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Species Diversity and Community Ecology of Mosses: A Case Study from Garhwal Himalaya

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ABSTRACT

A total of 177 species of mosses were recorded from twelve 50 m×10 m transects between 1500 m and 3700 m altitude in the Garhwal region of western Himalaya. Fifty six of the species were terricolous growing on soil, 31 species were lignicolous and corticolous species thriving on woody substrates and 6 species were saxicolous inhabiting rocks alone. The other 84 species occured on more than two major types of substrates. Amongst these, *Brachymenium ochianum*, *Leucodon sciuroides* and *Trachypodopsis serrulata* emerge as significant broad-niched species with respect to microhabitats, whereas *Entodon rubicundus* and *Oxystagus tenuirostre* appear as wide-niched species in terms of occurrence along the altitudinal gradient. The microhabitats and altitude seem to be the major ecological factors governing species diversity and composition. Unlike threats from deforestation, habitat transformation and fires, moss communities of Garhwal Himalaya do not seem to be adversely affected by the traditional livestock grazing.

Key Words : Biodiversity, Community ecology, Conservation, Deforestation, Grazing, Moss, Niche, Western Himalaya

INTRODUCTION

Mosses are one of the dominant plant communities of Himalaya at higher elevations,and contribute more than 50% of active biomass (Groombridge 1992). They are amongst the most important bioindicators (Bargagli et al 1995, Hedenås 1991, Steinnes 1995) besides playing several complex ecological roles in terrestrial as well as aquatic ecosystems (Brown and Bates 1990, During and Van Tooren 1990, Gjelstrup et al. 1991, Suren 1993). These lower plants have proved to be of some economic values as well (Flower 1957, Saxena and Glime 1991, Pant and Tiwari 1989, 1990, Zinsmeister et al 1991). However, despite considerable studies on the systematics of mosses, attempts to understand their species diversity patterns and community ecology have been meagre. The limited systematic studies in India have revealed more than 2000 species rich moss flora which accounts for 10% of the global moss species diversity (Groombridge 1992, Parihar et al. 1994). We report here probably the first such community level case study on mosses from India, focusing on landscapes of Garhwal region of Western Himalayas

The study area falls between 30°20′ to 30°35′ N Latitude and 79°10′ to 79°20′ E Longitude within the altitudinal range of 1500 m to 3700 m with an estimated area of 500 sq. km (Figure 1). Higher plant vegetation consists of broad-leaved temperate forest, temperate conifer forest and subalpine to alpine grasslands along with a *Quercus* forest at the lower altitude. Although systematic long-term observations are lacking but a few short-term local records estimate the precipitation to range from 1000 mm to 1500 mm per year including low to heavy snow fall during December to March. All the study sites are exposed to various kinds of human interferences including fuelwood collection and livestock grazing.

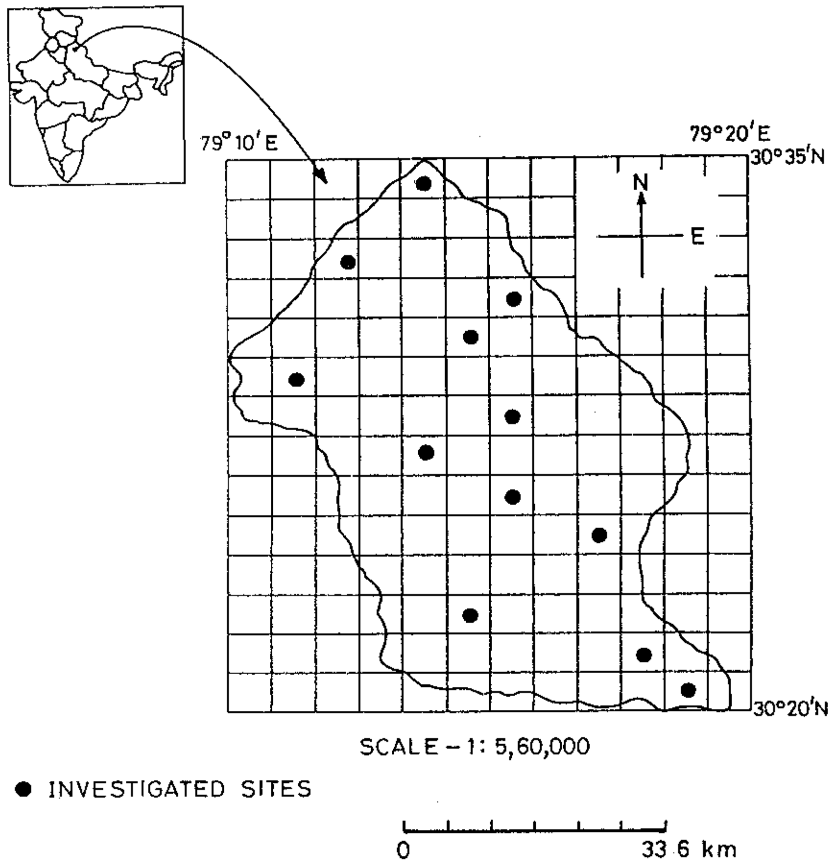

Figure 1. Gridded scaled map of a portion of Garhwal region in Western Himalaya showing the locations of the syudy sites.

METHODOLOGY

Moss communities were investigated during the summer of 1994 and 1995. Sampling method involved laying down twelve 50 m × 10 m transects in different localities covering broad-leaved temperate forest, temperate conifer forest, sub-alpine to alpine grasslands and a *Quercus* forest at the lower altitude. Records were maintained of macrohabitat type, altitude, mesohabitat conditions with respect to exposure to sun, exposure to wind, habitat slope and humidity as well as microhabitats of all the moss colonies encountered (Table 1). These include three major substrates viz rocks, soil and wood, with further discrimination of 23 soil microhabitat types and 55 types of microhabitats in relation to species specific wood bark, position on a tree and whether the wood is live or dead or deformed into coal (Table 2). Mesohabitat levels were assigned on the basis of ordinal scaling whereas the macrohabitat types were nominally categorized (Jongman et al. 1987) based on the ground vegetation. While mosses could not be sampled on trees above a height of 2.5 meters, many canopy species were encountered through collection of fallen branches and twigs on the ground.

RESULTS AND DISCUSSION

A total of 177 species belonging to 85 genera and 34 families constituted the moss community occurring in 8155 colonies over the 6000 sq. m. sampled (Table 3). Figure 2 depicts the frequency distribution of the species showing that most species had between 16 to 32 colonies The distribution curve does not fit satisfactorily to the lognormal model even at 10% level of significance (Figure 2) (Ludwig and Reynolds 1988). *Thuidium cymbifolium* is the most abundant of all the moss species recorded in the region occupying more than 9% of total colonies encountered(Table 3). Since the relative abundance of the successively dominent species does not differ much, we conclude that the species are more equitably distributed in the colonies than predicted by lognormal. This explains the high species richness that we captured using relatively small number of transects

Niche-Width

Niche-width of species computed as Shannon-Wiener index (Colwell and Futuyama 1971) with respect to fine divisions of the substrate (microhabitats), is as expected positively correlated with the number of colonies encountered. After correcting for this factor, *Brachymenium ochianum, Leucodon sciuroides* and *Trachypodopsis serrulata* emerge as significant broad niched species with respect to microhabitat usage (Figure 3). Whereas *Entodon rubicundus* and *Oxystagus tenuirostre* appear as wide niched species in terms of occurrence along the altitudinal gradient (Table 3). However rest of all the species including for example, *Hypnum cupressiforme* and *Duthiella declinata* falling above and relatively far from the regression line and *Encalypta streptocarpa* appearing far below and relatively away from the regression line also represent themselves as broad and narrow niched species respectively, their niche-width values fall within the confidence intervals at $P < 0005$ (Figure 3). Thus, these species may be considered as broad or narrow niched but can not be accepted as significant wide or narrow niched species.

Species Diversity

Species richness within a site i.e. α-diversity is one of the major components of species diversity (Krebs 1989). Table 1 provides details of the 12 sites in terms of macrohabitat

Table 1. Details of locality, macrohabitat, mesohabitat, abundance and species richness for the 12 50 m × 10 m transects. + indicates significantly high species richness at 1% level of significance. +* indicates significantly richest for moss species corrected after resorting to rarefaction followed by the chi square analysis. 1,2,3 represent low, moderate and high levels of mesohabitat conditions ranked based on ordinal scaling.

Locality name	Altitude (× 100 m)	Macrohabitat type (=LSE)	Mesohabitat levels Sn	Wn	Sl	Hm	Number of colonies	Number of species	Significance
Banjani	15	Banj* forest	1	1	2	2	508	29	
Dugalbetta	25	Panger*-Anyar*-Moru* dominated forest	2	2	2	2	540	31	
Banyakund	26	Ghenu*-Burans*-Kharasu* dominated forest	2	2	3	2	1126	47	+
Chopta	27	Kharasu* forest	1	1	2	2	368	43	+
Chopta	28	Morain rich grassy island in midst of Kharasu*-Burans* dominated forest	2	2	2	2	330	29	
Chopta	29	Morain rich habitat between grassland and Burans* forest	3	3	2	2	732	52	+
Chopta	30	Semru*-Ghenu*-Thuner*-Panger* forest	1	1	2	2	681	56	+
Bujgwali	31	Montane grassy ridge dotted with Burans*-Kharasu*-Ragu*-Thuner* trees	1	1	3	2	602	62	+*
Devdekhani	32	Semru* dominated forest	1	2	3	2	835	29	
Tunganath	34	Overgrazed Bugyal* patch	3	3	2	2	960	30	
Chandrashila	36	Takar* dominated habitat	3	3	3	2	990	26	
Chandrashila	37	Hill top of Bugyal**	3	3	3	2	551	36	

* = Local name

Botanical names:

Anyar = *Lyonia ovalifolia*
Ragu = *Abies* sp.
Thuner = *Taxus baccata*
Moru = *Quercus dilatata*
Pangar = *Aesculus indica*
Banj = *Quercus leucotrichophora*

** Bugyal = Sub-alpine to alpine grassland

Semru = *Rhododendron campanulatum*
Takkar = *Rhododendron anthopogon*
Ghenu = *Vibernum cotinifolium*
Burans = *Rhododendron arboreum*
Kharasu = *Quercus semicarpifolia*

Abbreviations:

Sn = Exposure to sun
Wn = Exposure to wind
Slp = Habitat slope
Hm = Humidity
LSE = Landscape element

Table 2. Fine divisions of major substrates into 79 microhabitats on which moss colonies were encountered

Major substrate	Finer divisions of the substrates (Microhabitats)	No. of Transects in which present	No of Colonies encountered	No. of species
Rock	Rock	12	626	57
Soil	Humus	11	1244	50
	Black soil	12	2077	80
	Red soil	9	459	37
	Red sandy soil	1	38	4
	Grey sandy soil	3	89	15
	Humus on rock	5	76	10
	Black soil on rock	11	1662	91
	Red soil on rock	4	28	12
	Red sandy soil on rock	2	14	2
	Grey sandy soil on rock	8	246	32
	Moss bed on humus	1	6	2
	Humus accumulation on aboveground roots of			
	- *Quercus semicarpifolia*	1	2	2
	- *Aesculus indica*	1	6	3
	- *Rhododendron campanulatum*	1	1	1
	Black soil accumulation on aboveground roots of			
	- *Quercus semicarpifolia*	1	2	1
	- *Rhododendron arboreum*	1	3	3
	- *Quercus leucotrichophora*	2	1	1
	Red soil accumulation on aboveground roots of			
	- *Quercus semicarpifolia*	1	3	3
	- *Rhododendron arboreum*	1	14	8
	Humus accumulation on dead wood log of			
	- *Rhododendron arboreum*	1	1	1
	Black soil accumulation on dead wood log of			
	- *Rhododendron campanulatum*	1	2	1
	Red soil accumulation on dead wood log of			
	- *Quercus leucotrichophora*	1	1	1
	Red sandy soil accumulation on dead wood log of			
	- *Acer caesium*	1	1	1
Wood	Main tree trunk bark of *Quercus semicarpifolia*	5	85	17
	- *Rhododendron arboreum*	4	129	20
	- *Aesculus indica*	1	16	7
	- *Abies* sp.	3	55	10
	- *Acer caesium*	1	18	6
	- *Gymnosporia royleana*	1	18	5
	- *Quercus dilatata*	1	32	4
	- *Quercus leucotrichophora*	1	87	11
	- *Vibernum cotinifolium*	3	19	8
	- *Rosa webbiana*	1	2	2
	- *Rhododendron campanulatum*	3	115	19

Major substrate	Finer divisions of the substrates (Microhabitats)	No. of Transects in which present	No of Colonies encountered	No. of species
	Standing dead tree trunk bark of			
	- *Quercus semicarpifolia*	1	10	7
	Standing dead tree trunck bark of *Abies* sp.	1	9	3
	- *Quercus leucotrichophora*	1	4	2
	- *Vibernum cotinifolium*	1	3	3
	Lower branches of *Quercus semicarpifolia*	3	54	10
	- *Quercus semicarpifolia*	3	48	10
	- *Abies* sp.	2	12	2
	- *Gymnosporia royleana*	2	24	3
	- *Quercus dilatata*	1	9	3
	- *Vibernum cotinifolium*	4	12	7
	- *Rosa webbiana*	1	2	2
	- *Rhododendron campanulatum*	4	83	19
	Branches of *Cotoneaster*	2	23	10
	Branches of *Berberis lycium*	2	13	5
	Branches of *Lonicera*	1	82	6
	Dead branches (Fallen dry twigs) of			
	- *Quercus semicarpifolia*	3	39	20
	- *Quercus semicarpifolia*	2	48	9
	- *Taxus buccata*	1	6	6
	- *Abies* sp	2	33	2
	- *Acer caesium*	1	3	1
	- *Quercus dilatata*	1	4	2
	- *Quercus leucotrichophora*	1	8	5
	- *Vibernum cotinifolium*	2	10	3
	- *Rosa webbiana*	1	1	1
	- *Rhododendron campanulatum*	3	29	8
	- *Cotoneaster*	1	6	2
	- *Rhododendron anthopogon*	1	2	1
	Above ground root bark of *Quercus semicarpifolia*	2	34	10
	- *Quercus semicarpifolia*	2	9	7
	- *Rhododendron campanulatum*	1	2	21
	- *Abies* sp.	1	6	3
	- *Aesculus indica*	2	29	13
	- *Quercus leucotrichophora*	1	3	1
	Dead wood log bark of *Quercus semicarpifolia*	2	15	6
	Dead wood log bark of *Abies* sp	3	86	16
	Standing dead tree trunck bark of *Prunus cornuta*	1	2	2
	Dead wood log bark of *Prunus cornuta*	1	5	2
	Unidentified dead wood log	7	172	37
	Dead wood log bark of *Quercus semicarpifolia*	1	2	2
	Branches of unidentified shrub	1	2	2
	Dead wood log bark of *Rhododendron campanulatum*	1	20	7
	Concrete cement wall	1	7	2
	Dead wood log bark of *Quercus leucotrichophora*	1	4	4
	Wood charcoal	1	2	2

Table 3. Moss species, with abbreviated family name in brackets [], of Garhwal Himalayas arranged in order of decreasing abundance on the three major substrate types; rock, soil and wood. + indicates significantly broad niched with respect to fine microhabitat preference. * indicates broad niched with respect to the occurance along the altitudinal gradient.

Species [Family]	Number of transects in	Altitude (×100 m)	Rock (1) No. of colonies	Soil (23) No. of colonies	Soil (23) No. of fine microhabit.	Wood (55) No. of colonies	Wood (55) No. of fine microhabit.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Thuidium squarrosullum Ren. et Card. [Thu]	1	15-15	17	0	0	0	0
Fabronia minuta Mitt. [Fab]	1	15-15	14	0	0	0	0
Splachnobryum sp. 1 [Spl]	1	31-31	4	0	0	0	0
Plagiothecium neckeroideum B.S.G. [Pla]	1	15-15	3	0	0	0	0
Bryum plumosum Doz. et Molk. [Bra]	1	15-15	3	0	0	0	0
Hyophila rosea Williams [Pot]	1	15-15	1	0	0	0	0
Encalypta streptocarpa Hedw. [Enc]	2	34-37	10	68	1	0	0
Homaliodendron sphaerocarpum Nog. [Nec]	3	30-34	9	49	3	0	0
Herpetineuron tccoae (Sul. et Lesq.) Card. [Thu]	1	15-15	1	35	5	0	0
Entosthodon wallichii Mitt. [Fun]	4	25-37	5	27	3	0	0
Vesicularia montaguei (Bel.) Broth. [Hyp]	3	26-34	7	18	3	0	0
Encalypta ciliata Hedw. [Enc]	2	31-34	15	4	1	0	0
Splachnobryum indicum Hamp. et Hamp [Spl]	2	34-37	2	5	2	0	0
Pylaisiopsis speciosa (Mitt.) Broth. [Sem]	2	29-30	3	3	1	0	0
Macrothamnium submacrocarpum (Ren. & Card.) Fleisch. [Hyl]	3	29-31	2	4	1	0	0
Mnium integrum Bosch & Lac. [Mni]	2	15-30	1	1	1	0	0
Thuidium sparsifolium (Mitt.) Jaeg. [Thu]	1	15-15	20	0	0	16	2
Hyophila involuta (Hook.) Jaeg. [Pot]	1	15-15	25	0	0	3	2
Hygrohypnum nairii Vohra [Amb]	1	25-25	4	0	0	3	1
Bryoerythrophyllum dentatum (Mitt.) Chen. [Pot]	2	27-28	1	0	0	3	1
Plagiothecium cavifolium (Brid.) Iwats. [Pla]	2	28-29	1	0	0	1	1
Thuidium cymbifolium (Doz. et Molk.) Doz. et Molk. [Nec]	11	25-37	51	607	9	127	23
Entodon rubicundus (Mitt.) Jaeg. [Ent]*	12	15-37	26	332	7	178	33

Racomitrium subsecundum (Hook. & Grev.) Mitt. [Gri]	10	26-37	987	305	7	11	3
Dicranodontium caespitosum (Mitt.) Par. [Dic]	9	25-37	14	353	9	26	8
Pogonatum aloides (Hedw.) P. Beauv. [Pol]	11	25-37	20	336	7	8	3
Bryum pseudotriquetrum (Hedw.) Schwaegr. [Bra]	8	25-37	26	323	8	5	1
Hypnum cupressiforme L. ex Hedw. [Hyp]	10	26-37	33	144	8	84	19
Rozea pterogonoides (Harv.) Jaeg. [Ent]	2	34-36	26	177	4	4	1
Rhynchostegium calderii Vohra [Bra]	3	25-32	9	138	5	48	9
Ectropothecium cyperoides (Hook.) Jaeg. [Hyp]	3	25-32	9	138	5	48	9
Bryoerythrophyllum wallichii (Mitt.) Chen. [Pot]	7	26-36	2	120	4	25	7
Amblystegium juratzkanum Schimp. [Amb]	4	26-32	3	119	6	20	6
Oxytegus tenuirostre (Hook. & Tayl.) A.J.E. Smith [Pot]*	10	15-37	7	115	6	16	6
Pseudoleskea laevifolia (Mitt.) Jaeg. [Les]	8	26-37	23	89	3	22	11
Rhynchostegiella humillima (Mitt.) Broth. [Bra]	10	25-37	6	83	8	41	14
Leucodon sciuroides (Hedw.) Schwaegr. [Leud]+	6	26-32	2	10	2	116	20
Trachypodopsis serrulata (P. Beauv.) Fleisch. [Tra]+	7	15-31	3	42	8	64	12
Amblystegium serpens (Hedw.) B.S.G. [Amb]	8	26-37	1	90	4	3	2
Mnium rostratum Schrad. [Mni]	7	25-37	3	81	7	2	2
Brachythecium rivulare B.S.G. [Bra]	2	25-26	35	35	2	10	3
Symblepharis vaginata (Hook.) Wijk. & Marg. [Dic]	6	25-32	1	2	1	72	9
Brachythecium salebrosum (Web. et Mohr) B.S.G. [Bra]	8	25-34	2	68	7	5	4
Dicranodontium didictyon (Mitt.) Jaeg. [Dic]	4	29-34	5	52	3	3	1
Macromitrium nepalense (Hook. & Grev.) Schwaegr. [Ort]	1	15-15	38	5	3	17	3
Brachythecium procumbens (Mitt.) Jaeg. [Bra]	4	29-34	7	44	3	7	3
Struckia argentata C. Muell. [Sem]	4	26-32	1	5	3	50	7
Aongstroemia orientalis Mitt. [Dic]	4	27-37	2	43	4	1	1
Racomitrium himalayanum (Mitt.) Jaeg. [Gri]	3	29-31	1	34	1	4	1
Anoectangium thomsonii Mitt. [Pot]	4	27-31	4	22	2	3	3
Brachythecium longicuspidatum (Mitt.) Jaeg. [Bra]	3	28-31	1	8	1	18	6
Mnium cuspidatum Hedw. [Mni]	2	28-29	2	20	4	1	1
Entodon luridus (Griff.) Jaeg. [Ent]	2	26-30	5	14	2	2	1
Bryum capillare L. ex Hedw. [Bra]	2	15-31	10	4	2	1	1
Entodon curvatus (Griff.) Haeg. [Ent]	3	27-29	1	4	2	6	3
Isopterygium lignicola (Mitt.) Jaeg. [Hyp]	3	15-32	1	4	1	5	2
Brothera leana (Sull.) C. Muell. [Dic]	2	27-28	1	1	1	1	1
Pogonatum microstomum (Schwaegr.) Brid. [Pol]	7	26-37	0	82	5	0	0

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rhodobryum roseum (Hedw.) Limpr. [Bry]	2	15-26	0	46	7	0	0
Rhytidiadelphus triquetrus (Hedw.) Warnst. [Rhy]	2	34-36	0	37	3	0	0
Mnium pseudopunctatum Bruch & Schimp. [Mni]	2	34-36	0	34	2	0	0
Entodon laetus (Griff.) Jaeg. [Ent]	1	15-15	0	33	3	0	0
Entodon plicatus C. Muell. [Ent]	1	15-15	0	33	3	0	0
Pohla flexuosa Hook. [Bry]	2	15-29	0	29	4	0	0
Campylium sommerfeltii (Myr.) Bryhn [Amb]	2	34-36	0	29	2	0	0
Vesicularia kurzii (Lac.) Broth. [Sem]	3	34-37	0	29	2	0	0
Anomobryum filiforme (Dicks) Solms in Rabenh. [Bra]	2	28-37	0	25	3	0	0
Entodon luteonitens Ren. & Car. [Ent]	1	15-15	0	23	3	0	0
Drepanocladus uncinatus (Hedw.) Warnst. [Amb]	1	36-36	0	21	1	0	0
Ptychomitrium tortula (Harv.) Jaeg. [Pty]	3	29-31	0	20	2	0	0
Brotherella amblystegia (Mitt.) Broth. [Sea]	1	36-36	0	19	2	0	0
Mnium japonicum Lindb. [Mni]	2	30-37	0	18	2	0	0
Fleischerobryum longicolle (Hamp.) Loesk. [Bar]	1	26-26	0	18	1	0	0
Campylopus alpigena Broth. [Dic]	1	36-36	0	16	1	0	0
Pohlia rigescens (Mitt.) Broth. [Bry]	2	36-37	0	15	2	0	0
Racomitrium fuscescens Wils. [Gri]	1	29-29	0	12	1	0	0
Pohlia longicolla (Hedw.) Lindb. [Bry]	1	26-26	0	12	2	0	0
Rhizogonium spiniforme (Hedw.) Bruch in Krauss [Rhi]	2	25-26	0	11	2	0	0
Mielichhoferia mielichhoferii (Hook.) Wijk & Marg. [Bra]	3	29-31	0	11	1	0	0
Brachythecium plumosum (Hedw.) B.S.G. [Bra]	2	29-31	0	8	1	0	0
Ditrichum darjeelingense Ren. & Card. [Dit]	2	27-28	0	8	3	0	0
Bryum recurvatum Mitt. [Bra]	1	30-30	0	7	1	0	0
Campylopus milleri Ren. et Card. [Dic]	2	27-28	0	6	2	0	0
Trolliela euendostoma Herz. [Sem]	1	37-37	0	6	3	0	0
Plagiothecium denticulatum (Hedw.) B.S.G. [Pla]	2	29-36	0	6	2	0	0
Atrichum flavisetum Mitt. [Pol]	2	32-37	0	5	2	0	0
Campylopus ericoides (Griff.) Jaeg. [Dic]	1	31-31	0	5	2	0	0
Rhynchostegiella divaricatifolia (Ren. et Card.) Broth. [Bry]	2	27-30	0	4	1	0	0
Didymodon constrictus (Mitt.) Saito [Pot]	1	31-31	0	4	1	0	0
Macrothamnium macrocarpum (Reinw. & Hornsch.) Fleisch. [Hyl]	1	26-26	0	4	1	0	0

Brachythecium buchananii (Hook.) Jaeg. [Bra]	1	31-31	0	3	1	0	0
Grimmia reduncа Wils. ex Mitt. [Gri]	1	31-31	0	3	1	0	0
Grimmia sp. 1 [Gri]	1	31-31	0	3	1	0	0
Weissia rutilans (Hedw.) Lindb. [Pot]	1	31-31	0	3	1	0	0
Brachythecium curvatulum (Broth.) Par. [Bra]	2	29-37	0	3	3	0	0
Campylopus laetus (Mitt.) Jaeg. [Dic]	1	31-31	0	3	1	0	0
Brachythecium falcatulum (Broth. [Bra]	1	31-31	0	2	1	0	0
Rhynchostegium celebicum (Lac.) Jaeg. [Bra]	1	26-26	0	2	1	0	0
Wijkia tanytrichia (Mont.) Crum [Sem]	1	30-30	0	2	1	0	0
Pseudoleskea incurvata (Hedw.) Loesk. [Les]	1	31-31	0	2	1	0	0
Macrothamnium stigmatophyllum Fleisch. [Hyl]	1	37-37	0	2	1	0	0
Bryum paradoxum Schwaegr. [Bra]	1	28-28	0	2	1	0	0
Brachythecium brachycladum (Broth.) Par. [Bra]	1	28-28	0	1	1	0	0
Pogonatum neesi (C. Muell.) Mitt. [Pol]	1	30-30	0	1	1	0	0
Timmia megapolitana Hedw. [Tim]	1	31-31	0	1	1	0	0
Penzigiella cordata (Hook.) Fleisch. [Pte]	1	31-31	0	1	1	0	0
Philonotis fontana (Hedw.) Brid. [Bar]	1	31-31	0	1	1	0	0
Philonotis nitida Mitt. [Bar]	1	29-29	0	1	1	0	0
Fabronia secunda Mont. [Fab]	1	27-27	0	1	1	0	0
Bryum caespiticum L. ex Hedw. [Bra]	1	31-31	0	1	1	0	0
Tetraplodon mnioides (Hedw.) B.S.G. [Spl]	1	37-37	0	1	1	0	0
Brachythecium formosanum Takaki [Bra]	1	30-30	0	1	1	0	0
Bryoerythrophyllum recurvirostrum (Hedw.) Chen. [Pot]	1	31-31	0	1	1	0	0
Dicranum spurium Hedw. [Dic]	3	34-37	0	220	3	16	1
Hylocomium himalayanum (Mitt.) Jaeg. [Hyl]	5	26-37	0	153	5	30	3
Orontobryum hookeri (Mitt.) Fleisch [Hoo]	8	25-37	0	129	5	20	5
Entodon myurus (Hook.) Hamp. [Ent]	1	15-15	0	91	9	16	2
Atrichum undulatum (Hedw.) P. Beauv. [Pol]	6	25-32	0	85	3	8	3
Brachythecium kamounense (Harv.) Jaeg. [Bra]	5	26-32	0	43	4	29	6
Atractylocarpus sinensis (Broth.) Herz. [Dic]	4	25-37	0	62	2	2	1
Bryum badhwari Ochi [Bra]	4	25-30	0	48	5	3	1
Eurhyachium striatum (Hedw.) Schimp. [Bra]	3	25-32	0	42	2	2	1
Pseudosymblepharis angustata (Mitt.) Hilp. [Pot]	5	26-37	0	3	2	32	9
Anomodon rugelii (C. Muell.) Keissl. [Thu]	5	27-32	0	13	2	20	8
Pohlia minor Schleich. ex Schwaegr. [Bry]	3	26-37	0	29	3	1	1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pohlia elongata Hedw. [Bry]	5	25-32	0	22	3	5	2
Brotherella pallida (Ren. & Card.) Fleisch. [Sea]	1	32-32	0	24	2	2	1
Brachythecium populeum (Hedw.) B.S.G. [Bra]	1	32-32	0	24	2	2	1
Rhynchostegiella sachensis Dix. [Bra]	2	27-32	0	17	2	7	1
Brachymenium ochianum Gangulee [Bry]+	8	15-31	0	6	2	17	8
Duthiella declinata (Mitt.) Zant. [Tra]	4	26-31	0	2	2	21	6
Dicranodontium capillifolium (Dix.) Tak. [Dic]	3	29-36	0	20	3	2	1
Vesicularia evieri Card. [Hyp]	2	26-32	0	15	1	6	3
Campylopus involutus (C. Muell) Jaeg. [Dic]	3	31-37	0	17	1	1	1
Dicranum sp. 1 [Dic]	3	31-37	0	11	3	4	1
Isopterygium albescens (Hook.) Jaeg. [Hyp]	2	30-31	0	5	1	9	2
Didymodon asperifolius (Mitt.) Crum et al. [Pot]	4	28-31	0	12	2	2	2
Meiothecium speciosa [Sem]	2	27-29	0	3	2	7	3
Campylium chrysophyllum (Brid.) J. Lauge [Amb]	2	26-37	0	6	3	2	1
Brachythecium pachytheceum (Dix.) Vohra [Bra]	1	31-31	0	4	2	3	1
Thamnobryum subseriatum (Hook.) Nog. [Nec]	2	30-31	0	3	1	3	1
Sematophyllum micans (Mitt.) Braithw. [Sem]	2	27-29	0	4	1	2	1
Bryoerythrophyllum recurvum (Griff.) Saito [Pot]	3	27-37	0	2	2	1	1
Isopterygium minutirameum (C. Muell). Jaeg. [Hyp]	2	27-29	0	1	1	2	2
Brachythecium obsoletinerve Dix. [Bra]	2	29-31	0	1	1	1	1
Vesicularia succosa (Mitt.) Broth. [Hyp]	2	30-31	0	1	1	1	1
Meteorium buchananii (Brid.) Broth. [Met]	2	25-26	0	0	0	91	10
Leptohymenium tenue (Hook.) Jaeg. [Hyl]	2	25-26	0	0	0	15	2
Zygodon sp. 1 [Ort]	4	25-29	0	0	0	11	5
Thuidium sp. 1 [Thu]	1	26-26	0	0	0	10	2
Stereophyllum wightii (Mitt.) Jaeg. [Pla]	1	15-15	0	0	0	9	2
Lindbergia longinervis Card. et Dix. [Les]	1	25-25	0	0	0	7	1
Ectropothecium buitenzorgii (Bel.) Mont. [Hyp]	2	25-29	0	0	0	5	2
Isopterygium longitheca (Mitt.) Jaeg. [Hyp]	1	31-31	0	0	0	5	1
Bryum atrovirens Brid. [Bra]	1	25-25	0	0	0	4	1
Gollania clarescens (Mitt.) Broth. [Rhy]	1	25-25	0	0	0	4	1
Aerobryidium filamentosum (Hook.) Fleisch. [Met]	1	15-15	0	0	0	3	1

Lindbergia koelzii Williams [Les]	1	15-15	0	0	0	3	1
Glossadelphus zollingeri (C. Muell.) Fleisch. [Sea]	2	26-29	0	0	0	3	2
Macromitrium moorcroftii (Hook. & Grev.) Schwaegr. [Ort]	1	25-25	0	0	0	3	1
Calyptothecium pinnatum Nog. [Nec]	1	15-15	0	0	0	3	1
Sematophyllum subhumile (C. Muell.) Fleisch. [Sem]	1	32-32	0	0	0	2	1
Schoenobryum concavifolium (Griff.) Gangulee [Cry]	1	15-15	0	0	0	2	1
Rhynchostegiella menadensis (Lac.) Bartr. [Bra]	1	31-31	0	0	0	1	1
Trichostomum bombayense C. Muell. [Pot]	1	30-30	0	0	0	1	1
Brachythecium wichurae (Broth.) Par. [Bra]	1	30-30	0	0	0	1	1
Sematophyllum phoenicum (C. Muell.) Fleisch. [Sem]	1	29-29	0	0	0	1	1
Didymodon hastatus (Mitt.) Zander [Pot]	1	30-30	0	0	0	1	1
Sematophyllum caespitosum (Schwaegr.) Grout [Bra]	1	30-30	0	0	0	1	1
Cirriphyllum cirrhosum (Schwaegr.) Grout [Bra]	1	30-30	0	0	0	1	1
Anomodon thraustus C. Muell. [Thu]	1	29-29	0	0	0	1	1
Didymodon eroso-denticulatus (C. Muell.) Saito [Pot]	1	27-27	0	0	0	1	1
Macromitrium hymenostomum Mont. [Ort]	1	15-15	0	0	0	1	1
Fissidens sp. 1 [Fis]	1	26-26	0	0	0	1	1
Isopterygium sp. 1 [Hyp]	1	29-29	0	0	0	1	1
Scopelophila sp. 1 [Cry]	1	15-15	0	0	0	1	1
Sematophyllum humile (Mitt.) Broth. [Sem]	1	30-30	0	0	0	1	1

Abbreviated families []:

Amblystegiaceae [Amb]
Bartramiaceae [Bar]
Brachytheciaceae [Bra]
Bryaceae [Bry]
Cryphaeaceae [Cry]
Dicranaceae [Dic]
Ditrichaceae [Dit]
Encalyptaceae [Enc]
Entodontaceae [Ent]
Fabroniaceae [Fab]
Fissidentaceae [Fis]
Funariaceae [Fun]
Grimmiaceae [Gri]
Hookeriaceae [Hoo]
Hylocomiaceae [Hyl]
Hypnceae [Hyp]
Leskeaceae [Les]
Leucodontaceae [Leud]
Meteoriaceae [Met]
Mniaceae [Mni]
Neckeraceae [Nec]
Orthotrichaceae [Ort]
Plagiotheciaceae [Pla]
Polytrichaceae [Pol]
Pottiaceae [Pot]
Pterobryaceae [Pte]
Ptychomitriaceae [Pty]
Rhizogoniaceae [Rhi]
Rhytidiaceae [Rhy]
Sematophllaceae [Sem]
Splachnaceae [Spl]
Thuidiaceae [Thu]
Timmiaceae [Tim]
Trachypodaceae [Tra]

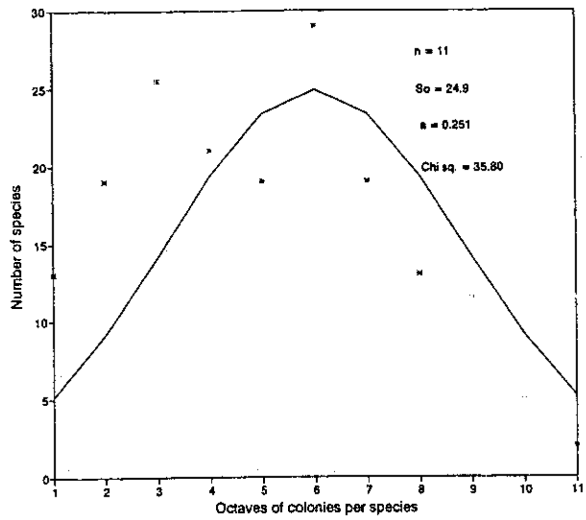

Figure 2. Frequency distribution of moss species count data plotted in octaves: Observed data shown as asterisks and fitted lognormal curve as solid line at χ^2 35.80 using $a = 0.251$, $S_0 = 24.9$, where S_0 is an estimate of the number of species in the model octave and parameter a is an inverse measure of the width of the distribution

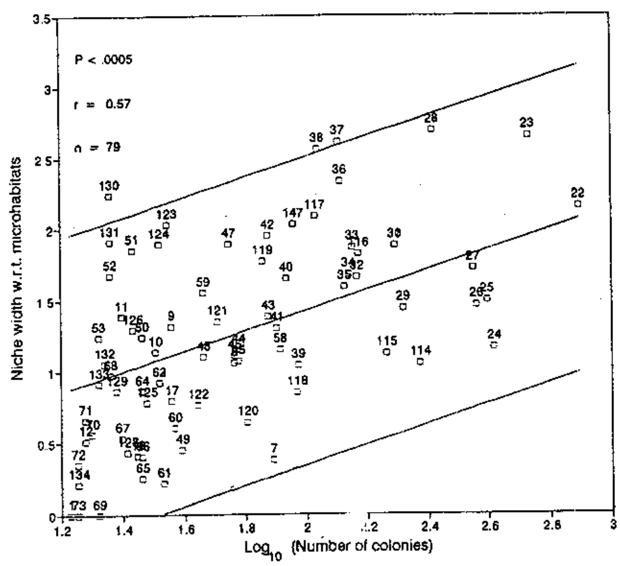

Figure 3 Relationship between the number of colonies encountered and the niche-width of 79 species occurring in more than 17 colonies with respect to microhabitat usage. The graph also shows the fitted regression lines with confidence intervals at $P < 0.0005$ The numbers correspond to the order in which species are listed in Table 3, indicating that *Brachymenium ochianum*, *Leucodon sciuroides* and *Trachypodopsis serrulata* are significantly broad-niched species.

type, altitude and mesohabitat levels. The species richness of different sites were compared by resorting to rarefaction (Ludwig and Reynold 1988). On the basis of Monte Carlo simulations, we can assign high levels of species richness at 1% level of significance to the sites belonging to middle altitudinal range of 2600 m, to 3100 m except to the site at 2800 m. The contrasting species poorty of the 2800 m site from this zone appears to be primarily due to absence of wood species as compared to the neighbouring sites. Interestingly, the site at 3400 m though more grazed than others, the species diversity levels were as high as expected by rarefaction. Though the site was extensively grazed, it harbored suitable soil and rock microhabitats unharmed by the grazing animals. Thus the traditional grazing in the subalpine or alpine meadows would probably have little or no effect on the moss diversity. The moss diversity levels will sharply reduce if their specialized microhabitats like shaded soil are damaged.

Species turnover or β - diversity, defined as unshared species as a proportion of total species between any two sites, is another important component of species diversity. To estimate turnover between sites we have used Jaccard's dissimilarity index (i.e 1 - Jaccard coefficient of similarity) (Magurran 1988) Using the turnover values between all pairs of sites, we have employed complete linkage dendrogram for representation (Mark and Roger 1984) (Figure 4). Wherein similar sites cluster together and the sites with larger turnover spread apart. Dendrogram clearly shows that the higher altitude and the middle altitude sites cluster together whereas, and the lower altitude site of *Quercus* forest separates owing to several species unshared with other sites. Apart from altitudinal gradient, mesohabitat conditions and the availability of microhabitats also seem to effect site similarities (and turnover). The species turnover between any two sites increases weakly but significantly (at P < .0005) with increasing altitudinal difference (Figure 5)

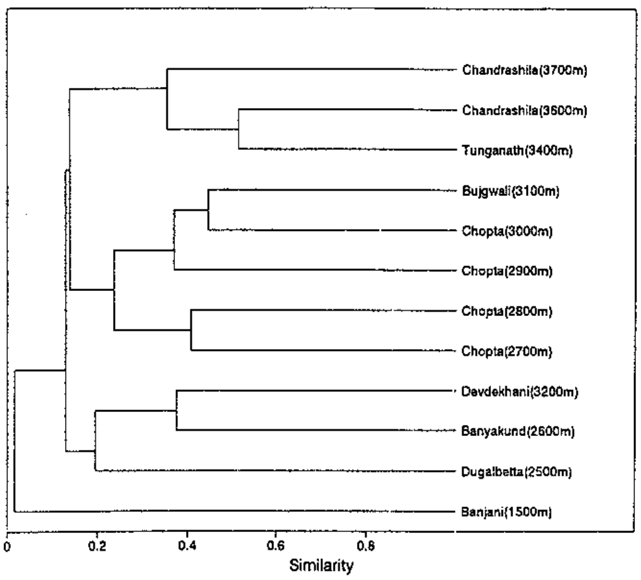

Figure 4. Complete linkage dendrogram of 12 sites based on Jaccard's coefficient of similarity with respect to composition of species.

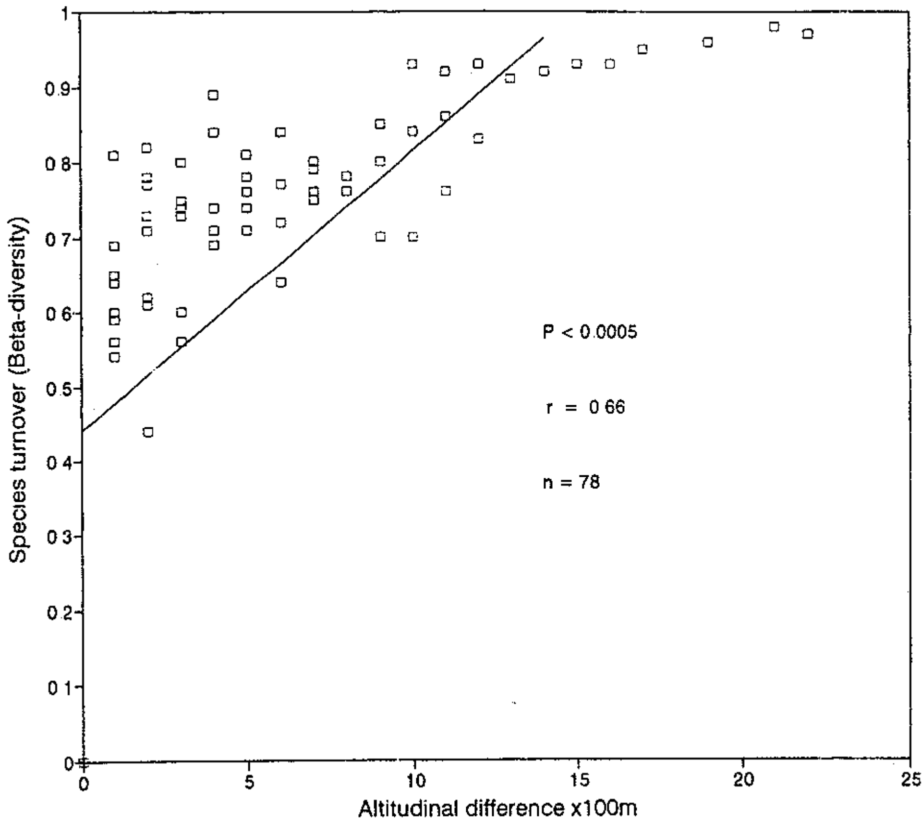

Figure 5 Relationship between the altitudinal difference between the sites and the species turnover (β-diversity) The graph shows the fitted regression line at $P < 0.0005$

Niche Overlap

An important parameter of community organization is the overlap between the niches (i e. their resource base) of different species Greater the niche overlap, lower is the specialization of resource harvest, lower the overall diversity For, only a few species can co-exist if their resource requirements are nearly the same In the present study, niche-overlap with respect to microhabitat usage is computed based on Pianka's measure of niche-overlap, which uses Jaccard's index of similarity to measure the co-occurrence between every pair of species (Pianka 1974) We measured niche overlap between all pairs of 21 species occurring in 100 or more colonies with respect to the usage of 79 microhabitats. figure 6 represents all such pairwise species similarities in a dendrogram using complete linkage analysis (Mark and Roger 1984). The species with similar micro-habitat preference tend to cluster together Further, we see atleast 2 major groups of species with 25% to 85% of niche overlap amongst the species within each group but much lesser between the groups (Figure 6).

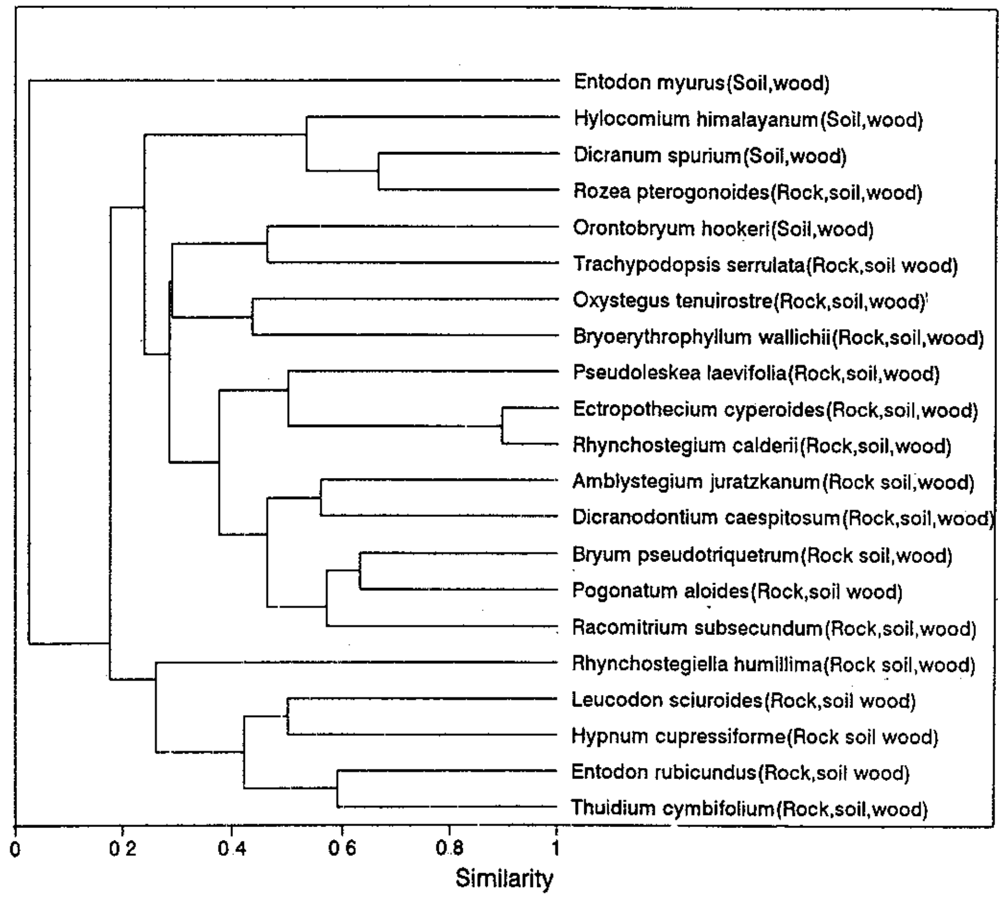

Figure 6 Complete linkage dendrogram for 21 species occurring in more than 100 colonies based on Pianka's measure of niche-overlap with respect to microhabitat usage

Microhabitat Preference

Table 2 depicts 79 types of microhabitats as the finer divisions of the three major substrates. For comparison, number of pooled colonies per species per specific major substrate from all the sites were allowed to rarefaction (Ludwig and Reynolds 1988) It turns out that soil supports greater richness of species specific to soil based microhabitats than the respective specific richness of wood based microhabitats and the rocks. Figure 7 is a Venn diagram of overall substrate preference of total 177 species. More than 45% of total species in the study area prefer more than two major substrate based microhabitats. This brings out the importance of these combination of microhabitats in promoting moss species diversity However there are a very few number of species confined to bare rocks which may require a special attention due to their narrow habitat preference with poor abundance (Table 3)

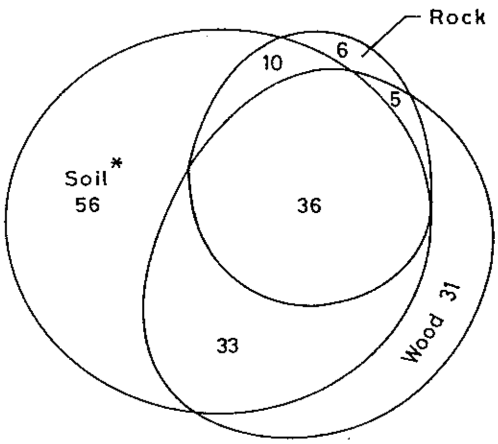

Figure 7 Venn diagram of distribution of 177 species of mosses on the three major substrates.
* indicates significantly (P < .01) rich with respect to microhabitat- specific species diversity.

CONSERVATION IMPLICATIONS

After the Rio Convention on biodiversity, interest in conservation biology has rapidly increased all over the world, including concern for lower plants (During 1992, Sonderstrom et al. 1992, Pant et al. 1994). But still in most of the countries, we lack even preliminary informations on conservation of mosses. Therefore it is particularly important to encourage, landscape and environmental specific case studies on community ecology of lower plants as well and share such information through long term collaborations and networking taxonomists, ecologists and local communities all over the world. Only then we can frame the management and conservation policies for biodiversity on a firm footing.

All the study sites in the region are exposed to various kinds and levels of human interference ranging from fuelwood collection to grazing and fire. Excessive fuelwood collection and fire appear to be major threats to the rich moss flora of the Himalaya. 63% of the fires are caused by human beings in the Garhwal Himalaya (Semwal and Mehta 1996). However, empirical evidence is lacking; the mosses may be severely threatened due to these fires. Summer grazing is prevalent in the subalpine and alpine meadows of the Himalayas. Although more data are required, this preliminary study indicates that the seasonal grazing in the sub-alpine to alpine meadows is unlikely to affect the moss species diversity and composition unless their microhabitats are unrecoverably damaged.

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