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Diversity and distribution of lichens in relation to altitude within a protected biodiversity hot spot, north-east India

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Abstract: A study of the diversity and distribution of lichens at 10 sites within the Mehao Wildlife Sanctuary in Arunachal Pradesh, India, revealed 177 species, belonging to 71 genera and 35 families. The Sanctuary exhibited almost all the habit and habitat groups of lichens within its climatically heterogenous and altitudinally (400–2700 m) varied landscape. Among the different habitat groups, obligately corticolous lichens were dominant (133 species), followed by facultatively corticolous lichens (occurring on both rock and bark; 25 species), saxicolous lichens (17 species) and terricolous lichens (2 species). The corticolous habitat group was dominated by crustose species while saxicolous and terricolous groups were made up of mostly fruticose species. A substantial number of species (77) occurred at single sites only, and each of the 10 sites supported a distinct lichen assemblage. Altitude and humidity were the putative key factors controlling the diversity and distribution of lichens within the Sanctuary. The mid altitude range 1400–1600 m had the greatest lichen diversity, which showed a unimodal pattern in relation to altitude.

Key words: alpha diversity, epiphytic lichens, indicator species, lichen communities

Introduction

Understanding the pattern of diversity and distribution of organisms is a key aspect in conservation and management. Ecologists are often concerned with patterns of species diversity, which, for any large region may be governed by multiple environmental gradients (Pausas & Austin 2001). In recent years, patterns of species richness and diversity along elevation gradients have attracted considerable interest (Rahbek 1997; Lieberman *et al.*1996; Odland & Birks 1999; Grytnes & Vetaas 2002; Vetaas & Grytnes 2002; Wang *et al.* 2002; Bhattarai & Vetaas 2003; Wangda & Ohsawa 2006). Most of these studies indicate that although species diversity tends to decrease with increasing elevation, it peaks at some intermediate level of elevation, giving rise to a humped-shaped relationship (Grytnes & Vetaas 2002; Sanchez-Gonzalez & Lopez-Mata 2005; Bruun *et al.* 2006). Elevation gradients reflect precipitation and temperature gradients (Whittaker *et al.* 2001; Wang *et al.* 2002). Thus, elevational trends in species richness are generally thought to mimic those that occur along latitudinal gradients (Rahbek 1997; Brown & Lomolino 1998; Givnish 1999). The role of temperature and moisture on the diversity and distribution of lichens has been discussed by several workers (Sheard & Jonesen 1974; Lehmkuhl 2004; Eversman 1982; Lesica *et al.* 1991; McCune & Geiser 1997; Crites & Dale-Mark 1998; Uliczka & Angelstam 1999), but there is comparatively little information on the effects of altitude on the distribution of lichens (Wolf 1993; Arseneau *et al.* 1997; Pentecost 1998; Negi 2000*a*; Pintado *et al.* 2001).

In India, some monographic, revisionary and floristic studies on lichens (*c.* 500 publications) are available, though ecological studies are lacking (Negi & Gadgil 1996; Negi & Upreti 2000; Balaji & Hariharan

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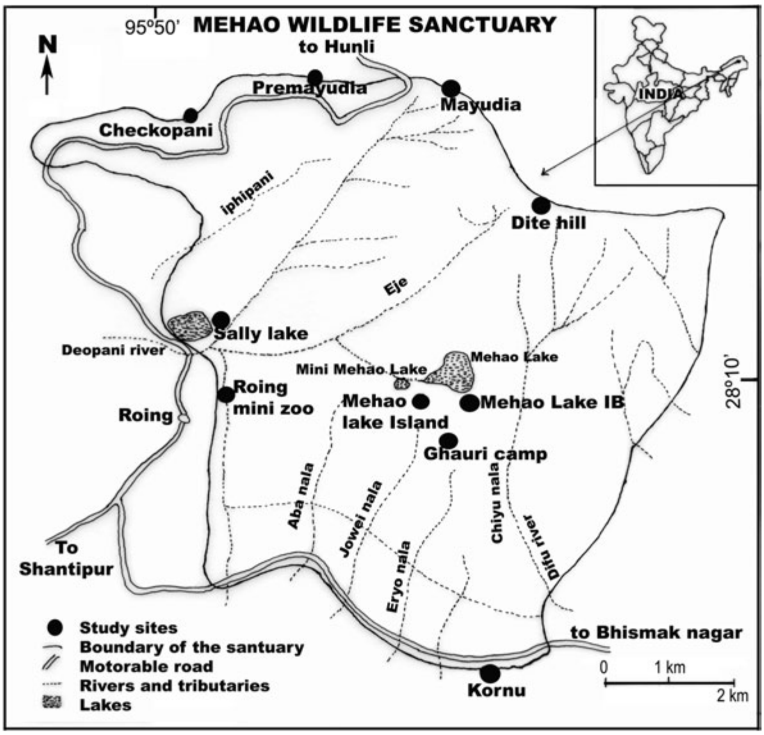

FIG. 1. Map showing location of the study sites in the Mehao Wildlife Sanctuary.

2004; Negi, 2000*a*, *b*; Pinokiyo *et al.* 2006). The present study documents lichen communities in Mehao Wildlife Sanctuary, a protected area in the Eastern Himalaya, and one of the 25 global terrestrial biodiversity hot spots (Myers *et al.* 2000). It emphasizes the significant role played by altitude and humidity in the diversity and distribution of lichens, for a vegetationally heterogenous area with an altitudinal range of *c.* 2500 m.

Materials and Methods

Study area

The Mehao Wildlife Sanctuary (MWLS) lies between 95°15′–93°30′E longitude and 28°5′–28°15′N latitude in the lower Debang valley district of Arunachal Pradesh (a part of the Eastern Himalayan region) in north-east India. It covers an area of 281·5 km^2. The terrain is hilly and relatively inaccessible, with an altitudinal range of 400–3560 m. Three lakes, viz., Sally Lake, Mehao Lake and mini Mehao Lake, occur in the area and the Deopani River drains the MWLS (Fig. 1). The boundary of the MWLS is delineated on the western side by Roing town, on the northern side by Mayudia, on the south side by Kornu, and on the eastern side by Dite Hill (Fig. 1). The vegetation of the area can be divided into the following altitudinal zones: (i) tropical (lower altitude, 400–<1400 m), (ii) subtropical (middle altitude, 1400–<2000 m), and (iii) temperate (high altitude, 2000–2700 m). Ten sites were selected for ecological study representative of the distinct vegetational zones at different altitudes (Table 1).

Methods

Lichens were sampled using 1 × 5 cm quadrats placed on tree trunks (at breast height), on rocks and on soil surfaces. From each site, 25 quadrats were randomly sampled. On tree trunks, the quadrats were randomized with respect to tree species and aspect, and on boulders, with respect to aspect. The total number of samples collected from the entire sanctuary was 250. The number of quadrats for each habitat (viz., tree, rock, soil) was determined subjectively according to the abundance of a habitat class at a given site.

Lichen assemblages were quantitatively analysed for density and frequency (Curtis & McIntosch 1950). The

TABLE 1. *Sites selected for lichen study in Mehao Wildlife Sanctuary*

Sites	Location in MWLS	Human interference	Altitude (m)	Temperature (°C)*	Humidity (%)*	Characteristics of vegetation
Sally Lake (SL)	Western boundary	No human interference	400	24·0	72	Tropical forest dominated by tall trees of *Terminalia myriocarpa* in association with *Bischofia javanica*, *Terminalia bellirica*
Roing mini zoo (RM)	South West boundary	No human interference	500	23·8	64	Tropical open forest consisting mostly of planted trees like *Mesua ferrea*, *Dillenia indica*, *Bombax ceiba*, *Kydia calycina*, *Terminalia chebula*
Kornu (KU)	Southern boundary	Permanent village with human settlement	500	31·0	58	Tropical semi-evergreen forests dominated by *Anthocephalus chinensis* and banana, tea plantations with bamboo breaks
Ghauri Camp (GC)	Central	No human interference	1400	11·4	89	Very dense subtropical evergreen forest dominated by *Alnus nepalensis* and *Castanopsis indica*
Pre Mayudia (PM)	Northern boundary	A vehicular traffic road	1500	21·0	63	Open mixed subtropical forest with massive boulders, dominated by *Quercus griffithi* and *Schima wallichii*
Mehao Lake Island (ML)	Central	Hunting place for villagers	1550	15·0	78	Dense subtropical forests dominated by *Alnus* sp., *Betula alnoides*, *Prunus cerasoides*, *Maesa* spp
Mehao Lake I.B. (MB)	Central	Except for I.B., no interference	1600	14·7	86	Mixed dense forest dominated by *Castanopsis indica*, *Populus* spp., *Quercus* spp. and *Albizia odoratissima*
Checkopani (CP)	Northern boundary	A vehicular traffic road	2050	10·8	75	Relatively open low temperate forest dominated by *Acer* spp., *Betula alnoides* and *Quercus* spp
Mayudia (MA)	Northern boundary	A vehicular traffic road	2400	15·5	67	Temperate open to close forests with massive rocks and dominated by small trees of *Talauma hodgsonii* and *Saussurea napalensis*
Dite Hill (DH)	North Eastern boundary	No human interference	2700	13·0	56	Dense close temperate forests dominated by species of *Quercus*, *Betula* and *Pinus*

*Data on temperature and humidity recorded between 31 October and 17 November 2002 at 11 am and 1 pm respectively.
I.B. = Inspection Bungalow.

importance value index (IVI) used here is the sum of relative frequency and relative density. Relative frequency (RF) and relative density (RD) were determined following Phillips (1959). In brief, RF=100 × (frequency of species *i*/sum of frequency values of all species), and RD=100 × (density of species *i*/sum of density values of all species).

Based on previous field notes collated within the Sanctuary, the lichen species were divided into habitat groups: strictly corticolous (occurring only on bark), facultatively corticolous (occurring both on rock and bark), saxicolous (occurring on rock) and terricolous (occurring on soil); and into growth forms: crustose, foliose, fruticose and squamulose. Species were attributed to genera and families following Erikson & Hawksworth (1998) with slight modifications (Kirk *et al.* 2001; Lücking *et al.* 2005; and Staiger 2002). Alpha diversity (H′) was estimated as the Shannon-Wiener index (Shannon & Weaver 1949):

$$H' = \Sigma p_i \ln p_i$$

where, p_i=density (number of thalli) of the species *i*/density of all species.

Principal Component Analysis (PCA) was used to summarize the compositional differences between the sites. For this analysis, we used the relative importance values of species (relative importance value of a species is 100 × IVI of that species/total IVI of all species where IVI is the importance value index) for each site. The PCA was performed using the correlations option in Biodiversity Pro ver. 2 software (1997). The amounts of variation explained by PCA axes 1 and 2 were calculated by PC-ORD version 5. Pearson's correlation coefficient were calculated to compare explanatory variables (altitude, temperature, humidity) and response variables (PCA axis scores, alpha diversity, species richness [number of species] of all lichens, and that of major growth [crustose, foliose, fruticose], and habitat [corticolous, saxicolous] forms). Regression analyses were performed to compare species richness and alpha diversity with altitude, and with humidity. Both linear as well as second degree polynomial equations were used to fit curves to the data. The sample size (10 sites) was relatively small for polynomial equations. However, only those that yielded significant r^2 or indicated biologically meaningful trends are reported here. All statistical analyses were performed using SPSS.

Results

There were considerable differences in species composition and abundance between the various sites (Table 2). Generally, the mid-altitude sites had the larger number of species (Fig. 2A). Species were relatively restricted in distribution; only one species, *Lecanora perplexa*, occurred at all the 10 sites, and 77 species (44%) were confined to single sites (Fig. 2B). The dominant (highest IVI) and co-dominant (next highest IVI) lichens differed from site to site, indicating distinct lichen assemblages at the different sites; this was confirmed by PCA. Only Sally Lake and Roing mini zoo were adjacent to each other in the PCA ordination space (Fig. 3). In this ordination, PCA axis 1 explained 17·3% of the variation in species composition and PCA axis 2 explained 13·2% variation, both axes together thus explained 30·6% variation in the species composition. The analysis required 9 components (axes) to account for 100% variation in the data set. However, we limit the analysis to the first two axes in this study. PCA axis 1 was significantly related to altitude and temperature, indicating that altitude (and consequently temperature) is the main factor differentiating lichen communities in this area (Table 3). Species richness (total number of lichen species) was also significantly related to axis 1 scores.

Alpha diversity, represented here by the Shannon-Wiener index, ranged from 2·42 (Mayudia) to 3·87 (Ghauri Camp). Species richness (total number of lichen species) among the 10 sites, ranged from 25 (Mayudia) to 68 (Ghauri Camp) (Fig. 2A), and is related to the differences in alpha diversity between lichen assemblages (Table 3).

There was no significant linear relationship between either altitude or temperature and diversity parameters (Table 3). However, polynomial fits to the data suggest that lichen communities at mid-altitude sites were more diverse (Fig. 4A), and the distribution of data points along the altitudinal gradient indicates that there were more lichen species in the mid-altitude region (Fig. 4B). Humidity was significantly related to alpha diversity, total number of species and the number of corticolous species (Table 3). Alpha diversity tended to increase substantially with humidity after the latter attained a threshold value of approximately 55% (Fig. 5A). Diversity of strictly corticolous lichens (y) also showed a non-linear positive increase with percent humidity (x) according to $y=8{\cdot}9-(2\times10^{-2})x+(2\times10^{-3})x^2$, $r^2=0{\cdot}71$, $P<0{\cdot}01$.

TABLE 2. *Species composition of lichen assemblages at ten sites in the Mehao Wildlife Sanctuary. Values are Importance Value Index (IVI)*

Species	SL*	RM	KU	GC	PM	ML	MB	CP	MA	DH
Aderkomyces albostrigosus	–	–	–	3·1	1·3	3·1	–	1·1	–	2·9
Anisomeridium calcicolum	2·8	–	–	–	–	–	–	–	–	–
Anthracothecium indicum	–	–	–	2·2	–	1·1	–	–	–	–
A. thwaitesii	1·7	–	–	2·8	–	3·4	2·8	–	–	–
Arthonia antillarum	2	–	–	–	–	–	–	–	–	–
A. recedens	3	13·3	–	1·2	–	–	–	–	–	–
Arthonia sp. 2	–	–	–	1·2	–	–	–	–	–	–
Aspicilia calcarea	–	–	–	–	1·3	–	–	–	16·5	–
A. dwaliensis	–	1·4	–	1	–	–	–	–	36·3	–
Bacidia nigrofusca	–	–	–	2·4	–	–	–	–	–	–
B. submedialis	3·4	3·1	3·7	–	–	2	–	–	–	–
Bacidiospora psorina	–	–	–	–	2·7	–	–	–	–	–
Buellia alboatra	–	–	–	–	–	–	–	–	–	2
B. leptocline	–	–	–	–	15·9	–	–	–	1·3	–
Bulbothrix isidiza	3·1	1·4	11·5	–	–	–	–	–	–	–
B. setschwanensis	–	–	–	10·6	3·6	4·5	8·3	6·1	–	–
Calicium sp.	–	1·2	–	–	–	–	–	–	–	–
Caloplaca ferruginea	–	–	–	–	–	–	–	–	–	1
C. malaensis	–	–	4·4	1	2·7	1·1	–	–	–	–
Catillaria sp.	–	–	–	1	–	–	–	–	–	–
Catillaria versicolor	–	–	–	–	–	4·5	–	–	–	–
Cetrelia cetrarioides	–	–	–	–	–	–	–	–	–	3·2
Cheilymenia luteopallens	–	–	–	–	–	0·9	–	–	–	–
Cladia aggregata	–	–	–	–	–	–	–	5·4	–	–
Cladonia cartilaginea	–	–	–	2·7	–	–	–	–	–	–
C. coccifera	–	–	–	–	–	–	–	1·1	–	–
C. corymbescens	–	–	–	–	–	–	–	–	–	2·2
C. fruticulosa	–	–	–	–	1·6	–	–	2·2	–	–
C. furcata	–	–	–	–	1·6	–	–	–	–	–
C. macilenta	–	–	–	–	–	–	–	–	2·8	–
C. singhii	–	–	–	–	1·3	–	–	–	–	–
C. yunnana	–	–	–	–	–	–	–	–	–	1·9
Clathroporina anoptella	–	–	–	–	10·1	–	–	–	–	–
Coccocarpia palmicola	10·6	2	5·5	–	1·1	–	–	–	–	–
C. pellita	5·8	23·7	–	–	–	–	–	–	–	
Coenogonium luteum	1·7	–	–	–	–	–	–	–	–	–
Collema pulcellum	1·3	–	5	–	–	–	–	2·5	–	–
Cryptothecia candida	–	–	8·1	–	–	–	–	–	–	–
C. polymorpha	–	–	1·3	–	–	–	–	–	–	–
Cryptothecia sp.	1·7	–	–	–	–	–	–	–	–	–
Dirinaria consimilis	3·4	1·2	8·7	–	–	–	–	–	–	–
D. picta	–	9·2	–	–	–	–	–	–	–	–
Everniastrum cirrhatum	–	–	–	3·7	2·4	–	2	3·6	–	–
E. nepalense	–	–	–	–	1·1	2·6	–	21	2·4	–
Graphina acharii	13·1	17·4	8·1	3·7	–	–	–	1·1	–	1
G. darjeelingensis	2	–	–	–	–	1·7	3·1	–	–	–
Graphina sp. 3	1·3	–	–	–	–	–	–	–	–	–
Graphis anguillaeformis	–	5·5	–	–	–	–	–	–	–	–
G. ceylanica	6·5	11	2·5	5·2	–	10·3	10·3	7·4	–	3·2
G. glaucescens	–	–	1·6	–	–	–	2	–	–	–
G. homichlodes	–	–	–	–	–	3·7	–	–	–	–
G. hossei	1·3	12·2	1·9	–	–	1·7	8·6	2·8	–	14·2
G. scripta	–	14·1	–	–	1·3	10	–	–	–	–

TABLE 2. *Continued*

Species	SL*	RM	KU	GC	PM	ML	MB	CP	MA	DH
G. sikkimensis	–	–	–	1·2	–	–	–	–	–	–
Graphis sp. 1	4·1	–	2·5	3·1	–	11·7	3·5	5·3	2·5	16·7
Graphis sp. 13	3	–	–	7·5	–9·2	9·4	–	–	20·9	
Graphis sp. 4	–	–	–	3·5	–	7·9	4·8	–	–	2·2
Graphis sp. 5	–	–	–	1	–	2·4	–	–	–	28·3
Graphis sp. 6	–	–	–	4·5	–	1·9	–	–	–	3·6
Graphis sp. 7	–	–	–	3·4	–	–	–	–	–	3·6
Graphis sp. 8	–	–	–	–	–	–	–	–	–	3·6
Graphis sp. 9	–	–	–	–	–	–	–	–	–	2·6
G. subdisserpens	4·2	–	–	–	–	–	–	–	–	–
Gymnoderma coccocarpum	–	–	–	–	–	–	–	–	–	1·2
Haematomma wattii	–	–	–	1	–	1·7	1	–	1·1	1
Hafellia disciformis	1·3	–	–	–	–	0·9	1·8	–	–	–
Hemithecium aphanes	–	22·2	–	1·5	–	4·7	7·2	–	–	–
Heterodermia angustiloba	–	–	–	–	5	–	–	–	–	–
H. barbifera	–	–	–	–	–	–	4·5	–	–	–
H. diademata	–	3·6	–	4·9	2·4	5	2	3·6	1·4	1·2
H. firmula	1·3	–	–	7·7	7·6	3·1	3·3	3·9	–	–
H. flabellata	–	–	–	–	–	–	–	1·8	–	–
H. himalayensis	–	1	–	–	–	–	–	–	–	–
H. leucomela	–	–	–	1	–	–	–	–	–	–
H. obscurata	–	–	–	–	3	0·9	2	5·7	2·2	–
H. podocarpa	–	1	–	1	–	5·5	–	4·3	–	–
H. punctifera	–	–	–	–	–	–	–	2·2	–	–
H. rubescens	–	1·2	2·5	1·2	–	–	3	3·2	–	–
H. speciosa	–	–	1·3	2	1·8	–	–	–	–	3
Hypotrachyna boquetensis	–	–	–	4·2	5·6	7·1	5·2	3·2	5·1	–
H. flexilis	6·3	–	–	6·1	5	–	2·8	7·1	–	–
H. imbricatula	–	–	–	–	–	–	–	1·4	–	–
H. infirma	–	–	1·3	–	–	–	–5	–	–	
H. koyaensis	–	–	–	–	–	–	–	2·5	–	–
H. osseoalba	–	–	–	–	–	2·9	–	–	–	–
H. physcioides	–	–	–	1·8	–	6·1	–	–	–	–
H. rigidula	1·3	–	–	1	–	–	2	8·2	3·7	1
H. scytophylla	–	–	–	–	13·4	–	–	1·4	–	–
H. thryptica	–	–	–	–	–	–	4·9	–	–	–
Ionaspis lacustris	–	1·2	–	1·5	–	–	–	–	–	–
Lecanora alba	–	–	–	–	–	–	–	–	–	1
L. conciliandra	–	–	–	3	8·8	1·4	–	–	20·3	1·2
L. fimbriatula	–	6·8	–	–	–	–	3	–	–	–
L. interjecta	–	–	–	2·9	7·2	3·6	–	–	2·5	9·5
L. perplexa	1·7	11·9	10·8	2·9	24·8	3	3·1	11·7	5·3	24·6
L. phaeocardia	2	–	–	7·2	5·7	3·5	3·7	3·2	6	15·1
Lecidea sp. 1	1·3	–	–	4·3	10·4	1·7	8·4	–	7·9	–
Lecidea sp. 2	–	–	–	3·7	–	–	–	–	–	–
Lecidea sp. 3	–	–	–	1	–	–	–	–	–	–
Leptogium askotense	–	–	–	–	–	1·7	1·6	–	–	–
L. austroamericanum	–	3·9	–	–	–	–	–	1·8	–	–
L. delavayi	–	–	–	–	4·6	–	–	–	2·4	–
L. denticulatum	31·5	8·4	–	1·9	–	–	–	–	–	–
L. javanicum	–	1·2	–	–	–	–	–	–	–	–
L. moluccanum	–	–	17·6	3·1	–	–	1	12·2	–	–
L. pedicellatum	–	–	–	–	–	–	–	3·6	–	–
L. trichophorum	–	–	–	1·2	–	–	–	8·6	–	–

Table 2. *Continued*

Species	SL*	RM	KU	GC	PM	ML	MB	CP	MA	DH
Letrouitia transgressa	–	–	2·5	–	–	–	–	–	–	–
Lobaria isidiosa	–	–	–	3·5	2·4	–	–	17·2	–	–
L. pseudopulmonaria	–	–	–	–	–	–	1·3	2·5	–	–
L. retigera	–	–	–	–	4·7	1·7	–	2·5	1·3	–
Malcolmella granifera	–	1	–	–	–	–	–	–	–	–
Maronea manipurensis	–	–	–	–	–	6	3·9	3·6	8·7	2·2
Megalaria laureri	–	–	–	–	–	–	1·3	–	–	–
Megalospora tuberculosa	–	–	–	–	–	1·7	1	–	–	1
Mycobilimbia philippina	–	–	–	1·5	–	–	–	1·1	33·3	–
Myelochroa aurulenta	–	6·7	1·3	–	–	–	–	1·4	–	–
Myriotrema sp. 1	3·4	–	–	–	–	–	3·5	–	–	7·4
Ocellularia papillata	–	–	–	–	–	0·9	1·6	–	–	–
Opegrapha sp.	–	–	–	–	–	–	–	–	–	1
Parmelaria thomsonii	–	–	–	4·6	–	–	–	1·1	–	1
Parmelinella simplicior	–	–	–	–	–	–	2·3	4·6	–	–
P. wallichiana	–	–	–	1·9	–	–	–	3·6	–	–
Parmelinopsis spumosa	–	–	2·5	–	–	–	–	–	–	–
Parmotrema mesotropum	–	1·2	–	–	–	–	–	–	–	–
P. robustum	–	1·7	1·3	–	–	–	–	–	–	–
Parmotrema sp.	–	–	–	–	–	2·7	–	–	–	–
P. tinctorum	1·3	–	2·5	–	–	–	–	–	–	–
P. zollingeri	–	–	–	1	2	3·7	1·8	1·4	–	–
Peltigera polydactylon	–	–	1·3	–	–	–	1	1·1	–	–
P. coronata	32·1	–	17·1	–	–	3·1	1·6	–	–	–
P. indica	–	3·8	–	–	1·8	–	–	–	2·5	–
P. quassiae	–	–	–	–	–	–	1	–	–	–
Pertusaria sp. 1	8·6	13	8·5	–	–	0·9	5·1	1·1	–	1·2
Phaeographina austroindica	–	2	–	–	–	–	–	–	–	–
Phaeographis angulosa	–	–	–	–	–	–	1	–	–	1
P. endophaeiza	–	–	–	3·1	–	12·7	4·1	–	1·5	–
Phaeographis sp. 2	–	–	–	–	–	2	3·5	–	–	–
Phaeographis sp. 3	–	–	–	–	–	1·1	–	–	–	–
Phaeophyscia endococcina	–	1·4	–	1·2	4	–	–	–	–	–
P. hispidula	–	–	–	–	1·8	1·1	–	–	–	–
Phlyctis sp.	–	–	–	1·8	–	–	–	–	3·5	–
Phyllopsora corallina	14·5	–	–	–	–	–	–	–	–	–
Physcia semipinnata	–	–	6·5	–	–	–	–	–	–	–
P. tribacioides	–	–	6·4	–	–	–	–	–	–	–
Porina sp.	–	–	1·6	6·5	–	–	3·8	–	–	–
P. andamanica	1·3	2·7	–	–	–	5·7	–	–	–	–
P. atroperiostiola	–	–	–	1·2	–	–	–	–	–	–
P. belanospora	3·4	–	–	8	–	–	1·8	–	–	–
P. glabra	–	–	–	–	1·8	–	–	–	–	–
P. innata	–	–	–	2	–	–	–	–	–	–
P. interstes	–	–	–	3·4	–	–	–	–	–	–
P. subinterstes	–	–	–	1·8	–	–	–	–	–	–
Pseudopyrenula diluta	–	–	–	–	–	–	4·3	–	–	–
P. pupula	–	–	–	1·9	–	–	1	–	–	–
Pyrenula fusco-olivacea	–	9	–	–	–	–	5·3	–	–	–
P. brunnea	–	–	–	8·5	–	–	2·3	–	–	
P. defossa	1·3	–	–	–	–	–	–	–	–	–
P. immersa	–	–	–	1·8	–	–	–	–	–1	
P. introducta	3·7	1	11·7	–	–	–	3·9	–	–	–
P. subacutalis	6·4	–	8·1	–	–	6·7	3·5	–	–	9·8

TABLE 2. *Continued*

Species	SL*	RM	KU	GC	PM	ML	MB	CP	MA	DH
Pyxine sorediata	–	1·2	–	–	–	–	–	–	–	–
Rimelia reticulata	–	–	–	1	–	–	9·4	–	–	1
Rinodina badiella	–	–	–	–	11·6	–	–	–	–	–
R. intrusa	–	–	1·3	–	–	–	–	–	–	–
R. mackenziei	–	–	–	2·2	1·3	–	2·5	–	–	–
R. sophodes	–	–	–	–	5·6	4·1	–	–	–	1·5
Sarcographa tricosa	1·3	–	–	–	–	0·9	1	–	–	–
Stereocaulon massartianum	–	–	–	–	–	1·6	–	–	–	–
S. togashii	–	–	–	2·4	–	–	2·2	25·7	–	
Sticta filicina	–	–	–	1	–	–	–	–	–	–
Thelotrema dilatatum	–	–	–	–	–	0·9	–	–	–	–
Trypethelium meghalayensis	–	–	–	–	–	–	2·8	–	–	–
Usnea cineraria	–	–	–	3·7	4	5·7	8·9	2·9	3·8	–
U. dasaea	–	–	–	4·6	2·9	–	–	–	–	–
U. pangiana	–	–	–	1·2	–	–	–	–	–	–
Verrucaria transiliens	–	–	5·7	1·2	–	–	–	–	–	–

*See Table 1 for explanation of site abbreviations; –=not present.

Total species richness (y) also increased with per cent humidity (x) (Fig. 5B). The lowest number of species (25) was recorded from the Mayudia site located at 2400 m, which is affected by human disturbance and pollution. Among the mid-altitude sites, the Premayudia site, located at 1500 m had only 41 species of lichens, whereas the other three sites in this altitudinal zone (Ghauri Camp, Mehao Lake I.B. & Mehao Lake Island) located near the Mehao Lake, each supported 54–68 species.

Among the different habitat groups, strictly corticolous lichens were dominant with 133 species, followed by facultatively corticolous lichens with 25 species, saxicolous lichens with 17 species and terricolous lichens with 2 species (Table 4). Interestingly, the numbers of species which were strictly corticolous and facultatively corticolous varied substantially between the sites (Table 4). Species richness of corticolous lichens contributed significantly to the differences in alpha diversity of the lichen assemblages of the Sanctuary (Table 3).

Among growth forms, crustose lichens accounted for 56% of the lichen flora, whereas foliose lichens represented 34% and fruticose lichens 8%. There was only one squamulose species, which was confined to bark (Table 4). Foliose species were represented most frequently in corticolous form, and fruticose species in the saxicolous habitat form. Species richness of the crustose lichens was greater than that of the other growth forms at 8 sites, whereas the foliose species were most numerous in only two localities (Premayudia 18 out of 41, and Chekopani 31 out of 46) (Table 4). Intermediate altitudes appeared to be relatively more favourable for the development of a foliose lichen flora as the number of foliose species (y) declined linearly between 1500 and 2700 m altitudes (x): $y = 32{\cdot}87 - (1{\cdot}02 \times 10^{-2})x$, $r^2 = 0{\cdot}72$, $P < 0{\cdot}01$. The number of crustose species (y) generally increased with relative humidity although in a non linear manner: $y = 223 - 619x + 469x^2$, $r^2 = 0{\cdot}597$, $P < 0{\cdot}04$. Fruticose lichens were absent in the lower altitude region and occurring only at sites at or above 1400 m (Table 4). Among the localities, the maximum number of foliose species occurred at Chekopani, while the minimum number occurred at Dite Hill (Table 4). The maximum number of crustose species was found at Ghauri Camp site and the minimum occurred at Chekopani, which also had the maximum number of foliose species.

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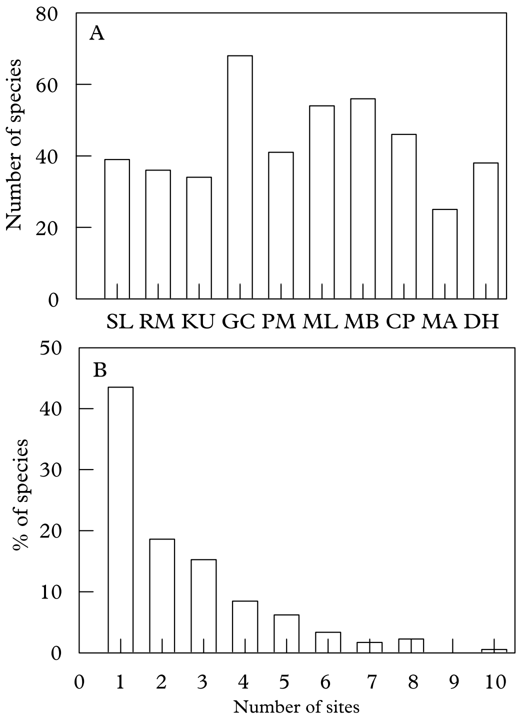

FIG. 2. The distribution and frequency of lichen species at sites in the Mehao Wildlife Sanctuary. A, number of species recorded at each site (sites are aligned along an altitudinal gradient from left (lower altitude) to right (higher altitude); B, frequency distribution of species occurring at different numbers of sites. SL=Sally Lake, RM=Roing mini zoo, KU=Kornu, GC=Ghauri Camp, PM=Pre Mayudia, ML=Mehao Lake Island, MB=Mehao Lake I. B., CP=Chekopani, MA=Mayudia, DH=Dite Hill.

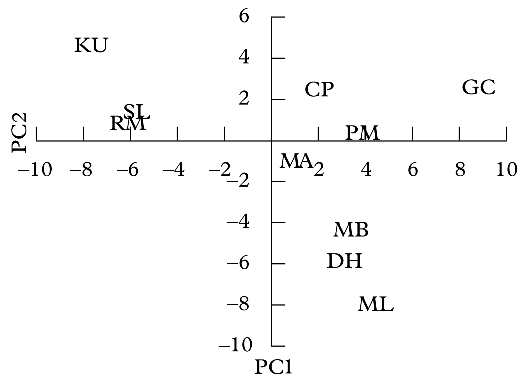

FIG. 3. PCA ordination plot of 10 study sites (=Lichen communities at the Mehao Wildlife Sanctuary). See legend for Fig. 2 for explanation of abbreviations for sites.

Species richness of foliose lichens significantly contributed to the differences in alpha diversity of lichen assemblages, and the number of fruticose species was significantly related to the PCA axis 1 scores, indicating it to be an important factor in differentiating lichen assemblages (Table 3).

Discussion

As many as 2050 lichen species are reported from India (Singh *et al.* 2002). Singh & Sinha (1997) divided India into 8 lichen regions. Among these, the Eastern Himalayan region harbours the largest number of species (approximately 850 species), followed by the Western Ghats (800 spp.) (Bujarbarua *et al.* 2002). With 177 species, 71 genera and 35 families, Mehao Wildlife Sanctuary (MWLS) represents 8·6% of the known Indian lichen flora, and is the richest of the protected areas in India examined so far (Upreti & Divakar 2003; Nayaka *et al.* 2001; Upreti & Negi 1995; Phatak *et al.* 2004; Balaji & Hariharan 2004; Negi & Upreti 2000; Nayaka *et al.* 2004). It is surpassed in the number of lichen species only by the Palni Hills in Western Ghats (318 spp.) (Negi 2000*b*). However, it should be emphasized that the number of species reported here from the MWLS is based on a sub-sample (250 random quadrats, each 1·25 m × 5 cm in size) only, and the actual number of species is likely to be far greater.

More lichen species were found on tree bark (133 spp.) than any other substratum, reflecting the importance of the woody component of the forest as a major lichen habitat. Negi (2000*a*) found that over 64% species of lichens occurred on woody components in two landscapes: Chopta-Tungnath and Nanda Devi Biosphere Reserve in India. Our study indicated that among the lichen growth forms, crustose lichens (56·5% of all lichen species) were predominant followed by foliose (34·5%), fruticose (8·5%) and squamulose (0·6%). Studies from other protected areas (Upreti &

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TABLE 3. *Pearson's Correlation coefficients between PCA axes and selected variables. (P values are given in parentheses)*

	PC1	PC2	ALT	TEMP	HUMI	SR	H	CRUS	FOL	FRU	CORT
PC2	−0·417										
ALT	0·676*	−0·508									
TEMP	−0·855**	0·451	−0·785**								
HUMI	0·555	−0·1	−0·007	−0·539							
SR	0·65	−0·159	−0·006	−0·509	0·835**						
H	0·519	−0·062	−0·118	−0·391	0·798**	0·957**					
CRUS	0·459	−0·482	−0·043	−0·311	0·621	0·755*	0·598				
FOL	0·226	0·438	−0·11	−0·241	0·466	0·519	0·691*	−0·148			
FRU	0·726*	0·007	0·627	−0·593	0·095	0·213	0·186	−0·208	0·394		
CORT	0·384	−0·327	−0·138	−0·304	0·702*	0·867**	0·792**	0·923**	0·167	−0·232	
SAXI	0·35	0·423	0·186	−0·189	0·022	−0·021	0·015	−0·47	0·445	0·792**	−0·497

*Correlation is significant at the 0·05 level (2-tailed); **correlation is significant at the 0·01 level (2-tailed).

ALT=altitude; HUMI=humidity; TEMP=temperature; SR=number of species of lichens; H=Shannon's diversity based on species density; CRUS=number of crustose lichen species; FOL=number of foliose lichen species; FRU=number of fruticose lichen species; CORT=number of corticolous lichen species; SAXI=number of saxicolous lichen species.

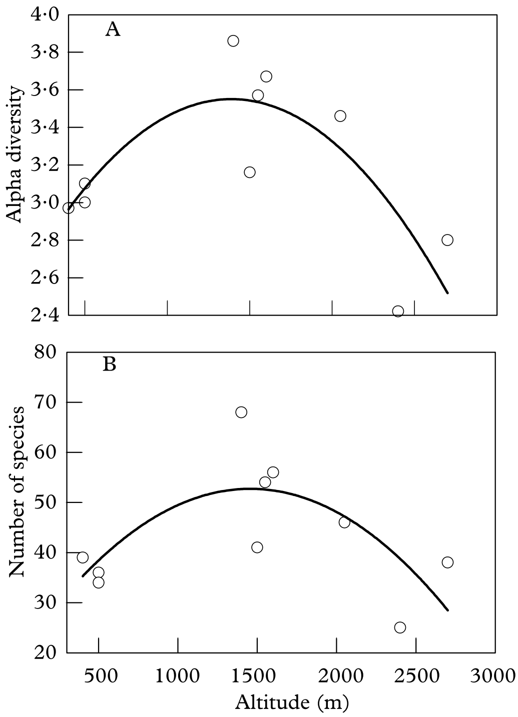

FIG. 4. Relationships between altitude and (A) alpha diversity (Shannon-Wiener) and (B) species richness of lichen communities at Mehao Wildlife Sanctuary. The polynomial equations are $y=2{\cdot}392+(1{\cdot}7\times 10^{-3})x-(6\times 10^{-7})x^2$, ($r^2=0{\cdot}64$, $P<0.03$) in (A) and $y=19{\cdot}55+0{\cdot}045x-(1{\cdot}57\times 10–5)x^2$, ($r^2=0{\cdot}50$, $P<0{\cdot}087$) in (B).

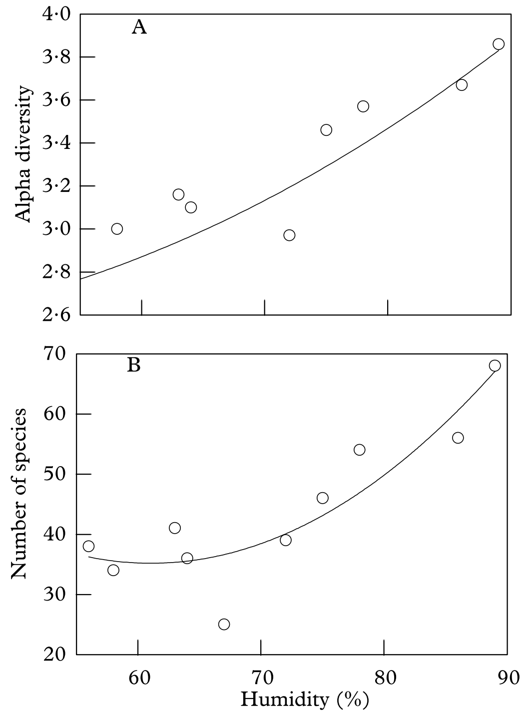

FIG. 5. Relationship between relative humidity and (A) alpha diversity (Shannon-Wiener) and (B) species richness of lichen communities at the Mehao Wildlife Sanctuary. The polynomial equations are $y=5{\cdot}597-9{\cdot}838x+8{\cdot}915x^2$, ($r^2=0{\cdot}67$, $P<0{\cdot}02$) in (A) and $y=0{\cdot}4x^2-4{\cdot}98x+187{\cdot}5$, ($r^2=0{\cdot}82$, $P<0{\cdot}002$) in (B).

Divakar 2003; Nayaka *et al.* 2001; Upreti & Negi 1995; Phatak *et al.*, 2004; Balaji & Hariharan 2004; Negi & Upreti 2000; Nayaka *et al.* 2004) have also shown crustose species to be more numerous than other growth forms, except for Nanda Devi Biosphere Reserve and Meghamalai Wildlife Sanctuary where foliose species were more numerous than crustose species. Singh & Sinha (1997) observed that more than 60% of the lichens recorded from India are crustose. This makes biodiversity monitoring more difficult since taxonomic knowledge of crustose lichens is rather poor.

Ecological factors play an important role in the growth, development, distribution and diversity of lichen species (Brunialti & Giordani 2003). Variations in microclimatic conditions, particularly light, water and nutrients, driven by local sources of disturbance, such as roads or farms, different land uses or habitat fragmentation can influence lichen diversity (Jonsson & Jonsell 1999; Sillett & Goslin 1999; Moen & Jonsson 2003). In the MWLS, the distribution of lichen species was not uniform and reflected variability in environmental conditions between the different sites. The undisturbed central zone (Mehao Lake I. B., Mehao Lake island and Ghauri Camp) supported more lichen species compared to the sites located along road sides towards the periphery of the Sanctuary. Furthermore, the presence of the large Mehao Lake in the central part of the Sanctuary is thought to be important in influencing the growth and development of lichens. The lake may create favourable local climatic conditions for the growth of lichenized fungi. Chekopani was

TABLE 4. *Numbers of lichen species in habitat groups and growth forms at study sites in the Mehao Wildlife Sanctuary*

	Habitat groups				Growth forms			
Sizes	Corticolous	Saxicolous	Terricolous	Facultatively corticolous	Crustose	Squamulose	Foliose	Fruticose
Sally Lake	38	1	–	–	28	1	10	–
Roing mini zoo	31	4	–	1	20	–	16	–
Kornu	33	1	–	–	18	–	16	–
Ghauri Camp	60	7	–	1	42	–	22	4
Pre Mayudia	21	12	2	6	17	–	18	6
Mehao Lake Island	53	1	–	–	38	–	14	2
Mehao Lake I.B.	56	–	–	–	37	–	18	1
Chekopani	28	8	–	10	10	–	31	5
Mayudia	14	7	–	4	15	–	7	3
Dite Hill	38	–	–	–	29	–	6	3
*All sites	133	17	2	25	100	1	61	15

– Habitat/growth form group absent; *totals include only those sites where a given habitat group was present.

found to be the site with the greatest diversity of corticolous foliose lichens and the lowest diversity of crustose lichens; this is the coolest site with relatively open forest and hence greater irradiance. It also exhibited the maximum alpha diversity for saxicolous fruticose lichens. Epiphytic macrolichens are known for their drought tolerance and high light requirement (Pentecost 1998). On the other hand, the corticolous fruticose lichen diversity was maximum in the dense forest at Ghauri Camp, possibly a response to greater availability of habitat. Furthermore, while disturbed and undisturbed sites occurred across the altitudinal gradient, tree species composition and tree diversity, varied across the sites, and could be an important factor in the distribution and abundance of lichens.

In our study, PCA ordination illustrated the occurrence of rather distinct lichen communities at different sites, and their distribution was significantly related to altitude, indicating that altitude is among the main factors differentiating the lichen assemblages. The change in species composition of these communities along the altitudinal gradient might reflect the different ecological conditions of the sites. Although humidity was not linearly related to altitude or to the scores of the first two axes of PCA, it too was a significant factor, as shown by 2nd degree polynomial regression, explaining 67% variability in alpha diversity and 82% variability in lichen species richness. Thus altitude and humidity appear to have a substantial effect on the distribution of lichen flora and communities in the MWLS.

At MWLS the relationship between alpha diversity and altitude was unimodal indicating maximum diversity at middle altitudes. Such observations have also been reported for the Colombian rainforest (Wolf 1993). In the montane forest of Thailand, a greater number of foliose and fruticose lichens occurred above 1500 m, while between 350 and 900 m crustose species increased (Wolseley & Aguirre-Hudson 1997). In our study, the intermediate altitudes supported a greater number of foliose species, and fruticose lichens were absent from lower altitudes. Arseneau *et al.* (1997) reported a decrease in fruticose lichen biomass and species at higher altitudes in Quebec.

The unimodal ('hump-shaped') relationship with altitude is thought to be caused by the regional pool of available species (Bruun *et al.* 2006). The low diversity of high altitude assemblages may result from environmental conditions that limit the pool of available species (Lieberman *et al.* 1996). At high altitudes, local communities are supposedly just samples of the regional species pool and, as the size of the species pool declines with increasing altitude, so does local species richness (Bruun *et al.* 2006). In our study, the number of unique species at the lowest elevation site, Sally Lake, was 10, which was equal to the number of unique species at the highest elevation site, Dite Hill, indicating that the species pool at high altitude may not be a limiting factor. Another potential explanation for the maximum species richness at mid-altitudes is the environmental heterogeneity hypothesis of Rosenzweig & Abramsky (1993), which proposes that diversity is positively related to heterogeneity, which in turn peaks with intermediate productivity. The mid-elevation sites in our study, supported mixed subtropical forest species which provided more heterogenous conditions (greater variety of phorophytes and consequently variable bark characteristics, etc.). Biodiversity of corticolous lichens, for example, may change due to characteristics such as tree age or tree species (Jüriado, *et al.* 2003; Pentecost 1998) and correspondent bark pH (Kuusinen 1996; van Herk 2001), or even due to tree health status (Hauck & Runge 2002). Smooth thin barked trees had a high diversity of lichens. In Thailand the corticolous lichen flora of the evergreen and deciduous trees occurring at the same altitude in a montane forest were different (Wolseley & Aguirre-Hudson 1997). Tree species diversity is also important for creating the conditions necessary for a diverse epiphytic lichen community (Jüriado *et al.* 2003). In addition, the subtropical forest sites in the MWLS represent a transition zone between tropical and temperate forests.

Overlapping species ranges in such transition zones are believed to underly the high species diversity of their epiphytic bryophytes and lichen communities (Wolf 1993).

In conclusion, the lichen flora of the MWLS is remarkably rich and diverse, with a unimodal pattern of species diversity with reference to altitude. These are distinct species assemblages at different sites, showing restrictive species distribution, and signifying a need for protection of large areas for lichen conservation.

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