On the patterns of abundance and diversity of macrolichens of Chopta-Tunganath in the Garhwal Himalaya

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A total of 3211 colonies of macrolichens, from twelve 50 m × 10 m plots distributed across four macrohabitat (vegetation) types between 1500 m–3700 m in the Chopta-Tunganath landscape of the Garhwal Himalaya, yielded 13 families with 15 genera and 85 species. *Lobaria retigera* stood out as a broad-niched generalist species with moderate levels of abundance in all the three major microhabitats, viz. rock, soil and wood across 83% of all the plots sampled, whereas *Umbilicaria indica* emerged as an abundantly occurring specialist confined to rock substrates. *Heterodermia incana* and *Leptogium javanicum* appeared to be rare members of the community as they were encountered only once during the field survey. Woody microhabitats turned out to be richer than rock and soil substrates for macrolichens. Amongst the macrohabitats, middle altitude (2500–2800 m) *Quercus* forest was richest in species and genera followed by high altitude (2900–3200 m) *Rhododendron* forest, higher altitude grasslands (3300–3700 m) and then the lower elevation (1500 m) *Quercus* forest. Species, genus and family level alpha- as well as beta-diversities were significantly correlated with each other, implying that higher taxonomic ranks such as genera may be used as surrogates for species thus facilitating cost- and time-effective periodic monitoring of the biodiversity of macrolichens. Dynamics of the diversity of lichen communities in relation to various forms of environmental disturbance including livestock grazing and tourism as dominant land use activities in the higher Himalaya need further research.

1. Introduction

Lichens are the most successful symbiotic organisms in nature, dominating 8% or more of the earth's terrestrial area (Ahmadjian 1995), and are amongst the most significant indicators of air pollution and ecosystem health (Richardson 1992; Upreti and Pandev 1994; Wolseley *et al* 1994; Upreti 1995; Sloof 1995; Mistry 1998; Vokou *et al* 1999). Many lichens have economic applications, including uses in traditional medicines (Richardson 1991; Gonzalez-Tejero *et al* 1995; Upreti 1994; Upreti and Negi 1996; Negi and Kareem 1996), besides some species serving as a staple diet of the Alaskan reindeer (Skunke 1969) and the Himalayan musk deer (Negi 1996). Although lichen compounds are known to act as defense agents against generalist herbivores, there are many specialized organisms that feed solely on them (Gerson and Seaward 1997; Syed and Seaward 1984; Lawrey 1991; Baur *et al* 1992).

With its share of just 2·4% of global land surface, India is a rich centre of lichen diversity, contributing nearly 15% of the 13,500 species of lichens so far recorded in the world (Groombridge 1992; Singh and Sinha 1997; Upreti 1998). This rich diversity with many endemic species (102) is in fact a poor record of a total expected 4000 species of lichens in India, as many more areas, especially mountains and the forest canopies are yet to be explored (Negi and Gadgil 1996; Negi 1999; Negi and Upreti 2000). Notably enough, 60% of the so far recorded lichens are crustose forms, most of which have only been recorded once in the history of more than six decades of lichenology in India (Awasthi 1991; Singh and Sinha

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1997). These crustose forms are very difficult to collect and identify, and are more likely to be overlooked in the field even by experts, as evident from Singh and Sinha's (1994) exhaustive surveys in Nagaland, where they could list only 139 species of microlichens as opposed to 209 species of macrolichens. The microlichens are therefore excluded from the present study.

While there have been systematic studies on macrolichens for several decades, investigations of their community ecology have only recently begun (Awasthi 1988; Negi and Gadgil 1996; Negi 1999; Negi and Upreti 2000). Community studies can be carried out at various spatial scales. Most of the past investigations on lichen diversity have been descriptive and have concentrated on regional and global scales (Groombridge 1992; Heywood 1995; Gaston 1996; Galloway 1996). The current focus of such studies is shifting from these higher spatial scales to locally manageable landscapes as land use decisions and management policies are most often implemented at these latter scales (Ricklefs and Schluter 1993; Nagendra and Gadgil 1999; Negi 1999). Moreover, floristic inventories particularly of lower plants suffer from lack of uniform field methods. This has partly hindered progress on long term monitoring of biological diversity and its conservation (Gadgil 1994, 1996; Negi and Gadgil 1997; Negi 1999). Formulating proper methodology for documenting floristic diversity with ecological correlates should therefore be a prerequisite for inventorying, periodic monitoring and conservation of bio-resources. This paper presents local patterns of relative abundance, alpha- and beta-diversities of species, genera and families of macrolichen communities of the Chopta-Tunganath landscape in the Garhwal Himalaya. The study examines the efficacy of using higher taxon ranks such as genera as reliable surrogates for predicting species diversity. A methodological approach is adopted so as to facilitate comparable investigations in future.

2. Materials and methods

2.1 *Study area, geology, climate, vegetation and land use*

Chopta-Tunganath lies between 30°20′–30°35′N latitude and 79°10′ to 79°20′E longitude in the Garhwal Himalaya (figure 1). The mountainous landscape with steep to moderate slopes spreads over an area of 500 sq km with elevation ranging between 1400 m–3700 m above mean sea level. Undulating topography in response to the dynamic geological formations in the Himalaya has given rise to a variety of edaphic conditions which are responsible for providing a unique environment for the distinctive flora and fauna (Ganser 1964; Gupta 1964). The weathering bedrock that provides the bulk of the loose material in these mountains is crystalline and metamorphic with sedimentary deposits formed during the Palaeozoic. Soils in the area are of coarse texture, well drained and acidic with pH levels varying between 4 to 5·5 in the alpine grasslands (Sundriyal 1992). Although there is no detailed analysis of variation of rainfall at different sites along the elevation gradient, average annual precipitation at Okhimath (30°30′N; 70°15′E, 2500 m) station, about 10 km west from Chopta, records 1888·5 ± 98·5 mm (SD) for 50 years of observations along with low to heavy snow fall during December to March. The maximum monthly temperature in the area varies from around 19°C to 37°C from the higher altitude grasslands to the lower elevation *Quercus* forests respectively during the snow-free months of May to October, while the minimum temperature drops as low as –15°C in the alpine grasslands during the months of December to February.

The higher plant vegetation of the study area is broadly classified as temperate mixed oak and coniferous forest through sub-alpine forest to alpine scrub or grassland along the altitude gradient (Gadgil and Meher-Homji 1990). The area harbours more than 250 vascular plant species (Semwal and Gaur 1981) and 177 species of mosses (Negi and Gadgil 1997) besides supporting a rich diversity of fauna including the highly endangered musk deer (*Moschus chrysogaster*) (Negi 1996).

Historically, the area has been a famous place of pilgrimage for Indian devotees for many centuries, as Tunganath Temple – one of the five "Kedars" of the Garhwal Himalaya, is situated in the alpine meadows of the Tunganath. With the advent of tourism during the last two decades, construction of guest houses and motorable roads connecting the area to the nearby National Highway and other Kedars such as Kedarnath in the region have triggered an influx of thousands of tourists, every year, from all over the world. The local human population settled in the lowland fringe areas comprises basically semi-pastoralists with livestock grazing and agriculture as their dominant land use activities. While low elevation woodlands such as *Quercus* forests are open for fodder and fuel wood collection throughout the year, grazing in the higher elevation forests and grasslands starts in early June, reaching a maximum in July–August, and stops in early October.

2.2 *Field methods and data recording*

A stratified random sampling method was employed (Greig-Smith 1983; Krebs 1989). The study landscape was stratified into five macrohabitat types based on the predominant vegetation cover along the elevation gradient. These types are: (i) Paddy fields (< 1400 m);

(ii) Lower altitude (1500 m) broad leaved forest dominated by *Quercus leucotrichophora*. This forest has been protected from felling by local people for more than 25 years; (iii) Middle altitude (2500 m–2800 m) broad leaved forest dominated by *Quercus semecarpifolia*; (iv) High altitude (2900 m–3200 m) mixed forests with dominant broad leaved species such as *Rhododendron arboreum*, *R. campanulatum* dotted with a few *Abies pindrow* and *Taxus baccata* trees; (v) Higher altitude (3400 m–3700 m) grasslands dominated by herb species of *Anemone*, *Potentilla*, *Aster*, *Geranium*, *Meconopsis*, *Primula* and *Polemonium*, and scattered pockets of shrubs of *Rhododendron anthopogon* and *Juniperus* species.

The data recording involved laying down twelve 50 m × 10 m plots distributed between the elevation of 1500 m to 3700 m covering the four macrohabitat types (table 1). Cultivated terraces at 1400 m were excluded from the sampling as they hardly seemed to support any macrolichen colonies. Three major substrates, viz. rock, soil and wood, were considered as the microhabitats. The woody substrates included tree trunks, branches, twigs, wood logs and stumps. Exhaustive search and representative collections for all colonies of macrolichens were carried out in each of the plots during the periods of June–October in 1994–95. A contiguous patch of 1 sq cm covering individuals of recognizable taxonomic units (RTUs) identified based on morphological differences was defined as a colony of that taxon, irrespective of their association with individuals of other taxa. Representative samples from the colonies of macrolichens were preserved in bamboo paper pouches (30 cm × 30 cm). The specimens were examined morphologically, anatomically and

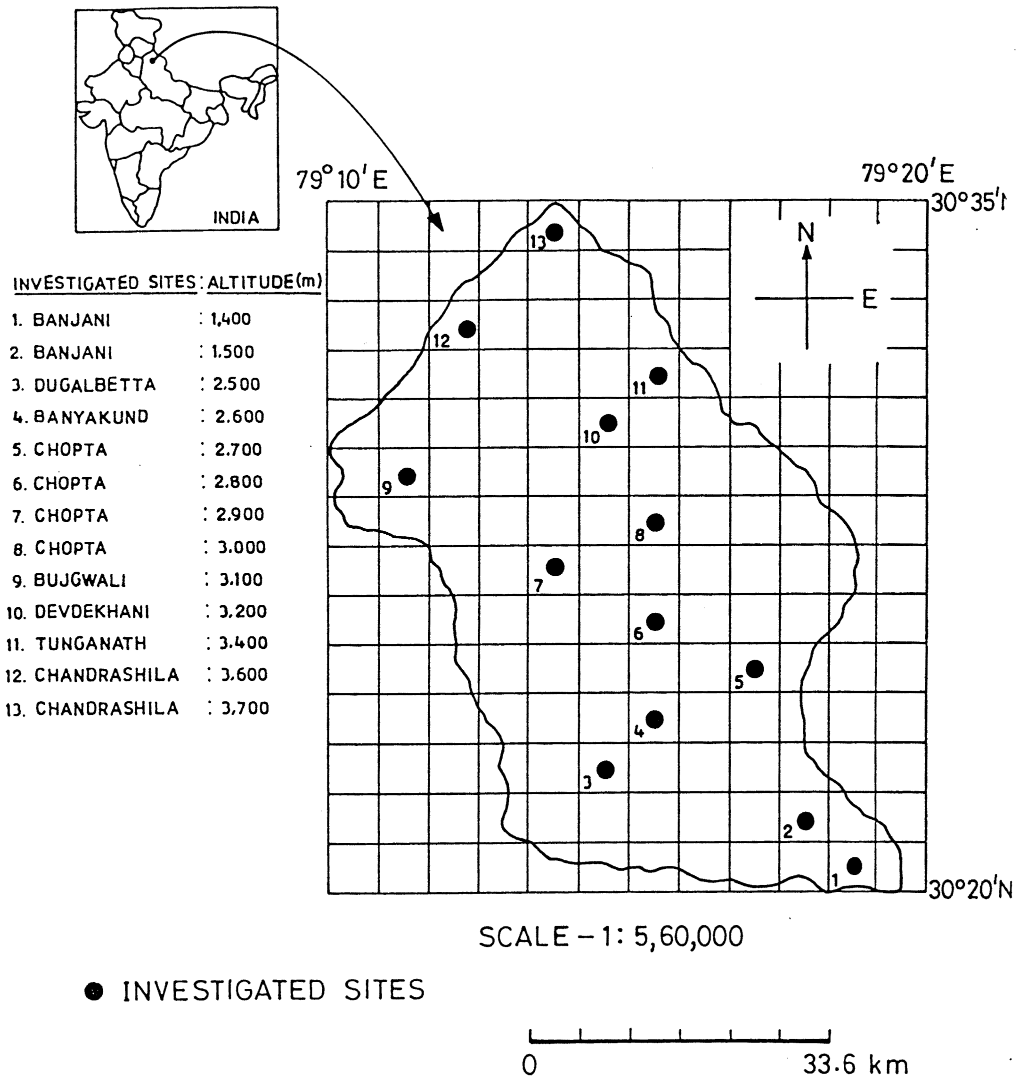

Figure 1. Geographical location map of the Chopta-Tunganath landscape.

Table 1. Attributes of 12 plots of 500 sq m each sampled for macrolichens and woody plants from Chopta-Tunganath landscape.

Plot no.	Site name	Altitude (× 100 m)	Macrolichens			Woody plants			
			MAC type	Colonies	Species	Genera	Families	Individuals	Species
1	Banjani	15	LQ	673	9	4	4	58	3
2	Dugalbetta	25	MQ	107	17	8	7	7	3
3	Banyakund	26	MQ	79	17	7	7	9	6
4	Chopta	27	MQ	310	32	11	9	10	3
5	Chopta	28	MQ	438	30	9	9	17	2
6	Chopta	29	HR	492	33	11	11	10	3
7	Chopta	30	HR	228	28	10	10	53	9
8	Bujgwali	31	HR	289	30	10	10	24	9
9	Devdekhani	32	HR	147	17	8	8	16	3
10	Tunganath	34	HG	180	8	6	6	0	0
11	Chandrashila	36	HG	153	7	5	5	19	4
12	Chandrashila	37	HG	115	8	4	4	12	2

MAC: Macrohabitat; LQ: Lower altitude *Quercus* forest; MQ: Middle altitude *Quercus* forests; HR: High altitude mixed forests of *Rhododendron*; HG: Higher altitude grasslands.

chemically at the Lichenology Laboratory, National Botanical Research Institute (NBRI), Lucknow. The species names were finally ascertained following Zahlbruckner's (1926) classification of lichens with modifications by Walker and James (1980) and Awasthi (1988). The specimens which could not be identified to the species level were either considered as distinct yet anonymous species (sp.) or assigned the name of a species to which the majority of its structural and ecological characteristics resembled. All voucher specimens are preserved at the Herbarium of NBRI (LWG). The numbers of trees above 10 cm girth at a height of 130 cm above the ground and patches of shrubs (> 10 cm height) in all plots were also noted. Although macrolichens could not be sampled on trees above a height of 2·5 metres, many canopy species of macrolichens were encountered through collection of fallen branches and twigs on the ground.

2.3 *Data analyses*

2.3a *Alpha- and beta-diversity*: Alpha-diversity, defined as taxon packing within a demarcated area, was measured as the numbers of species, genera or families of macrolichens per unit plot (Whittaker 1972). The species, genus or family replacement from one plot to another (beta-diversity or the turnover) was calculated as a chord-distance or dissimilarity index, which was preferred over Jaccard's similarity index (Ludwig and Reynold 1988). The former index is more robust, as it uses abundance information also, whereas the latter requires only presence–absence data.

Chord distance between the jth and kth plots is given as:

$$D_{jk} = \sqrt{2\left[1-\frac{\sum_{i=1}^{S_j} N_{ij} \sum_{i=1}^{S_k} N_{ik}}{\sum_{i=1}^{S_j} N_{ij}^2 \sum_{i=1}^{S_k} N_{ik}^2}\right]},$$

where N_{ij} and N_{ik} are the numbers of colonies of the ith taxon in the jth and kth transects, whereas S_j and S_k are the numbers of species, genera or families in the jth and kth plots respectively. The dissimilarity (distance) values vary from 0 to 1·42 for pairs of plots corresponding with having none to completely dissimilar taxonomic composition. The matrix of the dissimilarity values for all pairs of plots was subjected to simple linkage cluster analysis and depicted in the form of a dendrogram after re-scaling the chord distance values between 0 to 1 (Mark and Roger 1984).

2.3b *Rarefaction*: The sampling effort in terms of numbers of colonies of macrolichens across macrohabitats as well as microhabitats was highly unequal. I have therefore employed the rarefaction process to compare these habitats with respect to the taxon richness of the macrolichens (Simberloff 1979). How many species, genera or families do we get for an equal number of colonies sampled from each of the habitat types? Rarefaction addresses this question and involves linearly increasing the number of colonies drawn from the pooled data (i.e. all the colonies in a particular habitat type) and recording the numbers of species, genera and families encountered. The above process was repeated 100 times and the mean numbers of species, genera and families were calculated for the number of colonies sampled from each of the habitat types.

2.3c *Regression models and simulations*: The simple linear regression model was used to interpret the data on the relationships among species, genus and family level alpha- and beta-diversities. Since the beta-diversity values are not independent of each other, there is every possibility that the observed relationship may occur by chance alone. Moreover it causes uncertain degrees of freedom while establishing the magnitude of the relationship. To overcome this problem, computer simulations based on the randomization process were employed. Here beta-diversity values in one of the pairs in a taxonomic hierarchy (species, genus or family level) were scrambled with respect to the other, thus randomizing the process and the regression coefficient r was calculated. This procedure was repeated 1000 times for each pair yielding 1000 values of r. The level of significance value (P) was calculated as the proportion of the simulated values of r that were greater than the observed r. Thus, only relationships with r values at $P < 0{\cdot}005$ arrived at after simulations were considered significant.

3. Results

A total of 13 families with 15 genera and 85 species from 3211 colonies sampled over 6000 square metres constituted the macrolichen community of Chopta-Tunganath. The list of the macrolichen taxa with their attributes such as occurrence on major substrates, viz. rock, soil and wood, elevation range and average abundance is given in table 2. Taxonomic details for all the species are given elsewhere (Upreti and Negi 1998). The distribution of numbers of species, genera and families on the three substrates are depicted in the form of Venn diagrams (figure 2). 36·5% of the species, 26·7% of the genera and 15·4% of the families were lignicolous (on wood), 15·3% of the species, 13·3% of the genera and 15·4% of the families were saxicolous (on rocks), while none of the genera and families but 1·2% of the species were terricolous. 38·8% of the families, 26·7% of the genera and 27% of the species appeared to be generalists, occurring in all three substrata. The rest of the taxa shared two of the three microhabitats in the study area. There was a tendency towards niche separation in terms of habitat specialization with the process of diversification of species, as reflected in relatively higher proportions of generalists at higher levels of taxonomic ranks.

Heterodermia diademata and *Lobaria retigera* were broad-niched generalist species occurring frequently in all the three major substrates, viz. rock, soil and wood, spreading across wide elevation ranges. *Leptogium askotense*, *L. javanicum*, *Parmelia saccatiloba* and *Usnea stigmatoides*

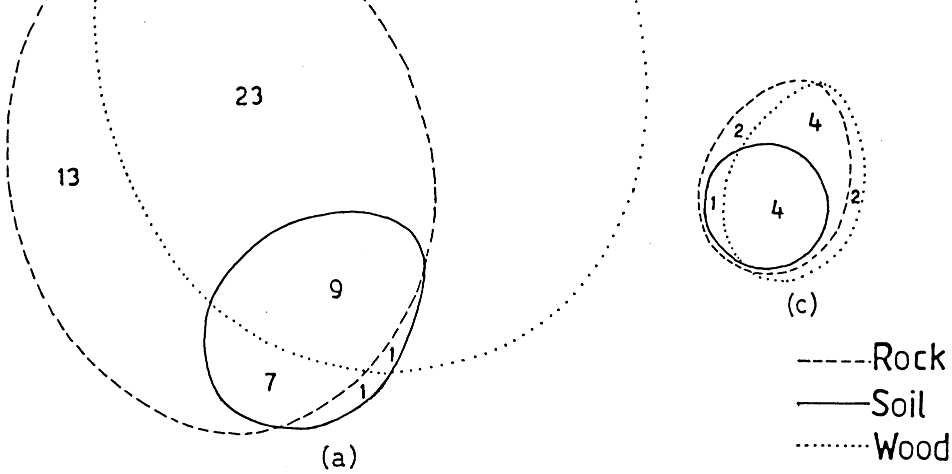

Figure 2. Venn diagrams depicting the distribution of (**a**) 85 species, (**b**) 15 genera, and (**c**) 13 families of macrolichens on three microhabitats, viz. rock, soil, wood from Chopta-Tunganath.

Table 2. List of 13 families with 15 genera and 85 species of macrolichens arranged in descending orders of average abundance per plot along with attributes of altitude range and occurrence on three substrates, viz. rock, soil and wood, in Chopta-Tunganath.

Family	Taxa	Alt. range Max (× 100 m)	Alt. range Min (× 100 m)	Fq	No. of colonies Rock	No. of colonies Soil	No. of colonies Wood	Abun/plot Avg	Abun/plot SD
Umbilicariaceae	*Umbilicaria indica* var. *nana* Frey and Poelt	37	28	6	431	0	0	35·92	53·22
Stereocaulaceae	*Stereocaulon foliolosum* Nyl.	37	27	7	189	94	0	23·58	39·53
Parmeliaceae	*Parmelia perisidians* Nyl.	15	15	1	223	0	33	21·33	73·90
Physciaceae	*Heterodermia diademata* (Taylor) Awasthi	32	15	8	125	4	125	21·17	64·87
Verrucariaceae	*Dermatocarpon miniatum* (L.) Mann	31	29	3	182	0	0	15·17	35·69
Parmeliaceae	*Parmelia cirrhata* Fr.	32	25	8	14	0	165	14·92	17·83
Cladoniaceae	*Cladonia fimbriata* (Florke) Sprengel	37	26	9	75	18	49	11·83	13·63
Parmeliaceae	*Parmelia nilgherrensis* Nyl.	32	25	7	6	0	110	9·67	9·29
Lobariaceae	*Lobaria retigera* (Bory) Trevisan	36	25	10	52	17	35	8·67	9·26
Parmeliaceae	*Parmelia nepalensis* Taylor	32	25	6	7	0	73	6·67	9·56
Usneaceae	*Usnea perplexans* Stirton	32	25	6	0	0	70	5·83	7·42
Cladoniaceae	*Cladonia coniocraea* (Florke) Sprengel	32	25	8	7	20	29	4·67	4·03
Collemataceae	*Leptogium delavayi* Hue	15	15	1	2	0	54	4·67	16·17
Usneaceae	*Usnea orientalis* Mot.	32	26	7	0	0	55	4·58	9·31
Physciaceae	*Heterodermia speciosa* (Wulfen) Trevisan	31	26	4	29	14	10	4·42	7·35
Collemataceae	*Leptogium pedicellatum* P Jorge.	32	15	2	9	0	40	4·08	13·83
Physciaceae	*Heterodermia leucomela* (L.) Poelt	32	27	4	4	0	43	3·92	8·21
Physciaceae	*Heterodermia pseudospeciosa* (Kurok.) Culb.	15	15	1	13	0	34	3·92	13·57
Cladoniaceae	*Cladonia furcata* (Huds) Schrader	37	26	4	4	33	2	3·25	7·50
Ramalinaceae	*Ramalina roesleri*	31	25	5	0	0	37	3·08	6·43
Usneaceae	*Usnea longissima* Ach.	32	31	2	0	0	37	3·08	7·35
Peltigeraceae	*Peltigera polydactyla* (Necker) Hoffm.	37	26	8	11	18	6	2·92	3·55
Cladoniaceae	*Cladonia pyxidata* (L.) Hoffm.	37	34	2	23	9	0	2·67	7·80
Parmeliaceae	*Parmelia wallichiana* Taylor	31	25	6	11	0	17	2·33	3·94
Physciaceae	*Heterodermia dissecta* var. Koyana (Kurok.)Awasthi	32	27	6	16	0	10	2·17	2·48
Cladoniaceae	*Cladonia scabriuscula* (Delise in Duby) Leighten	31	15	5	1	18	6	2·08	4·12
Cladoniaceae	*Cladonia* sp.	28	28	1	18	7	0	2·08	7·22
Ramalinaceae	*Ramalina* sp.4 of G Awasthi	31	29	2	20	0	5	2·08	6·61
Cladoniaceae	*Cladonia pleurota* (Florke) Schaerer	28	25	3	0	15	9	2·00	4·49
Peltigeraceae	*Peltigera praetextata* (Forke ex Sommerf.) Zopf.	30	25	4	8	8	7	2·92	2·97
Usneaceae	*Usnea subfloridana* Stirton	31	27	2	0	0	21	1·75	4·52
Cladoniaceae	*Cladonia parasitica* (Hoffm.) Hoffm.	29	29	1	18	0	1	1·58	5·48
Collemataceae	*Leptogium trichophorum* Mull. Arg.	30	27	3	0	0	19	1·58	3·58
Cladoniaceae	*Cladonia chlorophaea* (Florke) Sprengel	36	34	2	10	7	0	1·42	3·37
Ramalinaceae	*Ramalina sinensis* Jatta	31	30	2	15	0	2	1·42	3·63
Usneaceae	*Usnea eumitrioides* Mot.	31	27	4	0	0	16	1·33	2·90
Verrucariaceae	*Dermatocarpon vellereum* Zashacke	36	30	2	13	0	0	1·08	2·61
Parmeliaceae	*Parmelia stygia* (L.) Ach,	34	34	1	13	0	0	1·08	3·75
Peltigeraceae	*Peltigera canina* (L.) Willd.	32	27	3	4	0	9	1·08	2·07
Parmeliaceae	*Parmelia soredica* Nyl.	28	26	2	0	0	12	1·00	2.66
Physciaceae	*Heterodermia angustiloba* (Mull. Arg.) Awas.	32	26	4	4	0	7	0·92	1·51
Parmeliaceae	*Parmelia crenata* Kurok. in Hale and Kurok.	30	25	5	1	0	10	0·92	1·56
Usneaceae	*Usnea baileyi* (Stirton) Zahlbr.	27	25	2	0	0	11	0·92	2·15
Usneaceae	*Usnea himalayana* Church. Bab.	29	27	2	3	0	8	0·92	2·39
Parmeliaceae	*Parmelia reticulata* Taylor	31	26	3	0	0	10	0·83	1·85
Parmeliaceae	*Parmelia setschwanensis* Zahlbr.	15	15	1	2	0	8	0·83	2·89
Parmeliaceae	*Parmelia tinctorum* Nyl.	29	28	2	7	0	3	0·83	2·59
Physciaceae	*Phaeophyscia endococcina* (Korber) Moberg	25	25	1	0	0	10	0·83	2·89
Cladoniaceae	*Cladonia ramulosa* (With.) Laudon	15	15	1	0	9	0	0·75	2·60
Parmeliaceae	*Parmelia scytodes* Kurok. in Hale and Kurok.	25	25	1	0	0	9	0·75	2·60
Parmeliaceae	*Parmelia sulcata* Taylor	31	28	3	3	0	6	0·75	1·60
Cladoniaceae	*Cladonia coccifera* (L.) Willd.	37	37	1	1	6	0	0·58	2·02
Cladoniaceae	*Cladonia gymnopoda* Vainio	30	28	2	3	4	0	0·58	1·38
Parmeliaceae	*Parmelia robusta* Degel.	15	15	1	0	0	7	0·58	2·02
Parmeliaceae	*Parmelia rudecta* Ach.	31	27	3	1	0	6	0·58	1·24
Parmeliaceae	*Parmelia simlicior* Hale	30	27	2	0	0	7	0·58	1·38

		Alt. range			No. of colonies			Abun/plot	
		Max	Min						
Family	Taxa	(× 100 m)		Fq	Rock	Soil	Wood	Avg	SD
Physciaceae	*Heterodermia indica* (H. Magr. in Awas.) Awas.	31	28	2	6	0	0	0·50	1·45
Parmeliaceae	*Parmelia adducta* Nyl.	26	26	1	0	0	6	0·50	1·73
Parmeliaceae	*Parmelia saxatilis* (L.) Ach.	30	30	1	2	0	4	0·50	1·73
Stictaceae	*Sticta henryana* Mull. Arg.	32	32	1	0	0	6	0·50	1·73
Umbilicariaceae	*Umbilicaria vellea* (L.) Ach. Emondi. Frey	37	37	1	6	0	0	0·50	1·73
Ramalinaceae	*Ramalina himalayensis* Rasanan	34	34	1	5	0	0	0·42	1·44
Physciaceae	*Heterodermia punctifera* (Kurok.) Awasthi	30	30	1	0	0	4	0·33	1·15
Parmeliaceae	*Parmelia rhytidodes* (Hale) A. Singh	28	28	1	4	0	0	0·33	1·15
Peltigeraceae	*Peltigera rufescens* (Weiss) Humb.	28	26	2	1	3	0	0·33	0·89
Usneaceae	*Usnea* cf. *pseudosinensis* Asah. in Hara	29	29	1	4	0	0	0·33	1·15
Lobariaceae	*Lobaria isidiosa* (Mull. Arg) Vainio	28	28	1	3	0	0	0·25	0·87
Nephromataceae	*Nephroma helveticum* Ach.	27	27	1	0	0	3	0·25	0·87
Parmeliaceae	*Parmelia andina* (Mill.) Arg.	28	27	2	2	0	1	0·25	0·62
Parmeliaceae	*Parmelia awasthi* (Hale) Awasthi	31	31	1	0	0	3	0·25	0·87
Parmeliaceae	*Parmelia meiophora* Nyl.	30	29	2	0	0	3	0·25	0·62
Parmeliaceae	*Parmelia pindarensis*	25	25	1	3	0	0	0·25	0·87
Physciaceae	*Phaeophyscia hispidula* (Ach.) Essl.	27	27	1	0	0	3	0·25	0·87
Parmeliaceae	*Cetraria rhytidocarpa* Mont. and Bosch in Jungh.	27	27	1	0	0	2	0·17	0·58
Physciaceae	*Heterodermia comosa* (Eschw.) Follm. and Redon	27	27	1	0	0	2	0·17	0·58
Collemataceae	*Leptogium burnetiae* Dodge	30	30	1	2	0	0	0·17	0·58
Parmeliaceae	*Parmelia pseudosinuosa* Asah.	25	25	1	0	0	2	0·17	0·58
Stereocaulaceae	*Stereocaulon macrocephalum* Mill. Arg.	31	29	2	2	0	0	0·17	0·39
Physciaceae	*Heterodermia incana* (Stirton) Awasthi	27	27	1	0	0	1	0·08	0·29
Collemataceae	*Leptogium askotense* Awasthi	30	30	1	0	0	1	0·08	0·29
Collemataceae	*Leptogium javanicum* Mont.	31	31	1	0	0	1	0·08	0·29
Lobariaceae	*Lobaria* cf. *linita* (Ach.) Rapenh.	27	27	1	0	0	1	0·08	0·29
Parmeliaceae	*Parmelia saccatiloba* Taylor	27	27	1	0	0	1	0·08	0·29
Parmeliaceae	*Parmelia* sp.	29	29	1	0	0	1	0·08	0·29
Usneaceae	*Usnea stigmatoides* Garima Awasthi	29	29	1	0	0	1	0·08	0·29

Alt: Altitude; Max: maximum; Min: minimum; Fq: frequency of occurrence in plots; Abun: abundance; Avg: Average; SD.: standard deviation.

were encountered only once during the study period and hence can be considered as rare members of the community. *Umbilicaria indica* occurring in 75% of all the sampled plots above 2800 m with high average abundance may be recognized as a specialist species confined to rocks but with a broad spatial-elevation range distribution. *Parmelia perisidians* also turns out to be a rock specialist, but with a narrow spatial range, occurring only at 1500 m elevation.

Middle altitude *Quercus* forest had the highest number of species and genera, followed by high altitude mixed *Rhododendron* forest, higher altitude grassland and then the lower altitude *Quercus* forest (figure 3). However, at the family level, high altitude *Rhododendron* forest was rich in number of species of lichens compared to the middle altitude *Quercus* forest. The lower altitude *Quercus* forest consistently had fewer numbers of species, genera and families of macrolichens as compared to the higher altitude grassland.

Similarly, woody substrates supported the highest number of species followed by rock and soil microhabitats in the study area (figure 4). At the family level, rock again turned out to be the richest followed by wood and soil substrates. However, woody microhabitats remained rich for genera of macrolichens.

The change of macrolichen species composition across the plots i.e. beta-diversity or turnover along the elevation gradient, is illustrated in figure 5. The plots belonging to the same macrohabitat type tend to cluster depending upon their macrolichen species composition. The macrolichen assemblages therefore appear to reflect the characteristics of the macrohabitats in which they occur.

The relationships among taxonomic ranks of species, genera and families of macrolichens with respect to their alpha- and beta-diversities along with fitted regression equations (models) are given in figures 6 and 7. There was a significantly positive relationship ($P < 0{\cdot}005$) between species, genus and family level alpha-diversity (figure 6) as well as with respect to the beta-diversity (figure 7) of the macrolichens. The higher taxonomic units such as genera of families may therefore be employed as surrogates for predicting species diversity of the macrolichen community.

4. Discussion

Numbers of species or any other higher ranks of taxonomic organization in a site (species richness or alpha-diversity) and their compositional change across different habitat types (species turnover or beta-diversity) within a landscape are important parameters of biodiversity that have wide applications such as environmental monitoring and conservation evaluation (Magurran 1988, Pressey *et al* 1994; Negi 1999). The present study revealed that the macrolichen assemblages do vary depending upon the types of macrohabitats (under various external pressures such as the disturbance by humans and livestock grazing) in terms of both of these community level biodiversity attributes. Interestingly enough, the lower altitude *Quercus* forest turned out consistently poorer for the three taxonomic ranks of macrolichens as compared to the higher altitude grassland which hardly supports woody

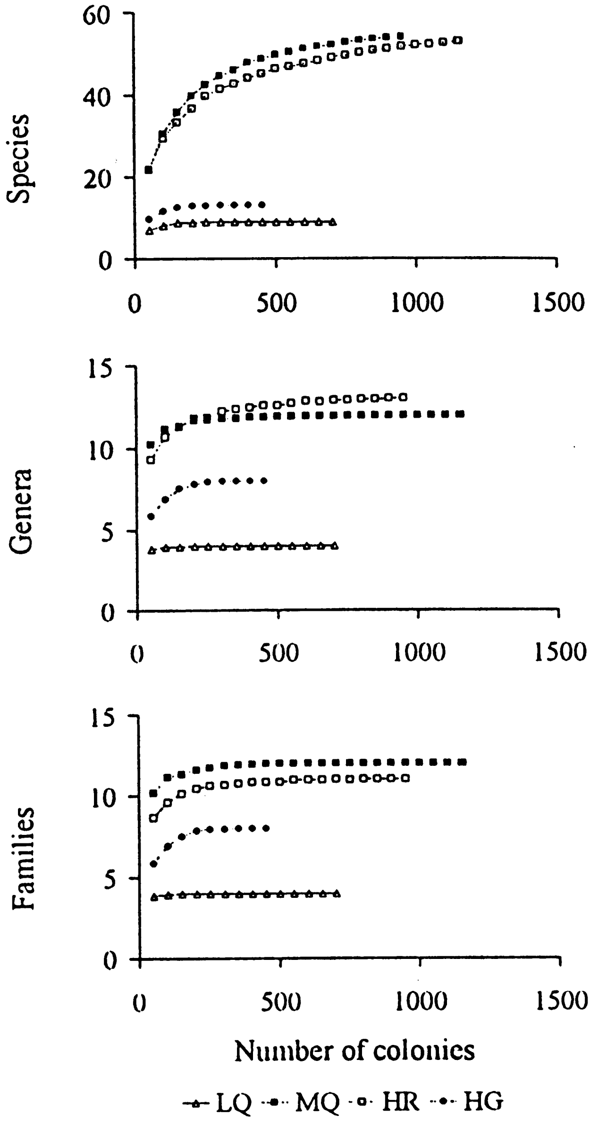

Figure 3. Accumulation of species, genera and families of macrolichens with increasing number of colonies in different macrohabitat types from Chopta-Tunganath. The macrohabitat types are: LQ: lower altitude *Quercus* forest (1500 m); MQ: middle altitude *Quercus* forest (2500–2800 m); HR: high altitude *Rhododendron* forest (2900–3200 m); HG: higher altitude grassland (3400–3700 m). The number of species, genera and families at each interval is an average of 100 simulations.

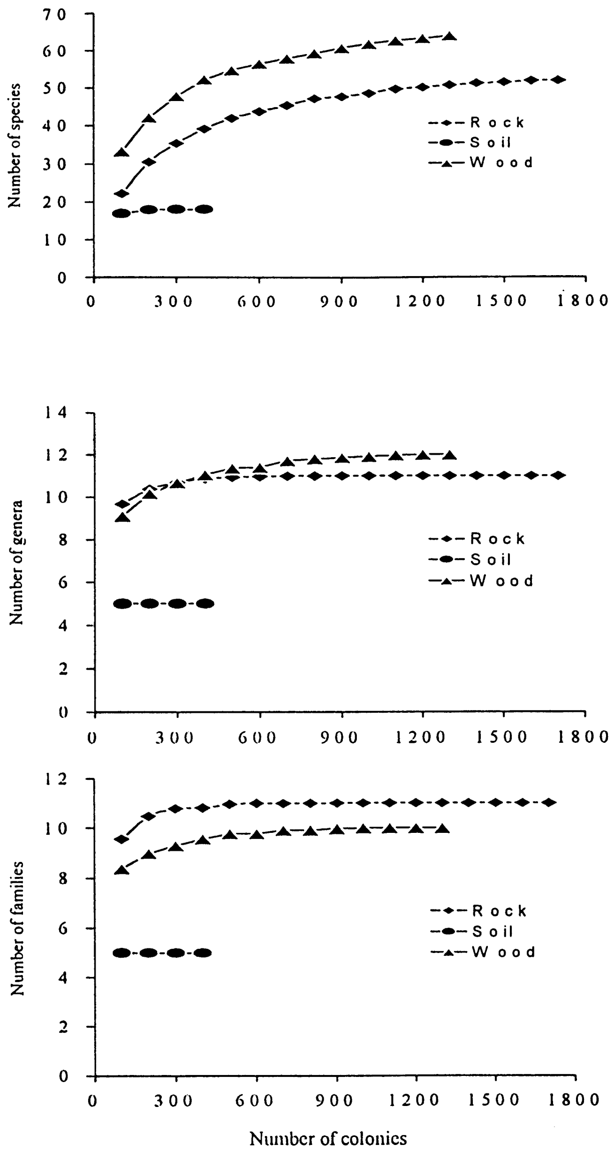

Figure 4. Accumulation of species, genera and families of macrolichens with increasing number of pooled colonies on three microhabitat types, viz. rock, soil and wood, in Chopta-Tunganath. The number of species, genera and families at each interval is an average of 100 simulations.

microhabitats. This disparity of richness may be attributed to the fact that though the lower altitude *Quercus* forest is managed by the local people for cutting and lopping, there is no control over grazing the undergrowth and collection of dry fuel wood throughout the year. This probably has caused the occurrence of only tree trunk bark-loving species along with a few rock inhabiting taxa. Higher altitude grasslands are also open for grazing but only during the summer season. Poor diversity of woody plants might have also contributed to the lower richness of macrolichens in the lower elevation *Quercus* forest as compared to the rest of the woodlands. However, there was no significant correlation between the numbers of species of woody plants and the lichens in the study area.

Although soil is the major microhabitat available everywhere in the study area, it harbours fewer species of lichens as compared to rock and wood substrates. This can be attributed to its unstable nature caused by various local factors such as grazing animals and collection of fuel wood and fodder. However, there are numerous species, genera and families occurring in all the three microhabitats. This brings out the importance of a combination of rock, soil and wood microhabitats in governing the overall diversity of macrolichens. The finding that rocks were richer than wood substrate for the higher taxon ranks, based on equal numbers of macrolichen colonies sampled, requires further investigation. There was a tendency for niche separation from the higher taxonomic hierarchy such as the families towards phylogenetically related lower units of taxonomy, such as the species in terms of their habitat specialization, as reflected in relatively higher proportions of generalist higher taxonomic ranks as compared to their lower rank counterparts.

Since there is a significant difference in the diversity of lichens across the habitats, it is 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 biodiversity. While a number of factors such as urbanization, commercial overexploitation, forest fires and grazing, deforestation and unsystematic forestry practices have been identified as the major threats to the lichen flora (Wolseley 1995; Upreti 1995), there are hardly any efforts to measure and monitor the extent of the actual impact of these land use changes on lichen abundance and diversity (Singh and Sinha 1997; Negi 1999; Negi and Upreti 2000). Livestock grazing and tourism are the dominant land use pressures prevailing in the study area. The macrolichens seem to markedly respond to these disturbances, as the diversity sharply declines from the seasonally grazed high altitude *Rhododendron* forest and alpine meadows to the highly disturbed *Quercus* forest in the lower elevation. The higher levels of macrolichen richness may be attributed to the moderate levels of disturbance in terms of grazing and other factors, such as frequency of human visits for fuel wood and fodder collection, which are activities which go on throughout the year in the *Quercus* forest. However, low temperature and high humidity in the high elevation habitats of *Rhododendron*

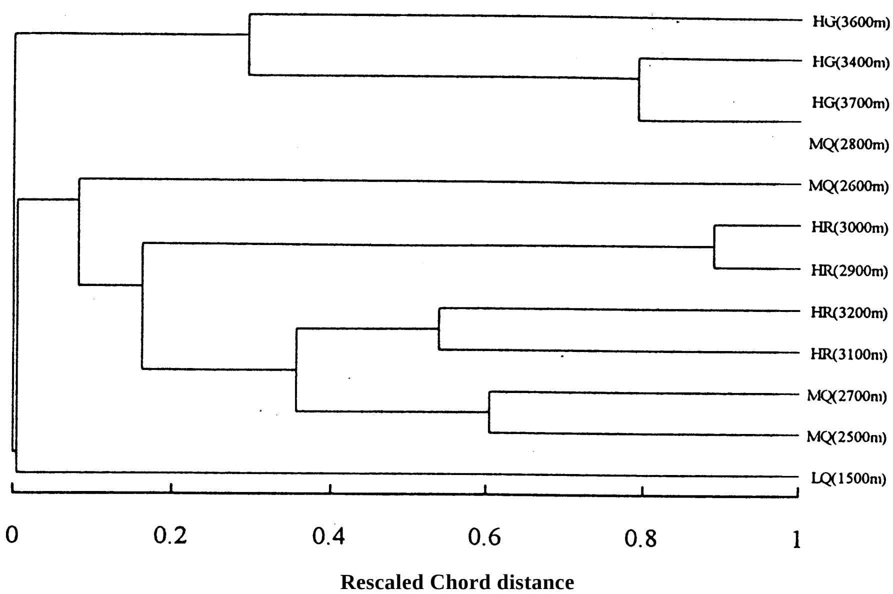

Figure 5. Complete linkage dendrogram of 12 plots sampled in different macrohabitat types in Chopta-Tunganath based on Chord distance with respect to composition of macrolichen species. The macrohabitats are: LQ: lower altitude *Quercus* forest; MQ: middle altitude *Quercus* forest; HR: high altitude *Rhododendron* forest; HG: higher altitude grassland.

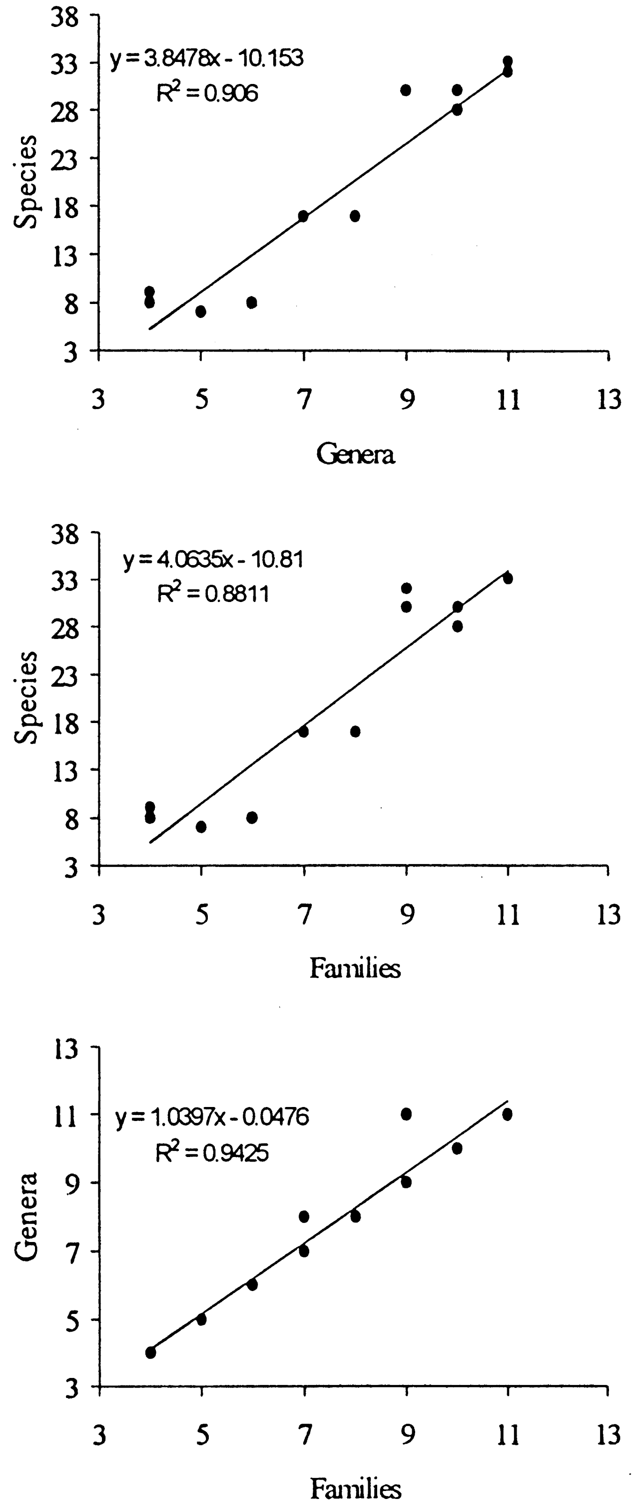

Figure 6. Relationship between species, genus and family level richness of macrolichens in Chopta-Tunganath.

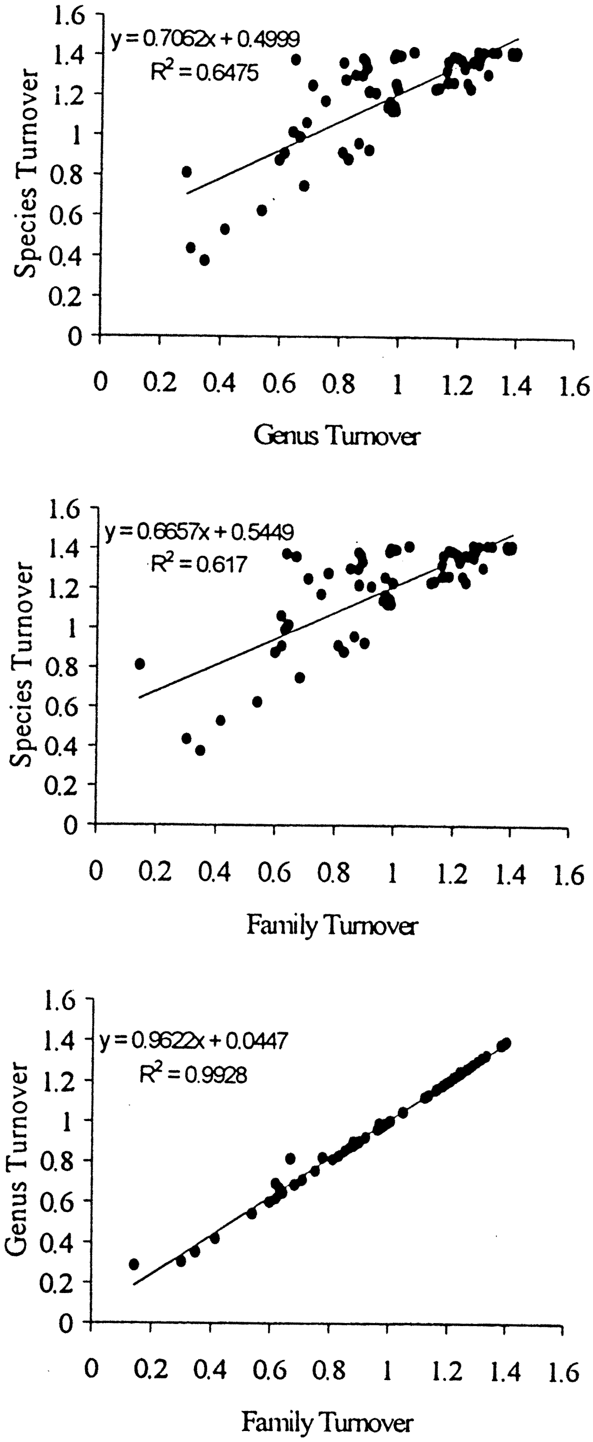

Figure 7. Relationship between species, genus and family level turnovers of macrolichen communities in Chopta-Tunganath.

and grasslands might have also contributed to the richness of macrolichens. Monitoring current land use oriented threats may therefore be of great significance for designing sustainable programmes for the conservation and management of lichen diversity. It is possible that the unregulated ever-increasing tourism in the area may lead to excess demand of fuel wood and livestock products such as meat and milk. These increasing demands for sustaining tourism in the name of development may lead to overgrazing of higher altitude grasslands and excessive wood collection from the woodlands in the area. Both these factors may cause severe damage to the lichen diversity. Similarly, mass trampling by tourists in the high altitude pastures and incidental fires triggered by campfires may also cause unrecoverable loss of many of the rare species in the area. The dynamics of lichen diversity in relation to livestock grazing and tourism as dominant land use activities in the higher Himalaya needs further research.

Inventorying of lower plants is rarely sufficiently funded to attempt the sampling and identification of all the species in a given area for periodic monitoring of diversity. This is because numbers of species are generally very high and their identification is time consuming. A reduced set of taxonomic ranks other than the species may be used as surrogates for time- and cost-effective assessment and monitoring of biodiversity (Gaston and Williams 1993; Prance 1994; Williams and Gaston 1994; Negi 1999). It is therefore necessary to establish the relationship between species diversity and the higher taxonomic ranks. The present investigation showed that even at the family level, inventory of macrolichens may help in accurately predicting species diversity of the community. Similar results have also been shown in moss communities from a different locality in the same region of the Himalaya (Negi 2000). The results therefore imply that inventorying and periodic monitoring at higher taxonomic ranks would save on taxonomic skills, time and cost.

Floristic studies, particularly on lower plants, lacked objective-oriented field methods that partly hindered the progress of long term monitoring of biological diversity and its conservation (Gadgil 1996; Negi and Gadgil 1997; Negi 1999). In this study, a methodological approach is adopted that would facilitate comparable studies and periodic monitoring of such taxa in the future. The study identifies rare species in the community of macrolichens based on quantitative information on the patterns of distribution of populations in a landscape. Without such information, any programme for meaningful conservation and sustainable management of bio-resources in the fragile ecosystems of the Himalaya will remain on shaky grounds. Although the findings presented here are from a relatively small area of about 500 sq km, the study points the way towards locality-specific representative inventorying, and monitoring and thereby conservation of the monitoring and thereby conservation of the diversity of macrolichens in the higher Himalayas.

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