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Species Diversity and Composition of Bryophytic Vegetation in Garhwal Himalaya with Special Reference to Kedarnath Wildlife Sanctuary (KWLS), Uttarakhand, India

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ABSTRACT

Species diversity, attributes and community composition of moss-dominated vegetation was assessed in Kedarnath Wildlife Sanctuary in Garhwal Himalaya, India. Eight sites (*viz*., Chopta, Devharital, Kanchula-khark, Pothivasha, Tungnath, Gaurikund, Sershi and Triyuginarayan) situated on an elevational gradient from 1760 m to 3662 m asl were selected for the study. The composition of moss communities was quantitatively analyzed by randomly sampled quadrat method. Considering the species diversity in all types of substrates (soil, boulders, tree bark) of the sites, maximum species richness (SR) was recorded in the site Kanchula-khark (30) with greater richness in the soil and the minimum in Tungnath (10). SR increased with increasing elevation up to middle elevations and then showed a sharp decline with further increase in elevation. SR was also negatively related with total annual rainfall. The Simpson's concentration of dominance (Cd) was maximum in Tungnath (0.10) and minimum in Kanchula-khark (0.03). The SR and Cd were inversely related with each other in the study area. The moss vegetation of Devharital and Tungnath showed logarithmic distribution curve, which infers that important ecological factors are being shared more or less between species at these sites. Whereas all the other study sites showed random-niche boundary curves, which infers that species in these cases combine self-limitation of population density with self-limitation of niche space and each species is restricted to fraction of community space. Most of the study sites shared less than 30% of the total species between them, which meant significant differences in the diversity of mosses across the habitats. The analysis provides a basis for assigning a workable conservation value to such an important heritage site consisting of mixed conifer forests and alpine meadows.

Key Words: Mosses, Diversity, Patch Density, Dominance, Garhwal Himalaya.

INTRODUCTION

Documenting patterns of diversity of species and assigning them a quantifiable ecological and economic value for developing biodiversity conservation strategies and action plans has been one of the major research areas in the recent years. Economic and ecological valuation of landscape elements, based on the species of high priority for conservation is one of the important inputs to formulate biodiversity strategies. Viewing on the role of lower plants as important functional groups in the ecosystem, the interest in biodiversity and conservation biology related to bryophytes is rapidly increasing (Kautz and Gradstein 2001, Vanderpoorten and Engels 2003). Himalaya is listed as the third richest region of the World in terms of bryophyte species diversity and mosses are one of the dominant plant communities of Himalaya at higher elevations and contribute more than 50% of active biomass (Groombridge 1992). They play complex ecological roles in the various ecosystems

(Brown and Bates 1990, Ghildiyal and Uniyal 2008, Sharma et al. 2010). Mosses are known to have the ability to respond to environmental variations at fine spatial scales (Frego and Carleton 1995). Mosses are remarkably successful colonizer on the variety of habitats. They can survive in extreme environmental conditions where only a few other plants grow. The main attributes of mosses are compact growth form, ability to retain moisture, ectohydric nature, poikilohydry and low growing habit. The occurrence of a particular species may reflect the microclimate of the locality (Govindapyari et al. 2012). Distribution of bryophyte species have been related to microclimatic changes that relate to vegetation type (Gónzalez-Mancebo et al. 2004, Holz and Gradstein 2005).

Despite considerable studies of moss systematics, attempts to understand their species richness patterns and community ecology especially in the Himalayan region have been meagre. As each component of the ecosystem including the inconspicuous plant groups is important, the current forest management practices in the Himalaya, the diversity and ecology of lower plants should be taken into consideration while devising conservation plans for forest areas. Loss of biodiversity continues to increase with developmental activities and there is an urgent need for objectively streamlining biodiversity conservation measures to develop practicable plans and strategies at different spatial scale. There are only a few reports on the study of bryophytes of this region (Negi and Gadgil 1997, Bahuguna 2009, Bahuguna et al. 2011) but detailed information about the diversity and distribution patterns of mosses along various environmental gradients is completely lacking. Keeping the aforesaid facts in view, the present study was undertaken to assess the species diversity and community composition of moss vegetation at different elevations in the Kedarnath Wildlife Sanctuary (KWLS) of Garhwal Himalaya.

STUDY AREA

The study was conducted in Kedarnath Wildlife Sanctuary in the Garhwal Himalaya, India (Figure 1). It is one of the largest protected areas in the Western Himalaya covering an area of 975 km^2 between latitudes 30º 25' and 30º 45' N and longitudes 78º 55' and 79º 36' E. The sanctuary is renowned for its rich diversity of flora and fauna as well as for its cultural heritage. The area is characterized by undulating topography with gentle slopes on the northern, north-eastern and north-western faces and somewhat steeper slopes on the southern and south-western sides. Numerous high ridges, deep gorges, precipitous cliffs, rocky crags and narrow valleys characterize the topography of the region. The sanctuary lies on the central axis of the great Himalaya, which consists of belts of metamorphic rocks. The central crystalline belt in the vicinity of Tungnath contains granite, biotite, schist and various types of gneisses (Agarwala 1973). The sanctuary consists of forest covered area (44.4 % and 48.8 %), alpine meadows and scrubs (7.7 %) and 42.1 % of the area is rocky or under permanent snow (Agrawala 1973). The forest vegetation comprises broadleaved and conifer tree species including 338 species of vascular plants (Semwal and Gaur 1981, Gairola et al 2010).

During a reconnaissance survey, eight study sites were selected: Chopta, Devharital, Kanchula-khark, Pothivasha and Tungnath in the southern region, and Gaurikund, Sershi and Triyuginarayan in the northern region of the KWLS (Table 1). Sershi has an elevation range of 1700 m to 1900 m asl and the site harbours temperate forests of broad leaved species *viz.*, *Quercus-Rhododendron* mixed forests. Gaurikund is situated at an elevation between 2100 m and 2350 m asl, containing rocky slopes, riverside vegetation, degraded land and mixed broadleaf forests. Elevation range at Pothivasha is 2200 m to 2400 m asl, which is characterized by dense forest of *Aesculus indica* (Colebr. ex Camb.) Hook., *Alnus nepalensis* D. Don, *Rhododendron arboreum* Sm., *Quercus leucotrichophora* A. Camus, *Quercus glauca* Thunb., *Pyrus pashia* Buch. Ham. ex D. Don, etc., forming highly moist habitats. Devharital has *Quercus-Rhododendron* mixed forest and attains an elevation of 2100 m to 2350 m asl. Triyuginarayan has a wide expansion between 2200 m and 2500 m asl, and comprises of *Quercus* mixed forest. Kanchula-khark attains elevation between 2600 m and 2800 m asl. Chopta is situated between 2700 m and 2800 m asl, and is dominated by *Abies pindrow* Royle, *Quercus semecarpifolia* Sm., *Rhododendron campanulatum* D. Don and *Taxus wallichiana* Zucc., Tungnath extends from sub-alpine to alpine meadow with a gentle to steep slope in between 3200 m and 3800 m asl.

METHODS

The composition of moss communities was analyzed quantitatively at different study sites. For quantitative

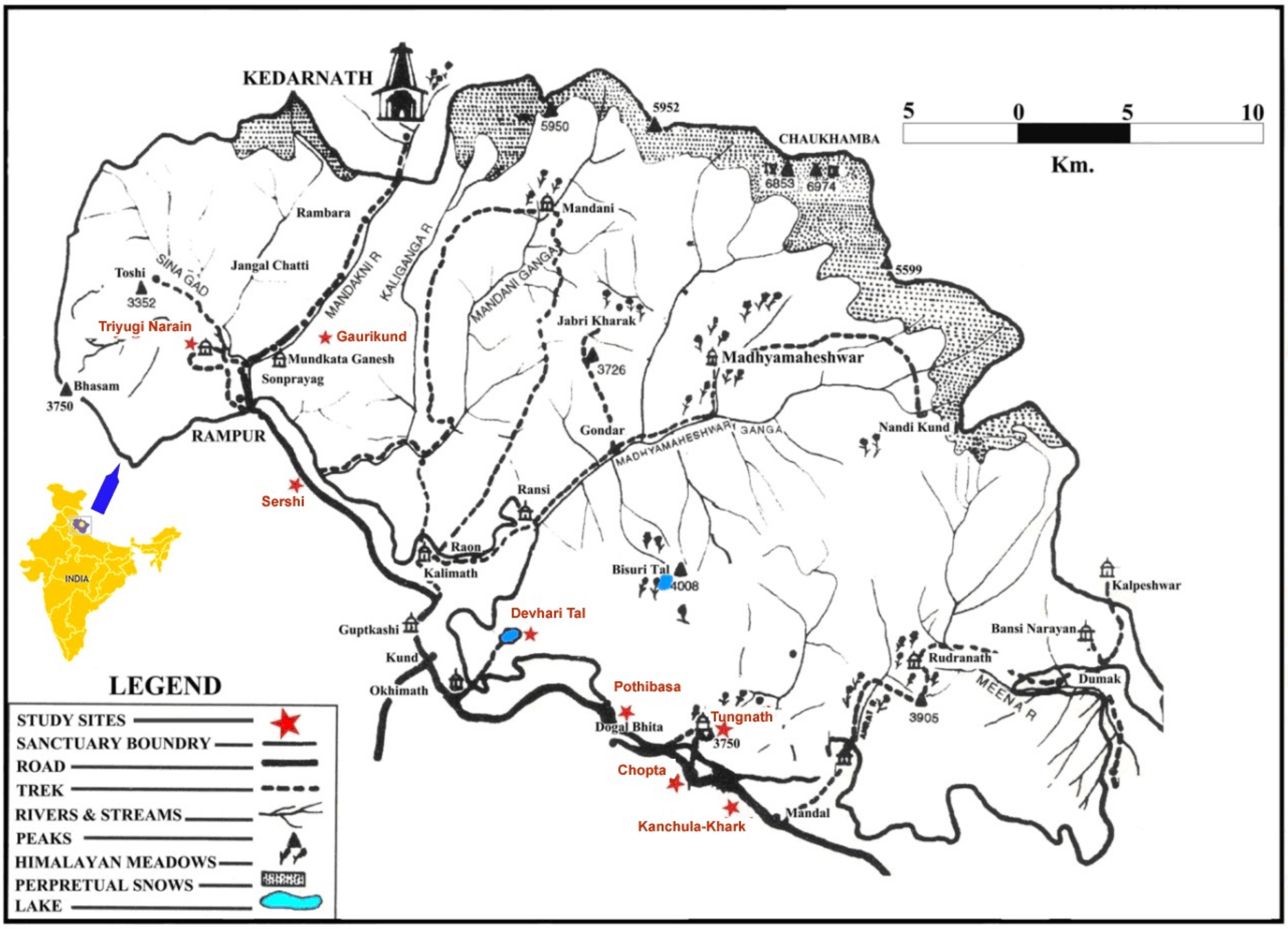

Figure 1. Map of the Kedarnath Wildlife Sanctuary in Uttarakhand. Inset map pf india shows the location of Uttarakhand (dark spot).The study sites are indicated by stars.

Table 1. General and meteorological details of the study sites.

Source Study sites	Elevation (m asl)	Forest type	Mean daily temperature (°C) Minimum	Maximum	Annual rainfall, mm
[1]Sershi	1760	Oak mixed broad leaf	6.0 (Jan) to 20.0 (Jul)	13.0 (Dec) to 28.0 (Aug)	3120
[2]Gaurikund	2125	Oak mixed broad leaf	4.3 (Dec) to 10.1 (Jun)	15.6 (Dec) to 26.4 (Jun)	2895
[3]Pothivasha	2235	Oak-*Rhododendron* mixed broad leaf	4.3 (Jan) to 10.7 (Jun)	16.3 (Jan) to 27.7 (Jun)	3033
[4]Devharital	2260	Oak-*Rhododendron* mixed broad leaf	4.5 (Jan) to 10.3 (Jun)	16.4 (Dec) to 26.4 (Jun)	3388
[5]Triyuginarayan	2340	Oak mixed broad leaf	5.2 (Jan) to 10.3 (Aug)	12.2 (Dec) to 28.6 (Jun)	3195
[6]Kanchula-khark	2685	Oak-*Rhododendron* mixed broad leaf	2.7 (Jan) to 9.3 (Jun)	7.5 (Jan) to 18.7 (Jun)	1735
[7]Chopta	2757	Oak-*Rhododendron* mixed broad leaf	3.8 (Jan) to 10.5 (Jun)	9.3 (Dec) to 21.4 (Jun)	2666
[8]Tungnath	3662	Alpine meadow	6.1 (Oct) to 10.4 (Jul)	18.5 (Oct) to 20.1 (Jun)	3928

Meteorological Data Sources: [1]Misra (2009); [2,4,7]Uttarakhand Forest Department; [3]High Altitude Plant Physiology Research Centre (HAPPRC), Field Station, Pothivasha; [5]GB Pant Institute of Himalayan Environment and Development, Garhwal Unit, Field Station; [6]Musk Dear Breeding Centre, Uttarakhand Forest Department; [8]HAPPRC Field Station, Tungnath.

comparison between moss communities growing at different sites and environmental conditions and three main substrate types soil, boulders and tree bark, were taken into consideration. As moss patches vary in size, we calculated the easily manageable average patch size for quantitative assessment. The total of 200 patches of different species of mosses were randomly measured from the study area and averaged to calculate average patch size. The average patch size was estimated at 5 cm × 5 cm. Each patch was then considered as one unit for phytosociological study and quantitative assessment. One transect of 50 m × 20 m was laid out at each of the selected eight study sites (Negi and Gadgil 1997, 2002). In each transect, twenty five randomly laid 1 m x 1 m quadrats were sampled. In each quadrat, patches of different species of mosses were measured. Larger patches of certain moss species were divided into 5 cm x 5 cm patches for the purpose of counting the number of patches. Generally pure patches of species were observed, but occasionally the shoots of other species were also recorded and considered for the evaluation of richness, frequency and density of species. In case where shoots of other species were present in a patch, the observations were recorded for the dominant species in that patch. The density of a species on the basis of percentage of cover area and also the number of species in each quadrat were recorded. Records were maintained of macro-habitat type, altitude, exposure to sunlight, habitat slop as well as microhabitats (occurrence on stones, wood and soil), of all moss colonies. The collected specimens were labeled and stored in paper bags and identified with the help of the floras of Gangulee (1969-1980) and Chopra (1975). The samples have been housed in the Herbarium of HNB Garhwal University, Srinagar, Garhwal (GUH).

The recorded data were analyzed for phytosociological synthetic community parameters such as patch frequency (%), patch density and patch abundance (Curtis and McIntosh 1950, Cottam and Curtis 1956). Species richness was simply taken as a count of total number of species at that particular study site. The Importance Value Index (IVI) was the sum of the relative patch frequency, relative patch density and relative patch abundance. Concentration of dominance (Cd), Simpson, 1949 and Sorenson Similarity Index Sorenson (1948) were calculated using the following formulae:

$$Cd = \sum_{i=1}^{i} \left(\frac{ni}{n} \right)^2 \quad (1)$$

$$I_s = \frac{2C}{A+B} \times 100 \quad (2)$$

where, Cd is Simpson's Concentration of dominance, s is the total number of species, *ni* is patch density of a species *i* at a study site, n is total patch density of all the species at a study site, I is Sorenson index of similarity, C is species common at both the study sites, A is total number of species in study site A, and B is total number of species in study site B.

While studying community ecology in nature, one question that often arises concerns how organisms are spatially organized and how they utilize and share their environmental resources? One way to deal with this question is to measure the specific niche parameters (Negi and Gadgil 2001). Therefore, dominance-diversity (d-d) curves were drawn to ascertain resource apportionment among different species at different study sites. The d-d curves *i.e.*, geometric, logarithmic, log-normal and random niche-boundary types, represented the relative importance of a species in the community as well as illustrated the role of certain species played in determining community structure. The relative importance value is an expressive measure of niche of species, thus treated as an expression of the relative niche size (Whittaker 1975). The dominance-diversity curves were drawn by a co-ordinate point of its relative importance index (IVI) on the y-axis and its position in the sequence of species from highest to lowest IVI on the x-axis (Whittaker 1975). Scatter plots were drawn to assess the relationship of total species richness with elevation and total annual rainfall.

RESULTS AND DISCUSSION

Table 2 shows Importance Value Index and patch density of different moss species at different study sites. Figure 2 shows total values of species richness (SR) and Simpson concentration of dominance (Cd) at different study sites. *Thuidium cymbifolium* was dominant at Sershi site followed by *Bryoerythrophyllum dentatum*, *Bryum badhwari* and *Calymperes calcuttense*. At Sershi some moss genera had two to three species each *viz.*, *Anoectangium*, *Bryum* and *Funaria*. At this site SR, patch density and Cd were recorded as 18, 29.7 P m^{-2} and 0.058, respectively. Members of the Pottiaceae and Bryaceae are observed to be pioneer colonizing taxa such as *Anoectangium*, *Hymenostylium*, *Hyophila* and *Bryum* that were mostly found on the stones and rocks and exposed and disturbed sites.

Table 2. Importance Value Index and patch density at different study sites.

Species	H No	Importance Value Index (Patches m^{-2})*							
		SH	GK	PV	DT	TRN	KK	CH	TN
Anoectangium bicolor Ren. & Card.	18616	15.17 (1.4)	-	-	-	14.19 (1.7)	8.98 (1.2)	-	-
A. clarum Mitt.	18621	16.93 (1.7)	-	-	-	10.74 (1.1)	9.51 (1.3)	-	-
A. stracheyanum Mitt.	18626	16.24 (1.6)	14.08 (1.4)	-	-	-	-	-	-
Anomobryum cymbifolium (Lindb.) Broth.	18633	11.98 (1.0)	19.01 (2.2)	-	-	-	-	-	-
A. filiforme (Dicks.)	18630	-	19.58 (2.3)	-	-	-	-	-	-
A. nitidum (Mitt.) Jaeg.	18708	-	20.39 (2.4)	15.76 (2.0)	-	-	10.00 (1.4)	-	-
Atrichum aculeatum Card. & P. Vard.	18664	-	-	-	-	16.96 (2.2)	-	18.62 (2.5)	-
A. obtusulum (C. Muell.) Jaeg.	18693	-	-	-	-	13.01 (1.5)	8.98 (1.2)	-	-
A. pallidum Ren. & Card.	18648	-	-	-	-	12.60 (1.4)	10.87 (1.6)	-	-
Bartramidula dispersa Card. & P. Vard.	18713	-	-	-	-	-	-	17.19 (2.1)	31.69 (3.1)
Brachymenium ochianum Gangulee	18637	-	-	17.96 (2.4)	-	-	9.49 (1.3)	-	-
B. longidens Ren. & Card.	18619	-	-	-	-	-	10.42 (1.5)	-	-
B. microstomum Harv.	18756	-	19.01 (2.2)	-	-	10.04 (1.0)	-	-	-
B. nepalense Hook.	18676	-	-	-	29.85 (2.4)	-	8.48 (1.1)	15.36 (1.9)	-
B. sikkimense Ren. & Card.	18679	17.62 (1.8)	16.62 (1.8)	-	-	-	-	-	-
Brachythecium kamounense (Harv.) Jaeg.	18703	-	-	12.37 (1.4)	-	-	-	-	-
B. longicuspidatum (Mitt.) Jaeg.	18775	-	-	-	-	-	8.98 (1.2)	-	-
B. wichurae (Broth.) Par.	18687	-	-	-	-	-	-	11.38 (1.2)	-
Bryhnia decurvans (Mitt.) Dix.	18689	-	-	-	-	-	8.27 (0.9)	14.21 (1.7)	-
Bryoerythrophyllum atrorubens (Besch.) Chen	18732	-	-	-	-	13.13 (1.5)	12.69 (2.0)	15.72 (1.9)	-
B. dentatum (Mitt.) Chen	18729	20.75 (2.3)	-	-	-	-	-	-	-
Bryum alpinum Huds. ex With.	18712	-	-	-	26.67 (2.1)	-	-	-	33.04 (3.3)
B. argenteum Hedw.	18770	16.24 (1.6)	-	13.62 (1.6)	-	-	-	-	-
B. badhwari Ochi	18762	18.89 (2.0)	-	-	-	-	-	-	-
B. coronatum Schwaegr.	18680	-	-	-	-	13.01 (1.5)	8.48 (1.1)	-	-
B. flaccum Wils. ex Mitt.	18627	14.41 (1.3)	-	-	-		-	-	-
B. paradoxum Schwaegr.	18681	-	17.30 (1.9)	-	-	13.01 (1.5)	-	-	-
B. plumosum Doz. & Molk.	18751	-	-	-	-	-	-	12.47 (1.4)	-
B. pseudotriquetrum (Hedw.) Schwaegr.	18696	-	13.57 (1.3)	-	-	-	-	11.38 (1.2)	-
B. uliginosum (Brid.) B.S.G.	18702	-	-	13.08 (1.5)	24.91 (1.9)	-	8.98 (1.2)	-	-
Calymperes calcuttense Bartr. & Gangulee	18745	18.27 (1.9)	-	-	-	18.42 (2.5)	-	-	-
Chionostomum rostratum (Griff.) C. Muell.	18772	-	-	7.89 (0.7)	19.50 (1.3)	-	-	-	-
Dicranum assamicum Dix.	18675	-	-	-	-	-	-	10.02 (1.0)	-
D. crispifolium C. Muell.	18717	-	-	-	-	-	-	-	24.61 (2.1)
D. orthophylloides Dix.	18640	-	-	-	-	-	-	11.38 (1.2)	-
D. scoparium Hedw.	18767	-	-	-	-	-	-	-	23.00 (1.9)
Ditrichum tortipes (Mitt.) Kuntze.	18736	-	-	9.97 (1.0)	21.55 (1.5)	10.74 (1.1)	-	-	-
Entodon chloropus Ren. & Card.	18671	-	-	11.78 (1.3)	-	-	12.27 (1.9)	-	-
E. prorepens (Mitt.) Jaeg.	18771	-	-	9.97 (1.0)	-	-	10.51 (1.5)	-	-
E. pulchellus (Griff.) Jaeg.	18641	-	-	-	27.55 (2.2)	-	-	-	-
Eurhynchium hians (Hedw.) Lac.	18652	-	-	-	-	-	-	11.89 (1.3)	-
E. riparioides (Hedw.) Richs.	18722	-	-		21.55 (1.5)	-	8.74 (1.1)	-	-
Fissidens grandifrons Brid.	18704	-	15.35 (1.6)	12.97 (1.5)	-	-	-	-	-
Funaria calcarea Wahlenb.	18764	-	12.08 (1.1)	-	-	-	10.51 (1.5)	-	-
F. hygrometrica Hedw.	18613	16.93 (1.7)	-	11.36 (1.2)	-	11.83 (1.3)	-	-	-
F. microstoma Bruch ex Schimp.	18725	14.08 (1.1)	14.71 (1.5)	-	-	-	-	-	-
Grimmia donniana Sm.	18678	-	-	-	-	-	-	-	28.92 (2.7)
Haplocladium stratosum (Mitt.) Dix.	18618	-	-	-	-	-	11.32 (1.7)	-	-
Holomitrium densifolium (Wils) Wijk & Marg.	18738	-	-	-	-	-	11.02 (1.6)	-	-
Homaliodendron exiguum (Bosch & Lac) Fleisch	18750	-	-	-	-	11.83 (1.3)	-	9.35 (0.9)	-
Hymenostylium recurvirostre (Hedw.) Dix.	18734	16.93 (1.7)	16.62 (1.8)	-	-	-	-	-	-
Hyophila involuta (Hook.) Jaeg.	18688	-	-	-	-	15.77 (2.0)	-	10.02 (1.0)	-
Hypnum cupressiforme L. ex Hedw.	18740	-	-	9.99 (1.0)	24.03 (1.8)	-	-	-	-

Species	H No	Importance Value Index (Patches m^{-2})* SH	GK	PV	DT	TRN	KK	CH	TN
Isopterygium albescens (Hook.) Jaeg.	18755	17.03 (1.7)	17.25 (1.9)	-	-	-	-	-	-
Leptodontium viticulosoides (P. Beauv.) Wijk. & Marg.	18684	-	-	14.16 (1.7)	32.05 (2.7)	-	8.98 (1.2)	-	-
Merceya gedeana (Lac.) Nog.	18730	14.17 (1.3)	19.01 (2.2)	11.78 (1.3)	21.55 (1.5)	15.24 (1.9)	-	-	-
M. ligulata (Spruc.) Schimp.	18727	-	-	12.97 (1.5)	-	11.24 (1.2)	-	-	-
Mniobryum ludwigii (Schwaegr.) Loesk.	18646	-	15.98 (1.7)	-	-	-	-	-	-
M. wahlenbergii (Web. & Mohr) Jenn.	18715	-	-	8.58 (0.8)	-	-	11.32 (1.7)	12.73 (1.4)	-
Mnium spinosum (Voit.) Schwaegr.	18705	-	-	-	-	-	7.55 (0.9)	13.63 (1.6)	-
Orthomnium bryoides (Griff.) Norkett	18714	-	-	-	-	-	9.96 (1.4)	11.38 (1.2)	26.73 (2.4)
Philonotis fontana (Hedw.) Brid.	18651	-	21.28 (2.6)	-	-	-	-	-	-
P. mollis (Doz. & Molk.) Mitt.	18612	17.03 (1.7)	-	9.97 (1.0)	-	-	-	-	-
Plagiomnium drummondii (Bruch & Schimp.) T. Kop.	18716	-	-	-	-	-	-	11.38 (1.2)	-
P. japonicum (Lindb.) T. Kop.	18691	-	-	14.16 (1.7)	-	-	10.87 (1.6)	-	-
P. rostratum (Schrad.) T. Kop.	18766	-	-	-	23.14 (1.7)	-	11.43 (1.7)	-	31.69 (3.1)
Plagiopus oederi (Brid.) Limpr.	18692	-	-	11.78 (1.3)	-	-	-	11.38 (1.2)	-
Pogonatum microstomum (Schwaegr.) Brid.	18674	-	-	-	-	14.78 (1.8)	-	13.63 (1.6)	31.01 (3.0)
P. thomsonii (Mitt.) Jaeg.	18711	15.79 (1.5)	15.35 (1.6)	9.97 (1.0)	-	-	-	-	31.01 (3.0)
Pohlia ampullacea Gangulee	18639	-	-	-	-	-	11.54 (1.9)	17.17 (2.2)	-
P. crudoides (Sull. & Lesq.) Broth.	18709	-	-	-	-	-	9.96 (1.4)	-	-
P. elongata Hedw.	18649	-	-	13.56 (1.6)	-	15.77 (2.0)	-	-	-
Polytrichum alpinum L. ex Hedw.	18769	-	-	-	-	-	-	11.38 (1.2)	38.30 (4.1)
Prionidium setschwanicum (Broth.) Hilp.	18625	-	-	-	-	14.19 (1.7)	-	-	-
Rhabdoweisia crenulata (Mitt.) James.	18653	-	12.83 (1.2)	-	-	-	-	-	-
Rhynchostegiella humillima (Mitt.) Broth.	18654	-	-	8.58 (0.8)	-	-	-	-	-
Symblepharis vaginata (Hook.) Wijk. & Marg.	18665	-	-	-	-	-	-	12.47 (1.4)	-
Thuidium assimile (Mitt.) Jaeg.	18662	-	-	-	-	-	8.48 (1.1)	15.88 (2.0)	-
T. cymbifolium (Doz. & Molk.) Doz. & Molk.	18628	21.53 (2.4)	-	-	-	-	-	-	-
T. haplohymenium (Harv.) Jaeg.	18635	-	-	-	-	15.24 (1.9)	11.43 (1.7)	-	-
T. squarrosulum Ren. & Card.	18666	-	-	15.23 (1.9)	27.64 (2.2)	-	9.96 (1.4)	-	-
T. talongense Besch.	18659	-	-	11.36 (1.2)	-	-	-	-	-
T. tamariscellum (C. Muell.) Bosch & Lac.	18636	-	-	11.18 (1.2)	-	14.71 (1.8)	-	-	-
T. vestitissimum Besch.	18652	-	-	-	-	13.60 (1.6)	-	-	-
		299.99 (29.7)	300.02 (32.7)	300.00 (33.6)	299.99 (22.8)	300.05 (35.5)	299.98 (42.3)	300.02 (34.3)	300.00 (28.7)

Abbreviations: H No= Herbarium number (YMB-GUH= Yateesh Mohan Bahuguna-Garhwal University Herbarium); SH= Sershi; GK= Gaurikund; PV= Pothivasha; DT= Devharital; TRN= Triyuginarayan; KK= Kanchula-khark; CH= Chopta; TN= Tungnath ; IVI= Importance Value Index.
*= Values in parentheses refer to density of 5x5 cm patches per m^2.

At Gaurikund study site, *Philonotis fontana* was dominant species and *Anomobryum nitidum*, *Anomobryum filiforme* var. *concinnatum*, *Anomobryum cymbifolium*, *Brachymenium microstomum*, *Bryum paradoxum*, *Merceya gedeana* were co-dominant species which are of hygrophilous nature. At this site SR, patch density and Cd were calculated as 18, 32.7 P m^{-2} and 0.059, respectively. At Pothivasha site *Brachymenium ochianum* was abundant (dominant) followed by *Anomobryum nitidum*, *Bryum argenteum* var. *lanatum*, *Bryum uliginosum*, *Leptodontium viticulosoides*, *Plagiomnium japonicum* and *Thuidium squarrosulum*, whereas *Chionostomum rostratum* was the least frequent species at this site. At Pothivasha site SR, patch density and Cd were recorded as 25, 33.6 P m^{-2} and 0.044, respectively. At Devharital site, *Leptodontium viticulosoides* was the dominant species and *Brachymenium nepalense*, *Bryum alpinum*, *Entodon pulchellus* and *Thuidium squarrosulum* were co-dominant species, which occupy the forest floors and tree bases. In this site SR, patch density and Cd were calculated as 12, 22.8 P m^{-2} and 0.087, respectively.

At Triyuginarayan site, *Atrichum aculeatum* and *Calymperes calcuttense* were dominant, followed by

Hyophila involuta, *Merceya gedeana*, *Pohlia elongata* and *Thuidium haplohymenium*. In this site SR, patch density and Cd were recorded as 22, 35.5 P m^{-2} and 0.048, respectively. At Kanchula-khark site, *Bryo-erythrophyllum atrorubens* and *Entodon chloropus* were the dominant species. The co-dominant species included *Haplocladium stratosum*, *Mniobryum wahlenbergii*, *Plagiomnium rostratum*, *Pohlia ampullacea* and *Thuidium haplohymenium*. In Kanchula-khark site SR, patch density and Cd were recorded as 30, 42.3 P m^{-2} and 0.035, respectively.

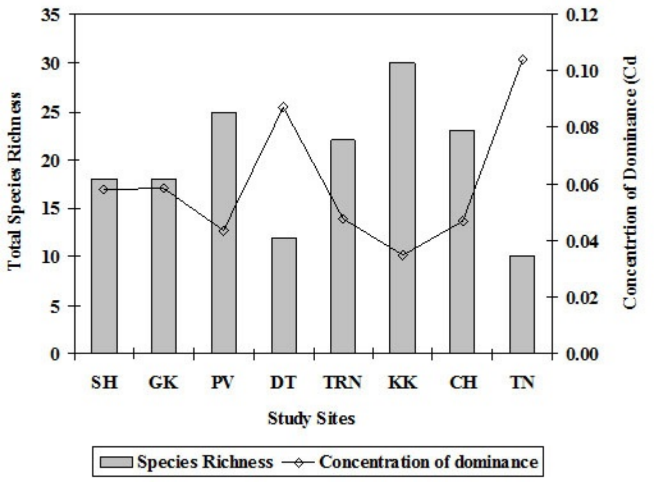

Figure 2. Total species richness and concentration of dominance at the different study sites (abbreviations same as in Table 2).

In Chopta site, *Atrichum aculeatum* was dominant and *Bartramidula dispersa*, *Pohlia ampullacea*, *Thuidium assimile* were the co-dominant species. The values of IVI at this site were similar for most of the species *viz*., *Brachythecium wichurae*, *Bryum pseudotriquetrum* var. *pallescens*, *Dicranum assamicum*, *Dicranum orthophylloides*, *Homaliodendron exiguum*, *Hyophila involuta*, *Mniobryum wahlenbergii*, *Orthomnium bryoides*, *Plagiomnium drummondii*, *Plagiopus oederi*, and *Polytrichum alpinum,* respectively. In all 23 species were identified at this site and patch density and Cd were recorded as 34.3 P m^{-2} and 0.047, respectively. At Tungnath, *Polytrichum alpinum* achieved highest IVI value and other co-dominant alpine bryophytic species were *Bryum alpinum*, *Bartramidula dispersa*, *Pogonatum microstomum*, *P. thomsonii* and *Plagiomnium rostratum*. In this site SR, patch density and Cd were recorded as 10, 28.7 P m^{-2} and 0.104, respectively. It is an alpine pasture where the sun tolerant species *viz*., *Grimmia donniana*, *Pogonatum microstomum*, *P. thomsonii* and *Bryum alpinum* were found common.

Sorenson similarity index revealed very low similarity between species composition of different sites (Table 3). Highest similarity was observed between Sershi and Gaurikund study sites (44.4%); whereas no similarity was observed between species composition of Sershi and Chopta. The highest species richness was observed at Kanchula-khark (30) study site, followed by Pothivasha (25), while Tungnath (10) exhibited lowest species richness (Figure 2). Whereas inverse trend was observed for Cd, with maximum value at Tungnath (0.104) followed by Devharital (0.087), while Kanchula-khark (0.035) had lowest Cd (Figure 2). Moss vegetation of Devharital study site showed logarithmic distribution curve, where *Leptodontium viticulosoides* dominated the community, followed by *Brachymenium nepalense*, *Thuidium squarrosulum* and *Entodon pulchellus*. Bryophytic vegetation of Tungnath also showed logarithmic distribution, where *Polytrichum alpinum* followed by *Bryum alpinum*, *Bartramidula dispersa* and *Plagiomnium rostratum* were the dominant species and were present at top left portion of the d-d curve. Whereas, bryophytic vegetation of Chopta, Pothivasha,

Table 3. Sorenson Similarity Index between different study sites (abbreviations same as in Table 2).

	SH	GK	PV	DT	TRN	KK	CH
GK	44.44	-	-	-	-	-	-
PV	23.26	18.60	-	-	-	-	-
DT	6.67	6.67	37.84	-	-	-	-
TRN	25.00	15.00	25.53	11.76	-	-	-
KK	8.33	8.33	32.73	28.57	26.92	-	-
CH	0.00	4.88	8.33	5.71	22.22	30.19	-
TN	7.14	7.14	5.71	18.18	6.25	10.00	24.24

Sershi, Gaurikund, Triyuginarayan and Kanchula-khark showed random-niche boundary curves (Figure 3). As illustrated in Table 2, because of high IVI values, *Atrichum aculeatum* followed by *Bartramidula dispersa, Pohlia ampullacea* and *Thuidium assimile* in Chopta; *Brachymenium ochianum* followed by *Anomobryum nitidum*, *Thuidium squarrosulum* and *Leptodontium viticulosoides* in Pothivasha; *Thuidium cymbifolium* followed by *Bryoerythrophyllum dentatum*, *Bryum badhwari* and *Calymperes calcuttense* in Sershi; *Philonotis fontana* followed by *Anomobryum nitidum*, *Anomobryum filiforme* and *Anomobryum cymbifolium* in Gaurikund; *Calymperes calcuttense* followed by *Atrichum aculeatum*, *Hyophila involuta* and *Pohlia elongata* in Triyuginarayan; *Bryoerythrophyllum atrorubens* followed by *Entodon chloropus*, *Pohlia ampullacea* and *Plagiomnium rostratum* in Kanchula-khark occupied top positions on the respective d-d curves. Species richness increased with increasing elevation up to middle elevations and then showed sharp decline with increasing elevation (Figure 4). Total species richness showed negative relationship with total annual rainfall (Figure 5).

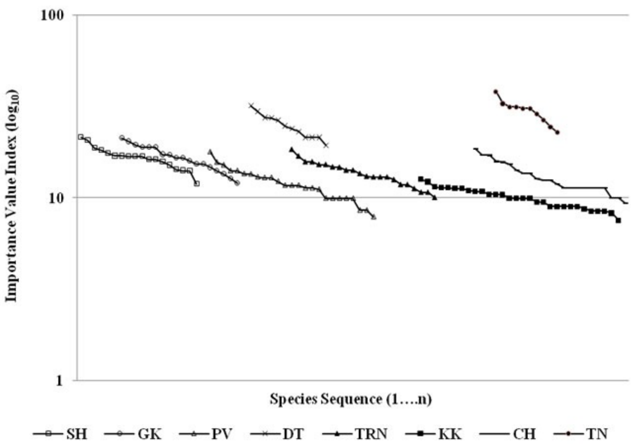

Figure 3. Dominance-diversity curves of bryophytic vegetation at the different study sites. (Abbreviations same as in Table 2).

Mountains provide greater environmental heterogeneity such as different slopes exposure, parent rocks, soils, microclimates and elevation. These factors influence species richness and abundance and allow more species to inhabit. According to Colwell et al. (2004), due to the mid domain effect the species diversity is high at middle elevation. Species are most numerous in the middle of a

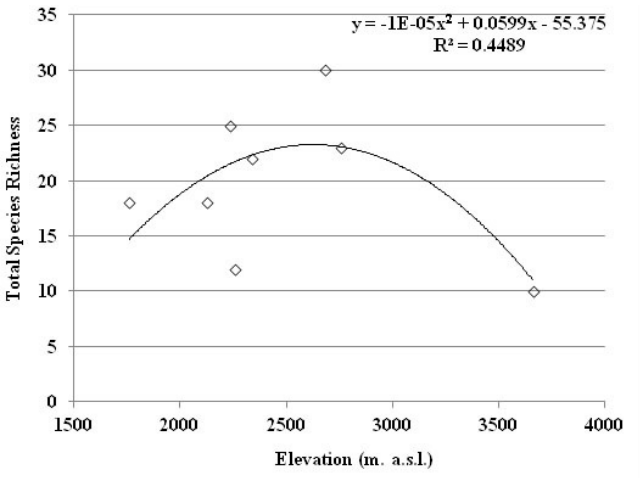

Figure 4. Relationship between total species richness and elevation

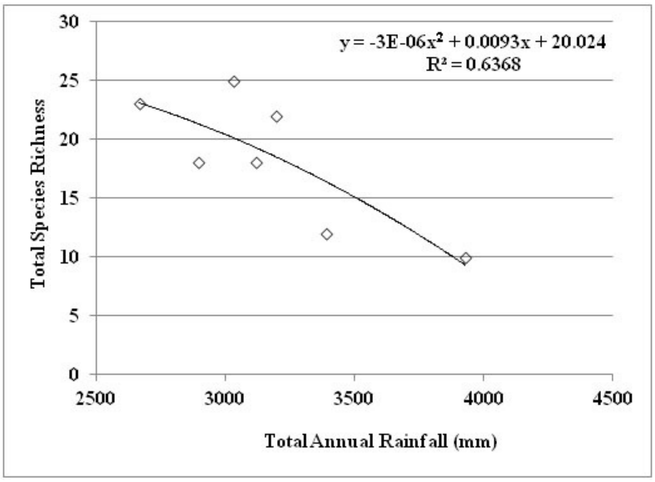

Figure 5. Relationship between total species richness and annual rainfall.

gradient bounded by definite limits, which represent absolute barriers to the dispersal or survival of species. Present study indicates that the region harbours high species richness and it appears that the disparity of species richness may be attributed to the presence of broad leaved trees forest especially *Quercus* spp. dominated.

The d-d curves are often used to interpret the community organization in terms of resource sharing and niche space (Whittaker 1975). This is based on the assumption that there is some correspondence between the share of community's resource a species utilizes and the share of community's niche space it occupies

(Whittaker 1975). The community utilizes the resources in a very efficient way under high diversity conditions. Thus, degree of resource apportionment is considered as a measure of resource conservation. Minor differences in d-d curves reflect the importance of each species in community. The logarithmic series indicates that moderately common species reflect most closely the nature of the environment. Moss vegetation of Devharital and Tungnath study site showed logarithmic distribution curve, and *Leptodontium viticulosoides* and *Polytrichum alpinum* were dominant species at these sites, respectively. A logarithmic series result, if the interval between the arrivals of the species was random rather than regular (Boswell and Patil 1971). It is applicable in the situations where one or few factors dominate the ecology of the community. A logarithmic series were found for both Devharital and Tungnath, it can be interpreted by the fact that important ecological factors are being shared more or less between species. Respectively these sites host mainly corticolous mosses for Devharital and light tolerant species (rupicolous and terricolous). It can be inferred that the two sites hosts a group of species of equal competitive ability jostling for niche space.

Moss vegetation of Chopta, Pothivasha, Sershi, Gaurikund, Triyuginarayan and Kanchula-khark study sites showed random-niche boundary curve. In vascular plant communities curves approximating geometric series are of fairly wide occurrence and random-niche boundary curves are rare (Whittaker 1965). However, contrary to that in the present study moss communities at none of the study sites showed geometric curve, whereas most of the study sites showed random-niche boundary curves. In random-niche boundary curve species combine self-limitation of population density with self-limitation of niche space, each species restricted to fraction of community space. Consequently, no species reaches the degree of dominance which might be possible with unrestricted competition, and the relative importance of species is much less divergent than in the case with vascular plants. The steep geometric curve and random-niche boundary curve may thus represent limiting cases in organisms with widely different kinds of interaction and modes of population limitation (Whittaker 1965).

Many environmental factors (e.g. temperature, precipitation, atmospheric pressure, solar and UV-B radiation, and wind velocity) change systematically with elevation. Therefore, elevational gradients are among the most powerful 'natural experiments' for testing ecological and evolutionary responses of biota to environmental changes (Korner 2007). Elevational variation effect species richness patterns of most of the biological communities. Therefore changes in species composition and species richness along elevational gradients have been studied by ecologists for a long time (Lomolino 2001). Ah-Peng et al. (2007) stated that along the elevational transect on a homogenous substrate the heterogeneity of a bryophyte community exists at a very small scale, which is strongly linked to the nature of the microhabitat. Such studies contribute towards elocution of the ecological significance of growth form and its influence upon the ecological amplitude of moss species (Dierssen 2001). There was no strong relationship between SR and elevational gradient. However, SR increased with increasing elevation up to middle elevations and then showed sharp decline with increasing elevation. The low values of species richness at Tungnath site owes to greater open space and high light conditions and the competition with the grasses and herbs.

The high SR at middle elevations may be due to forest vegetation and high humidity in the high elevation habitats of *Rhododendron*, which might have contributed to the richness of the moss flora. Negi and Gadgil (2002) are also of the view that the SR of macrolichens and mosses may be positively correlated with that of woody plants, which may be the possible reason for this pattern of SR with elevation. Similar observations were also made by Negi and Gadgil (2001) and Daniels and Kariyappa (2007). In contrary to that Grytnes et al. (2006) stated that for bryophytes, the elevational gradient in species composition does not affect the species-richness pattern. SR showed strong negative relationship with total annual rainfall (Figure 5).

A total of 84 species of mosses were identified in the present study from all the study sties. Among which 20 species of mosses were rare as they were present only at one site and had low IVI values (<20). These species were *Bryum flaccum* at Sershi; *Anomobryum filiforme*, *Mniobryum ludwigii, Rhabdoweisia crenulata* at Gaurikund; *Brachythecium kamounense*, *Rhynchostegiella humillima* at Pothivasha; *Prionidium setschwanicum*, *Thuidium vestitissimum* at Triyuginarayan; *Brachythecium longicuspidatum*, *Brachymenium longidens*, *Pohlia crudoides*, *Haplocladium stratosum*, *Holomitrium densifolium* at Kanchula-khark; *Dicranum assamicum*, *Dicranum orthophylloides, Eurhynchium hians*, *Bryum plumosum*, *Brachythecium wichurae*; *Plagiomnium drummondii*, *Symblepharis vaginata* at Chopta.

Sorenson similarity index revealed that there was very low similarity between SR of various study sites (Table 3). Highest similarity was observed between Sershi and Gaurikund study sites. Most of the study sites shared less than 30% of the total species between them, which showed that there were significant differences in the diversity of mosses across the habitats. Therefore, it may be necessary to protect a mosaic of habitats in a landscape, instead of preserving only a patch of forest or grassland, so as to ensure conservation of overall bio-diversity. While a number of factors such as urbanization, commercial overexploitation, forest fires and grazing, increasing tourism, deforestation and unsymmetrical forestry practices may be identified as the major threats to the moss flora of the region. Livestock grazing and tourism are the dominant land use pressures prevailing in the study area. Monitoring current land use oriented threats may therefore be of great significance for designing sustainable programs for the conservation and management of bryophyte diversity.

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