP	0	0	0	2(3.57)	1(1.43)	0	2(3.51)	0	0	3(2.32)	-	-

APPENDIX 7: Diversity of vascular plants grouped into chorotypes at different spatial scales (1x1m quadrat level, 3x3m plot level and landscape level). The statistical significance (p-value) and χ^2 values were obtained from Kruskal-Wallis test.

Chorotype	Different Elevation bands (m asl)									Overall	χ^2	p-value
	3800	3900	4000	4100	4200	4300	4400	4500	4600			
1x1m quadrat level												
HE	3.93±0.23	3.33±0.27	3.83±0.28	4.83±0.42	5.43±0.34	5.77±0.34	6.17±0.25	5.23±0.3	5.4±0.26	5.12±0.12	94.846	<0.0001
PH	3.67±0.29	2.83±0.27	2.8±0.29	4.2±0.28	3.67±0.38	4.5±0.37	5.27±0.33	6.1±0.25	4.47±0.24	4.25±0.11	83.377	<0.0001
BR	2.13±0.26	1.77±0.24	1.83±0.24	2.2±0.25	2.67±0.33	3.1±0.21	3.27±0.23	3.83±0.19	4.2±0.19	2.64±0.09	103.87	<0.0001
3x3m plot level												
HE	7.33±0.61	6.33±0.92	7±0.97	8.67±1.54	9.67±1.28	11.67±1.33	11±0.93	10.17±1.19	8.5±0.5	9.22±0.39	24.269	0.0089
PH	7±0.82	6±0.82	7.5±0.76	7.83±0.75	8.33±1.09	9.17±0.48	10±0.45	9±0.58	7.33±0.33	8.13±0.26	20.52	0.0149
BR	5±0.73	4.17±0.87	3.17±0.6	4.67±0.71	4.17±0.79	5.17±0.31	5.33±0.21	5.83±0.6	5.67±0.21	4.67±0.21	17.956	0.0356
Overall landscape level												
HE	20(41.67)	15(38.46)	13(34.21)	27(48.21)	33(47.14)	29(52.73)	27(47.37)	23(48.94)	15(40.54)	64(49.61)	-	-
PH	16(33.33)	16(41.03)	18(47.37)	19(33.93)	25(35.71)	18(32.73)	20(35.09)	15(31.91)	14(37.84)	44(34.11)	-	-
BR	12(25)	8(20.51)	7(18.42)	10(17.86)	12(17.14)	8(14.55)	10(17.54)	9(19.15)	8(21.62)	21(16.28)	-	-

APPENDIX 8: List of indicator species recorded in the study site along lateral and terminal moraine of Bhimthan glacier.

Abbreviation	Name of species	Life form	Chorotype	Indicator value	p-value
Lateral moraine (Lower elevation band, 3700-4100 m asl)					
Rho_lep	<i>Rhododendron lepidotum</i> Wall. ex G. Don	PHP	HE	72.55	0.0001
Cot_mic	<i>Cotoneaster microphyllus</i> Wall. ex Lindl.	CHP	HE	64.14	0.0001
Sal_lin	<i>Salix lindleyana</i> Wall. ex Andersson	HCP	HE	52	0.0001
Gau_tri	<i>Gaultheria trichophylla</i> Royle	CHP	PH	26	0.0001
Fes_cum	<i>Festuca cuminsii</i> Stapf	HCP	HE	22.82	0.0001
Gal_pus	<i>Galium pusillosetosum</i> H. Hara	CHP	PH	21.41	0.0001
Neo_cuc	<i>Neottianthe cucullata</i> (L.) Schltr.	CRP	BR	20.74	0.0001
Pon_chu	<i>Ponerorchis chusua</i> (D. Don) Soo	CRP	BR	20.17	0.0001
Ner_sp.	<i>Nervilia</i> sp.			20	0.0001
Ast_don	<i>Astragalus donianus</i> DC.	CHP	HE	13.33	0.0001
Swe_cun	<i>Swertia cuneata</i> Wall. ex D. Don	CHP	HE	12.79	0.0081
Hed_man	<i>Hedysarum manaslense</i> (Kitam.) H. Ohashi	CHP	HE	12	0.0001
Leo_str	<i>Leontopodium stracheyi</i> (Hook. f.) C. B. Clarke ex Hemsl.	CHP	PH	10.14	0.0003
Pla_ero	<i>Plantago erosa</i> Wall.	HCP	PH	9.33	0.0001
Lon_spi	<i>Lonicera spinosa</i> (Jacquem. ex Decne.) Walp.	PHP	PH	8.67	0.0006
Sib_cun	<i>Sibbaldia cuneata</i> Hornem. ex Kuntze	CHP	BR	8.38	0.029
Cyp_him	<i>Cypripedium himalaicum</i> Rolfe apud Hemsl.	CRP	HE	8.33	0.0056
Bot_lun	<i>Botrychium lunaria</i> (L.) Sw.	CRP	PH	7.38	0.0028
Gen_dep	<i>Gentiana depressa</i> D. Don	HCP	HE	7.33	0.0007
Car_him	<i>Carex himalaica</i> T. Koyama	HCP	HE	6.67	0.0018
Gen_cap	<i>Gentiana capitata</i> Buch.-Ham. ex D. Don	HCP	HE	5.4	0.0186
Tha_cul	<i>Thalictrum cultratum</i> Wall.	CHP	PH	5.4	0.0202
Ana_roy	<i>Anaphalis royleana</i> DC.	CHP	PH	5.33	0.0071
Ast_ast	<i>Aster asteroides</i> (DC.) Kuntze	HCP	PH	5.33	0.0061
Lon_obo	<i>Lonicera obovata</i> Royle ex Hook. f. and Thomson	PHP	PH	5.33	0.0078
Ste_him	<i>Stellaria himalayensis</i> Majumdar	HCP	HE	4.67	0.015
Terminal moraine (Higher elevation band, 4200- 4600 m asl)					
Ger_pra	<i>Geranium pratense</i> L.	CHP	BR	76	0.0001
Bis_viv	<i>Bistorta vivipara</i> (L.) Gray	CRP	BR	67.3	0.0001
Cor_dep	<i>Cortia depressa</i> (D. Don) C. Norman	HCP	HE	46.67	0.0001
Eup_str	<i>Euphorbia stracheyi</i> Boiss.	HCP	PH	44.67	0.0001
Swe_ne	<i>Swertia nervosa</i> (G. Don) C. B. Clarke	CHP	PH	42.42	0.0001
Pot_mic	<i>Potentilla microphylla</i> D. Don	HCP	HE	39.08	0.0001
Eup_him	<i>Euphrasia himalayica</i> Wettst	CHP	PH	37.06	0.0001
Ped_sip	<i>Pedicularis siphonantha</i> D. Don	CHP	HE	36.26	0.0001

Abbreviation	Name of species	Life forms	Chorotype	Indicator value	p-value
Sil_gon	<i>Silene gonosperma</i> (Rupr.) Bocquet	CHP	BR	33.15	0.0001
Her_wal	<i>Heracleum wallichii</i> DC.	CHP	HE	28.67	0.0001
Mor_nep	<i>Morina nepalensis</i> D. Don	HCP	PH	27.33	0.0001
Pleu_ang	<i>Heracleum nepalense</i> D. Don	CHP	HE	25.33	0.0001
Cya_mic	<i>Cyananthus microphyllus</i> Edgew.	CHP	HE	24.67	0.0001
Cya_lob	<i>Cyananthus lobatus</i> Wall. ex Benth.	CHP	HE	24.14	0.0001
Rho_bup	<i>Rhodiola bupleuroides</i> (Wall. ex Hook. f. and Thomson) S. H. Fu	CHP	HE	22.83	0.0001
Pot_fru	<i>Potentilla fruticosa</i> L.	CHP	PH	22	0.0001
Bup_lon	<i>Bupleurum longicaule</i> Wall. ex DC.	CHP	PH	21.88	0.0002
Tha_alp	<i>Thalictrum alpinum</i> L.	CHP	BR	19.5	0.0001
Gen_tub	<i>Gentiana tubiflora</i> (G. Don) Griseb.	HCP	HE	19.35	0.0001
Car_dut	<i>Carex duthiei</i> C.B.Clarke	HCP	HE	17.14	0.0001
Tar_eri	<i>Taraxacum eriopodum</i> DC.	CHP	HE	14.69	0.0001
Kob_nep	<i>Kobresia nepalensis</i> (Nees) Kuk.	HCP	HE	13.89	0.0012
Cal_scr	<i>Calamagrostis scabrescens</i> Griseb.	HCP	HE	13.36	0.0001
Ple_ben	<i>Pleurospermum benthamii</i> (Wallich ex de Candolle) C. B. Clarke	CHP	HE	12.67	0.0001
Her_bru	<i>Heracleum brunonis</i> (DC.) C. B. Clarke	CHP	HE	11.33	0.0001
Kob_roy	<i>Kobresia royleana</i> (Nees) Boeck.	HCP	PH	11.33	0.0001
Cre_arn	<i>Cremanthodium arnicoides</i> (DC. ex Royle) R. Good	HCP	HE	10.89	0.0038
Jun_tho	<i>Juncus thomsonii</i> Buchenau	CRP	BR	10.89	0.0044
Ger_don	<i>Geranium donianum</i> Sweet	CHP	PH	9.38	0.0007
Pri_sik	<i>Primula sikkimensis</i> Hook. f.	CHP	HE	9.33	0.0001
Spi_arc	<i>Spiraea arcuata</i> Hook. f.	PHP	HE	9.33	0.0001
And_sar	<i>Androsace sarmentosa</i> Wall.	CHP	HE	7.38	0.0033
Bro_him	<i>Bromus himalaicus</i> Stapf apud Hook. f.	HCP	HE	7.33	0.0004
Bis_aff	<i>Bistorta affinis</i> (D. Don) Greene	CRP	PH	6.67	0.0012
Ped_ans	<i>Pedicularis anserantha</i> T. Yamaz.	CHP	HE	6.67	0.0017
Ped_roy	<i>Pedicularis roylei</i> Maxim.	CHP	PH	6	0.0034
Aco_mol	<i>Aconogonum molle</i> var. <i>frondosum</i> (D. Don) H. Hara	CHP	HE	5.33	0.0069
And_glo	<i>Androsace globifera</i> Duby	CHP	HE	4.67	0.0142
Ane_pol	<i>Anemone polyanthes</i> D. Don	HCP	HE	4	0.0295

APPENDIX 9: Result of Man-Whitney U test comparing the frequency and cover of individual species in between open and closed canopy types along the lateral and terminal moraines of Bhimthan glacier.

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Aconogonum molle</i> (D. Don) H. Hara	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000	3.00	2.67	34.67	40.00	112.0	0.962	112.0	0.962
<i>Acronema tenerum</i> (DC.) Edgew.	1.00	1.00	0.13	2.13	112.5	1.000	104.0	0.498	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Agrostis pilosula</i> Trinius	22.33	22.33	183.07	71.87	112.5	1.000	108.5	0.866	21.33	30.33	128.93	218.40	94.0	0.427	97.5	0.520
<i>Aletris pauciflora</i> (Klotzsch) Hand.-Mazz.	6.67	6.67	44.27	29.20	112.5	1.000	106.0	0.739	2.33	3.33	4.93	4.93	109.0	0.845	105.0	0.675
<i>Anaphalis contorta</i> (D. Don) Hook. f.	0.33	0.33	8.00	4.00	112.5	1.000	112.0	0.962	0.33	0.00	0.67	0.00	105.0	0.317	105.0	0.317
<i>Anaphalis nepalensis</i> (Spreng.) Hand.-Mazz	4.67	4.67	48.53	12.67	112.5	1.000	58.0	0.019	3.67	3.33	21.73	16.67	107.0	0.778	106.0	0.739
<i>Anaphalis royleana</i> DC.	4.33	4.33	0.00	21.47	112.5	1.000	90.0	0.073	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Anaphalis triplinervis</i> (Sims) C. B. Clarke	0.00	0.00	3.33	0.00	112.5	1.000	97.5	0.150	2.00	0.67	9.33	2.27	111.5	0.944	110.5	0.888
<i>Androsace globifera</i> Duby	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000	0.00	6.33	0.00	54.67	97.5	0.150	97.5	0.150
<i>Androsace sarmentosa</i> Wall.	0.00	0.00	2.67	0.00	112.5	1.000	105.0	0.317	7.00	1.33	40.67	7.60	99.0	0.450	99.5	0.467
<i>Anemone polyanthes</i> D. Don	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000	0.33	4.00	10.67	60.00	104.0	0.498	104.0	0.498
<i>Arabidopsis himalaica</i> (Edgew.) O.E.Schulz	0.00	0.00	0.27	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Aster asteroides</i> (DC.) Kuntze	1.33	1.33	17.73	9.33	112.5	1.000	112.0	0.962	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Astragalus donianus</i> DC.	3.33	3.33	86.67	14.67	112.5	1.000	101.0	0.520	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Athyrium spinulosum</i> (Maximowicz) Milde	0.33	0.33	0.00	1.33	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Bistorta affinis</i> (D. Don) Greene	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000	9.33	0.00	84.00	0.00	97.5	0.150	97.5	0.150
<i>Bistorta vivipara</i> (L.) Gray	24.00	24.00	22.93	90.13	112.5	1.000	71.5	0.065	80.67	80.67	689.33	585.33	107.0	0.813	90.0	0.350
<i>Botrychium lunaria</i> (L.) Sw.	5.33	5.33	1.07	7.60	112.5	1.000	94.0	0.324	0.33	0.00	2.67	0.00	105.0	0.317	105.0	0.317
<i>Bromus himalaicus</i> Stapf apud Hook. f.	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000	2.33	2.33	8.27	15.33	105.5	0.655	105.0	0.632
<i>Bupleurum longicaule</i> Wall. ex DC.	2.33	2.33	9.07	8.80	112.5	1.000	108.0	0.801	12.67	6.67	26.27	15.20	83.5	0.203	87.5	0.274

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Calamagrostis scabrescens</i> Griseb.	0.00	0.00	0.67	0.00	104.5	0.682	105.0	0.317	7.00	6.00	162.00	160.00	104.5	0.682	104.5	0.682
<i>Carex atrata</i> L.	13.00	13.00	20.40	72.53	108.0	0.801	84.5	0.190	13.00	12.00	157.33	149.33	107.5	0.780	108.0	0.801
<i>Carex duthiei</i> C.B.Clarke	1.67	1.67	3.20	3.33	106.0	0.755	106.0	0.605	10.67	14.67	74.67	67.60	105.0	0.719	106.0	0.755
<i>Carex filicina</i> Nees	0.00	0.00	9.33	0.00	105.0	0.317	105.0	0.317	0.33	0.00	0.27	0.00	105.0	0.317	105.0	0.317
<i>Carex himalaica</i> T. Koyama	2.33	2.33	26.93	11.33	112.5	1.000	112.5	1.000	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Carex nubigena</i> D. Don	0.33	0.33	3.60	2.67	112.5	1.000	112.0	0.962	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Cortia depressa</i> (D. Don) C. Norman	0.00	0.00	0.00	0.00	106.5	0.800	112.5	1.000	34.67	27.67	147.33	122.00	101.0	0.626	106.5	0.800
<i>Corydalis juncea</i> Wall.	0.00	0.00	0.00	0.00	97.5	0.150	112.5	1.000	0.00	0.67	0.00	1.60	97.5	0.150	97.5	0.150
<i>Cotoneaster microphyllus</i> Wall. ex Lindl.	70.00	70.00	1084	2853.33	90.5	0.218	49.0	0.008	5.00	2.67	200.67	26.00	92.5	0.263	90.5	0.218
<i>Cremanthodium arnicoides</i> (DC. ex Royle) R. Good	0.00	0.00	48.00	0.00	112.0	0.976	97.5	0.150	6.33	8.33	34.67	56.67	112.0	0.976	112.0	0.976
<i>Cyananthus lobatus</i> Wall. ex Benth.	1.00	1.00	5.33	1.33	100.0	0.548	112.0	0.962	25.67	14.67	156.67	92.00	98.5	0.501	100.0	0.548
<i>Cyananthus microphyllus</i> Edgew.	0.00	0.00	0.00	0.00	109.5	0.891	112.5	1.000	13.33	21.33	86.93	110.00	106.0	0.766	109.5	0.891
<i>Cypripedium himalaicum</i> Rolfe apud Hemsl.	8.33	8.33	15.33	54.00	105.0	0.317	103.5	0.615	0.00	3.00	0.00	44.67	105.0	0.317	105.0	0.317
<i>Dactylorhiza hatagirea</i> (D. Don) Soo	22.67	22.67	112.40	106.40	109.5	0.900	106.0	0.787	12.00	14.33	60.67	70.00	82.5	0.181	109.5	0.900
<i>Delphinium kamaonense</i> Huth	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	0.33	0.00	0.40	105.0	0.317	105.0	0.317
<i>Dryopteris barbigera</i> (T. Moore ex Hooker) Kuntze	0.00	0.00	34.67	0.00	105.0	0.317	105.0	0.317	0.00	3.33	0.00	26.67	105.0	0.317	105.0	0.317
<i>Dubyaea hispida</i> DC.	0.00	0.00	2.00	0.00	105.0	0.317	105.0	0.317	1.33	0.00	4.00	0.00	105.0	0.317	105.0	0.317
<i>Elsholtzia strobilifera</i> (Benth.) Benth.	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	1.00	0.00	4.67	105.0	0.317	105.0	0.317
<i>Epilobium wallichianum</i> Hausskn.	0.33	0.33	44.80	0.27	107.5	0.825	65.0	0.011	6.67	6.67	16.40	10.80	107.5	0.823	107.5	0.825
<i>Erigeron multiradiatus</i> (Lindl. ex DC.) C. B. Clarke	8.33	8.33	96.00	52.67	100.5	0.599	96.5	0.471	5.00	8.67	18.27	26.40	86.5	0.253	100.5	0.599
<i>Eritrichium canum</i> (Benth.) Kitam.	0.00	0.00	29.60	0.00	104.0	0.587	97.5	0.150	5.67	1.67	14.13	2.67	104.5	0.609	104.0	0.587
<i>Euphorbia stracheyi</i> Boiss.	0.00	0.00	0.00	0.00	100.0	0.592	112.5	1.000	34.33	29.67	148.00	102.00	105.5	0.764	100.0	0.592
<i>Euphrasia himalayica</i> Wettst	4.33	4.33	7.87	10.53	101.0	0.622	105.0	0.675	34.00	25.67	87.33	53.73	101.0	0.622	101.0	0.622

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Festuca cuminsii</i> Stapf	12.67	12.67	72.00	24.00	105.5	0.577	97.0	0.457	0.33	0.67	2.67	4.00	105.0	0.550	105.5	0.577
<i>Fragaria nubicola</i> Lindl. ex Lacaite	0.00	0.00	26.67	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Galium pusillosetosum</i> H. Hara	22.33	22.33	46.67	55.33	112.5	1.000	100.5	0.553	0.67	0.33	2.00	2.00	112.0	0.962	112.5	1.000
<i>Gaultheria trichophylla</i> Royle	18.67	18.67	189.33	164.67	112.5	1.000	103.0	0.627	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Gentiana capitata</i> Buch.-Ham. ex D. Don	1.33	1.33	7.60	8.67	105.0	0.317	107.0	0.725	0.33	0.00	0.67	0.00	105.0	0.317	105.0	0.317
<i>Gentiana depressa</i> D. Don	3.33	3.33	15.60	19.33	112.5	1.000	106.0	0.678	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Gentiana tubiflora</i> (G. Don) Griseb.	0.00	0.00	0.13	0.00	110.5	0.915	105.0	0.317	19.33	14.00	33.33	24.00	110.5	0.915	110.5	0.915
<i>Gentianella azurea</i> (Bunge) Holub	0.00	0.00	0.00	0.00	104.5	0.524	112.5	1.000	0.67	0.33	1.60	0.27	105.0	0.550	104.5	0.524
<i>Geranium donianum</i> Sweet	0.33	0.33	0.00	0.27	95.5	0.313	105.0	0.317	1.33	4.33	3.87	38.27	95.0	0.298	95.5	0.313
<i>Geranium pratense</i> L.	0.00	0.00	0.00	0.00	92.5	0.406	112.5	1.000	61.33	54.33	384.40	284.07	93.5	0.427	92.5	0.406
<i>Hedysarum manaslense</i> (Kitam.) H. Ohashi	3.33	3.33	30.13	50.00	112.5	1.000	111.5	0.953	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Heracleum brunonis</i> (DC.) C. B. Clarke	0.00	0.00	0.00	0.00	97.0	0.277	112.5	1.000	2.67	9.00	18.67	85.33	97.0	0.277	97.0	0.277
<i>Heracleum wallichii</i> DC.	0.00	0.00	0.00	0.00	106.0	0.770	112.5	1.000	13.33	15.67	150.93	134.00	97.5	0.499	106.0	0.770
<i>Herminium duthiei</i> Hook. f.	2.67	2.67	2.13	6.27	105.0	0.675	104.0	0.587	8.67	5.67	17.07	9.60	104.0	0.634	105.0	0.675
<i>Herminium josephii</i> Rehb. f.	7.67	7.67	14.80	18.13	81.0	0.119	90.0	0.302	7.00	2.00	11.33	3.47	81.5	0.125	81.0	0.119
<i>Impatiens racemosa</i> DC.	0.33	0.33	0.00	0.27	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Iris goniocarpa</i> Baker	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.33	0.00	0.67	0.00	105.0	0.317	105.0	0.317
<i>Juncus concinnus</i> D. Don	0.00	0.00	4.00	0.00	111.5	0.944	105.0	0.317	3.67	1.00	23.33	12.00	110.5	0.888	111.5	0.944
<i>Juncus himalensis</i> Klotzsch	0.33	0.33	4.00	0.27	96.0	0.247	112.0	0.962	1.00	2.00	0.53	5.20	98.0	0.309	96.0	0.247
<i>Juncus thomsonii</i> Buchenau	1.33	1.33	6.13	2.67	94.0	0.300	105.0	0.550	12.33	6.67	32.67	29.33	91.5	0.240	94.0	0.300
<i>Juniperus indica</i> Bertol.	3.33	3.33	101.33	68.67	87.0	0.154	106.5	0.737	1.67	9.00	16.67	421.33	88.5	0.179	87.0	0.154
<i>Juniperus squamata</i> Buch.-Ham. ex D. Don	1.00	1.00	1.33	10.00	97.5	0.150	104.0	0.498	1.00	0.00	1.33	0.00	97.5	0.150	97.5	0.150
<i>Kobresia nepalensis</i> (Nees) Kuk.	1.00	1.00	40.67	24.00	100.5	0.522	98.0	0.309	13.33	12.67	124.67	205.33	101.0	0.540	100.5	0.522

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Kobresia pygmaea</i> (C. B. Clarke) C. B. Clarke	20.00	20.00	133.07	110.00	102.5	0.674	110.5	0.932	49.67	39.33	279.33	247.33	95.0	0.461	102.5	0.674
<i>Kobresia royleana</i> (Nees) Boeck.	0.00	0.00	0.00	0.00	107.0	0.725	112.5	1.000	8.00	11.67	66.40	108.00	106.5	0.701	107.0	0.725
<i>Leibnitzia nepalensis</i> (Kuntze) Kitam	0.33	0.33	0.00	0.67	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Leontopodium stracheyi</i> (Hook. f.) C. B. Clarke ex Hemsl.	2.33	2.33	27.20	4.93	105.0	0.317	80.0	0.119	0.67	0.00	3.33	0.00	105.0	0.317	105.0	0.317
<i>Lilium nanum</i> Klotzsch	1.33	1.33	14.67	2.13	103.5	0.666	110.5	0.888	2.67	4.33	6.00	7.07	101.0	0.579	103.5	0.666
<i>Lonicera obovata</i> Royle ex Hook. f. and Thomson	4.67	4.67	40.00	85.33	112.5	1.000	105.0	0.550	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Lonicera spinosa</i> (Jacquem. ex Decne.) Walp.	2.33	2.33	50.67	44.00	112.5	1.000	110.5	0.915	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Meconopsis paniculata</i> Prain	0.00	0.00	4.67	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Morina nepalensis</i> D. Don	0.00	0.00	0.00	0.00	92.5	0.359	112.5	1.000	11.33	16.67	71.33	108.00	96.0	0.449	92.5	0.359
<i>Neopicrorhiza scrophulariiflora</i> (Pennell) D.Y. Hong	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	0.33	0.00	0.67	105.0	0.317	105.0	0.317
<i>Neottianthe cucullata</i> var. <i>calcicola</i> (W.W.Sm.) Soó	16.33	16.33	21.07	29.87	89.0	0.133	68.0	0.051	2.67	0.33	4.67	0.27	89.0	0.133	89.0	0.133
<i>Nervilia</i> sp.	15.67	15.67	14.00	42.00	112.5	1.000	68.0	0.051	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Parnassia nubicola</i> Wall. ex Royle	1.07	1.07	6.40	2.13	103.5	0.615	89.0	0.189	5.67	3.00	6.53	4.00	103.0	0.595	103.5	0.615
<i>Pedicularis anserantha</i> T. Yamaz.	0.00	0.00	0.00	0.00	103.5	0.565	112.5	1.000	1.67	2.33	6.67	13.33	105.0	0.631	103.5	0.565
<i>Pedicularis rhinanthoides</i> Schrenk	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	0.33	0.00	0.67	105.0	0.317	105.0	0.317
<i>Pedicularis roylei</i> Maxim.	0.00	0.00	0.00	0.00	98.0	0.309	112.5	1.000	3.33	1.00	26.67	4.27	98.0	0.309	98.0	0.309
<i>Pedicularis siphonantha</i> D. Don	0.00	0.00	43.33	0.00	68.0	0.056	105.0	0.317	23.67	14.00	98.40	51.73	75.5	0.112	68.0	0.056
<i>Plantago erosa</i> Wall.	4.00	4.00	6.53	12.40	112.5	1.000	97.5	0.458	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Pleurospermum angelicoides</i> (Wall.) Benth. ex C. B. Clarke	0.00	0.00	0.00	0.00	103.0	0.648	112.5	1.000	9.67	10.67	76.67	106.00	106.5	0.773	103.0	0.648
<i>Pleurospermum apiolens</i> C. B. Clarke	2.33	2.33	0.00	6.53	97.0	0.277	97.5	0.150	5.00	0.67	44.13	8.00	97.0	0.277	97.0	0.277
<i>Pleurospermum benthamii</i> (Wallich ex de Candolle) C. B. Clarke	0.00	0.00	0.00	0.00	87.5	0.183	112.5	1.000	5.00	6.00	53.33	34.67	86.5	0.165	87.5	0.183
<i>Polygonatum hookeri</i> Baker	43.67	43.67	223.33	208.93	104.0	0.722	106.5	0.803	42.67	36.67	137.87	118.53	106.0	0.785	104.0	0.722
<i>Polystichum shensiense</i> Christ	0.00	0.00	2.67	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Ponerorchis chusua</i> (D. Don) Soo	6.00	6.00	29.20	23.20	112.0	0.962	101.5	0.620	0.33	1.33	0.67	2.00	112.0	0.962	112.0	0.962
<i>Potentilla atosanguinea</i> G.Lodd. ex D.Don	5.00	5.00	26.67	14.67	106.0	0.605	107.0	0.725	3.00	3.33	13.33	15.33	106.0	0.605	106.0	0.605
<i>Potentilla coriandrifolia</i> D. Don	0.00	0.00	0.00	0.00	99.0	0.343	112.5	1.000	1.00	1.33	3.60	5.33	99.0	0.343	99.0	0.343
<i>Potentilla fructicosa</i> L.	0.00	0.00	0.00	0.00	81.0	0.149	112.5	1.000	6.00	15.00	90.67	413.33	78.5	0.119	81.0	0.149
<i>Potentilla griffithii</i> Hook. f.	0.00	0.00	1.33	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Potentilla microphylla</i> D. Don	8.67	8.67	41.33	61.33	101.0	0.619	108.0	0.801	49.67	36.33	286.00	231.07	100.5	0.600	101.0	0.619
<i>Primula capitata</i> Hooker	0.67	0.67	0.00	4.00	112.0	0.962	97.5	0.150	0.33	0.33	0.27	2.67	112.5	1.000	112.0	0.962
<i>Primula involucrata</i> Wall. ex Duby	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	1.00	0.00	2.00	105.0	0.317	105.0	0.317
<i>Primula sikkimensis</i> Hook. f.	0.00	0.00	0.00	0.00	112.0	0.976	112.5	1.000	3.33	5.67	23.33	29.33	112.0	0.976	112.0	0.976
<i>Ranunculus brotherusii</i> var. <i>brotherusii</i> Freyn	0.00	0.00	0.00	0.00	112.0	0.962	112.5	1.000	0.33	1.00	0.67	8.00	112.0	0.962	112.0	0.962
<i>Rhodiola bupleuroides</i> (Wall. ex Hook. f. and Thomson) S. H. Fu	2.33	2.33	11.33	6.93	108.0	0.848	110.5	0.905	9.33	8.67	48.53	37.73	109.0	0.881	108.0	0.848
<i>Rhodiola himalensis</i> (D. Don) S.H. Fu	1.00	1.00	9.33	4.27	112.5	1.000	112.0	0.962	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Rhododendron anthopogon</i> D. Don	1.33	1.33	0.00	46.67	106.0	0.605	105.0	0.317	0.67	3.00	14.67	66.67	106.0	0.605	106.0	0.605
<i>Rhododendron lepidotum</i> Wall. ex G. Don	79.33	79.33	1587.33	1990.00	90.0	0.231	89.0	0.329	3.00	28.67	43.33	1240.0	90.0	0.230	90.0	0.231
<i>Salix lindleyana</i> Wall. ex Andersson	33.00	33.00	557.33	560.27	112.5	1.000	97.0	0.515	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Salix sikkimensis</i> Andersson	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.33	0.00	4.00	0.00	105.0	0.317	105.0	0.317
<i>Sanicula elata</i> Buch.-Ham. ex D. Don	0.00	0.00	0.00	0.00	104.0	0.498	112.5	1.000	0.33	0.67	0.67	2.67	105.0	0.550	104.0	0.498
<i>Saussurea nepalensis</i> Spreng.	0.00	0.00	4.00	0.00	105.0	0.317	105.0	0.317	1.00	0.00	3.33	0.00	105.0	0.317	105.0	0.317
<i>Saussurea uniflora</i> Wall. ex Sch.	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	1.33	0.00	6.93	0.00	105.0	0.317	105.0	0.317
<i>Saxifraga brachypoda</i> D. Don	6.33	6.33	14.67	14.80	85.0	0.103	96.0	0.428	2.00	3.67	3.33	8.40	85.0	0.102	85.0	0.103
<i>Saxifraga brunonis</i> Wall. ex Ser.	3.33	3.33	23.47	6.53	99.0	0.472	104.0	0.690	2.00	2.67	4.93	4.40	102.0	0.575	99.0	0.472
<i>Saxifraga parnassifolia</i> D. Don	17.67	17.67	49.87	39.60	98.5	0.560	102.5	0.652	49.33	30.33	126.40	89.60	73.5	0.104	98.5	0.560
<i>Scrophularia pauciflora</i> Benth.	0.00	0.00	12.00	0.00	112.0	0.962	105.0	0.317	0.67	0.67	12.00	2.00	112.5	1.000	112.0	0.962

Name of species	Lateral moraine (3700 m asl – 4100 m asl)								Terminal moraine (4200 m asl – 4600 m asl)							
	Frequency		Cover		Frequency comparison		Cover comparison		Frequency		Cover		Frequency comparison		Cover comparison	
	open	closed	open	closed	U	p	U	p	open	closed	open	closed	U	p	U	p
<i>Sedum oreades</i> (Decne.) Raym.-Hamet	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	1.00	0.00	2.67	0.00	105.0	0.317	105.0	0.317
<i>Selinum wallichianum</i> (DC.) Raizada and Saxena	11.33	11.33	135.73	110.00	111.5	0.963	104.5	0.733	12.33	10.67	113.20	159.33	111.5	0.963	111.5	0.963
<i>Senecio kunthianus</i> Wall. ex DC.	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	1.67	0.00	8.00	0.00	105.0	0.317	105.0	0.317
<i>Sibbaldia cuneata</i> Hornem. ex Kuntze	3.00	3.00	24.40	7.73	112.0	0.962	106.5	0.749	5.33	0.33	38.00	0.67	112.0	0.962	112.0	0.962
<i>Silene gonosperma</i> (Rupr.) Bocquet	3.00	3.00	6.93	4.40	78.0	0.145	104.5	0.654	22.00	8.33	58.27	16.93	74.0	0.103	78.0	0.145
<i>Spiraea arcuata</i> Hook. f.	0.00	0.00	0.00	0.00	111.0	0.929	112.5	1.000	4.33	5.67	44.00	52.67	109.0	0.835	111.0	0.929
<i>Stellaria congestiflora</i> H. Hara	0.00	0.00	6.67	0.00	112.5	1.000	97.5	0.150	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Stellaria himalayensis</i> Majumdar	1.00	1.00	14.00	0.53	112.5	1.000	106.0	0.605	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
<i>Swertia cuneata</i> Wall. ex D. Don	0.00	0.00	9.87	0.00	98.0	0.537	97.5	0.150	35.33	26.67	83.87	68.53	97.5	0.523	98.0	0.537
<i>Swertia nervosa</i> (G. Don) C. B. Clarke	12.33	12.33	46.13	27.73	99.0	0.343	111.0	0.933	2.67	3.33	4.67	6.53	99.0	0.343	99.0	0.343
<i>Taraxacum eriopodum</i> DC.	0.33	0.33	0.00	0.27	91.0	0.252	105.0	0.317	9.67	3.00	37.60	8.27	92.0	0.275	91.0	0.252
<i>Thalictrum alpinum</i> L.	0.33	0.33	3.33	0.67	91.0	0.271	104.5	0.524	11.00	22.33	34.67	67.33	89.5	0.239	91.0	0.271
<i>Thalictrum cultratum</i> Wall.	1.33	1.33	5.33	0.67	105.0	0.317	89.0	0.133	0.33	0.00	0.67	0.00	105.0	0.317	105.0	0.317
<i>Vicia angustifolia</i> L.	0.00	0.00	0.00	0.00	105.0	0.550	112.5	1.000	0.67	1.00	0.40	1.07	105.5	0.577	105.0	0.550
<i>Viola biflora</i> L.	3.67	3.67	20.27	10.00	97.5	0.150	112.0	0.976	0.00	2.67	0.00	12.00	97.5	0.150	97.5	0.150
Unknown A	0.00	0.00	2.67	0.00	112.5	1.000	105.0	0.317	0.00	0.00	0.00	0.00	112.5	1.000	112.5	1.000
Unknown B	0.00	0.00	0.00	0.00	105.0	0.317	112.5	1.000	0.00	0.67	0.00	4.00	105.0	0.317	105.0	0.317

Bold entries represent statistically significant values

APPENDIX 10: Mean values of key functional traits of the individual species along the elevation. The values represent Mean±SE of the values.

Key functional traits	Elevation bands (m asl)									
	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600
<i>Cotoneaster microphyllus</i>										
Plant height (cm)	20.4±2.54	22.1±3.89	23.5±2.49	20.72±3.17	19.88±3.74	28.6±4.57	16.8±4.55	13.68±2.45	20.7±2.18	9.7±2.12
Plant size (cm ²)	2363.05±461.22	1372.85±272.17	904.25±193.24	7487.6±2501.85	1893.01±603.71	1331.76±141.89	3943.19±1205.9	2245.62±588.35	3028.55±797.31	1880.78±590.8
Stem girth (cm)	2.82±0.13	4.48±0.34	3.62±0.43	4.1±0.22	3.86±0.15	4±0.06	3.56±0.17	4±0.37	4.12±0.18	2.62±0.62
SLA (cm ² g ⁻¹)	34.79±2.7	39.31±2.21	48.76±8.02	58.23±4.15	86.56±4.34	76.15±1.57	88.28±3.75	99.15±11.01	110.16±6.75	123.78±9.52
LDMC (g g ⁻¹)	0.79±0.01	0.82±0.03	0.67±0.02	0.52±0.02	0.47±0.05	0.56±0.05	0.53±0.04	0.45±0.03	0.46±0.04	0.52±0.03
LT (mm)	0.038±0.003	0.032±0.001	0.037±0.005	0.035±0.003	0.026±0.002	0.025±0.002	0.024±0.003	0.025±0.002	0.021±0.001	0.018±0.003
Reproductive output	50.6±14.28	46.6±6.85	46.8±3.92	80.2±7.33	57±12.51	97.2±6.91	106.4±7.13	94.6±12.72	120±21.23	129.6±8.35
FDMC (g g ⁻¹)	0.329±0.015	0.351±0.02	0.313±0.026	0.323±0.007	0.345±0.015	0.333±0	0.321±0.022	0.343±0.01	0.536±0.047	0.461±0.019
<i>Rhododendron lepidotum</i>										
Plant height (cm)	25.56±3.95	46.9±6.2	38.6±9.09	28.46±2.33	24.76±1.84	16.7±0.94	22.3±2.01	24.2±6.51	23.22±1.23	11.1±1.47
Plant size (cm ²)	495.88±57.05	773.52±251.65	689.54±188.1	984.75±90.68	408.27±72.07	451.73±71.33	598.4±69.32	507.12±58.06	456.82±59.45	69.22±15.27
Stem girth (cm)	2.88±0.36	2.22±0.31	3.44±0.24	3.28±0.12	2.8±0.19	1.44±0.05	2.26±0.09	3.1±0.17	2.22±0.12	1±0.1
SLA (cm ² g ⁻¹)	81.1±9.28	455.56±16.4	75.07±7.84	85.27±5.17	78.41±6.11	85.4±7.75	101.49±5.34	77.75±4.12	92.79±8.33	87.63±6.45
LDMC (g g ⁻¹)	0.4±0.04	0.33±0.06	0.43±0.07	0.49±0.03	0.5±0.05	0.39±0.06	0.44±0.02	0.46±0.06	0.58±0.04	0.59±0.03
LT (mm)	0.036±0.003	0.009±0.002	0.077±0.035	0.025±0.001	0.03±0.004	0.048±0.013	0.023±0.002	0.033±0.004	0.02±0.001	0.02±0.001
Reproductive output	18±6.59	19.8±6.32	33.6±8.97	32.2±6.97	15.6±1.63	7.6±1.29	11.6±3.91	6.8±1.02	13.6±2.58	34.2±5.39
FDMC (g g ⁻¹)	0.4±0.06	0.36±0.01	0.21±0.03	0.36±0.03	0.42±0.01	0.4±0.04	0.46±0.07	0.53±0.11	0.38±0.04	0.04±0.01
<i>Dactylorhiza hatagirea</i>										
Plant height (cm)	32.68±3.54	32.98±1.51	29.56±2.23	36.94±5.13	39.02±1.06	51.86±5.94	51.84±1.34	43.28±1.8	38.66±2.63	23.74±5.58
Stem girth (cm)	1.94±0.18	2.28±0.06	2.34±0.13	2.46±0.15	2.62±0.2	3.3±0.3	3.71±0.55	2.34±0.4	2.7±0.34	2.26±0.19

Key functional traits	Elevation bands (m asl)									
	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600
SLA (cm ² g ⁻¹)	355.02±30.83	497.71±52.69	654.86±55.78	589.12±61.02	630.78±89.87	474.02±54.12	512.02±55.66	680.55±123.92	656.43±68.35	1068.08±170.91
LDMC (g g ⁻¹)	0.18±0.02	0.1±0.01	0.09±0.01	0.11±0.01	0.11±0.01	0.14±0.02	0.11±0.01	0.1±0.01	0.11±0.01	0.06±0.01
LT (mm)	0.019±0.002	0.024±0.001	0.02±0.001	0.017±0.001	0.017±0.001	0.017±0.001	0.019±0.001	0.018±0.002	0.017±0.002	0.018±0.001
Reproductive output	33±7.98	38.8±5.29	36.2±4.16	30±5.59	39.2±7.11	60.6±8.22	80.6±11.83	35.8±6.6	53.8±9	35.6±6.22
FDMC (g g ⁻¹)	0.24±0.02	0.24±0.004	0.23±0.02	0.2±0.02	0.17±0.02	0.11±0.01	0.15±0.01	0.16±0.02	0.14±0.001	0.21±0.05
<i>Cypripedium himalaicum</i>										
Plant height (cm)	-	-	30.52±2.79	27.34±1.79	25.42±2.08	26.04±1.41	30.2±1.02	22.04±1.3	18.26±1.32	-
Stem girth (cm)	-	-	1.62±0.12	1.44±0.13	1.7±0.1	1.84±0.19	2.02±0.06	1.9±0.15	1.74±0.07	-
SLA (cm ² g ⁻¹)	-	-	239.05±14.27	300.12±35.35	317.1±23.11	329.99±17.9	346.51±28.87	412.56±45.37	332.98±37.16	-
LDMC (g g ⁻¹)	-	-	0.13±0.004	0.09±0.005	0.09±0.012	0.1±0.006	0.09±0.003	0.08±0.004	0.08±0.004	-
LT (mm)	-	-	0.04±0.002	0.04±0.003	0.04±0.005	0.04±0.002	0.03±0.002	0.04±0.001	0.03±0.002	-
FDMC (g g ⁻¹)	-	-	0.14±0.02	0.16±0.02	0.17±0.01	0.13±0.01	0.14±0.01	0.15±0.01	0.15±0.01	-
<i>Rhodiola bupleuroides</i>										
Plant height (cm)	34.7±5.56	35.08±4.9	40.52±5.13	27.2±1.82	27.98±1.48	28.66±3.11	31.46±1.68	30.8±1.62	25.52±2.67	17.72±1.87
Stem girth (cm)	5.88±0.49	5.04±0.29	6.4±0.38	6.3±0.56	5.92±0.52	4.88±0.63	5.8±0.69	6.22±0.6	5.32±0.38	5.2±0.47
SLA (cm ² g ⁻¹)	163.98±32.09	148.91±19.42	130.3±18.15	116.75±12.28	81.65±8.99	75.39±14.06	91.73±17.19	57.5±7.26	86.83±11.67	80.3±15.12
LDMC (g g ⁻¹)	0.12±0.01	0.13±0.01	0.15±0.02	0.14±0.03	0.19±0.04	0.24±0.04	0.18±0.03	0.19±0.03	0.17±0.02	0.16±0.01
LT (mm)	0.07±0.01	0.06±0.01	0.06±0.01	0.09±0.02	0.08±0.01	0.09±0.01	0.08±0.01	0.13±0.03	0.08±0.01	0.13±0.04
Reproductive output	143.6±53.58	84.6±39.69	176.8±37.8	138±54	82±24.52	44.2±13.86	73±17.98	313.2±69.7	53.4±16.91	44.4±12.16
FDMC (g g ⁻¹)	0.25±0.02	0.4±0.13	0.5±0.13	0.46±0.09	0.37±0.03	0.34±0.02	0.27±0.08	0.32±0.02	0.19±0.02	0.35±0.1

APPENDIX 11: Regression statistics of plant functional traits. GLM was run upto 2nd order polynomials.

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value
<i>Cotoneaster microphyllus</i>								
Plant size and elevation	Null	0	49	91961	-	-	-	-
	GLM	1	48	91918	1	43.694	0.0153	0.902
	GLM	2	47	88077	2	3884.7	0.7525	0.4768
Plant height and elevation	Null	0	49	177.3	-	-	-	-
	GLM	1	48	157.91	1	19.388	5.7956	0.01996
	GLM	2	47	143.91	2	33.393	5.4798	0.00726
Stem girth and elevation	Null	0	49	10.352	-	-	-	-
	GLM	1	48	10.29	1	0.06199	0.3158	0.5767
	GLM	2	47	8.7407	2	1.611	4.4431	0.01709
SLA and elevation	Null	0	99	1540.74	-	-	-	-
	GLM	1	98	475.22	1	1065.5	211.32	<0.0001
	GLM	2	97	447.94	2	1092.8	113.38	<0.0001
LDMC and elevation	Null	0	99	4.8087	-	-	-	-
	GLM	1	98	2.966	1	1.8427	61.68	<0.0001
	GLM	2	97	2.5732	2	2.2355	41.617	<0.0001
LT and elevation	Null	0	99	0.38159	-	-	-	-
	GLM	1	98	0.24598	1	0.13562	51.93	<0.0001
	GLM	2	97	0.24411	2	0.13748	26.252	<0.0001
Reproductive output and elevation	Null	0	49	845.44	-	-	-	-
	GLM	1	48	382.39	1	463.05	57.125	<0.0001
	GLM	2	47	381.07	2	464.37	27.984	<0.0001
FDMC and elevation	Null	0	49	0.83319	-	-	-	-
	GLM	1	48	0.5497	1	0.28348	23.472	<0.0001
	GLM	2	47	0.42055	2	0.41264	21.783	<0.0001
<i>Rhododendron lepidotum</i>								
Plant size and elevation	Null	0	49	9922.8	-	-	-	-
	GLM	1	48	8088.1	1	1834.7	11.524	0.00139
	GLM	2	47	6795.6	2	3127.1	11.097	0.00011
Plant height and elevation	Null	0	49	307.86	-	-	-	-
	GLM	1	48	217.18	1	90.684	19.74	<0.0001
	GLM	2	47	213.42	2	94.446	10.165	0.00021
Stem girth and elevation	Null	0	49	15.822	-	-	-	-
	GLM	1	48	12.549	1	3.2731	13.16	0.00069
	GLM	2	47	11.257	2	4.5651	9.9096	0.00026
SLA and elevation	Null	0	99	7044	-	-	-	-
	GLM	1	98	5582.1	1	1461.9	21.838	<0.0001
	GLM	2	97	5415.9	2	1628	12.685	<0.0001

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value
	Null	0	99	6.4411	-	-	-	-
LDMC and elevation	GLM	1	98	5.7267	1	0.71442	12.844	0.00053
	GLM	2	97	5.7038	2	0.73734	6.5741	0.0021
	Null	0	98	2.429	-	-	-	-
LT and elevation	GLM	1	97	2.356	1	0.07257	1.539	0.217
	GLM	2	96	2.276	2	0.15279	1.729	0.182
	Null	0	49	423.9	-	-	-	-
Reproductive output and elevation	GLM	1	48	379.91	1	43.991	5.1688	0.02751
	GLM	2	47	379.26	2	44.639	2.5653	0.08762
	Null	0	49	4.3647	-	-	-	-
FDMC and elevation	GLM	1	48	4.2951	1	0.06966	0.8496	0.3613
	GLM	2	47	3.6825	2	0.68227	4.3588	0.01834
<i>Dactylorhiza hatagirea</i>								
	Null	0	49	165.35	-	-	-	-
Plant height and elevation	GLM	1	48	162.44	1	2.9068	0.8819	0.3524
	GLM	2	47	111.74	2	53.605	11.228	0.0001
	Null	0	49	10.4184	-	-	-	-
Stem girth and elevation	GLM	1	48	9.8047	1	0.61373	2.8377	0.09857
	GLM	2	47	7.6757	2	2.7427	8.1818	0.00089
	Null	0	99	13238	-	-	-	-
SLA and elevation	GLM	1	98	10610	1	2628.3	21.486	<0.0001
	GLM	2	97	10375	2	2862.8	11.92	<0.0001
	Null	0	99	1.9891	-	-	-	-
LDMC and elevation	GLM	1	98	1.7914	1	0.19767	10.954	0.0013
	GLM	2	97	1.7911	2	0.19801	5.4241	0.00585
	Null	0	99	0.1103	-	-	-	-
LT and elevation	GLM	1	98	0.10461	1	0.0057	5.3545	0.02276
	GLM	2	97	0.10301	2	0.00729	3.4725	0.03495
	Null	0	49	477.41	-	-	-	-
Reproductive output and elevation	GLM	1	48	446.71	1	30.702	3.1542	0.08207
	GLM	2	47	405.42	2	71.99	4.0763	0.02331
	Null	0	49	0.92801	-	-	-	-
FDMC and elevation	GLM	1	48	0.71862	1	0.20939	12.475	0.0009
	GLM	2	47	0.59765	2	0.33036	12.271	<0.0001
<i>Cypripedium himalaicum</i>								
	Null	0	34	39.553	-	-	-	-
Plant height and elevation	GLM	1	33	26.92	1	12.634	15.337	0.00043
	GLM	2	32	24.67	2	14.883	9.5322	0.00057
	Null	0	34	1.9649	-	-	-	-
Stem girth and elevation	GLM	1	33	1.7038	1	0.26113	5.2788	0.02806
	GLM	2	32	1.5929	2	0.37204	3.9341	0.02967

Response variables	Model	Polynomial order	Res.	Res. Dev.	DF	Deviance	F	p-value
	Null	0	69	2189.4	-	-	-	-
SLA and elevation	GLM	1	68	1345.5	1	843.89	36.46	<0.0001
	GLM	2	67	1339.3	2	850.11	18.274	<0.0001
	Null	0	69	0.41992	-	-	-	-
LDMC and elevation	GLM	1	68	0.31996	1	0.09996	22.226	<0.0001
	GLM	2	67	0.30655	2	0.11336	12.733	<0.0001
	Null	0	69	0.16327	-	-	-	-
LT and elevation	GLM	1	68	0.13981	1	0.02346	10.878	0.00155
	GLM	2	67	0.1356	2	0.02767	6.6138	0.00239
	Null	0	34	0.19982	-	-	-	-
FDMC and elevation	GLM	1	33	0.198	1	0.00183	0.3168	0.5773
	GLM	2	32	0.19778	2	0.00204	0.1714	0.8433
<i>Rhodiola bupleuroides</i>								
	Null	0	49	128.326	-	-	-	-
Plant height and elevation	GLM	1	48	95.403	1	32.923	16.513	0.00018
	GLM	2	47	92.345	2	35.981	9.0208	0.00048
	Null	0	49	11.524	-	-	-	-
Stem girth and elevation	GLM	1	48	11.267	1	0.2574	1.1317	0.2927
	GLM	2	47	11.127	2	0.3976	0.8715	0.425
	Null	0	99	3280.5	-	-	-	-
SLA and elevation	GLM	1	98	2492.4	1	788.12	30.215	<0.0001
	GLM	2	97	2389.9	2	890.57	18.113	<0.0001
	Null	0	99	3.9283	-	-	-	-
LDMC and elevation	GLM	1	98	3.7423	1	0.18603	4.1981	0.04314
	GLM	2	97	3.5014	2	0.42692	5.4065	0.00594
	Null	0	99	2.5865	-	-	-	-
LT and elevation	GLM	1	98	2.2607	1	0.3258	11.28	0.00112
	GLM	2	97	2.2583	2	0.32821	5.6683	0.0047
	Null	0	49	3238.6	-	-	-	-
Reproductive output and elevation	GLM	1	48	2964.3	1	274.32	4.3731	0.04183
	GLM	2	47	2952.6	2	286.02	2.2455	0.1171
	Null	0	49	4.6551	-	-	-	-
FDMC and elevation	GLM	1	48	4.4659	1	0.18921	2.0567	0.158
	GLM	2	47	4.3175	2	0.33756	1.7995	0.1766

PHOTOPLATES

PHOTOPLATE 1. Some photographs of the study area.



Bhimthan glacier and the glaciated landscape, Manang (Photo Credit: YR. Paneru)



Terminal moraine of Bhimthan glacier including Ponker Hill and Ponker lake



Rocky slopes along the lateral moraine of Bhimthan glacier

PHOTOPLATE 2. Plot set up, data collection, photography, voucher specimen collection and maintenance.



Plot set up for vegetation sampling



Data collection (Photo credit: YR. Paneru)



Photography (Photo credit: YR. Paneru)



Pressing voucher specimen (Photo credit: L. Khaniya)

PHOTOPLATE 3. Photographs of characteristic plant species.



Lonicera obovata



Potentilla fruticosa



Dactylorhiza hatagirea



Ephedra gerardiana



Meconopsis horridula



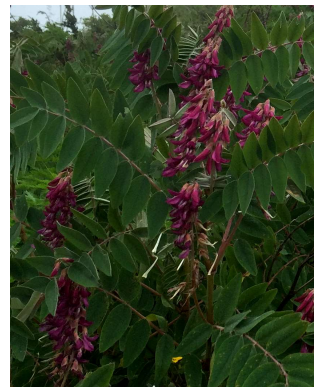
Botrychium lunaria



Nardostachys grandiflora



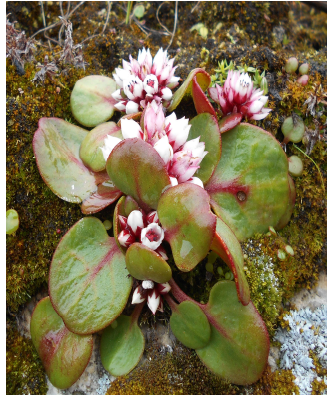
Ponerorchis chusua



Hedysarum manaslense



Cynanthus lobatus



Rhodiola prainii



Bistorta affinis

PHOTOPLATE 4. Plant species considered for functional trait analysis.



Rhododendron lepidotum



Cotoneaster microphyllus



Rhodiola bupleuroides



Dactylorhiza hatagirea



Cypripedium himalaicum