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Ecological variables influencing the diversity and distribution of macrolichens colonizing *Quercus leucotrichophora* in Uttarakhand forest

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Abstract: Ecological variables play a significant role in determining the diversity and distribution of any living organism on earth. Lichens are not exceptional and are quite sensitive in comparison to other organisms; hence the present study focuses on the impact of ecological variables on the diversity and distribution of epiphytic macrolichens colonizing *Quercus leucotrichophora* across eight different sites (50 m × 50 m) in Thal Ke Dhar forest, Kumaun Himalaya, Uttarakhand, India. For sampling of macrolichens, 200 trees (25 trees from each site) of *Q. leucotrichophora* were selected from each site and five quadrats of 5 cm × 10 cm (1000 quadrats in totality) were drawn at the tree trunk. From all the sampled trees, a total of 54 species of epiphytic macrolichens belonging to 18 genera and five families were recorded. Various ecological variables, namely altitude, aspect, slope, diameter at breast height (DBH), and lopping percent (partial cutting of the twigs as disturbance), were also analyzed to investigate their influence on macrolichen species composition and distribution pattern in the study area. For the determination of relationships between these variables, statistical analysis, namely Pearson's Correlation Coefficient, Polynomial regression analysis and Principal Component Analysis (PCA) were performed. Out of all variables, lopping was significantly correlated to species richness of epiphytic macrolichens (0.712*, $p<0.05$) and it was confirmed by Pearson's Correlation Coefficient. Despite of having high anthropogenic pressure or impact through lopping, the maximum number of macrolichen species was recorded at elevation 2267 meter above sea level (m asl). The present study revealed that besides other ecological variables, lopping practices can act as a key parameter in

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controlling the diversity and distribution not only of epiphytic macrolichens but also of other life forms such as bryophytes, pteridophytes, insects, birds etc. and can be either negatively or positively correlated.

Keywords: Conservation; Epiphytic macrolichens; Kumaun Himalaya; Lopping; *Quercus;* Banj oak

Introduction

The Western Himalaya comprising two broader regions, Garhwal and Kumaun, is a rich repository of biodiversity. Oak (*Quercus*) which is considered as a keystone species in a wide range of habitats from the Mediterranean semi desert to subtropical rainforest have considerable conservation significance and in Himalaya it provides numerous ecosystem services and serves as lifeline for the local communities (Singh and Rawat 2012). Besides ecological and economical services to mankind, oaks also support system to various life forms such as pteridophytes, bryophytes, avifauna, insects, lichens etc. Owing to their immense importance, Oaks are under severe threat in the wild (Oldfield and Eastwood 2007). In comparison to other oak species, *Quercus leucotrichophora* is the dominant tree species in the sub-tropical to temperate regions of Kumaun Himalaya (Singh et al. 2016). More than 70% livelihood of this region is totally dependent on this species for fuel wood and fodder. Due to the overexploitation of oak in Kumaun Himalaya, many life forms like epiphytic lichens have been affected, which are quite sensitive to environmental variables such as altitude, climate, light, temperature, humidity, substrate and age of the forest.

Lichens which are designated as the most significant bioindicators (Kricke and Loppi 2002) of forest health and ecological continuity as well as atmospheric pollution (McCune 2000; Brunialti and Giordani 2003; Wolseley et al. 2006), are widespread in many forest ecosystems where they constitute an important component of the total biodiversity (Dettki and Esseen 2003) and also have several ecological applications in forest ecosystems such as increase in structural complexity, modify canopy water regimes, influence nutrient cycling and provide habitat, food and nest material for many animals (Galloway 1992). The diversity and distribution of these sensitive organisms are influenced by several factors, among which anthropogenic pressure is one of the most important factors, affecting species composition and distribution. Although the role of different environmental variables on the diversity and distribution of lichens have been studied (Negi 2000a, b; Pintado et al. 2001; Lehmkuhl 2004; Pinokiyo et al. 2008; Rai et al. 2012, 2015) but only a few studies are available related to effect of disturbance on lichen diversity and distribution pattern (Friedel et al. 2006; Werth et al. 2006; Yeshitela 2008; Rai et al. 2012, 2015). In India, several studies have been performed to document lichen species (Divakar and Upreti 2005; Awasthi 2007; Singh and Sinha 2010), but only a few studies are available on their ecological aspects (Negi 2000a, b; Negi and Upreti 2000; Balaji and Hariharan 2004; Pinokiyo et al. 2008; Rai et al. 2012, 2015; Bisht et al. 2013; Joshi et al. 2016). However, diversity and distribution of macrolichens in Kumaun Himalaya along with ecological variables have not been investigated till date. Specifically, we conducted this study in Thal Ke Dhar forest of Kumaun Himalaya to answer the following research questions: (i) whether there are any quantitative differences on diversity and distribution of epiphytic macrolichens in various sites, and (ii) what is the impact of different ecological variables on diversity and distribution pattern of epiphytic macrolichen species?

1 Materials and Methods

1.1 Study site

The present study was carried out in January 2015 in Thal Ke Dhar Forest (Pithoragarh district) of Kumaun Himalaya, a part of Western Himalaya, which is stretched over an area of 1315.60 hectare and lies between 29°30.965' to 29°31.106'N latitude and 80°14.376' to 80°12.634'E longitude. The forest was divided into four macrohabitats based on the dominant vegetation type: (1) *Quercus leucotrichophora* forest, (2) *Q. lanata* and *Q. leucotrichophora* mixed forest, (3) *Rhododendron arboreum* forest and (4) *R. arboreum* and *Q. leucotrichophora* mixed forest and is characterized by variability in elevation (2100 to 2500 m asl) (Table 1) and climatic parameters, such as mean annual temperature (5.5°C-8.0°C) and rainfall (367 mm). The macrohabitats were further divided into eight subgroups across altitudinal gradient and among these four macrohabitats the sampling for epiphytic macrolichens was done only on *Q. leucotrichophora* trees.

1.2 Sample collection

Eight sites each of 50 m × 50 m within four macrohabitats were selected across altitudinal gradient and *Q. leucotrichophora* was selected from each site as a phorophyte for macrolichen sampling. Twenty five trees (five trees from each corner and five from the centre of the plot) of *Q. leucotrichophora* were selected from each site for sampling macrolichens. Thus a total of 200 trees were selected from eight sites of the study area and five quadrats of 5 cm × 10 cm (1000 quadrats in totality) were drawn at whole circumference of the tree (so as to reduce biasness) at DBH (1.37 m above the ground level). All the individuals of macrolichens falling within the quadrats were collected (Negi 2000a).

1.3 Sample identification and herbarium documentation

Samples were examined under Stereo-zoom dissecting microscope (OLYMPUS CX21i) and identified with the help of available literature (Divakar and Upreti 2005; Awasthi 2007). Chemical examination [aqueous solution of Potassium hydroxide (K), Steiner's stable solution of *para*-phenylenediamine (P) and Sodium hypochlorite solution (C) and Thin Layer Chromatography (TLC)] of macrolichens was performed following standard methodology (Orange et al. 2001). Macrolichen samples are deposited in the herbarium of Kumaun University, Almora (KU).

1.4 Data analysis

Epiphytic macrolichen assemblage was quantitatively analyzed for density (number of individuals of a species/total studied quadrats), frequency [(number of quadrats in which species occurred/total studied quadrats) × 100] and abundance [(number of individuals of a species/number of quadrats in which species occurred)] as per Curtis and McIntosh (1950) and Pinokiyo et al. (2008). The Importance Value Index (IVI) for the epiphytic macrolichens was determined as the sum of the relative frequency and relative density as per Pinokiyo et al. (2008). Relative frequency and relative density were determined as per Phillips (1959).

The ratio of abundance and frequency (A/F) was used to interpret the distribution pattern of the species and was calculated using Whitford (1949). The ratio indicates regular or uniform distribution if the value comes below 0.025; random distribution if value falls between 0.025 to 0.05; and contagious or clumped distribution if value comes >0.05 (Curtis and Cottam 1956).

Alpha diversity (H′) was calculated as Shannon-Wiener index (Shannon and Weaver 1949) for the establishment of alternative estimates of species diversity in eight sites of Thal Ke Dhar forest. Simpson’s Concentration of Dominance was analyzed as per Simpson (1949). The Sorenson’s Coefficient (Sorenson 1948) was calculated for expressing similarity in epiphytic macrolichen species composition between the eight sites of the study area.

Diameter at breast height [*DBH*= Circumference at breast height (*CBH*)/π] was calculated for the identification of effective DBH class for the epiphytic macrolichen diversity and the classes were divided into six groups i.e., (1) A=1–10 cm, (2) B=10.1–20 cm, (3) C=20.1–30 cm, (4) D=30.1–40 cm, (5) E=40.1–50 cm and (6) F=50.1–60 cm because the diversity and distribution of macrolichens varies from diameter to diameter (Friedel et al. 2006).

Lopping percent [100 × (number of lopped trees/Sampled trees)] as a disturbance factor was also analyzed for determining its impact on epiphytic macrolichen diversity.

Principal Component Analysis (PCA) used to summarize the compositional differences between various sites was analyzed using PAST software (Hammer et al. 2001). The degree of variance explained by PCA axis 1 and axis 2 were considered as Principal Components by using the same software. Relative importance value index [RIVI= (IVI of a species/sum of the IVI of total species) × 100] calculated as per Pinokiyo et al. (2008) was used for this determination for all the eight sites. For knowing the relationship between explanatory variables (*altitude*, *lopping percent*) and response variables [*score of PC1* and *PC2*, *alpha diversity*, *concentration of dominance* (*Simpson diversity index*), *species richness*], Pearson's correlation coefficient was determined by using SPSS software 16.0 version. Polynomial regression analysis was performed to compare the species richness with altitude, lopping percent and DBH classes; and alpha diversity and number of genera with altitude by using PAST software.

2 Results

2.1 Species composition of epiphytic macrolichens

A total of 54 species of epiphytic macrolichens belonging to 18 genera and 5 families were recorded in 200 sampled trees of *Q. leucotrichophora* at eight studied sites (Table 1 and 2). Parmeliaceae was the dominant family (46.30%) followed by Collemataceae (27.77%), Physciaceae (20.37%), Ramalinaceae (3.70%) and Candelariaceae (1.85%). The fourth site had a larger number of epiphytic macrolichen population (30 species) as compared to the other sites (Table 1). The most common species having a high importance value across all studied sites were *Bulbothrix setschwanensis*, *Parmotrema melanothrix*, *P. reticulatum* and *Phaeophyscia hispidula*. In contrast, *Bulbothrix isidiza*, *Canoparmelia texana*, *Collema auriforme*, *C. subflaccidum*, *Heterodermia microphylla*, *Leptogium delavayi*, *L. pseudopapillosum*, *L. trichophorum*, *Myelochroa upretii*, *Phaeophyscia endococcina* and *Punctelia rudecta* were having low importance values (Table 2). Out of 54 recorded species, 21 macrolichen species (38.88%) were unique and recorded from only a single site (Table 2). However, only 4 species namely, *Bulbothrix setschwanensis*, *Hypotrachyna cirrhata*, *Parmotrema melanothrix* and *Parmotrema reticulatum* occurred at all the eight sites of the study area (Table 2).

As far as macrolichen distribution across altitudinal gradient is considered, macrolichens *viz.* *Collema auriforme*, *Hyperphyscia adglutinata*, *Leptogium* cfr. *asiaticum*, *L. delavayi*, *Phaeophyscia pyrrhophora* and *Punctelia rudecta* showed their distribution up to 2300 m, while *Bulbothrix isidiza*, *B. meizospora*, *Collema subflaccidum*, *C. thamnodes*, *Heterodermia microphylla*, *Leptogium pseudopapillosum*, *Myelochroa upretii*, *Parmotrema grayanum* and *Usnea* cfr. *vegae* were reported above 2300 m (Table 2). However, the mid altitudinal range (2213 to 2311 m asl) exhibited the maximum diversity of macrolichen species (Figure 1a).

The DBH class 10.1-20 cm and 20.1-30 cm bears maximum number of macrolichens (41 and 36 species, respectively), while the higher classes of DBH bear less epiphytic macrolichens (5 species) in comparison to lower classes (Figure 1b). Analysis of lopping percent revealed that the fourth site has comparatively higher anthropogenic pressure (83.33%; Figure 1a).

Table 1 Qualitative and quantitative characteristics of all the studied sites.

Parameters	Sites							
	1	2	3	4	5	6	7	8
Elevation (m asl)	2113	2170	2213	2267	2311	2360	2412	2476
Aspect	E	ES	ES	E	S	S	N	NW
Slope (°)	65°	70°	80°	65°	70°	70°	65°	80°
Species Richness	22	19	23	30	23	13	18	23
No. of Genera	14	12	14	16	13	9	12	12
No. of cyanolichens	4	5	7	6	1	4	3	2
Shannon-Weiner Index (H')	1.19	0.86	1.24	1.37	1.26	1.05	1.12	1.24
Simpson's Coefficient (CD)	0.91	0.90	0.93	0.94	0.92	0.90	0.90	0.93
Lopping (%)	75	58.3	50	83.33	33.33	16.66	0	41.66
Microhabitat	Qleuco	Qleuco	Qlana/ Qleuco	Qlana/ Qleuco	Rh/ Qleuco	Rh/ Qleuco	Rh/ Qleuco	Rh/ Qleuco

Notes: Qleuco=*Quercus leucotrichophora*; Qlana=*Quercus lanata*; Rh=*Rhododendron arboreum*. E=East; S=South; N=North; W=West.

Table 2 Species composition of macrolichen assemblages at the study sites in Thal Ke Dhar forest with Importance Value Index (IVI)

Species of macrolichens	Family	Sites								Total
		1	2	3	4	5	6	7	8	
Bulbothrix isidiza (Nyl.) Hale	Par.	-	-	-	-	-	-	-	3.6	0.45
B. meizospora (Nyl.) Hale	Par.	-	-	-	-	7.8	-	-	-	0.97
B. setschwanensis (Zahlbr.) Hale	Par.	12.6	3.2	14.9	10.6	26.6	16.0	36.7	26.5	18.38
Candelaria concolor (Dicks.) Arnold	Can.	3.1	-	-	3.6	-	-	-	-	0.83
Canoparmelia texana (Tuck.) Elix & Hale	Par.	-	-	-	3.6	-	-	-	-	0.45
Collema auriforme (With.) Coppins & J.R. Laundon	Coll.	-	6.8	-	-	-	-	-	-	0.85
C. coccophorum Tuck.	Coll.	-	-	-	3.6	-	-	-	-	0.45
C. kauaiense H. Magn.	Coll.	-	-	-	6.1	-	13.6	-	-	2.46
C. leptaleum Tuck.	Coll.	4.1	-	3.0	-	-	-	-	-	0.88
C. subconveniens Nyl.	Coll.	-	31.9	7.4	-	-	-	5.1	-	5.55
C. subflaccidum Degel.	Coll.	-	-	-	-	-	-	-	3.6	0.45
C. thamnodes Tuck.	Coll.	-	-	-	-	-	9.0	-	-	1.12
Flavoparmelia caperata (L.) Hale	Par.	-	3.2	3.0	8.7	13.1	-	-	-	3.5
Flavopunctelia flaventior (Stirt.) Hale	Par.	3.1	-	7.4	-	7.7	-	-	6.4	3.07
Heterodermia boryi (Fee) Kr.P. Singh & S.R. Singh	Phy.	12.8	17.7	8.0	2.5	-	-	5.1	-	5.76
H. diademata (Taylor) D.D. Awasthi	Phy.	5.4	-	19.1	8.1	5.3	9.0	5.1	9.0	7.62
H. microphylla (Kurok.) Skorepa	Phy.	-	-	-	-	-	-	-	2.6	0.32
H. podocarpa (Bel.) D.D. Awasthi	Phy.	-	-	-	3.6	5.3	-	-	-	1.11
Hyperphyscia adglutinata (Flörke) H. Mayrhofer & Poelt	Phy.	-	-	4.2	-	-	-	-	-	0.52
Hypotrachyna cirrhata (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch	Par.	10.5	12.9	13.5	6.1	3.8	18.2	7.2	14.4	10.82
H. nepalensis (Taylor) Divakar, A. Crespo, Sipman, Elix & Lumbsch	Par.	7.4	-	3.0	8.7	13.1	-	5.1	2.6	4.98
Leptogium askotense D.D. Awasthi	Coll.	-	-	7.4	-	-	-	-	-	0.92
L. burnetiae C.W. Dodge	Coll.	-	23.3	14.9	3.6	5.3	-	9.5	3.6	7.52
L. cfr. *asiaticum* P.M. Jørg.	Coll.	-	-	3.0	-	-	-	-	-	0.37
L. delavayi Hue	Coll.	-	-	3.0	-	-	-	-	-	0.37
L. fallax Müll. Arg.	Coll.	3.1	3.2	3.0	3.6	-	34.3	12.6	-	7.47
L. pedicellatum P.M. Jørg.	Coll.	6.2	3.2	-	-	7.7	-	-	-	2.13
L. pseudopapillosum P.M. Jørg.	Coll.	-	-	-	-	-	9.0	-	-	1.12
L. trichophorum Müll. Arg.	Coll.	-	-	-	3.6	-	-	-	-	0.45
Myelochroa aurulenta (Tuck.) Elix & Hale	Par.	12.8	10.9	13.0	10.3	5.3	16.0	10.3	-	9.82
M. upretii Divakar & Elix	Par.	-	-	-	-	3.8	-	-	-	0.47
Parmotrema austrosinense (Zahlbr.) Hale	Par.	-	-	-	-	-	-	5.1	3.6	1.08
P. crinitum (Ach.) M. Choisy	Par.	6.4	3.2	-	3.6	-	-	-	-	1.65
P. grayanum (Hue) Hale	Par.	-	-	-	-	-	-	7.2	-	0.90
P. hababianum (Gyeln.) Hale	Par.	-	3.2	3.0	10.6	6.8	9.0	-	7.4	5.00
P. indicum Hale	Par.	-	-	-	7.0	3.8	-	-	3.6	1.80
P. melanothrix (Mont.) Hale	Par.	18.2	7.9	16.0	8.7	19.9	9.0	5.1	9.0	11.72
P. mesotropum (Müll. Arg.) Hale	Par.	-	-	-	-	3.8	-	-	4.7	1.06
P. praesorediosum (Nyl.) Hale	Par.	-	3.2	-	-	-	-	-	3.6	0.85
P. reticulatum (Taylor) M. Choisy	Par.	16.2	14.1	14.9	31.1	20.3	29.5	5.1	6.4	17.2
P. tinctorum (Despr. ex Nyl.) Hale	Par.	-	-	-	6.1	-	-	-	-	0.76
Phaeophyscia endococcina (Körb.) Moberg	Phy.	-	-	-	-	3.8	-	-	-	0.47
P. hispidula (Ach.) Essl.	Phy.	26.4	26.7	24.2	20.5	-	11.4	27.2	9.0	18.17
P. pyrrhophora (Poelt) D.D. Awasthi & M. Joshi	Phy.	3.1	-	-	-	-	-	-	-	0.38
Physcia dilatata Nyl.	Phy.	-	-	3.0	5.2	3.8	16.0	10.3	25.8	8.01
Punctelia rudecta (Ach.) Krog	Par.	3.1	-	-	-	-	-	-	-	0.38
P. subrudecta (Nyl.) Krog	Par.	3.1	-	-	3.6	-	-	-	-	0.83
Pyxine berteriana var. *himalaica* D.D. Awasthi	Phy.	6.2	-	-	3.6	10.7	-	17.8	16.4	6.83
P. sorediata (Ach.) Mont.	Phy.	3.1	7.7	-	3.6	-	-	-	-	1.80
Ramalina conduplicans Vain.	Ram.	9.6	3.2	7.4	5.2	12.1	-	17.8	28.1	10.42
R. sinensis Jatta	Ram.	-	-	-	3.0	3.8	-	-	12.7	2.43
Usnea himalayana C. Bab.	Par.	-	-	-	3.0	-	-	-	9.0	1.50
U. longissima Ach.	Par.	22.7	7.7	30.0	10.3	3.8	-	7.2	-	10.21
Usnea cfr. *vegae* Motyka	Par.	-	-	-	-	-	-	-	3.6	0.45
Total	199.2	193.2	226.3	211.4	197.4	200.0	199.5	215.2		

Notes: Par.=Parmeliaceae; Can.=Candelariaceae; Coll.=Collemataceae; Phy.=Physciaceae; Ram.=Ramalinaceae.

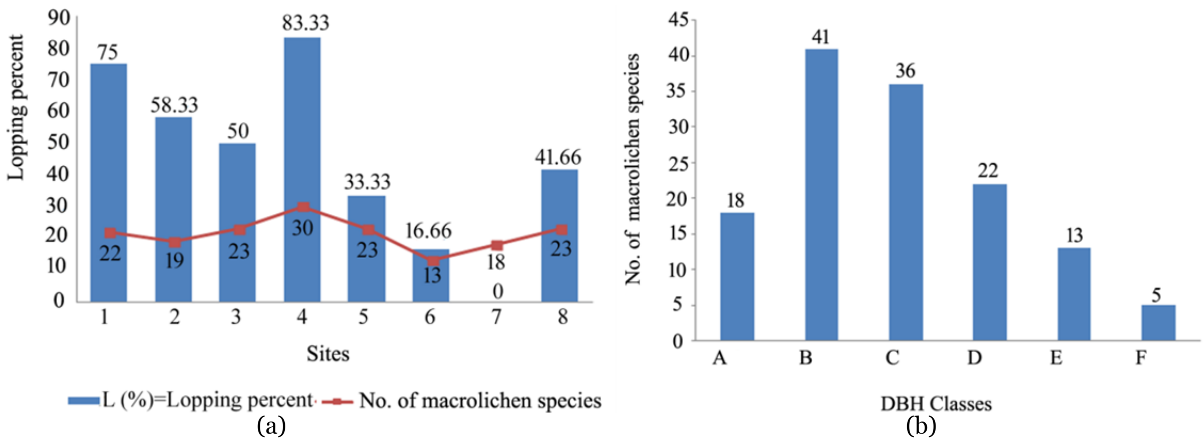

Figure 1 Distribution of epiphytic macrolichens of Thal Ke Dhar forest (a) number of macrolichen species in all the sites with lopping percent and (b) number of macrolichen species falling in different diameter at breast height (DBH) classes.

2.2 Distribution pattern of the epiphytic macrolichen species

The analysis of the distribution pattern of reported epiphytic macrolichen species in eight sites indicate that majority of species in first, second, fourth, sixth, seventh and eighth sites were contagiously distributed (21, 15, 27, 12, 17 and 20 species respectively), while in the third and fifth sites regular distribution was more prevalent (Table 3). Out of 54 species of epiphytic macrolichens, 26 species were randomly distributed in the study site, while 19 species were contagiously distributed and 9 shows regular distribution (Table 3).

2.3 Similarity coefficient among all the eight sites

The epiphytic macrolichen composition of the different eight sites was compared by means of similarity coefficient calculated on the basis of species richness (Table 4). The low degree of similarity among the different sites is understandable, as the number of macrolichen species were different in each sites of the study area. Among all the sites, highest similarity in the composition of epiphytic macrolichens was seen between the sites third and seventh (Table 4). However, occurrence of the highest number of same epiphytic macrolichen species was recorded between sites first and fourth and sites fourth and fifth. These sites shared 17 species of epiphytic macrolichens. It was followed by site third and fourth (16 species), site second and fourth (15 species), site third and seventh (15 species), site fourth and seventh (15 species), site fourth and eighth and others (Table 4).

2.4 Relationship between lichen composition and ecological variables

Considerable differences in species composition and abundance between various sites were observed (Table 2). Generally the mid-altitude sites had the larger number of species (Figure 1a). Principal Component Analysis (PCA) exhibited that the dominant (highest *IVI*) and co-dominant epiphytic macrolichens differed from site to site; indicating distinct macrolichen assemblages at the different sites. There were no sites adjacent to each other in the PCA ordination plot (Figure 2).

In the PCA ordination plot, *PCA axis 1* explained 43.68% of the variation in species composition, while *PCA axis 2* and *3* explained 27.64% and 18.18% variations, respectively. The entire three axes explained 89.5% in the species composition. *PCA axis 1* was significantly related to lopping; indicating that *lopping* is the main factor differentiating epiphytic macrolichen communities in the study area (Table 5). Similarly, *alpha diversity* was significantly related to *PCA axis 2* indicating *species richness* of macrolichens in the studied sites (Table 5). *Species richness* was significantly related to *PCA axis 1* scores and *number of genera*, *Simpson's index* and *lopping percent* (Table 5) and tend to increase substantially with *lopping percent* (Figure 3a). *Species richness*,

Table 3 Distribution of the macrolichen species in the eight studied sites

Species	Sites								Average	Class
	1	2	3	4	5	6	7	8		
Bulbothrix isidiza	-	-	-	-	-	-	-	0.240	0.030	B
B. meizospora	-	-	-	-	0.000	-	-	-	0.000	A
B. setschwanensis	0.040	0.120	0.045	0.080	0.032	0.090	0.048	0.024	0.059	C
Candelaria concolor	0.120	-	-	0.240	-	-	-	-	0.045	B
Canoparmelia texana	-	-	-	0.240	-	-	-	-	0.030	B
Collema auriforme	-	0.480	-	-	-	-	-	-	0.060	C
C. coccophorum	-	-	-	0.240	-	-	-	-	0.030	B
C. kauaiense	-	-	-	0.090	-	0.480	-	-	0.071	C
C. leptaleum var. *leptaleum*	0.240	-	0.000	-	-	-	-	-	0.030	B
C. subconveniens	-	0.024	0.090	-	-	-	0.120	-	0.029	B
C. subflaccidum	-	-	-	-	-	-	-	0.240	0.030	B
C. thamnodes	-	-	-	-	-	0.240	-	-	0.030	B
Flavoparmelia caperata	-	0.120	0.000	0.053	0.035	-	-	-	0.028	B
Flavopunctelia flaventior	0.120	-	0.090	-	0.000	-	-	0.090	0.037	B
Heterodermia boryi	0.080	0.060	0.600	0.120	-	-	0.120	-	0.055	C
H. diademata	0.180	-	0.038	0.150	0.160	0.240	0.120	0.053	0.117	C
H. microphylla	-	-	-	-	-	-	-	0.120	0.015	B
H. podocarpa	-	-	-	0.240	0.160	-	-	-	0.050	B
Hyperphyscia adglutinata	-	-	0.240	-	-	-	-	-	0.030	B
Hypotrachyna cirrhata	0.053	0.030	0.037	0.090	0.000	0.120	0.240	0.028	0.074	C
H. nepalensis	0.090	-	0.000	0.053	0.035	-	0.120	0.120	0.052	C
Leptogium askotense	-	-	0.090	-	-	-	-	-	0.011	B
L. burnetiae	-	0.052	0.045	0.240	0.160	-	0.360	0.240	0.137	C
L. cfr. *asiaticum*	-	-	0.000	-	-	-	-	-	0.000	A
L. delavayi	-	-	0.000	-	-	-	-	-	0.000	A
L. fallax	0.120	0.120	0.000	0.240	-	0.120	0.090	-	0.086	C
L. pedicellatum	0.060	0.120	-	-	0.000	-	-	-	0.022	B
L. pseudopapillosum	-	-	-	-	-	0.240	-	-	0.030	B
L. trichophorum	-	-	-	0.240	-	-	-	-	0.030	B
Myelochroa aurulenta	0.080	0.053	0.080	0.030	0.160	0.090	0.060	-	0.069	C
M. upretii	-	-	-	-	0.000	-	-	-	0.000	A
Parmotrema austrosinense	-	-	-	-	-	-	0.120	0.240	0.045	B
P. crinitum	0.500	0.150	-	0.240	-	-	-	-	0.111	C
P. grayanum	-	-	-	-	-	-	0.240	-	0.030	B
P. hababianum	-	0.120	0.000	0.080	0.240	0.240	-	0.120	0.100	C
P. indicum	-	-	-	0.120	0.000	-	-	0.240	0.045	B
P. melanothrix	0.070	0.120	0.052	0.053	0.035	0.240	0.120	0.053	0.092	C
P. mesotropum	-	-	-	-	0.000	-	-	0.360	0.045	B
P. praesorediosum	-	0.120	-	-	-	-	-	0.240	0.045	B
P. reticulatum	0.120	0.037	0.045	0.034	0.080	0.037	0.120	0.090	0.070	C
P. tinctorum	-	-	-	0.090	-	-	-	-	0.011	A
Phaeophyscia endococcina	-	-	-	-	0.000	-	-	-	0.000	A
P. hispidula	0.070	0.040	0.022	0.075	-	0.360	0.052	0.053	0.084	C
P. pyrrhophora	0.120	-	-	-	-	-	-	-	0.015	A
Physcia dilatata	-	-	0.000	0.060	0.000	0.090	0.060	0.066	0.034	B
Punctelia rudecta	0.120	-	-	-	-	-	-	-	0.015	A
P. subrudecta	0.120	-	-	0.240	-	-	-	-	0.045	B
Pyxine berteriana var. *himalaica*	0.060	-	-	0.240	0.080	-	0.053	0.038	0.058	C
P. sorediata	0.120	0.090	-	0.240	-	-	-	-	0.056	C
Ramalina conduplicans	0.150	0.120	0.090	0.060	0.100	-	0.053	0.019	0.074	C
R. sinensis	-	-	-	0.120	0.000	-	-	0.045	0.020	A
Usnea himalayana	-	-	-	0.120	-	-	-	0.053	0.021	B
U. longissima	0.110	0.090	0.000	0.030	0.000	-	0.240	-	0.058	C
Usnea cfr. *vegae*	-	-	-	-	-	-	-	0.240	0.030	B

Notes: A=Regular; B=Random; C=Contagious.

Table 4 Sorenson's Similarity Coefficient (SSC) of eight different sites in Thal Ke Dhar forest of Kumaun Himalaya

Sites	Similar species	SSC	Sites	Similar species	SSC
Site 1 and Site 2	13	0.634	Site 3 and Site 5	14	0.608
Site 1 and Site 3	14	0.622	Site 3 and Site 6	10	0.555
Site 1 and Site 4	17	0.653	Site 3 and Site 7	15	0.731
Site 1 and Site 5	13	0.577	Site 3 and Site 8	12	0.452
Site 1 and Site 6	8	0.457	Site 4 and Site 5	17	0.641
Site 1 and Site 7	13	0.650	Site 4 and Site 6	11	0.511
Site 1 and Site 8	10	0.444	Site 4 and Site 7	15	0.625
Site 2 and Site 3	14	0.666	Site 4 and Site 8	15	0.566
Site 2 and Site 4	15	0.612	Site 5 and Site 6	8	0.444
Site 2 and Site 5	11	0.523	Site 5 and Site 7	12	0.585
Site 2 and Site 6	8	0.500	Site 5 and Site 8	14	0.608
Site 2 and Site 7	11	0.594	Site 6 and Site 7	9	0.580
Site 2 and Site 8	8	0.380	Site 6 and Site 8	8	0.444
Site 3 and Site 4	16	0.603	Site 7 and Site 8	12	0.585

Table 5 Correlation between different response and explanatory variables

	PC1	PC2	Alt.	Slope	SR	G	CL	H'	CD	L
PC1	1									
PC2	0.000	1								
Alt.	-0.616	0.697	1							
Slope	0.046	0.337	0.274	1						
SR	0.820*	0.459	-0.190	0.015	1					
G	0.881**	0.225	-0.445	-0.154	0.929**	1				
CL	0.643	-0.432	-0.551	0.057	0.217	0.383	1			
H'	0.503	0.788*	0.178	0.083	0.746	0.646	-0.027	1		
D	0.801*	0.580	-0.058	0.292	0.923**	0.796*	0.278	0.835**	1	
L	0.905**	-0.179	-0.678	-0.081	0.712*	0.737*	0.486	0.287	0.640	1

Notes: *Correlation is significant at the 0.05 level (2- tailed); **Correlation is significant at the 0.01 level (2- tailed) PC1=Principal component 1; PC2=Principal Component 2; Alt.=altitude; SR=species richness; G=number of genera; CL=number of cyanolichens; H'=Shannon's diversity index; CD=concentration of dominance (Simpson's index); L=lopping.

number of genera and *Simpson's Index* were also significantly related to *axis 1* scores. *Alpha diversity* represented by Shannon-Weiner index, ranged from 0.8611 (site 2) to 1.3757 (site 4) while Species richness (number of species) ranged from 13 (site 6) to 30 (site 4; Table 2).

No significant relationship of *altitude* and *slopes* was detected with other variables (Table 5). Polynomial fits to the data suggest that macrolichen communities at mid-altitude sites were more diverse [$y= -1.60 - 06x^2 + 0.007x - 7.78$ ($r^2= 0.05$)] and the distribution of data points along the altitudinal gradient indicates that there were more lichen species and number of genera in mid-altitude sites [$y= -2.31 - 05x^2 + 0.098x - 82.71$ ($r^2= 0.04$) and $y= -9.53 - 06x^2 + 0.036x - 20.38$ ($r^2= 0.20$)].

DBH classes B and C appeared to be relatively more favorable for the development of epiphytic macrolichen diversity as the number of macrolichen species (y) declined linearly between

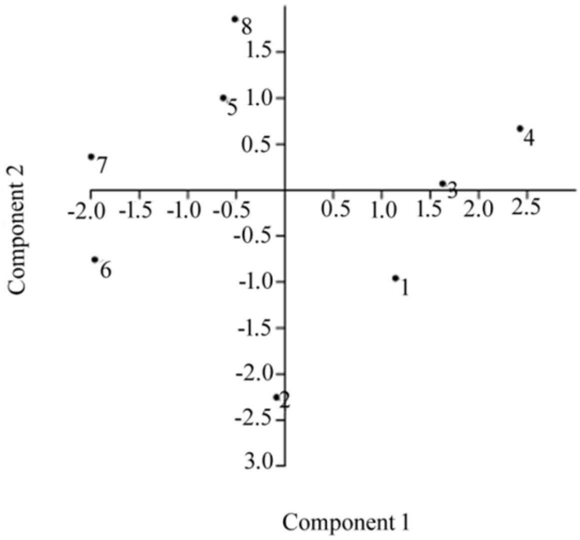

Figure 2 Principal Component Analysis (PCA) plot of eight studied sites in four microhabitats of Thal Ke Dhar forest.

DBH class third to sixth (Figure 1b and Figure 3b). Hence, diversity of epiphytic macrolichens showed

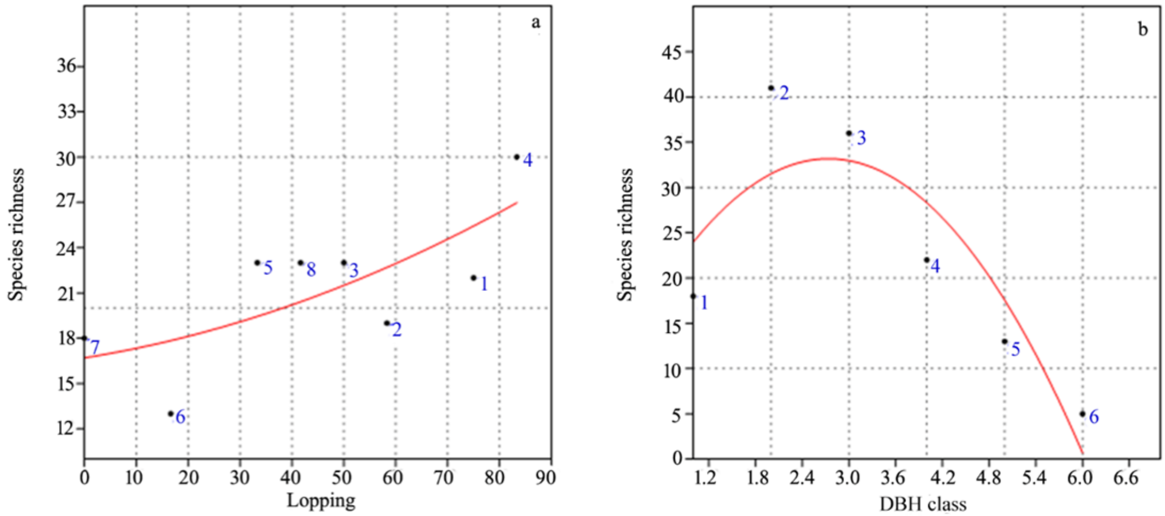

Figure 3 Relationship between species richness and (a) Lopping percent, $y= 0.0008x^2 + 0.055x + 16.7$ ($r^2= 0.52$) and (b) Diameter at breast height (DBH) class at Thal Ke Dhar forest, $y= -3.054x^2 + 16.72x + 10.3$ ($r^2= 0.77$).

a non-linear significant relation with *DBH classes* (Figure 3b).

3 Discussion

Diversity and distribution pattern of an organism at a particular place is strongly influenced by environmental variables (Baniya 2010; Baniya et al. 2012; Kumar et al. 2012, 2014) and among these variables, *altitude*, *nature of substrate* (*texture*, *pH*, *diameter of tree*) and *lopping* are the most important ones. Since lichens are not exceptional and it was mentioned by several workers that their diversity and distribution are also influenced significantly by altitude in the mountainous landscapes of Himalaya (Bruun et al. 2006; Pinokiyo et al. 2008; Baniya 2010; Huang 2010; Baniya et al. 2012; Rai et al. 2012, 2015), but the present study exhibits contrasting results with those of earlier studies since there is not so much altitudinal variation in the present study site. However, mid-altitude provides favorable conditions for epiphytic macrolichen diversity in the study area (Figure 1a) and the results corroborate with studies conducted by Pinokiyo et al. (2008) and Rai et al. (2012, 2015).

Likewise study conducted by Pentecost (1998) at Rwenzori mountains mentioning that at places with high *lopping* percentage the diversity of macrolichen increases indicating that *lopping* practice creates congenial environment (i.e. light) for lichen growth and favors increase in their diversity, our study also indicates that *lopping percent* is the most important disturbance factor affecting the macrolichen diversity in the study area (Figure 1a and Figure 3a). Meanwhile, the distribution and diversity of light sensitive species *Leptogium* and *Collema* were not affected by *lopping* in the present study. The results of our study also corroborate with studies conducted by Nkongmeneck et al. (2002), Larrea and Werner (2010), Adhikari et al. (2016) mentioning that the epiphytic species will be higher in numbers in opened forests in comparison to closed forests. Not only lichens, but other epiphytic plants also face impact of the disturbance on their diversity and distribution (Adhikari et al. 2012 a, b, 2016). Wolf (2005) observed that anthropogenic pressure threatens epiphytic diversity and he along with Adhikari et al. (2016) advocated the practice of integration of epiphytes in forest management to know the response of epiphytes to anthropogenic disturbances.

Since *DBH* is positively related to the *age of the tree* (Oheimb et al. 2003) and trees with more diameters are characterized by a larger heterogeneity of micro-sites and provide habitats to species with particular ecological requirements (Friedel et al. 2006). According to Friedel et al. (2006), *DBH* is the most important factor for epiphytic species richness and species composition. Aude and Poulsen (2000), Schumacher (2000) and McGee and Kimmerer (2002) also observed an increase in species richness with an increasing phorophyte diameter. However, in the present study the *DBH classes* of 10.1–20 cm and 20.1–30 cm came out as the best *DBH* for the species richness of macrolichens, while the phorophytes with higher *DBH classes* were poorly colonized by macrolichens and were fully covered by bryophytes and mosses (Figure 1b). In contrast, the mid aged trees in the present study were found suitable for the diversity and distribution of epiphytic macrolichens and this was also confirmed by the polynomial fits of the data points (Figure 3b). Therefore, the disturbance (*lopping*) and mid aged trees came out as suitable factors for the diversity and distribution of epiphytic macrolichens in the study area.

Besides this, among various substrates the woody component is represented as best substrate for lichen diversity (Negi 2000a; Pinokiyo et al. 2008). The present study performed on one such woody substrate (*Q. leucotrichophora*), also corroborates this statement and is supporting high macrolichen diversity in the study area (54 species).

4 Conclusion

Epiphytic lichens are very sensitive to anthropogenic pressure in forest ecosystems because of their poikilohydric nature and sensitivity to small changes in *light intensity*, *temperature* and *moisture*. In the present study, *lopping* has significantly impacted the species richness of epiphytic macrolichens and suggested that this practice can be a good alternative to *logging* (clear cutting) for the conservation of epiphytic lichen species. Boudreault et al. (2013) also suggested that partial cutting is good for the diversity of epiphytic lichens, and are more likely to succeed if dense clumps of residual trees (*canopy cover*>70%) are retained in the treated stands (partial cutting stands). Hence, understanding the impact of small-scale disturbances, such as *lopping*, may play an important role in management implications in selecting forestry interventions that are compatible with the conservation of residual populations of epiphytic lichens (Boudreault et al. 2013), as low light conditions are known to restrict the growth of epiphytic lichen species in some forests (Jansson et al. 2009). Including *lopping* in forest management practices may also affect many other life forms either negatively or positively. Therefore, such types of studies are required on a large scale in Western Himalaya with respect to all groups of organisms including different ecological parameters because livelihood totally depends on the forests as well as meadows in this region.

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