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Influence of macro-scale environmental variables on diversity and distribution pattern of lichens in Badrinath valley, Western Himalaya.

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Abstract

Morphological growth forms confer ecological adaptability to lichens species and are indicators of habitat conditions and various climatic as well as zooanthropogenic pressures. Lichens samples from six sites in two locations of Badrinath valley were studied in order to assess the influence of macro-scale environmental variables (i.e. altitude, relative humidity and temperature) on diversity and distribution of lichens, using ordination (PCA and hierarchical clustering) and correlation analysis. The study recorded 106 lichen species in the valley. *Parmeliaceae* was a dominant family. Lichen species constitution in sites resulted in different groups, which were determined by the dominant growth forms and substrate preferences. Lichen growth form distribution was significantly correlated with studied macro-scale environment variables. On rock (saxicolous) substrate was the main substrate of lichen inhabitancy in the valley. The study concluded that macro-scale environmental variables play determining role in lichen community constitution of alpine habitats in Himalayas.

Key words – Cluster analysis – crustose – dimorphic – foliose – fruticose –*Parmaliaceae* – principal component analysis – saxicolous – terricolous

Introduction

Lichens, mutualistic associations of a dominant fungus (mycobiont) and a green (phycobiont) and/or blue-green algae (cyanobiont), are by far known as one of the most successful symbionts in nature (Galloway 1992). Lichen thallus is a relatively stable and well-balanced symbiotic system with both heterotrophic and autotrophic components and is often regarded as a self-contained miniature ecosystem (Farrar 1976, Seaward 1988).

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Lichens exhibit a wide range of morphological growth forms which confer lichen with ecological efficiency to adapt according to various climatic as well as zooanthropogenic stresses (Ahti 1959, Sheard 1968, Ahti et al. 1973, Rai et al. 2012a, b). The dominance of specific lichen growth forms in a habitat is outcome of multiple interacting environmental factors which ultimately decide the constitution of a lichen community (Eldridge and Rosentreter 1999, Zedda et al. 2011, Rai et al 2012 a, b). Himalayan habitats are regions with harsh climate, characterized by regular orographic precipitation, longer periods of snow fall, higher UV radiation and freezing minimum temperatures (Rai et al. 2012 a, b, Khare et al. 2010). Lichen growth forms in such alpine habitats in Himalayas are indictors of habitat variability, and change in macro- scale environmental variables i.e. altitude, relative humidity and temperature (Rai et al. 2012 a, b)

The present study deals with the influence of macroscale environmental variables (altitude, temperature and relative humidity) on diversity and distribution pattern of lichens in an alpine habitat of Garhwal Himalayas.

Materials & Methods

Study area

Badrinath valley is situated in north-west extreme (N30^{0}44’1.43” E79^{0}29’37.4”–N30^{0}46’33.74” E79^{0}29’32.08”) of Chamoli district in the state of Uttarakhand, India (Fig. 1). Situated in the floodplains of Alaknanda river (a tributary of Ganges), the valley houses the temple of Badrinath, one of the most important pilgrimage sites among the four Hindu Charm Dhams. With an average elevation of 3,300 m, the valley is situated in outer Himalaya and represents typical alpine habitats; characterized by alpine-grassland vegetation, extreme temperature and precipitation regimes.

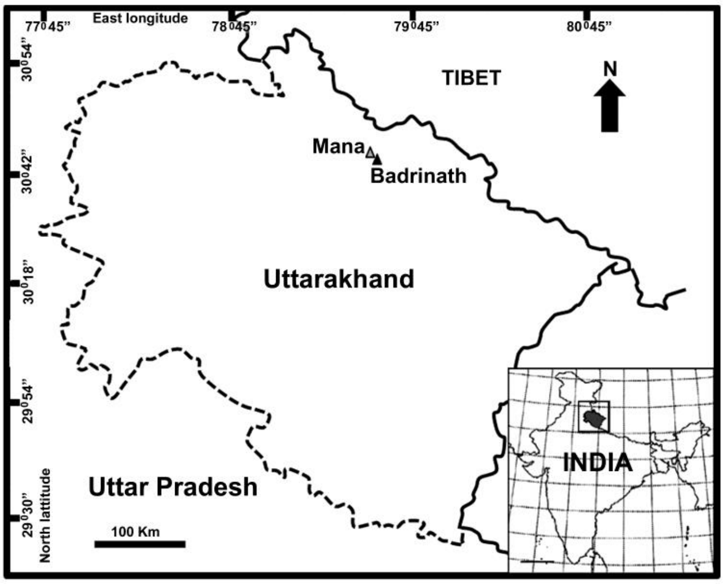

Fig. 1 – Location map of study locales in Badrinath valley.

The landscape of the area is typically mountainous, with steep slopes (46–60°) and elevation rising from 2,950 to 3,670 m. The topography comprises ridges and exposed rocks with patches of inclined alpine grassland. Precipitation occurs as snow, hail, heavy rain and showers. Snowfall occurs from December to March, and snowmelt occurs during April and May— providing an abundance of soil water prior to the monsoon period. Maximum rainfall is in July–Oct (Indian Meteorological department- IMD) (Fig. 2).

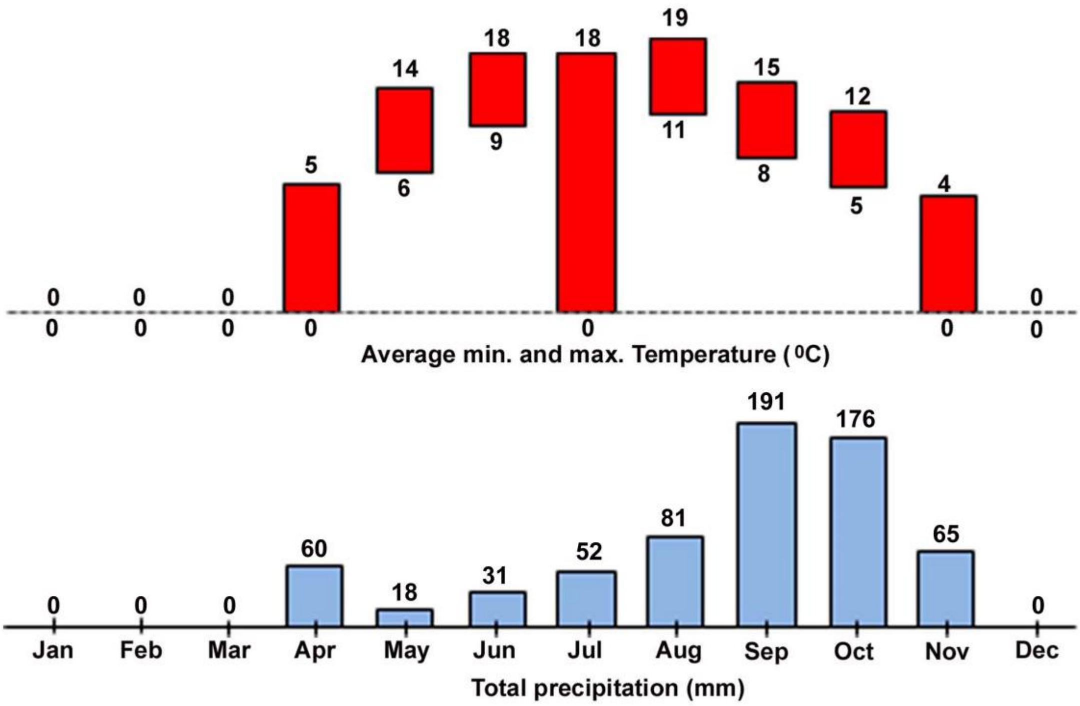

Fig. 2 – Climograph of Badrinath valley showing average annual temperature regime and annual total precipitation

The maximum monthly temperatures in the area vary from 18-19°C in the months of June–Aug, while minimum temperatures as low as -22°C are recorded during December–February (Fig. 2). The vascular plant vegetation is broadly alpine, with alpine scrub or grassland dominated by crataegus (Hawthorns) species with sporadic presence of tree species of *Betula*, *Salix* and stunted *Rhododendron*.

Landuse by the local human population is mainly semipastoral agriculture based on livestock grazing, agriculture, and the collection of fodder and fuel from alpine grasslands. Open grasslands (Bugyals) at 2,900–3,400 m are extensively used as pasturelands by native populations and nomads (Bhotiyas). In addition, land around the Badrinath shrine and at Mana is occupied during the pilgrimage season. The most favoured microhabitats for lichens in the area are rocks, soil patches amongst rocks, soil in rock crevices and woody shrubs.

The study was conducted on lichen samples of two locations in Badrinath valley- in and around (i) Badrinath town (N30⁰44’35.41” E79⁰29’38.18”) and (ii) Mana town (N30⁰46’21.55” E 79⁰29’43.86”) (Fig. 1), deposited in lichenology herbarium (LWG) of CSIR-National Botanical Research Institute (CSIR-NBRI), Lucknow, Uttar Pradesh, India.

Data recording

The study recognized three major sites each, in both of the localities (Table 1). Data of all macroscale environmental variables (altitude, temperature and relative humidity) were recorded either from herbarium records (altitude) or from climate data obtained from IMD. Vegetation of sampling sites was recorded during recent collections (2012-13).

Unidentified and freshly collected lichen samples were examined and identified upto species level using a stereomicroscope, light microscope (morpho-anatomically), and chemically with the help of spot tests, UV light and standardized thin-layer chromatography (Elix and Ernst-Russel 1993, Orange et al. 2001). Keys and monographs employed for authentication included those of Ahti (2000), Awasthi (2007), Saag et al. (2009) and Rai et al. (2014). Data regarding lichen species diversity at all 6 collection sites of the two localities and their growth form diversity was carefully recorded.

Table 1 Macroscale environmental variables and vegetation attributes of sampling sites of the study area.

Locations	Average Altitude* (m)	Sites†	Average Temperature* (^{0}C)		Average Relative humidity* (%)	Vegetation
			Min.	Max.		
Badrinath	3180±0.5	Badrinath town (B1) at Devdarshini(B2) Brahmini Village(B3)	12±1.1	24±0.2	66±0.5	Mainly dominated by shrub species of *Berberis, Cotoneaster, Rosa*, and *Juniperus;* herbs species of *Gentiana, Swertia, Anaphalis, Morina, Tanacetum, Gaultheria, Nepeta, Cyananthus, Potentilla, Thalictrum, Rumex, Thymus, Dracocephalum, Astragalus, Pedicularis, Saussurea* along with stunted *Rhododendron* and tree species of *Hipphophae* and *Betula* .
Mana	3420±1.1	Mana (M1) Bhimpul (M2) enroute Vasudhara falls(M3)	8±0.5	18±0.2	55±0.3	Mainly dominant by shrub species of *Berberis* alongwith herbaceous species of *Anaphalis, Gentiana, Swertia, Nepeta, Bistorta, Sedum, Rosularia, Thalictrum, Oxyria, Rhodila, Taraxacum,* and sporadic presence of few trees of *Betula* and *Salix.*

*****Values are in mean ± standard deviation; †abbreviations for each site are reported in parentheses.

Data analysis

An indirect gradient ordination method, principal component analysis (PCA), was used to summarize the compositional differences between the sites (Gauch 1982, ter Braak and Prentice 1988, Rai et al. 2012). Two tailed bivariate correlation analysis was performed by calculating Pearson's correlation coefficients to compare explanatory variables– i.e. altitude, temperature, relative humidity) and response variables– i.e. growth forms (Pinokiyo et al. 2008, Rai et al. 2012 b). Lichen groups from both Badrinath and Mana were sought through hierarchical cluster analysis (Ludwig and Reynolds 1988, Jongman et al. 1995, Rai et al. 2011, 2012b) using presence (1) absence (0) data matrices, employing Raup-Crick similarity measure (Rai et al. 2011) and unweighted pair-group moving average (UPGMA) algorithm, on two criteria: lichen growth form diversity and their substratum of occurrence (i.e. on rock, on soil, on soil over rock, on twig and on cement plaster) (Scutari et al. 2004, Rai et al. 2012a, b). The PCA and cluster analysis were performed using multivar option in PAST 2.17c (Hammer et al. 2001, Rai et al 2012b); all the other above mentioned statistical analyses were done using IBM SPSS Statistics ver. 20.

Results

The study recorded occurrence of 106 lichen species from the 6 sites of two localities. All the six sites of the two localities support a diverse, but somewhat different assemblage of lichen species both in terms of species and growth form constitution.

Macroscale variables (i.e. minimum, maximum temperature and percentage relative humidity) of the landscape varied along the altitudinal gradient; there was a gradual decrease observed in the ambient temperature (maximum and minimum) and relative humidity (%) from Badrinath town to Mana (Table 1).

Taxonomic diversity

The lichen assemblage at Badrinath consisted of 57 species belonging to 29 genera and 19 families. *Peltigeraceae* (9 spp.) and *Parmeliaceae* (8 spp.) were dominant families followed by

Physciaceae, and *Teloschistaceae* (Table 2) at Badrinath. The lichen assemblage at Mana consisted of 58 species belonging to 33 genera and 18 families. *Parmeliaceae* (11spp.) and *Physciaceae* (9 spp.) were dominant families followed by *Acarosporaceae*, and *Teloschistaceae* (Table 2) at Mana. Among both the locations, Badrinath exhibits dominance of cyanolichen genera (*Peltigera*, *Leptogium*, *Stereocaulon*, *Nephroma*) than Mana (*Nephroma*, *Stereocaulon*).

Growth form distribution patterns

Four growth forms i.e. crustose (squamulose and leprose are treated as subtypes; Nash III 2002), foliose, fruticose and dimorphic (squamules as primary thallus bearing erect fruticose body as secondary thallus) were recorded at both locations (i.e. Badrinath and Mana). Among the different growth forms foliose dominated, followed by crustose, fruticose and dimorphic growth forms. While the relative proportion of crustose growth form was higher in Mana than Badrinath, the other two growth forms i.e. fruticose and dimorphic were higher in proportion in Badrinath than Mana (Table 2; Fig 4, 5).

Lichen community composition (PCA analysis)

The PCA analysis required 5 components (axis) to account for 100% variation in the data set. The first two axes explained 78% (axis 1, 60 and axis 2, 18% respectively) of variance in the study (Fig. 3). Among the 6 sites of the two localities where, sites B2, B3, M2 and M1 formed cluster showing somewhat similar species constitution, sites M3 and B1 were with totally different species constitution (Fig. 3). Sites B3 and M2 clustered due to the presence of nearly equal proportion of both foliose and crustose growth forms whereas sites B2 and M1 fall apart due to greater proportion of crustose growth forms in B2 and foliose in M1(Table 2). Sites M3 and B1 clustered apart significantly due to distinct dominance of crustose and foliose growth forms respectively in these sites (Table 2, Fig. 3).

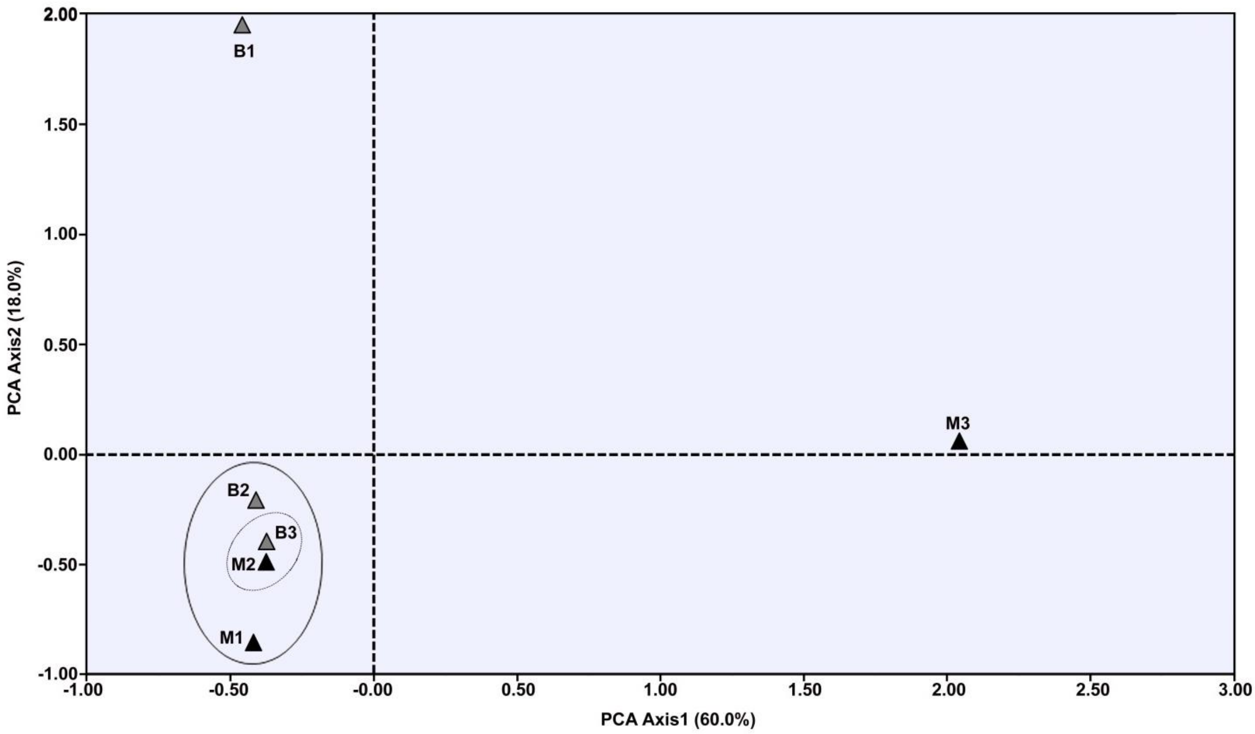

Fig. 3 – PCA ordination plot of 6 study sites in two locations of Badrinath valley-Badrinath and Mana towns, (refer Table 1 for abbreviations).

Table 2 Lichen species recorded in the Six sampling in Badrinath and Mana town location in Badrinath valley

Species	Family	Badrinath B 1	B 2	B 3	Mana M 1	M 2	M 3	Substratum	Growth Form†
Acarospora angolensis H. Magn.	*Acarosporaceae*	-	-	-	+	-	-	On rock	Cr
Acarospora bullata Anzi.	*Acarosporaceae*	-	-	-	+	-	-	On rock	Sq*
Acarospora carnegiei Zahlbr.	*Acarosporaceae*	-	-	-	-	+	-	On rock	Cr
Acarospora oxytona (Ach.)Massal.	*Acarosporaceae*	-	-	-	-	-	+	On rock	Cr
Acarospora saxicola Fink.	*Acarosporaceae*	-	-	-	+	-	-	On rock	Cr
Acarospora scabra (Pres.) T. Fries	*Acarosporaceae*	-	-	-	+	-	-	On rock	Sq*
Acarospora smaragdula (wahlenb in Ach.) Massal.	*Acarosporaceae*	+	-	-	-	-	+	On rock	Cr
Aspicilia griseocinerea Räsänen	*Megasporaceae*	-	+	-	-	-	-	On soil over rock	Cr
Aspicilia almorensis (Räsänen). Awasthi	*Megasporaceae*	+	-	-	-	-	-	On rock	Cr
Aspicilia alphoplaca (Wahlenb.in. Ach) Poelt	*Megasporaceae*	-	-	-	+	-	-	On rock	Cr
Aspicilia calcarea (L.). Mudd	*Megasporaceae*	-	-	-	+	+	-	On rock	Cr
Aspicilia maculata (Magn.) D.D. Awasthi	*Megasporaceae*	-	-	-	-	+	-	On rock	Cr
Buellia aethalea (Ach.) Th. Fr.	*Caliciaceae*	+	-	-	-	-	-	On rock	Cr
Buellia asterella Poelt & M. Sulzer	*Caliciaceae*	-	-	-	-	-	+	On soil	Cr
Caloplaca flavovirescens (Wulfen) Dalla. Torre & Sarnth.	*Teloschistaceae*	-	-	-	+	-	+	On rock	Cr
Caloplaca lithophila Mangn.	*Teloschistaceae*	-	-	-	+	-	-	On rock	Cr
Caloplaca subsoluta (Nyl.) Zahlbr.	*Teloschistaceae*	+	-	-	-	-	-	On rock	Cr
Canomaculina subtinctoria (Zahlbr.) Elix	*Parmeliaceae*	+	-	-	-	-	-	On rock	Fo
Candelaria concolor (Dicks.) Arnold	*Candelariaceae*	+	-	-	-	-	-	On rock	Cr
Candelaria indica (Hue) Vain	*Candelariaceae*	-	-	-	-	+	-	On rock	Fo
Candelariella aurella (Hoffm.) Zahlber.	*Candelariaceae*	+	-	-	-	-	-	On rock	Cr
Candelariella grimmiae Poelt & Reddi	*Candelariaceae*	-	-	-	-	-	+	Cement Plaster	Cr
Cladonia borealis S.Stenroos	*Cladoniaceae*	+	-	-	-	-	-	On soil over rock	Dm
Cladonia cartilaginea Krempelh.	*Cladoniaceae*	-	+	-	-	-	-	On soil over rock	Dm
Cladonia furcata (Huds.)Schards	*Cladoniaceae*	-	-	-	-	-	+	On soil	Dm
Cladonia mongolica Ahti.	*Cladoniaceae*	-	+	-	-	-	-	On rock	Dm
Cladonia pyxidata (L.) Hoffm.	*Cladoniaceae*	-	-	-	-	-	+	On soil	Dm
Dermatocarpon miniatum (L.) W. Mann	*Verrucariaceae*	+	+	+	-	-	-	On soil over rock	Fo
Dermatocarpon vellereum Zschacke.	*Verrucariaceae*	-	-	-	+	+	-	On rock	Fo
Dimelaena oreina (Ach.) Norman	*Caliciaceae*	-	-	-	+	+	-	On rock	Cr
Diploschistes gypsaceus (Arch.) Nyl.	*Thelotremataceae*	-	-	-	-	+	-	On rock	Cr
Diploschistes muscorum (Scop.)R. Sant.	*Thelotremataceae*	-	-	+	-	-	+	On soil over rock	Cr
Diploschistes rampoddensis (Nyl.)Zahlbr.	*Thelotremataceae*	+	-	-	-	-	-	On rock	Cr
Diploschistes scruposus (Schreb.) Norman	*Thelotremataceae*	+	-	-	-	+	-	On rock	Cr

Species	Family	Badrinath			Mana			Substratum	Growth Form†
		B 1	B 2	B 3	M 1	M 2	M 3		
Endocarpon subrosettum Ajay Singh & Upreti	*Verrucariaceae*	-	-	-	+	-	-	On rock	Cr
Evernia mesomorpha Nyl.	*Parmeliaceae*	-	-	-	-	-	+	On twigs	Fr
Flavoparmelia caperata (L.) Hale	*Parmeliaceae*	+	-	-	-	+	-	On rock	Fo
Flavopunctelia flavertior (stirton) Hale	*Parmeliaceae*	-	-	-	-	-	+	On twigs	Fo
Heterodermia diademata (Toylor). Awasthi	*Physciaceae*	-	-	-	+	-	-	On fallen twigs	Fo
Heterodermia hypocaesia (Yasudu) Awasthi	*Physciaceae*	+	-	-	-	-	-	On soil over rock	Fo
Heterodermia leucomelos (L.) Poelt.	*Physciaceae*	-	-	-	-	-	+	On soil over rock	Fo
Heterodermia pseudospeciosa (Wulfen) Trevis.	*Physciaceae*	+	-	-	-	-	+	On soil over rock	Fo
Lasallia pertusa (Rass.) Llano	*Umbilicariaceae*	+	-	-	-	-	+	On rock	Fo
Lasallia pustulata (L.) Mérat	*Umbilicariaceae*	+	-	-	-	-	-	On rock	Fo
Lecanora muralis (Schreb.) Rabenh.	*Lecanoraceae*	+	+	+	+	-	-	On soil over rock	Cr
Lecanora phadrophthalma Poelt	*Lecanoraceae*	-	+	-	-	-	-	On soil over rock	Cr
Lecanora pseudistera Nyl.	*Lecanoraceae*	+	-	-	-	-	-	On rock	Cr
Lecidea confluens (Weber) Ach.	*Lecideaceae*	-	-	+	-	-	-	On soil over rock	Cr
Lecidea lapicida (Ach.) Ach.	*Lecideaceae*	-	-	+	-	-	-	On soil over rock	Cr
Lepraria lobificans Nyl.	*Stereocaulaceae*	-	-	-	+	-	-	On rock	Lp*
Leptogium burnetiae C.W. Dodge	*Collemataceae*	+	-	-	-	-	-	On rock over soil	Fo
Lobothalia praeradiosa (Nyl.)Poelt & Leuck.	*Megasporaceae*	+	+	+	+	-	+	On soil over rock	Fo
Lobothallia alphoplaca (Wahlenb.) Hafellner	*Megasporaceae*	+	-	-	-	-	-	On soil over rock	Fo
Melanelia panniformis (Nyl.) Essl.	*Parmeliaceae*	-	-	-	-	-	+	On soil	Fo
Melanelia villosella (Essl.) Essl.	*Parmeliaceae*	-	-	-	-	-	+	On soil over rock	Fo
Nephroma parile (Ach.) Ach.	*Nephromataceae*	-	-	+	-	-	-	On soil over rock	Fo
Nephroma helveticum Ach.	*Nephromataceae*	-	-	-	-	-	+	On soil over rock	Fo
Peltigera canina (L.) Willd	*Peltigeraceae*	+	-	-	-	-	-	On soil over rock/ On soil	Fo
Peltigera didactyla (With.) J.R. Laundon	*Peltigeraceae*	+	-	-	-	-	-	On soil	Fo
Peltigera elisabethae Gyeln.	*Peltigeraceae*	+	-	-	-	-	-	On soil over rock	Fo
Peltigera lepidophora (Nyl.) Bitter	*Peltigeraceae*	+	-	-	-	-	-	On soil	Fo
Peltigera malacea (Ach.) Funck	*Peltigeraceae*	+	-	-	-	-	-	On soil over rock	Fo
Peltigera membranacea (Ach.) Nyl.	*Peltigeraceae*	+	-	-	-	-	-	On soil	Fo
Peltigera praetextata (Flörke ex Sommerf.) Zopf	*Peltigeraceae*	+	-	-	-	-	-	On soil	Fo
Peltigera rufescens (Weiss) Humb.	*Peltigeraceae*	+	-	-	-	-	-	On soil	Fo
Pertusaria leucosora Nyl.	*Pertusariaceae*	-	-	-	+	-	-	On rock	Fo
Phaeophyscia ciliata (Hoffm.) Moberg	*Physciaceae*	-	-	-	+	-	-	On rock	Fo
Phaeophyscia hispidula (Ach.)Essl.	*Physciaceae*	-	-	-	+	+	+	On rock\ on twigs	Fo
Phaeophyscia orbicularis (Necker) Moberg	*Physciaceae*	-	-	-	+	+	-	On rock	Fo
Phaeophyscia primaria (Poelt) Trass	*Physciaceae*	-	-	-	+	-	-	On soil over rock	Fo
Physcia biziana (A. Massal.)	*Physciaceae*	+	-	-	-	-	-	On soil over rock	Fo

Species	Family	Badrinath			Mana			Substratum	Growth Form[†]
		B 1	B 2	B 3	M 1	M 2	M 3		
Physcia caesia (Hoffm.) Hampe ex Fürnr.	*Physciaceae*	+	+	-	-	-	-	On soil over rock	Fo
Physcia leptalea (ach.) DC	*Physciaceae*	-	-	+	-	-	-	On soil over rock	Fo
Physconia detersa (Nyl.) Poelt.	*Physciaceae*	-	-	-	-	-	+	On rock	Fo
Physconia enteroxantha (Nyl.) Poelt.	*Physciaceae*	-	-	-	-	+	-	On soil over rock	Fo
Physconia muscigena (Ach.) Poelt	*Physciaceae*	+	-	-	-	-	-	On soil over rock	Fo
Porpidia crustulata (Ach.) Hertel & Knoph	*Porpidiaceae*	-	-	+	-	-	-	On soil over rock	Cr
Punctelia borreri (Sm.)Krog	*Parmeliaceae*	-	-	-	+	-	-	On rock	Fo
Punctelia rudecta (Taylor) Elix & J. Johnst.	*Parmeliaceae*	+	-	-	-	-	-	On rock	Fo
Rhizocarpon disporum (Naeg.ex. Hepp)Müll. Arg	*Rhizocarpaceae*	-	-	-	-	+	-	On rock	Cr
Rhizocarpon geographicum (L.) DC	*Rhizocarpaceae*	+	-	-	+	-	+	On rock	Cr
Rhizocarpon macrosporum Räsänen	*Rhizocarpaceae*	-	-	+	+	-	-	On rock	Cr
Rhizocarpon sublucidum Räsänen	*Rhizocarpaceae*	-	+	+	-	-	-	On rock	Cr
Rhizoplaca chrysoleuca (Sm.) Zopf.	*Lecanoraceae*	+	-	+	-	+	+	On rock	Cr
Stereocaulon foliolosum Nyl.	*Stereocaulaceae*	-	-	-	-	-	+	On rock	Fr
Stereocaulon alpinum Laurer	*Stereocaulaceae*	+	-	-	-	-	-	On soil over rock	Fr
Stereocaulon myriocarpum Th.Fr.	*Stereocaulaceae*	-	+	+	-	-	-	On soil over rock	Fr
Tephromela khatiensis (Räsänen) Lumbsch	*Tephromelataceae*	+	-	-	+	-	-	On rock	Cr
Umbilicaria indica var. *indica* Frey	*Umbilicariaceae*	+	-	-	-	-	-	On rock	Fo
Umbilicaria vellea (L.) Ach.	*Umbilicariaceae*	+	-	-	-	-	-	On rock	Fo
Verrucaria acrotella Ach.	*Verrucariaceae*	-	-	-	+	-	-	On rock	Cr
Xanthoparmelia bellatula (Kurok.& Filson) Elix & al.	*Parmeliaceae*	-	-	-	+	-	-	On soil over rock	Fo
Xanthoparmelia australasica D.J. Galloway	*Parmeliaceae*	-	-	-	+	-	-	On rock	Fo
Xanthoparmelia coreana (Gyeln.) Hale	*Parmeliaceae*	+	-	-	-	-	-	On rock	Fo
Xanthoparmelia mexicana (Gyeln.) Hale.	*Parmeliaceae*	+	-	-	-	-	-	On soil over rock	Fo
Xanthoparmelia somloensis (Gyeln.)Hale.	*Parmeliaceae*	+	-	-	-	-	-	On soil over rock	Fo
Xanthoparmelia stenophylla (Ach.) Ahti & Hawksw.	*Parmeliaceae*	+	-	-	-	-	+	On soil over rock	Fo
Xanthoparmelia taractica (Kremp.) Hale	*Parmeliaceae*	+	-	-	-	-	-	On soil over rock	Fo
Xanthoparmelia terricola Hale. Nash & Elix in Hale	*Parmeliaceae*	-	-	-	-	-	+	On rock	Fo
Xanthoparmelia tinctina (Maheu & A. Gillet) Hale	*Parmeliaceae*	-	-	-	+	-	-	On rock	Fo
Xanthoria candelaria (L.) Th.Fr.	*Teloschistaceae*	+	+	-	-	-	-	On soil over rock	Fo
Xanthoria elegans (Link.)Th.Fr.	*Teloschistaceae*	+	-	-	+	+	+	On rock	Fo
Xanthoria fallax var. subsorediosa (Räsänen) D.D. Awasthi	*Teloschistaceae*	+	-	-	-	-	-	On soil over rock	Fo
Xanthoria sorediata (Vainio). Poelt	*Teloschistaceae*	-	-	+	+	+	+	On soil over rock	Fo
Xanthoria ulophyllodes Räsänen	*Teloschistaceae*	+	-	-	+	-	-	On rock\ on twigs	Fo

Correlations

Among the macroscale variables analyzed altitude, relative humidity, minimum and maximum temperature were significantly correlated with diversity of the four growth forms recorded, indicating a gradual increase in crustose growth forms than others (e.g. foliose, fruticose, and dimorphic) with increasing altitude; decreasing relative humidity and ambient atmospheric temperature (Table 3). The diversity of foliose, fruticose, and dimorphic growth forms was negatively correlated with crustose (Table 3). Relative humidity and minimum and maximum temperatures negatively correlated to the altitude (Table 3).

Lichen groups

Hierarchical cluster analysis resulted in three major clusters (I–III) in Badrinath and two in Mana(I, II) (Fig. 4, 5). In both locations the clustering clearly demarcated lichen communities based on growth forms, which were further differentiated on the basis of substratum preferences. In Badrinath the major cluster I consisted of fruticose and dimorphic species (*Stereocaulon* and *Cladonia*), whereas the major clusters II and III consisted of foliose and crustose growth forms respectively (Fig. 4). In Mana the major cluster I consisted mainly of foliose growth forms, whereas the major clusters II consisted of crustose growth form (Fig. 5). *Cladonia pyxidata* appears as an outlier in Mana as it was the only species with dimorphic growth form. These major clusters in both locations were further subclustered according to their substrate preferences. In both locations saxicolous (on rock) substratum dominated over the all other substratums (Fig. 4, 5). Diversity of crustose lichen was higher in Mana than Badrinath (Fig. 4, 5).

Table 3 Pearson's correlation coefficients for selected variables (significant correlations are tagged).

	Cr	Fo	Fr	Dm	Rh	Alt	MinT
Fo	-1.000*						
Fr	-1.000*	1.000*					
Dm	-1.000*	1.000*	1.000*				
Rh	-1.000*	1.000*	1.000*	1.000*			
Alt	1.000*	-1.000*	-1.000*	-1.000*	-1.000*		
MinT	-1.000*	1.000*	1.000*	1.000*	1.000*	-1.000*	
MaxT	-1.000*	1.000*	1.000*	1.000*	1.000*	-1.000*	1.000*

*Correlation is significant at the 0.01 level (2-tailed).

Variables: Cr=crustose growth form, Fo =foliose growth form, Fr = fruticose growth form, Dm = dimorphic growth form, Rh= percentage average relative humidity, Alt = altitude, MinT= average annual minimum temperature, MaxT= average minimum temperature.

Discussion

Organism's occurrence in a habitat is the function of limited range of various environmental variables, and within these range they are found to be most abundant, indicating their specific environmental optimum (Körner 2003). Altitude linked macro-scale environmental variables such as relative humidity, temperature and precipitation influence both the taxonomic as well as growth form diversity of lichen communities, worldwide (Ahti 1964, John and Dale 1990, Wolf 1993, Pirintsos et al 1995, Upreti and Negi 1998, Grytnes et al 2006, Pinokiyo et al 2008). The phytogeographical distribution of Indian lichens is found to be influenced by climatic factors which are derived from elevation gradients throughout the country (Upreti 1998). Himalayan habitats due to higher environment lapse rate coupled with increasing zooanthropogenic pressures constitute some of the most fragile ecosystems. Lichen communities in Himalaya are characterized by specific growth forms and habitat subsets along elevational gradients (Upreti 1998). Lichens in

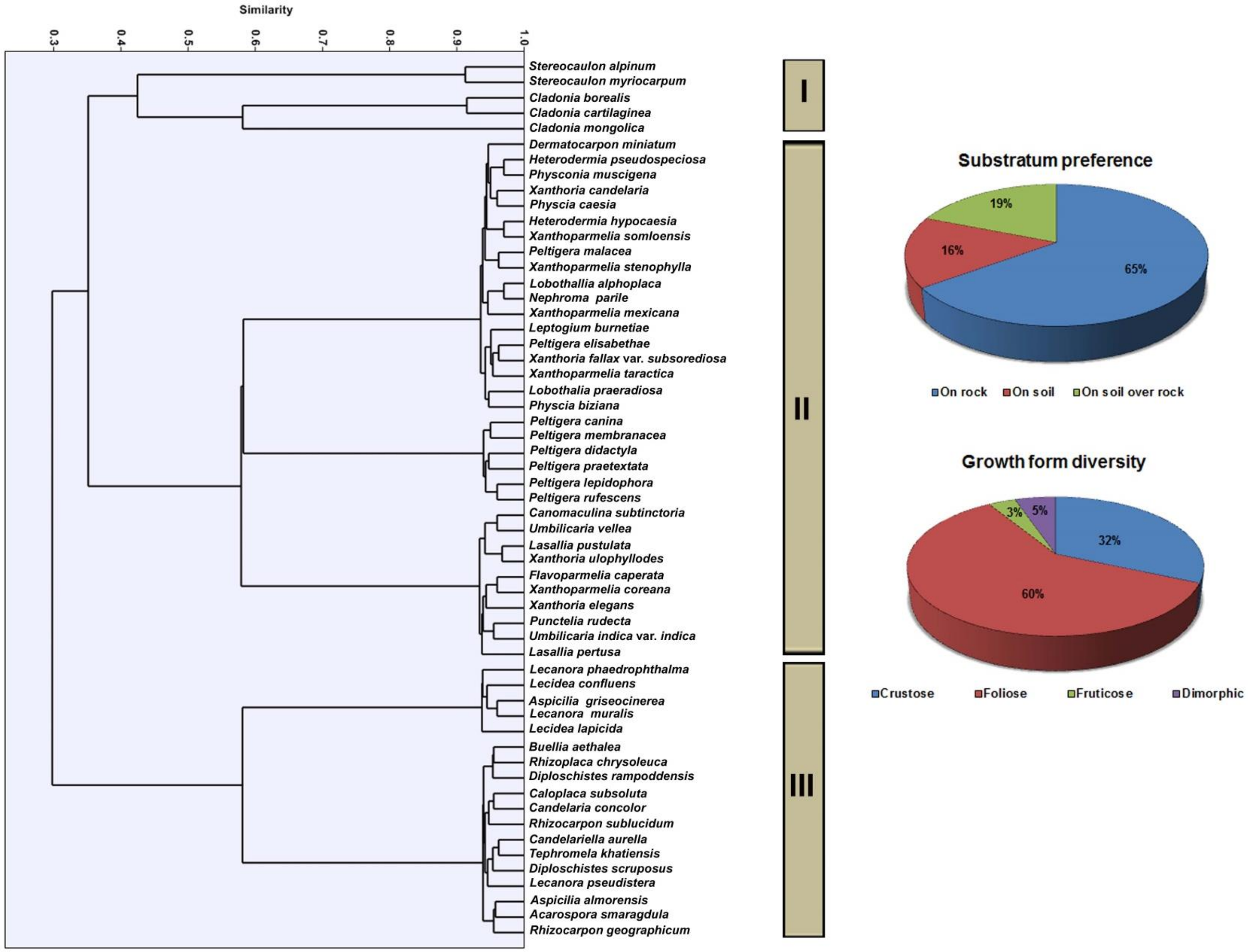

Fig. 4 – Groups of lichen species in and around Badrinath town resulting from hierarchical cluster analysis based on growth form diversity and substrate preferences.

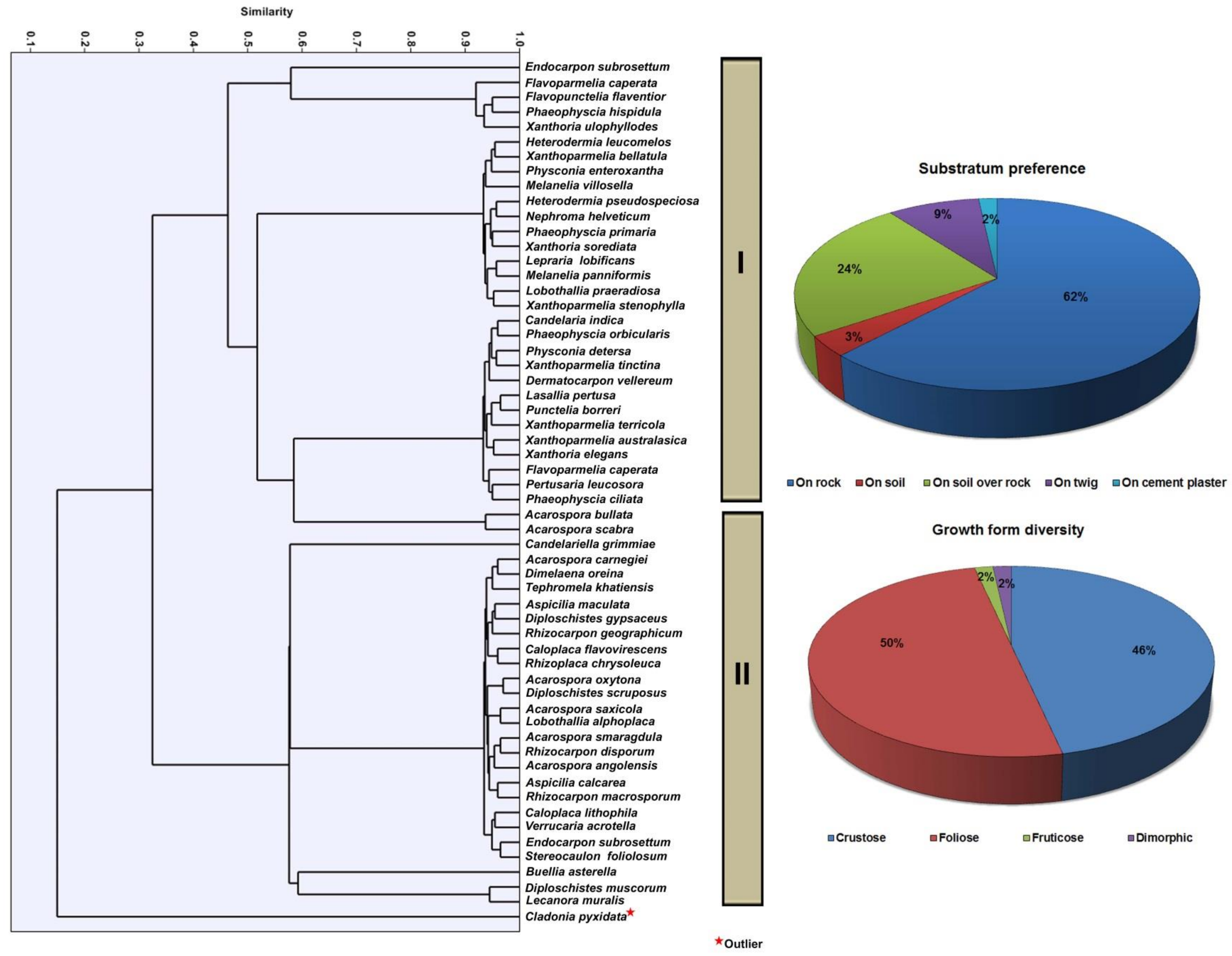

Fig. 5 – Groups of lichen species in and around Mana town resulting from hierarchical cluster analysis based on growth form diversity and substrate preferences.

Himalayas are dominated by epiphytic, foliose growth forms upto 3000 m, followed by terricolous and saxicolous; foliose, fruticose and crustose growth forms at higher altitudes (≥ 3200 m) (Negi 2000, Negi and Gadgil 2002, Negi and Upreti 2000, Upreti and Negi 1998). Lichen communities above treeline (≥ 3500 m) in Himalayas are influenced by both availability of suitable substrate and severity of harsh climates, which allow specific tolerant growth forms to survive (Negi 2000, Negi and Upreti 2000, Rai et al 2012 a, b, Rai 2012).

Badrinath valley, situated in alpine regions of Himalayas, by virtue of its stressed climatology (i.e. higher environmental lapse rate, high wind velocity, high UV radiation, low atmospheric pressure and low precipitation), and delimiting nutrient and exposure regime, support relatively simple ecosystems, characterized by limited trophic levels and relatively very few plant growth forms and species (Rai et al 2010). Absence of dominant growth of angiospermic vascular plants in the valley reduces vegetative competition, which allows lichens to flourish and inhabit all available relevés. The overall dominance of *Parmeliaceae* over other families in both locations (i.e Badrinath and Mana) is a characteristic feature of Himalayan lichens (Upreti 1998, Negi 2000, Negi and Upreti 2000). The richness of cyanolichen species in Badrinath than Mana can be attributed to higher moisture and less harsh temperature regime in Badrinath (Blum 1973, Kershaw 1985, Lange et al 1986, Lange 2003, Rai et al. 2013). Though foliose growth form dominated in Badrinath valley, other characteristic terricolous (soil inhabiting) growth forms of alpine Himalayan habitats, i.e. fruticose (*Stereocaulon*) and dimorphic (*Cladonia*) (Rosentreter et al. 2014) were delimited to Badrinath town, due to greater soil cover which tends to decrease towards Mana (Rai et al 2012b). As shown by correlation analysis the comparative increase in proportion of crustose growth forms in Mana can be attributed to increasing altitude, low relative humidity and lower atmospheric temperature in mountainous habitats of Mana (Dietrich and Scheidegger 1996, 1997, Shrestha and St. Clair 2011). The comparative clustering of the six sampling sites of the two localities in PCA reflects the constitutional difference in lichen growth forms in these sites, which are influenced by environmental as well as land scape (soil cover) variables (Lalley 2006, Rai et al 2012b). The hierarchical clustering of lichen species at both the locations in Badrinath valley concluded that lichen communities in the valley form natural clusters based on growth forms which are further differentiated in two sub-clusters according to substrate variability (Scutari et al. 2004, Rai et al 2012b). As the harsh climate of the valley is able to sustain small diversity of other ground flora, rock and soil over rock was the dominant substrate for lichens in the valley (Rai et al. 2012b). The clustering exemplifies the role of altitude linked changes in macro-scale environmental variable which influence the comparative abundance of different lichen growth forms (Rai et al 2012b).

It is evident from the above observations that lichen communities in alpine habitats of Himalaya are influenced both by macro-scale environmental as well as land scape variables, which cluster lichens according to ecologically viable growth form groups over period of time. Broad similar land use in both the locations of study in Badrinath valley, suggest that the environmental variables which sustain the growth of lichens species must be monitor and conserved as lichen communities play crucial role in stabilizing the ecology of the region.

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