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Community Characteristics, Diversity, and Aspects of Ecology

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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 Khangchendzonga range result in a landscape level differentiation of the Outer, Inner, and Tibetan Himalaya in just 50 km. 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 3 environmental gradients of rainfall, elevation, and soil were found to be the primary determinants of vegetation patterns. A total of 585 species of angiosperms belonging to 67 families and 243 genera were recorded in a 390-km^2 area. Compared to the 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 depauperated scrub zone.*

Keywords: *Species diversity; vegetation classification; multivariate analysis; environmental gradients; sedge meadow; Eastern Himalaya; Sikkim; India.*

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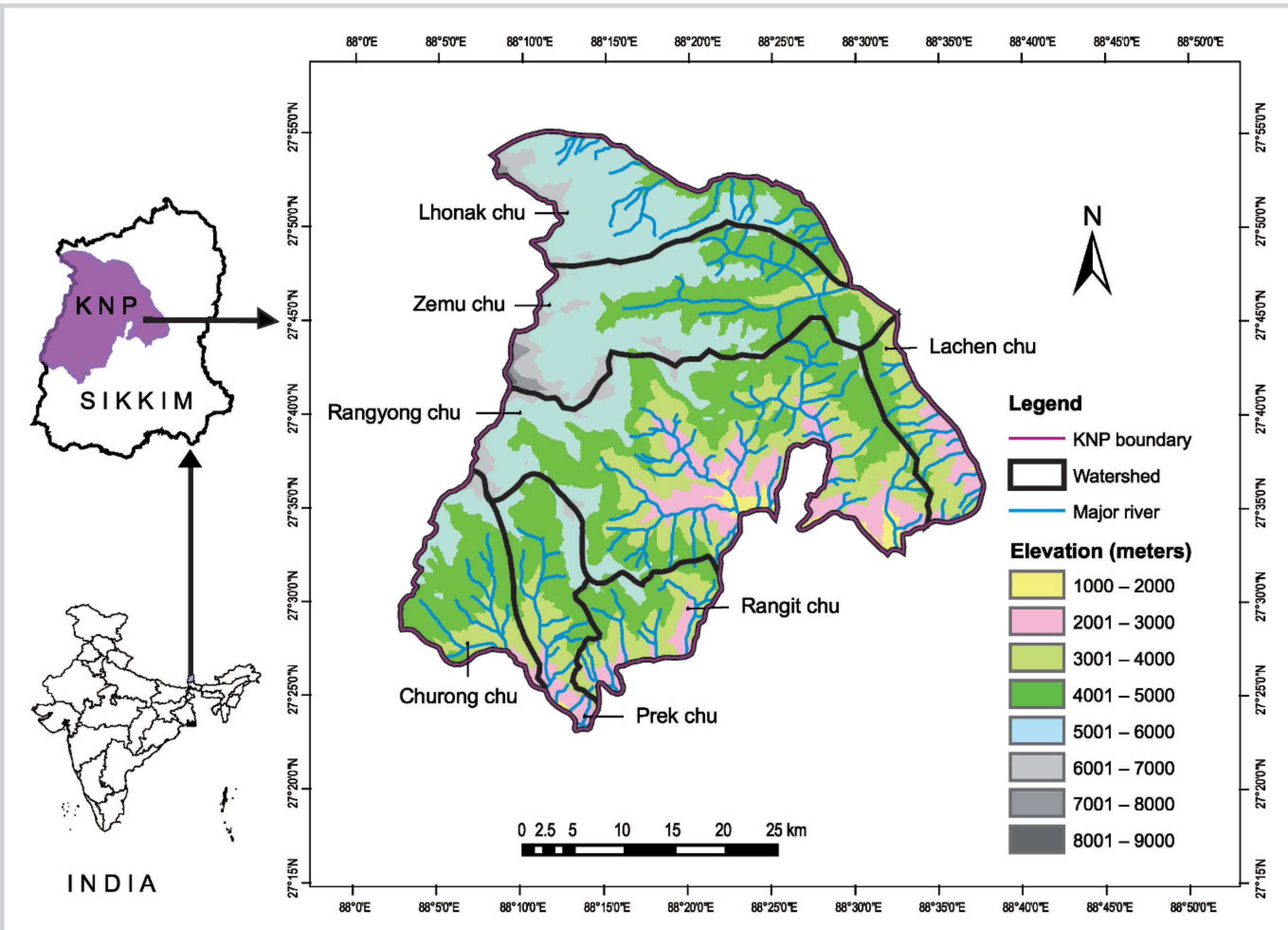
Introduction

The alpine zone in the Himalaya is lined up as an archipelago on high mountains at the southern periphery of high central Asia, where mountains are separated by deeply incised transverse valleys (Miehe 1997). This zone exhibits much variation in topography, precipitation, floristics, physiognomy of vegetation, and palaeohistory. In the extreme west this zone merges with the arid Eurasian mountains, whereas 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, phytogeographers, and naturalists (see Rawat 1998 for a review; Dickoré and Nüsser 2000). However, ecological studies in the region are rather scanty. A perusal of the 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% from Central Asia and Himalaya (Körner 1999). Most of the literature on alpine vegetation in the region is based on the studies conducted in the Western Himalaya (WH) and Nepal, due to comparatively easier access.

The alpine zone of the WH is much more extensive in geographical coverage than the same zone in the 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, about 1200 species (Rawat 2007). Rawat (2007) has reported that the diversity of alpine plants in the WH is highest between 3600–3800 m, especially within mixed herbaceous formations. Similarly, plant community structure and patterns of diversity among various alpine communities in the WH have been worked out (eg Kala et al 1998; Rawat 2005). However, to date no documentation is available on the community structure and patterns of species diversity in the alpine region of EH. Information on these parameters is crucial for improving our understanding of the 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, Mt Khangchendzonga (8586 m). The greater

FIGURE 1 Physiographic map of KNP showing the geographic location, major rivers, watersheds, and elevation zones. (Map by Sandeep Tambe)



Khangchendzonga landscape spreads across eastern Nepal and the Indian state of Sikkim and has a considerable alpine area. The park (ca 1784 km^2; 27°30′–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 ecofloristic studies in temperate and subalpine 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 that belonged to 38 families (90% dicots, 9% monocots, and 1% gymnosperms). Based on a detailed floristic survey, Maity and Maiti (2007) reported 1580 species of vascular plants from KNP and adjacent areas, including 106 species of pteridophytes, 11 gymnosperms, and 1463 angiosperms. However, the detailed ecology of alpine plant communities across the larger landscapes has not been addressed so far.

Methods

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

Vegetation sampling

Based on satellite remote sensing data, survey of India topo maps, earlier experience, and reconnaissance of the study area, the vegetation in the subalpine and alpine zone of KNP was stratified into 4 physiognomic units: (a) *Krummholz* thicket, (b) alpine scrub, (c) alpine meadow, and (d) riverine scrub (Table 1). Vegetation data from 280

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TABLE 1 Vegetation plot data collected from the alpine zone of KNP, Sikkim Himalaya, India. Compare relevé identities with Figure 2.

Physiognomy type	Vegetation type	Relevé IDs
Krummholz thicket	Krummholz thicket	12, 38, 43
Riverine thicket	Riverine willow (*Salix sikkimensis*) thicket	4, 5, 13, 41, 50
Alpine scrub	Juniper scrub	6, 7, 8, 9, 10
	Rhododendron scrub	11, 36, 42, 49
	Morainic scrub	14, 15, 16, 17, 44
	Riverine (*Myricaria rosea*) scrub	1, 18, 19, 20, 39
Alpine meadow	*Kobresia duthiei* moist meadow	21, 22, 35, 56, 57
	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

quadrats covering 56 sampling stations in the study area included abundance values for 150 species of vascular plants collected during the peak growing season, 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 1 m × 1 m for herbaceous ground flora and 5 replicates each of 5 m × 5 m for alpine scrub were laid following the standard phytosociological approach (Mueller-Dumbois and Ellenberg 1974; Kent and Coker 1992). These broad vegetation classes can form the basis for more detailed phytosociological studies in future. Most of the plants were identified closest to the genera and species in the field using regional flora, specifically *Flowers of Himalaya* (Polunin and Stainton 1987) and *Flora of Bhutan*, which include collections from Sikkim (Grierson and Long 1983; Noltie 1994, 2000).

Phytosociological analysis

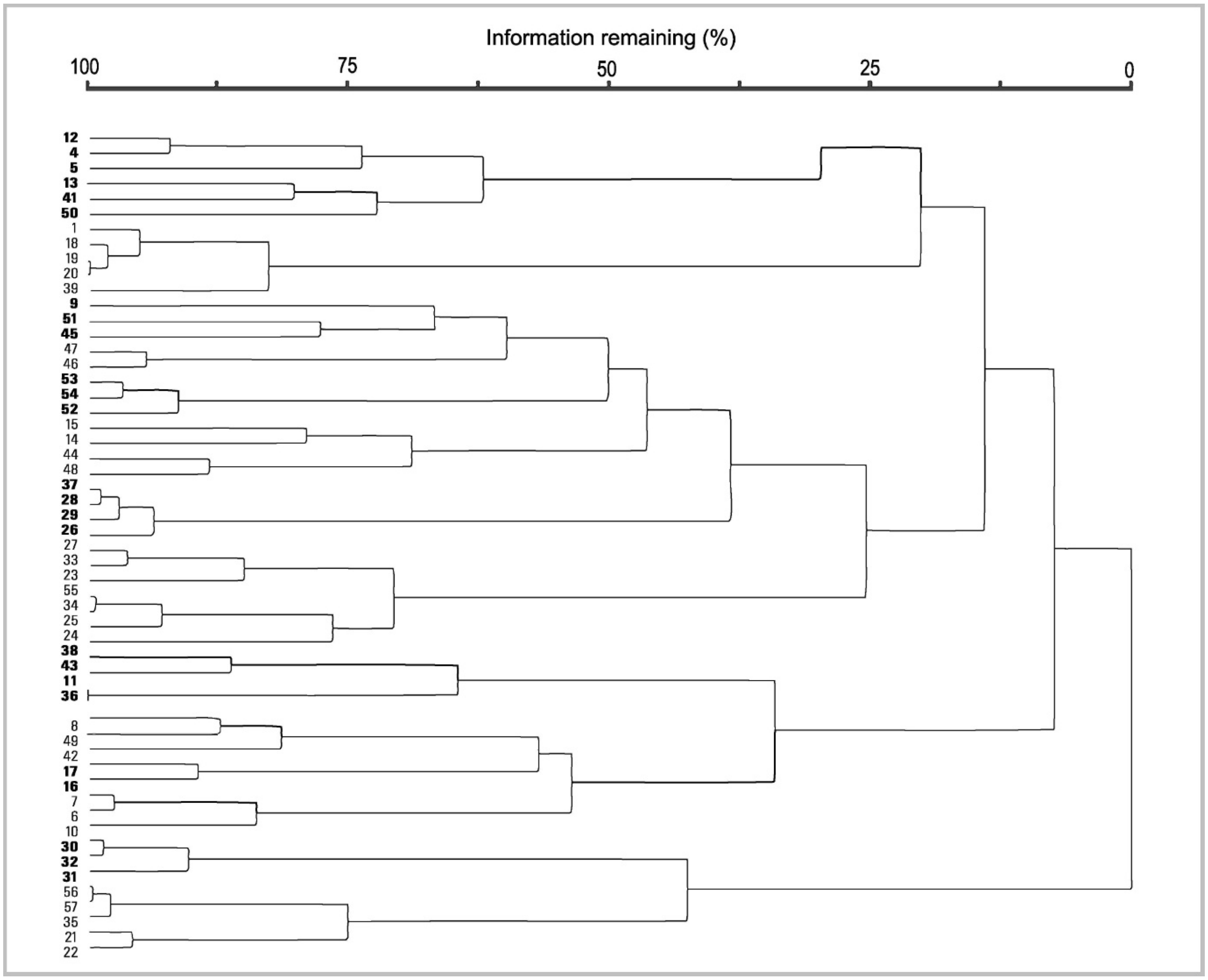
Numerical analysis software that relies more on multivariate analysis, namely, PC-ORD (version 4.20), TURBOVEG (version 2.41), and JUICE (version 6.4.50) (McCune and Mefford 1999; Hennekens and Schaminée 2001; Lubomír 2002), was used. PCORD software was used to perform the cluster analysis and calculate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

Results

Landscape level differentiation: Outer, Inner, and Tibetan Himalaya

The Khangchendzonga massif dominates the physiography of KNP. The 7 watersheds or river subsystems, the Lhonak, Zemu, Lachen, Rangyong, Rangit, Prek, and Churong, although located adjacent to one another, show significant variation in physiography and climate (Figure 1; *Supplemental data*, Appendix S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00058.S1). Although the Greater Himalaya generally runs in an east–west direction, the chief ridge of the Khangchendzonga range here is aligned in north–south inclination with west–east transverse spurs. The monsoon winds blowing from a southeasterly direction bring heavy precipitation and are obstructed by successive west–east ridge formations, significantly reducing the precipitation toward the north. The annual rainfall decreases from 2.75 m in the southeastern part to 0.75 m in the north, with the average being 2.14 m (NBSSLUP 2000). Although the southern part of the KNP (Rangit, Prek, and Churong) represents the wet part, that is, the Outer Himalaya, the

FIGURE 2 Vegetation communities of the alpine zone of KNP, using cluster analysis. For relevé IDs, see Table 1.



central part (Zemu, Lachen, Rangyong) represents the transitional Inner Himalaya, and the high valley of Lhonak the Tibetan Himalaya (Schweinfurth 1984).

Vegetation structure and composition

Based on numerical classification, the vegetation of the alpine zone was segregated into 11 types: 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 (Table 1; Figure 2). There is a need for more systematic and intensive phytosociological studies in future. The synoptic table of the diagnostic, constant, and dominant species is provided in *Supplemental data*, Appendix S2 (http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00058.S1). A brief description of the structure and composition of these 11 vegetation communities is given below.

Juniper scrub, which favors warmer slopes in the 3700–4400-m elevation range, was found to harbor 2 communities:

1. *Juniperus squamata* scrub: This category is found generally between 3700 and 4100 m on warmer slopes that receive about 2230 mm of average annual rainfall. The dominant shrub, *Juniperus squamata*, is prostrate in habit; this community has at least 40% shrub cover whereas the grasses and sedges have up to 30% cover. *Carex alpina*, *Poa alpina*, *Calamogrostis filiformis*, and

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Kobresia nepalensis are the important grasses and sedges. The important constituents of the herb layer are *Rhodiola bupleuroides*, *Bistorta vivipara*, and species of *Arisaema*, *Potentilla*, *Primula*, and *Pleurospermum*.

2. *Juniperus indica* scrub: This vegetation is found between 4000 and 4400 m; in the inner dry valleys it reaches up to 4800 m. *J. indica* usually occurs in the form of an erect shrub, and in this association, *Rhododendron lepidotum* also 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.

Moreover, the following further communities were found:

3. *Rhododendron* scrub: Dwarf Rhododendron scrub is widespread in the higher reaches above the *krummholz* zone. This vegetation (less than 1 m tall) represents alpine moist scrub and favors the cooler aspects between 3900 and 4600 m. However, in the inner dry valleys, it can ascend up to 4900 m. It can withstand a high rainfall gradient of 1300–2500 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 codominated by *Rhododendron anthopogon*, *Rhododendron setosum*, and *R. lepidotum*.
4. Morainic scrub: This category is found mainly in the glaciated valleys along the lateral and terminal moraines between 3900 and 4500 m. 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.
5. Riverine willow (*S. sikkimensis*) thicket: This is confined to the banks of rivers and hill streams between 3500 and 4200 m. *S. 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 codominants in the top canopy include *Hippophae salicifolia*, *Betula utilis*, *Acer campbellii*, and *R. hodgsonii*.
6. Riverine (*M. 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 up to 4600 m. The vegetation is characterized by mat-forming prostate shrubs interspersed with herbs, grasses, and sedges less than 0.3 m in height. *M. rosea* is the characteristic species, and the cover varies considerably (from 7–64%) with microtopography and edaphic conditions.

Based on the numerical classification, it was found that the alpine meadow vegetation segregated broadly into 3 clusters: sedge meadow, marsh meadow, and herbaceous meadow. Sedge meadow further separated into 3 classes: *K. nepalensis*, *K. duthiei*, and *K. pygmaea*.

7. *K. 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 *K. nepalensis* varies greatly with microtopography and codominates with *Bistorta milletii*, *Potentilla peduncularis*, *R. lepidotum*, *Primula capitata*, and species of *Arenaria*, *Juncus*, and *Carex*.
8. *K. duthiei* moist meadows: This is found in shady moist valleys and rocky slopes in the 4000–4600 m elevation zone. The vegetation is tussock-forming dominated by *K. duthiei* (cover greater than 40%) with an average height of 0.30 m. *K. nepalensis*, *Kobresia capillifolia*, *R. acuminatum*, *R. anthopogon*, *Geranium donianum*, and species of *Heracleum*, *Swertia*, *Pleurospermum*, and *Juncus* are usually found in openings.
9. *K. pygmaea* dry meadows: These are 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 4400–5100 m. As the name suggests, in the upper reaches this vegetation is stunted, having an 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., *B. milletii*, *R. fruiticosa*, and *Aster falconeri* codominate.

Apart from these 3 *Kobresia* communities, we also found marsh meadow communities that consisted of the following:

10. *D. caespitosa* marsh meadows: These meadows occur in the waterlogged flats adjacent to alpine lakes and in the upper courses of meandering streams, between 4000 and 4600 m. This vegetation is tussock-forming with the top height being less than 1 m Floristically *D. caespitosa* clumps are dominant (cover greater than 40%), especially at the 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.

Finally, the mixed meadows contained the following:

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TABLE 2 Correlation scores from PC-ORD CCA output for the first 3 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

11. *Anaphalis xylorhiza* mixed meadows: These meadows are found in the inner valleys on the glaciated flats of Lhonak, usually between 4500 and 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%. *A. xylorhiza* is the dominant species (cover greater than 20%), with other associates such as *B. vivipara*, *K. schoenoides*, *K. nepalensis*, *Lancea tibetica*, and various species of *Arenaria* and *Pedicularis*.

Environmental determinants

Of the 5 environment variables—altitude, rainfall, edaphic, aspect, and slope—the ordination space was found to be strongly correlated with the first 3 (Monte Carlo *P* value = 0.001) (Tables 2 and 3). The first CCA axis negatively correlated with altitude and positively with rainfall. The second axis was negatively correlated with rainfall and soil type, and the third axis was positively correlated to soil type. Altitude and rainfall were found to be negatively correlated, that is, rainfall decreases with increasing altitude. The biplot of the first 2 axes shown in Figure 3 indicates that areas with higher rainfall are heterogeneous and harbor a higher number of vegetation communities and vice versa.

Vegetation richness and diversity

Table 4 gives the richness and evenness diversity indices for the various vegetation associations. In 1-m 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 *K. pygmaea* dry meadows of the Zemu valley (S = 13, H = 2.48), followed by morainic scrub (S = 12.80, H = 2.39). The morainic scrub represents early to midseral stage. The richness and diversity values were lowest in the 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). Great evenness and higher values of Simpson's diversity index (D′) were shown (E = 0.97, D′ = 0.91) by *K. pygmaea* dry meadow in the Zemu valley and by *A. xylorhiza* dry meadow in the Lhonak valley.

Floristic structure and species diversity

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 subalpine and alpine zones include *Taxus baccata* subspecies *wallichiana*, *Tsuga dumosa*, *A. densa*, *Juniperus recurva*, *J. squamata*, *J. indica*, and *Ephedra gerardiana*.

Discussion and conclusions

At the landscape level, the west–east transverse spurs from the north–south main Khangchendzonga range,

TABLE 3 Monte Carlo test results: species–environment correlations.

Randomized data Real data Monte Carlo test, 999 runs					
Axis	Species–environment correlation	Mean	Minimum	Maximum	p[a)]
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.

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

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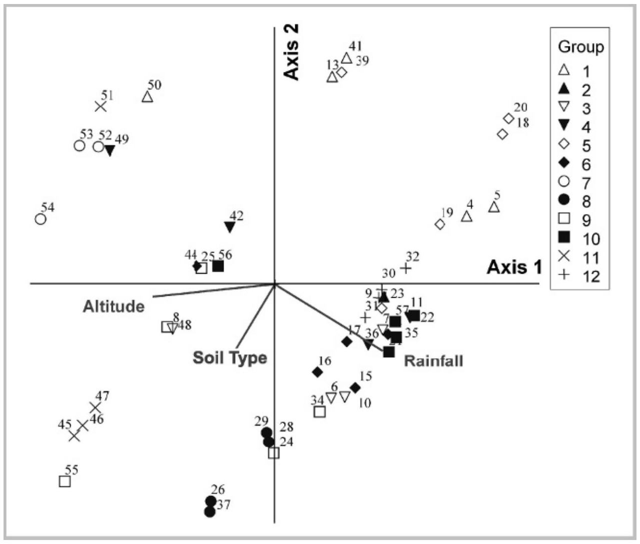
FIGURE 3 Canonical correspondence ordination biplot of the alpine vegetation communities and environmental variables of altitude, rainfall, and soil type. The 12 vegetation groups have the same serial number as used in Table 4.



creating a barrier for the southeasterly monsoon winds and resulting 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 treeline vegetation reviewed by Schickhoff (2005) across the length of the Himalayan range comprising 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 WH, are dominated by sedges: in the moist meadows *K. nepalensis* (on smooth slopes) and *K. duthiei* (on broken slopes), and in the dry meadows *K. pygmaea* and *K. schoenoides*. These Cyperaceae mats play a vital environmental role in protecting large alpine areas against erosion (Miehe et al 2008). In the extreme north, the dry meadows of *K. pygmaea* and *A. xylorhiza* in the Lhonak and Zemu valleys resemble the vegetation described by Miehe (1989) in the Mt Everest region and by Miehe et al (2008) on the Tibetan plateau. By contrast, in the southern part the *K. nepalensis* and *K. 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 WH and were virtually absent in KNP (Rawat 2005). The major grass-dominated vegetation in the KNP is the *D. caespitosa* marsh meadow, found only on the fringes of glacial lakes and streams. The subalpine thickets and alpine scrub vegetation is much broader in the Sikkim Himalaya.

Three environmental parameters, that is, 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 the alpine meadows of the 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 in the 87-km^2 area of Valley of Flowers National Park. In the

TABLE 4 Richness, evenness, and alpha indices of diversity in the vegetation types found in the alpine zone of KNP, Sikkim Himalaya, India. S numbers are also used in Figure 3.

S no.	Vegetation type	Richness (S)	Evenness (E)	Shannon's diversity index (H)	Simpson's diversity index (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

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 over an extremely short distance (80 km), thereby resulting in telescoped or narrow ecozones. 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 the WH (Dickoré and Nüsser 2000), favor 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, albeit 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 phytogeographical studies.

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Supplemental data

Appendix S1 Comparison of landscape features showing variation in physiography and climate across major watersheds (sequenced north to south; see also Figure 1) in Khangchendzonga National Park.

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Appendix S2 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 taken as 4, threshold frequency value for constant species as 60, and dominance indicated by average percentage cover).

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