ALPINE VEGETATION OF THE KHANGCHENDZONGA LANDSCAPE, SIKKIM HIMALAYA: COMMUNITY CHARACTERISTICS, DIVERSITY AND ASPECTS OF ECOLOGY

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ABSTRACT

The alpine vegetation of the Sikkim Himalaya has received limited attention despite being a part of the eastern Himalaya global biodiversity hotspot. The current study undertaken in the third highest landscape in the world - the Khangchendzonga National Park (KNP), provides information on the different alpine vegetation communities and aspects of their ecology. The transverse spurs from the unique north-south running Khangchendzonga range result in a landscape level differentiation of the Outer, Inner and Tibetan Himalaya in just 50 km distance. The alpine vegetation based on numerical classification has been segregated into 11 types with the extensive ones being *Juniperus indica* scrub, *Rhododendron* scrub, *Kobresia duthiei* moist meadow, *Kobresia nepalensis* moist meadow, *Kobresia pygmaea* dry meadow and *Anaphalis xylorhiza* mixed meadow. Based on Canonical Correspondence Analysis, the three environmental gradients of rainfall, elevation, and soil were found to be the primary determinants of vegetation pattern. A total of 585 species of angiosperms belonging to 67 families and 243 genera were recorded in 390 km^2 area. Compared to the alpine zone of western Himalaya, proportions of alpine scrub and sedge meadows were higher whereas herbaceous formations and grassy meadows were limited in extent. The alpha species diversity was found to be lower mainly because the alpine region here is partly isolated, narrower, fragmented and dominated by a depauperate scrub zone.

KEYWORDS: *eastern Himalaya; multivariate analysis; environment gradients; vegetation classification; sedge meadow; species diversity*

Androsace sarmentosa

Meconopsis horridula - Himalayan Blue Poppy amongst the most beautiful high altitude plants

INTRODUCTION

The alpine zone in the Himalaya is lined up as an archipelago on high mountains at the southern periphery of the high central Asia, separated from each other by deeply incised transverse valleys (Miehe 1997). This zone exhibits a great deal of variation in topography, precipitation, floristics, physiognomy of vegetation and palaeohistory. On the extreme west this zone merges with the arid Eurasian mountains while its eastern flank shows closer affinities with the humid Sino-Japanese floristic region (Sakai and Malla 1981). The alpine zone in the Himalaya has attracted the attention of a large number of plant explorers, phyto-geographers and naturalists (see Rawat 1998 for review; Dickore and Nusser 2000), however, ecological studies in the region are rather scanty. A perusal of literature on the ecology of alpine vegetation across the globe reveals that most of the information comes from Europe and North America and only about 6% papers are from Central Asia and Himalaya (Korner 1999). Most of the literature on the alpine vegetation in the region is based on the studies conducted in the Western Himalaya (WH) and Nepal due to relatively easier access.

The alpine zone of the WH is much more extensive in geographical coverage compared to Eastern Himalaya (EH). This is reflected in the larger pool of vascular plants in the WH (1800 – 1900 species) as compared to the EH where the number of species is less i.e., ca. 1200 species (Rawat 2007). Rawat (2007) has reported that diversity of alpine plants in WH is highest between 3600–3800m especially within mixed herbaceous formations. Similarly, plant community structure and patterns of diversity among various alpine communities in the WH have been worked out (e.g., Kala *et al.* 1998; Rawat 2005). However, there is no documentation on the community structure and patterns of species diversity in the alpine region of EH till date. Information on these parameters would be crucial in better understanding of nature of alpine vegetation in the Himalaya**.** In this paper, we present the results of a recent ecological study (2004 – 2008) on the structure and composition of alpine vegetation in the Sikkim Himalaya.

The study was conducted in the upper catchments of Khangchendzonga National Park (KNP), which is named after the third highest peak in the world, i.e, Mt. Khangchendzonga (8586 m). The greater Khangchendzonga landscape spreads across eastern Nepal and the Indian state of Sikkim, and has a considerable area under alpine zone. The park (*ca*. 1784 km^2; 27° 30' to 27° 55' N latitudes and 88° 02'and 88° 37' E longitudes; Figure 1) covers nearly 25% of the geographical area of the state and forms a part of EH global biodiversity hotspot (Mittermeier *et al*., 2004). Earlier, Singh and Chauhan (1997) and Rai *et al*. (2000) conducted eco-floristic studies in temperate and sub-alpine regions of KNP. Singh and Sundriyal (2005) studied the floristic composition of an alpine meadow in southern KNP and reported the occurrence of 202 species of higher plants which belonged to 38 families (90% dicots, 9% monocots and 1% Gymnosperms). Based on a detailed floristic survey, Maity and Maiti (2007) have reported 1580 species of vascular plants from KNP which include 106 species of pteridophytes, 11 gymnosperms and 1463 angiosperms. However, detailed ecology of alpine plant communities across the larger landscape have not been addressed so far.

METHODS

The alpine zone in KNP lies between 4000 - 5000m elevation. At around 4000m the treeline and sub-alpine *krummholz* thickets end giving way to a belt of alpine scrub followed by various physiognomic categories of herbaceous formations upto about 5000m above which sparse subnival vegetation takes over until the beginning of permanent snowline that varies between 5000 to 5500m. About 22% of the geographical area (390 km^2) within KNP falls within the alpine zone.

Rheum nobile - The giant rhubarb is found on rocky habitats at high elevations. The white bracts create a greenhouse like environment and protect the flower inside

Vegetation Sampling

Based on the satellite remote sensing data, Survey of India topo maps, earlier experience and reconnaissance of the study area, the vegetation in the sub-alpine and alpine zone of KNP was stratified into four physiognomic units namely: (a) *Krummholz* thicket (b) alpine scrub (c) alpine meadow and (d) riverine scrub (Table 1). Vegetation data from 280 quadrats covering 56 sampling stations in the study area included abundance values for 150 species of vascular plants collected during the peak growing season i.e., June - July. Vegetation structure and species composition across various physiognomic units in the alpine zone were recorded using stratified random quadrats. Ten square plots of 1m x 1m for herbaceous ground flora and five replicates each of 5m x 5m for alpine scrub were laid following standard phytosociological approach (Mueller-Dumbois and Ellenberg 1974; Kent and Coker 1992). These broad vegetation classes can form the basis for more detailed phyto-sociological studies in future. Most of the plants were identified closest to the genera and species in the field using the regional floras namely Flowers of Himalaya (Polunin and Stainton 1987) and Flora of Bhutan which includes collections from Sikkim (Grierson and Long 1983; Noltie 1994, 2000).

Phyto-sociological Analysis

Numerical analysis software that rely more on multivariate analysis namely PC-ORD (version 4.20), TURBOVEG (version 2.41) and JUICE (version 6.4.50) (McCune and Mefford 1999; Hennekens and Schaminée 2001; Lubomír 2002) were used. PCORD software was used to perform the cluster analysis, calculate the alpha diversity indices and the Canonical Correspondence Analysis (CCA) (ter Braak 1994). The following 5 environment variables were recorded from each site: altitude (in m using GPS), aspect (on a scale of 1-4 indicating warmer aspect using GPS), slope (degrees) was visually assessed, mean annual rainfall on a scale of 1-3 (from rainfall distribution map of NBSSLUP 2000), and soil type was evaluated from the soil particle size on a scale of 1–6 (from gravel, sand, silt to clay). After classification, synoptic table was prepared in JUICE software and the threshold fidelity value for diagnostic species was set as 4 and the threshold frequency value for constant species as 60.

RESULTS

Landscape level differentiation: Outer, Inner and Tibetan Himalaya

The Khangchendzonga massif presides over the physiography of KNP. The seven watersheds or river sub-systems namely the Lhonak, Zemu, Lachen, Rangyong, Rangit, Prek and Churong though located adjacent to one another, show significant variation in physiography and climate (Figure 1, Table 2). Although the Greater Himalaya generally runs in an east-west direction, the chief ridge of Khangchendzonga range here is aligned in north-south inclination with west-east running transverse spurs. The monsoon winds blowing from the south-easterly direction bring heavy precipitation and are obstructed by successive west-east ridge formations, significantly reducing the precipitation towards the north. The annual rainfall decreases from 2.75 meter in the southeastern part to 0.75 meter in the north with the average being 2.14 meter (NBSSLUP 2000). While the southern part of KNP (Rangit, Prek and Churong), represents the wet part that is the Outer Himalaya, central part (Zemu, Lachen, Rangyong) represents the transitional inner Himalaya, and the high valley of Lhonak the Tibetan Himalaya (Schweinfurth 1984).

Saussurea obvallata or Brahma-kamal is regarded as a sacred flower and occurs in the alpine areas of North Sikkim

Gentiana urnula - another beautiful plant from the alpine areas of Lhonak

Aster flaccidus - A wild aster

Vegetation Structure and Composition

Based on numerical classification the vegetation of the alpine zone was segregated into 11 types namely Juniper scrub, Rhododendron scrub, morainic scrub, riverine willow (*Salix sikkimensis*) thicket, riverine (*Myricaria rosea*) scrub, *Kobresia nepalensis* moist meadow, *Kobresia duthiei* moist meadow, *Kobresia pygmaea* dry meadow, *Deschampsia caespitosa* marsh meadow and *Anaphalis xylorhiza* mixed meadows (Table1, Figure 2). There is a need for more systematic and intensive phyto-sociological studies in future. The synoptic table of the diagnostic, constant and dominant species is provided in Table 3. A brief description of the structure and composition of these 11 vegetation communities is placed below:

Juniper scrub which favours warmer slopes in the 3700 – 4400 meters elevation range was found to harbour two communities:

(i) *Juniperus squamata* scrub: This category is found generally between 3700 to 4100 m on warmer slopes which receive about 2230 mm of average annual rainfall. The dominant shrub *Juniperus squamata*, is prostrate in habit and this community has at least 40% cover of shrubs while the grasses and sedges have upto 30% cover. *Carex alpina, Poa alpina, Calamogrostis filiformis* and *Kobresia nepalensis* are the important grasses and sedges. While the important constituents of the herb layer are *Rhodiola bupleuroides, Bistorta vivipara* and species of *Arisaema, Potentilla, Primula* and *Pleurospermum.*

(ii) *Juniperus indica* scrub: This vegetation is found between 4000 to 4400 m and in the inner dry valleys ascends upto 4800 m. *Juniperus indica* usually occurs in the form of an erect shrub and in this association, besides junipers *Rhododendron lepidotum* has a tendency to colonize the openings. Herbs and grasses cover at least 10% with the herbaceous species being *Rhodiola bupleuroides, Rheum acuminatum* and species of *Pleurospermum* and *Potentilla*. This vegetation is quite extensive and occupies large areas throughout the alpine zone of KNP.

Megacodon stylophorus is a tall alpine plant belonging to the Gentianaceae family

(iii) *Rhododendron* scrub: Dwarf Rhododendron scrub is widespread in the higher reaches above the *Krummholz* zone. This vegetation (less than 1 meter tall) represents alpine moist scrub and favours the cooler aspect between 3900 to 4600 m. However in the inner dry valleys it can ascend upto 4900 m. It can withstand a high rainfall gradient of 1300 to 2500 mm. Heavy snow pack in winter insulates it from wind exposure and cold. This vegetation is very dense and the Ericaceous cover is more than 50% with very few gaps or openings. The shrub layer is co-dominated by *Rhododendron anthopogon, Rhododendron setosum* and *Rhododendron lepidotum.*

(iv) Morainic scrub: This category is found mainly in the glaciated valleys along the lateral and terminal moraines between 3900 and 4500 m elevation. This shrub-dominated vegetation is diverse in the lower reaches and becomes stunted and sparse in the upper reaches. *Potentilla fruticosa* is the diagnostic species of this vegetation and most prominent in the middle elevations.

Potentilla fruticosa - a dominant plant of the morainic scrub habitat

(v) Riverine willow (*Salix sikkimensis*) thicket: Is confined to the banks of rivers and hill streams between 3500 - 4200 m. *Salix sikkimensis* is the diagnostic species of this vegetation with high cover (>30%). In moist valleys *Rhododendron lanatum, Sorbus microphylla, Rhododendron thomsonii, Rhododendron hodgsonii, Rosa sericea* and *Abies densa* are the main associates. In the inner valleys co-dominants in the top canopy include *Hippophae salicifolia, Betula utilis, Acer campbellii* and *Rhododendron hodgsonii.*

(vi) Riverine (*Myricaria rosea*) scrub: This category is usually found in the upland valleys and stream courses characterized by skeletal and sandy soils in the subalpine and alpine zone upto 4600 m. The vegetation is characterized by mat forming prostate shrubs interspersed with herbs, grasses and sedges less than 0.3 m in height. *Myricaria rosea* is the characteristic species and the cover varies considerably (from 7% to 64%) with micro-topography and edaphic conditions.

Based on the numerical classification it was found that the alpine meadow vegetation segregated broadly into three clusters namely sedge meadow, marsh meadow and herbaceous meadow. Sedge meadow further separated into three classes namely *Kobresia nepalensis, Kobresia duthiei* and *Kobresia pygmaea.*

(vii) *Kobresia nepalensis* moist meadows: This is the most widespread and dominant vegetation in altitudes ranging from 4000 to 5100 m receiving a mean annual rainfall of 2230 mm. It occurs on smooth slopes and ridge tops, in the upper reaches of moist, exposed, glaciated valleys. This dense soft mat like formation has an average height of 0.1 m. The cover of *Kobresia nepalensis* varies a lot with micro-topography and co-dominates with *Bistorta milletii, Potentilla peduncularis, Rhododendron lepidotum, Primula capitata* and species of *Arenaria, Juncus* and *Carex.*

(viii) *Kobresia duthiei* moist meadows: Is found in shady moist valleys and bouldery slopes in the 4000 to 4600 m elevation zone. The vegetation is tussock forming dominated by *Kobresia duthiei* (cover greater than 40%) with an average height of 0.30 m. In openings *Kobresia nepalensis, Kobresia capillifolia, Rheum acuminatum, Rhododendron anthopogon, Geranium donianum* and species of *Heracleum, Swertia, Pleurospermum* and *Juncus* are usually found.

Geranium donianum

(ix) Kobresia pygmaea dry meadows: Is found in the upper reaches of the glaciated and relatively dry Zemu and Lhonak valleys (mean annual rainfall of 1500 mm) in the elevation range of 4400 to 5100 m. As the name suggests in the upper reaches this vegetation is stunted having average height of 0.05 m. In the lower reaches, especially along streams *Kobresia schoenoides* and *Bistorta vivipara* and in the upper reaches *Kobresia spp., Bistorta milletii, Potentilla fruiticosa* and *Aster falconeri* co-dominate.

Saussurea tridactyla occurs in very high altitude areas

(x) *Deschampsia caespitosa* marsh meadows: These meadows occur in the waterlogged flats adjacent to alpine lakes and in the upper courses of meandering streams, between 4000 to 4600 m. This vegetation is tussock forming with the top height being less than one meter. Floristically *Deschampsia caespitosa* clumps are dominant (cover greater than 40%), especially in edges of perennial watercourses. In the openings, commonly occurring species include *Carex setigera, Lagotis kunawarensis, Potentilla coriandrifolia, Festuca valesiaca, Calamogrostis filiformis, Epilobium wallichianum* and species of *Pedicularis, Juncus,* mosses and lichens.

Pedicularis longiflora - Sikkim Himalaya is regarded as hot spot of *Pedicularis* diversity, having about 55 species comprising 70% of the Indian Himalayan Taxa

(xi) *Anaphalis xylorhiza mixed meadows:* These meadows are found in the inner valleys on the glaciated flats of Lhonak usually between 4500 to 5100 m. This Tibetan steppe like vegetation grows in dry, arid conditions (average annual rainfall of 1300 mm) and is characterized by dwarf mixed herbaceous formations (average height is 0.1 m). The total vegetation cover is not more than 40%. *Anaphalis xylorhiza* is the dominant species (cover greater than 20%) with other associates such as *Bistorta vivipara, Kobresia schoenoides, Kobresia nepalensis, Lancea tibetica* and various species of *Arenaria* and *Pedicularis.*

Environmental variables determining vegetation structure

Of the five environment variables namely altitude, rainfall, edaphic, aspect and slope, the ordination space was found to be strongly correlated to the first three (Monte Carlo p-value = 0.001) (Table 4, 5). The first CCA axis negatively correlated with altitude and positively with rainfall. The second axis was negatively correlated to rainfall and soil type, while the third axis was positively correlated to soil type. Altitude and rainfall were found to be negatively correlated, i.e. rainfall decreases with increasing altitude. The biplot of the first two axes shown in Figure 3 indicates that areas with higher rainfall are heterogeneous and harbour a higher number of vegetation communities and *vice versa*.

Vegetation richness, Richness, Evenness and diversity indices

Table 6 gives the richness, evenness and diversity indices diversity indices for the various vegetation associations. In one-meter square plots, Richness (S) and Shanon's diversity index (H) varied from 4 to 13 and 1.44 to 2.48 respectively. Species richness and diversity were highest in *Kobresia pygmaea* dry meadows of Zemu valley (S=13, H=2.48) followed by morainic scrub (S=12.80, H=2.39). The morainic scrub represents early to mid seral stage. The richness and diversity values were lowest in case of marsh meadows (S=5, H=0.91) and nutrient rich livestock camping sites (S=5, H=0.91). The Evenness (E) and Simpson's diversity index (D`) varied from 0.76 to 0.97 and 0.69 to 0.91 respectively. Alpine scrub habitats showed low evenness and low values of Simpson's diversity index (D`) due to the dominance of Juniper (E=0.76, D`=0.69) and *Rhododendron* (E=0.85, D`=0.71). While high evenness and higher values of Simpson's diversity index (D`) was shown (E=0.97, D`=0.91) by *Kobresia pygmaea* dry meadow in Zemu valley and *Anaphalis xylorhiza* dry meadow in Lhonak valley.

We recorded a total of 585 species of angiosperms within the alpine zone of KNP during the present study. These belong to 67 families and 243 genera. The dominant families are Asteraceae (69 species), Ranunculaceae (35 species), Poaceae (32 species), Scrophulariaceae (30 species), Cyperaceae (28 species) and Rosaceae (28 species). The prominent genera are *Pedicularis* (21 species), *Carex* (18 species), *Saxifraga* (18 species) and *Rhododendron* (17 species). The gymnosperms in the sub-alpine and alpine zones include *Taxus baccata* subspecies *wallichiana, Tsuga dumosa, Abies densa, Juniperus recurva, Juniperus squamata, Juniperus indica,* and *Ephedra gerardiana.*

Gentiana stipitata

Cynanthus incanus found in North Sikkim

DISCUSSION

At the landscape level, the west-east running transverse spurs from the north-south running main Khangchendzonga range create a barrier for the south-easterly monsoon winds and result in a clear regional differentiation of the Outer, Inner and Tibetan Himalaya within KNP (Schweinfurth 1984). This results in a variation in climate from oceanic in the southern part to continental in the central and arid in the extreme north and has a marked influence on the vegetation patterns as well. Consequently the tree-line vegetation reviewed by Schickhoff (2005) across the length of the Himalayan range comprising of evergreen *Rhododendron*, deciduous *Betula* and *Acer* and *Juniperus* spp. are telescoped within just 50 km along the North-South gradient in KNP.

The alpine meadows of KNP (unlike in the western Himalaya), are dominated by sedges namely *Kobresia nepalensis* (on smooth slopes) and *Kobresia duthiei* (on broken slopes) in the moist meadows and *Kobresia pygmaea* and *Kobresia schoenoides* in the dry meadows. These Cyperaceae mats play a vital environmental role of protecting large alpine areas against erosion (Miehe *et al.* 2008). In the extreme north, the dry meadows of *Kobresia pygmaea* and *Anaphalis xylorhiza* in the Lhonak and Zemu valleys resemble the vegetation described by Miehe (1989) in Mount Everest and Miehe *et al.* (2008) on the Tibetan plateau. While in the southern part, the *Kobresia nepalensis* and *Kobresia duthiei* moist meadows were akin to those described by Kikuchi and Ohba (1988) from the Rolwaling Himal which is located in central Nepal. Grassy meadows of *Danthonia cachemyriana* and tall forb communities in deep soil are more characteristic of the Western Himalaya and were virtually absent in KNP (Rawat 2005). The major grass-dominated vegetation in the KNP is the *Deschampsia caespitosa* marsh meadow found only in the fringes of glacial lakes and streams. The subalpine thickets and alpine scrub vegetation is much broader in the Sikkim Himalaya.

The three environmental parameters namely rainfall, elevation and edaphic factors play a major role in determining the vegetation patterns in the alpine zone of KNP. The alpine area of KNP, compared to alpine meadows of WH, has lower

species diversity (Kala *et al*. 1998; Samant and Joshi 2004). For example, Kala *et al.*, (1998) reported around 500 species of angiosperms from 87 km^2 area of Valley of Flowers National Park. In the present study we estimate about 585 species of angiosperms in an area of over 390 km^2. Over the whole length of the Himalaya, Schaller (1977) observed that the Sikkim Himalaya are the steepest, and rise from the Indian plains to the crest in an extremely short distance (80 km), thereby resulting in telescoped or narrow eco-zones. The increasingly tropical latitude and geographical proximity to the Bay of Bengal results in decreasing winter cold and strongly increasing humidity levels (Schickhoff 2005). Consequently the climate here is characterized by a relatively small annual range of temperature, high rainfall in summer and rather high humidity (Sakai and Malla 1981). These climatic conditions, unlike in the alpine zone of WH (Dickore and Nusser 2000), favour shrub growth and consequently the alpine zone in the KNP is dominated by a depauperate ericaceous scrub zone.

Interestingly, the pattern of east-west directional increase in alpha diversity of alpine species along the length of the Himalaya was found to be mirrored within the alpine zone of KNP, along the south-north direction. In general, the dry alpine zone in the northern part of KNP showed relatively higher levels of alpha diversity compared to the moister alpine zone in the southern and central part of KNP. The 50 km long, north-south oriented Khangchendzonga range in KNP, broadly mimics in condensed form, the environmental and biological gradients existing along the 3000 km long, west-east running Himalayan range, and thus provides a unique natural laboratory for future phyto-geographical studies.

Eriophyton wallichii - a high altitude plant that uses a wooly appearance to adapt to the harsh alpine habitat

Table 1: Vegetation plot data collected from the alpine zone of Khangchendzonga National Park, Sikkim Himalaya, India

Physiognomy type	Vegetation type	Releve ids
Krummholz thicket	Krummholz thicket	12,38,43
Riverine thicket	Riverine willow (*Salix sikkimensis*) thicket	4,5,50,13,41
Alpine scrub	Juniper scrub	6,7,8,9,10
	Rhododendron scrub	11,42,49,36
	Morainic scrub	14,15,44,16,17
	Riverine (*Myricaria rosea*) scrub	1,18,19,20,39
Alpine meadow	*Kobresia duthiei* moist meadow	21,22,56,57,35
	Kobresia nepalensis moist meadow	24,25,34,48,55
	Kobresia pygmaea dry meadow	45,46,47,51
	Deschampsia caespitosa marsh meadow	26,28,29,37
	Anaphalis xylorhiza mixed meadow	52,53,54
	Potentilla peduncularis herbaceous meadow	23,30,31,32
	Subnival vegetation	27,33

Table 2. Comparison of landscape features showing variation in physiography and climate across major watersheds (sequenced north to south, also see Figure 1) in KNP

Landscape features			Watershed						
Category	**Features**	**Unit**	**Lhonak**	**Zemu**	**Lachen**	**Rangyong**	**Rangit**	**Prek**	**Churong**
Physiography	Regional differentiation	O, I, T [α]	T	I	I	I	O	O	O
	Dominant valley glacier	VG, NG [β]	VG	VG	VG	NG	NG	VG	VG
	Orientation	direction	W-E	W-E	N-S	W-E	N-S	N-S	N-S
	Area	km^2	243	368	95	664	118	144	152
	Percentage area of KNP	%	14	21	5	37	7	8	9
	Mean elevation	m	5250	5112	3447	4173	4176	3562	4591
	Highest elevation	m	7459	8586	5064	8476	5825	6691	7338
	Lowest elevation	m	3100	2700	1800	1220	2200	2200	2200
	Total relief	m	4359	5898	3264	7256	3625	4491	5138
	Basin length	m	44065	42697	27171	31413	10747	25626	23953
	Relief ratio	ratio	0.10	0.14	0.12	0.23	0.34	0.18	0.21
Climate	Mean annual rainfall	mm	1334	1643	1812	1866	2250	2230	2037
	Climatic zone		cold arid	continental	continental	continental	oceanic	oceanic	oceanic

[a] *O = Outer Himalaya, I = Inner Himalaya, T = Tibetan Himalaya*
[i] *VG = Dominant valley glacier, NG = No dominant valley glacier*

Table 3: Synoptic table of the vegetation types in the alpine zone of the Khangchendzonga National Park, Sikkim Himalaya, India (with the threshold fidelity value for diagnostic species is taken as 4, threshold frequency value for constant species as 60 and dominance indicated by average percentage cover)

Vegetation type	Diagnostic species	Constant species	Dominant species
Riverine willow (*Salix sikkimensis*) thicket	*Salix sikkimensis 6.6, Carex orbicularis 4.6*	*Salix sikkimensis 100, Epilobium wallichianum 60*	*Salix sikkimensis 40*
Juniperus squamata scrub	*Poa alpina 7.4, Juniperus squamata 6.6*	*Juniperus squamata 100*	*Juniperus squamata 50*
Juniperus indica scrub	*Juniperus indica 6.2*	*Juniperus indica 100*	*Juniperus indica 60*

Vegetation type	Diagnostic species	Constant species	Dominant species
Rhododendron scrub	*Rhododendron setosum 4.5, Morina nepalensis 4.1*	*Rhododendron setosum 100, Rhododendron anthopogon 75*	*Rhododendron anthopogon 50, Rhododendron setosum 25*
Morainic scrub	*Potentilla fruticosa 5.0, Spiraea arcuata 4.6*	*Potentilla fruticosa 100, Rhododendron anthopogon 60, Kobresia nepalensis 60*	*Rhododendron lepidotum 20, Potentilla fruticosa 20*
Riverine (*Myricaria rosea*) scrub	*Myricaria rosea 6.0, Parrya platycarpa 4.6*	*Myricaria rosea 100, Juncus spp. 80, Epilobium wallichianum 60*	*Myricaria rosea 60*
Kobresia duthiei moist meadow	*Kobresia duthiei 7.4, Kobresia capillifolia 4.6, Rheum acuminatum 4.2*	*Kobresia duthiei 100, Rheum acuminatum 80, Potentilla peduncularis 80, Kobresia nepalensis 60, Juncus spp. 60*	*Kobresia duthiei 80*
Kobresia nepalensis moist meadow	*Cremanthodium spp. 4.6,*	*Kobresia nepalensis 100,*	*Kobresia nepalensis 60*
Kobresia pygmaea dry meadow	*Bistorta milletii 5.2, Thalictrum alpinum 5.1, Primula capitata 5.1, Kobresia pygmaea 5.1, Kobresia spp. 5.1, Aster falconeri 5.1, Hedysarum sikkimense 5.0*	*Parnassia spp. 75, Kobresia schoenoides 75, Hedysarum sikkimense 75, Bistorta milletii 75*	
Deschampsia caespitosa marsh meadow	*Deschampsia caespitosa 4.8*	*Deschampsia caespitosa 100 Juncus spp. 75*	*Deschampsia caespitosa 50*
Anaphalis xylorhiza mixed meadow	*Saxifraga spp. 6.6, Arenaria spp. 6.6, Saussurea nepalensis 6.0, Lancea tibetica 6.0, Euphorbia spp. 6.0, Ephedra gerardiana 6.0, Anaphalis xylorhiza 6.0*	*Saxifraga spp. 100, Kobresia schoenoides 100, Kobresia nepalensis 100, Festuca valesiaca 100, Arenaria spp. 100, Anaphalis xylorhiza 100, Saussurea nepalensis 67, Lancea tibetica 67, Euphorbia spp. 67, Ephedra gerardiana 67, Arenaria spp. 67*	*Anaphalis xylorhiza 33*

Table 4: Correlation scores from PC-ORD CCA output for the first three axes with the 5 environmental variables

Variable	Correlations		
	Axis 1	Axis 2	Axis 3
Altitude	-0.890	-0.103	-0.297
Aspect	0.131	-0.244	-0.101
Slope	0.243	-0.070	-0.159
Rainfall	0.786	-0.532	0.047
Soil type	-0.278	-0.516	0.737

Table 5: Monte Carlo test results - Species-Environment Correlations

Randomized data Real data Monte Carlo test, 999 runs					
Axis	Species-Env Correlation	Mean	Minimum	Maximum	p
1	0.958	0.879	0.796	0.932	0.0010
2	0.949	0.863	0.777	0.937	n.a.
3	0.947	0.847	0.749	0.930	n.a.

p = proportion of randomized runs with species-environment correlation greater than or equal to the observed species-environment correlation; i.e.,
p = (1 + no. permutations >= observed)/(1 + no. permutations)
p is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values. n.a. = not applicable.

Table 6: Richness, evenness and alpha indices of diversity in the vegetation types found in the alpine zone of the Khangchendzonga National Park, Sikkim Himalaya, India

S. No*	Vegetation Type	Richness	Evenness	Shannon`s diversity index	Simpson`s diversity index
		S	E	H	D`
1	Riverine willow (*Salix sikkimensis*) thicket	10.60	0.95	2.12	0.84
2,3	Juniper scrub	8.20	0.76	1.73	0.69
4	Rhododendron scrub	9.25	0.85	1.76	0.71
5	Riverine (*Myricaria rosea*) scrub	6.00	0.91	1.62	0.76
6	Morainic scrub	12.80	0.96	2.39	0.89
7	*Anaphalis xylorhiza* mixed meadow	12.67	0.97	2.46	0.91
8	*Deschampsia caespitosa* marsh meadow	5.00	0.91	1.44	0.72
9	*Kobresia nepalensis* moist meadow	7.60	0.88	1.70	0.73
10	*Kobresia duthiei* moist meadow	6.80	0.91	1.74	0.78
11	*Kobresia pygmaea* dry meadow	13.00	0.97	2.48	0.91
12	*Potentilla peduncularis* moist meadow	5.00	0.91	1.44	0.72

Figure 1: Physiographic map of Khangchendzonga National Park (KNP) showing the geographic location, major rivers, watersheds and elevation zones

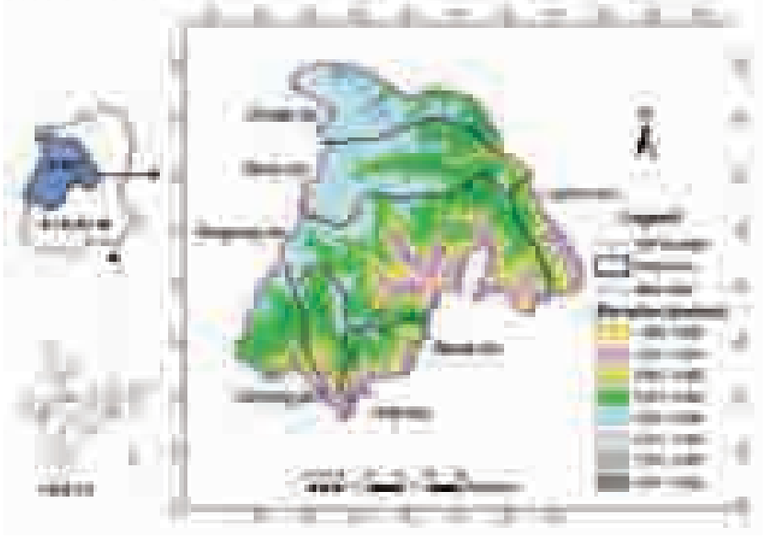
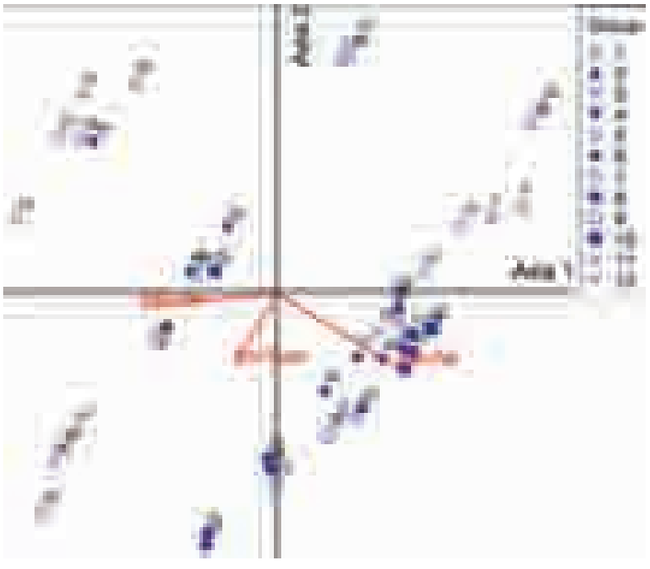


Figure 2: Vegetation communities of the alpine zone of Khangchendzonga National Park (KNP) using cluster analysis

Figure 3: Canonical correspondence ordination biplot of the alpine vegetation communities and environmental variables of altitude, rainfall and soil type. The 12 vegetation groups have the same serial number as used in Table 6*



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