13 Community-Level Lichen Diversity Assessment in Alpine Zone of Indian Himalaya: Climate Change Implications

Rajesh Bajpai, C. P. Singh, and Dalip Kumar Upreti

Abstract

Lichens have prolonged history as excellent biomonitors of air pollutants and their responses are documented in climate change assessment. Lichen species composition within a community and change in composition are powerful tools to retrieve information about changes in climate, air quality and biological processes in the area. In this study, the composition of lichen communities in sub-alpine (3000–3500 m), moist alpine scrub (3500–4000 m) and dry alpine scrub (4000–4500 m) of Indian alpine Himalayan regions has been documented. A total of 18 bioindicator lichen communities are recorded which comprised 732 species under 148 genera and 47 families. Among different indicator communities, Parmelioid dominates the areas followed by Lecanorioid, Dimorphic and Physcioid communities represented by 185, 87, 71 and 64 species, respectively. It is assumed that Cyanophyceans are the most sensitive communities distributed at the middle range of altitude between 3000 and 4000 m in the studied areas. Furthermore, substratum and growth form also

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played a significant role in the assessment of varied environmental conditions. This study provides a baseline data about potential taxa having higher sensitivity to change in climate and which may exhibit migration, adaptation, and acclimation, in the near future.

Keywords

Altitudinal range · Biomonitoring · Habitats · Indicator community · Lichen

13.1 Introduction

The alpine zone in the Himalaya has attracted the attention of a large number of plant explorers, phyto-geographers, ecologist and naturalists since a very long time (Dickore and Nusser 2000). However, few studies of lichens are available in alpine areas of the Himalaya in the context of their relation to ecology, climate change and pollution. The lichens may allow a rapid assessment of forest health and status in regions where other forms of environmental monitoring are expensive or impractical. The identification of 'indicator communities' amongst lichens can provide a basis for management recommendations and can also be used to assess climatic change and potential forest recovery in areas where deforestation has caused a change in local climate and phanerogamic as well as cryptogrammic communities (Wolseley and Aguirre-Hudson 2007). However, lichens are valuable bio-indicators for evaluating the consequences of human activities that are progressively changing the Earth's ecosystems. Lichens have been referred as extremophiles because they have the ability to endure conditions ranging from Arctic/Antarctic to hot desert and high alpine regions (Hill and Hawksworth 1984). Lichens are often abundant in areas where vascular plants do not have ability to grow such as Antarctica and mountain peaks (Brodo et al. 2001).

The lichens survive in diverse climatic conditions, due to their peculiar poikilohydric nature, where they cannot regulate their own water content and depend on the immediate atmosphere for moisture mainly in the form of fog, dew and vapour. The poikilohydric nature enables lichens to tolerate extreme desiccation and hydration (Smith and Molesworth 1973). Owing to the mutualistic symbiotic nature, the lichens have an ability to sustain extreme environment and colonise on all available perennial substrata as well as man-made artefacts. On the bare substratum, the fungus provides a home for the alga, the alga supplies photosynthetic energy to the fungus. The unique morphology enables lichens to colonize a vast variety of substrates, such as bark of trees (Corticolous), rock (Saxicolous), leaves (Foliicolous), soil (Terricolous) and mosses (Muscicolous). The substratum plays an important role in colonization by selective taxa. The lichen growth forms depend upon arrangement of cortical algal and medullary tissue and mode of attachment to the substratum (Hale 1983). Lichens have the ability to produce vast array of different secondary metabolites as defence from high UV light and temperature stress in alpine areas (Elix and Stocker-Wörgötter 2008).

The increasing UV light, anthropogenic activities, deforestation and species' range extension have increased the necessity to understand ecosystem in which lichen communities are growing (Ellis and Coppins 2006; Hylander and Jonsson 2007). Lichens are involved in ecological processes from the canopy to the ground of an ecosystem, where they store, intercept and redistribute water and nutrients. In addition, lichens are a food source and habitat for various fauna and flora. Lichens play an important role in successional stages of plant communities, where certain lichen species are primary colonizers that create suitable conditions for later successional stages. Furthermore, in forest ecosystems, lichens represent a major part of the species diversity, and their diversity can exceed that of vascular plants (McCune et al. 1997). Consequently, there is high demand for lichenologists to contribute to the knowledge of forest ecosystems (Hylander and Jonsson 2007).

The composition of lichen communities based on different species of lichens can be used as lichen bioindicator communities for assessment of environmental disturbances in an area. Lichens are ideal systems for exploring the patterns and processes of community structure across space and time. For more than a decade, lichens have been recognised as an integral component of ecosystems and knowledge about the ecology of epiphytic lichens has enabled scientists to answer questions about environmental changes, sustainable forestry practices and forest health (McCune et al. 2000; Sillett et al. 2000). Furthermore, epiphytic lichens have been used as old-growth forest indicator species, such as, their presence or absence may suggest the present ecological conditions of the area, and thus they are used as an indicator of climate change (Boudreault et al. 2002).

The present studies discuss variation in lichen diversity in different altitudinal gradients (3000–4500 m) and their potential use as bioindicator of environmental alterations in alpine range. Further, the study examines the community patterns in Western Himalaya (WH) and Eastern Himalaya (EH) for recommending management practices to maintain and enhance cryptogamic diversity in different vegetation types in the area. The available information will provide baseline information on lichen communities in alpine areas and would also enhance our understanding of the mountain ecosystem which is vital for future management and restoration approaches in terms of climate change mitigation.

13.2 Material and Methods

13.2.1 Study Area and Sample Collection

The study is based on the specimens of lichens deposited in the herbarium of CSIR-National Botanical Research Institute, Lucknow (LWG) and collection from high alpine areas (altitudes between 3000 and 4500 m) in Indian Himalayan region (IHR) during the period 2013–2019 under the aegis of (HIMalayan Alpine Dynamics Research Initiative (HIMADRI). The data were collected from Jammu & Kashmir

(N 34° 5′ 1.1616″; E 74° 47′ 50.5356″), Himachal Pradesh (N 31° 6′ 16.5780″; E 77° 10′ 24.3264″), Uttarakhand (N 30° 19′ 18.8940″; E 78° 1′ 35.8284″), Sikkim (N 27° 20′ 20.1696″; E 88° 36′ 23.4216″), Arunachal Pradesh (N 27° 50′ 42.5328″; E 95° 14′ 50.4420″). The secondary lichen diversity data were generated from the past published literatures available in different monographs, revisionary, floristic studies on lichens of IHRs (Upreti and Nayaka 2000; Srivastava 2005; Prasher and Chander 2005; Yadav 2005; Thakur and Chander 2018; Bajpai et al. 2018). The collected specimens were identified using routine microscopic and laboratory techniques based on the following keys and taxonomic treatments (Awasthi 1991, 2007; Orange et al. 2001; Elix 2014). The lichen communities were grouped according to James et al. (1977) and Alatalo et al. (2017). The graphs were prepared using MS Excel.

13.3 Results

The variation in the diversity and composition of lichen communities along the altitudinal gradient (3000–4500 m) resulted in occurrence of 732 species of lichens belonging to 148 genera and 47 families of alpine areas of Indian Himalayan regions (Table 13.1). The area is dominated by the members of Parmeliaceae followed by Physciaceae and Cladoniaceae including 254, 64 and 48 species respectively. The dominant genera include *Parmotrema*, *Usnea*, *Bryoria*, *Heterodermia*, *Cladonia* and *Lecanora*. Out of the 47 families known from the area, 14 families are represented by single species within single genus (Table 13.1).

In the area, 133 species are crustose, 226 species are foliose with broad lobes, 72 species are with foliose narrow lobes, 69 species are fruticose filamentous and remaining are intermediates reported from the area. In this study a total of 40 broad lobe lichens with gelatinous nature are reported from the area. The gelatinous nature thalli are well known for their soil binding nature and capacity for production of soil humus as well as good indicator of moisture in the soil (Wade 1959). The species exhibit wide substratum preference, as 48 species prefer to grow on soil, 148 species on rocks, 233 species on bark and twigs, 4 on mosses and 7 on different plant leaves and remaining species grown on mixed type of substratum.

13.4 Discussion

A total of 18 lichen indicator communities were encountered in the area, among them Parmelioid community was the most dominant followed by lecanorioid, dimorphic and physcioid represented with 185, 87, 71 and 64 species respectively in the alpine areas. Lichens also have important biological roles in forests, including nitrogen fixation, and we found 56 species of cyanophycean community followed by Usnioid community with 61 species indicating good air quality. However, Arthonoid, Leprarioid, Pertusorioid and Lichenoid communities are in infirmity situations. Such findings on lichen community assemblage contribute to the investigation of several key forest ecosystem issues like contamination of natural resources, biodiversity status, productivity and sustainability.

Table 13.1 Lichen families represented by number of genera and species

S. No.	Families	Genera	Species
1	Acarosporaceae	3	19
2	Arthoniaceae	1	1
3	Baeomycetaceae	1	2
4	Caliciaceae	6	7
5	Candelariaceae	2	6
6	Catillariaceae	1	1
7	Cladoniaceae	2	48
8	Coccocarpiaceae	1	4
9	Coenogoniaceae	1	2
10	Collemataceae	2	37
11	Coniocybaceae	1	1
12	Gomphillaceae	1	1
13	Graphidaceae	3	12
14	Haematommataceae	1	1
15	Icmadophilaceae	4	6
16	Lecanoraceae	6	46
17	Lecideaceae	3	10
18	Leprocaulaceae	1	1
19	Lichinaceae	2	4
20	Lobariaceae	4	23
21	Megalariaceae	1	1
22	Megalosporaceae	1	1
23	Megasporaceae	2	11
24	Monoblastiaceae	1	1
25	Mycoblastaceae	1	1
26	Nephromataceae	1	5
27	Ochrolechiaceae	1	3
28	Pannariaceae	2	5
29	Parmeliaceae	44	254
30	Peltigeraceae	2	21
31	Peltulaceae	1	2
32	Pertusariaceae	1	6
33	Physciaceae	8	64
34	Pilocarpaceae	2	4
35	Porinaceae	1	1
36	Psoraceae	1	1
37	Pyrenulaceae	1	1
38	Ramalinaceae	4	19
39	Rhizocarpaceae	1	12
40	Roccellaceae	1	1
41	Sphaerophoraceae	1	2
42	Stereocaulaceae	2	18
43	Teloschistaceae	10	27

(continued)

Table 13.1 (continued)

S. No.	Families	Genera	Species
44	Tephromelataceae	1	2
45	Trapeliaceae	3	4
46	Umbilicariaceae	2	18
47	Verrucariaceae	6	15

13.4.1 Lichen Diversity along the Altitudinal Gradients

In all, 732 species of lichens were found throughout the altitudinal gradients, with highest richness observed between 3000 and 4000 m. The lowest values were recorded at an altitude of 4500 m. It appears that, the high altitudes bear the scanty substratum and have harsh climatic conditions which reduce the diversity of lichens but support the growth of some exclusive lichen taxa. The most recent account of lichens available from India revealed that more than 80% of species are from the Himalayan area (Singh and Sinha 2010; Singh et al. 2018). Among the study states, Uttarakhand, Sikkim and Arunachal Pradesh showed higher dominance of species than that in Himachal Pradesh and Jammu & Kashmir (Fig. 13.1).

However, Throughout the world, the lichen families Parmeliaceae, Physciaceae and Cladoniaceae showed highest species dominance (Lücking et al. 2016). The family Parmeliaceae, a widely distributed lichen family with cosmopolitan distribution, has higher abundance and wider distribution in high-altitude ecosystems (Giordani and Incerti 2008; MacDonald et al. 2013). Graphidaceae, Lecanoraceae, Arthoniaceae, Pyrenulaceae, and Trypetheliaceae are the dominant elements in low elevation forests with dry and humid areas, whereas the families namely Lobariaceae, Collemataceae, Peltigeraceae, Ramalinaceae are more frequent at middle altitudes with shaded conditions (Hekking and Sipman 1988). Foliose or fruticose lichens are not favoured in the areas with higher pollution load and higher humidity found mainly at lower elevations as compared to pristine higher elevation areas, because lichen thallus gets supersaturated with water, inhibiting photosynthesis. The crustose lichens exhibit strategies to avoid super saturation and can survive in high humidity environments (Lakatos et al. 2006). Low diversity is generally recorded when the natural vegetation is removed and replaced by exotic species, limiting the source area of lichen propagules or suitable substrata for colonization. Stumpy diversity in lower altitudes may have resulted because the recovery of specialist lichen species (mostly foliose and fruticose) is slow due to poor dispersal (Wolseley et al. 2007) and absence of specialised habitats in forest stands.

In this study, we found that, the crustose lichen families dominate mostly at lower altitudes. To withstand, adapt to the high UV radiation and bright sunlight the lichens develop bright pigments in their upper cortical regions while some secondary metabolites are produced in medulla to protect the photobiont against light stress conditions. Waring (2008) reported increase in depside concentrations in response to increasing light exposure, suggesting that compounds may have a photo protective role in higher altitudes. Shukla et al. (2017) studied the diversity of lichens with

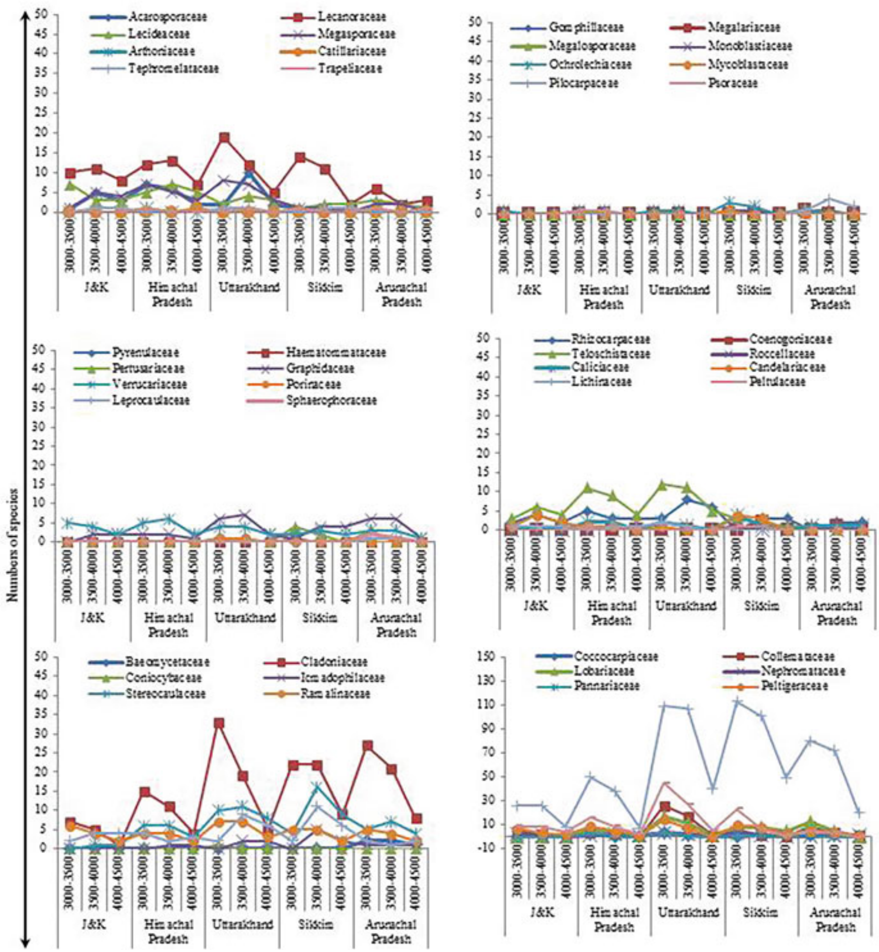

Fig. 13.1 Dominance of lichen families along altitudinal gradients of respective sites

qualitative assessment of secondary metabolites and suggested that secondary metabolites confer resistance to lichens against biotic and abiotic stresses.

The lichen families containing bigger thallus exhibit dominance in middle altitudes of 3000–3500 m. As compared to higher altitudes, the lower altitudes are drier and more disturbed and thus have poor lichen diversity, while higher altitudes being pristine correspond to rich lichen diversity. At higher altitudes, climate seems to favour growth of lichens but the incident solar radiation, low precipitation, low temperature acts as limiting factors and hence lead to decline in the diversity as the altitude increases. The similar findings have been reported by Grytnes et al. (2006) as the species diversity exhibits gradually increasing trend with altitude up to 2100 m indicating the impact of microclimatic conditions and forest cover on species composition.

13.4.2 Species Composition

It was found that the foliose and crustose growth forms dominated the area followed by fruticose and squamulose lichens. Further, the growth forms can be subdivided into different intermediate growth forms such as foliose bigger lobes (FB) dominated by 31%, foliose narrow lobate (FN) represented by 10% whereas crustose growth forms governs 18% of the total diversity (Fig. 13.2).

In lower altitudes, crustose lichens shared their dominance, which gradually decreased at higher elevation. The dominance at lower altitudes may be due to the survival potential of crusotse forms against various anthropogenic disturbances and by developing potential tolerance. As mentioned previously, crustose lichens have adaptations to the high humidity conditions at low elevations and can photosynthesize under low light intensity conditions (Lakatos et al. 2006). On the other hand, foliose forms dominate in higher altitude, because they no longer have problems of water supersaturation and can outcompete crustose lichens by virtue of their larger thalli (Sipman 1996; Lakatos et al. 2006). In addition, the increase of mist favours the growth of foliose lichens because of their three-dimensional morphology

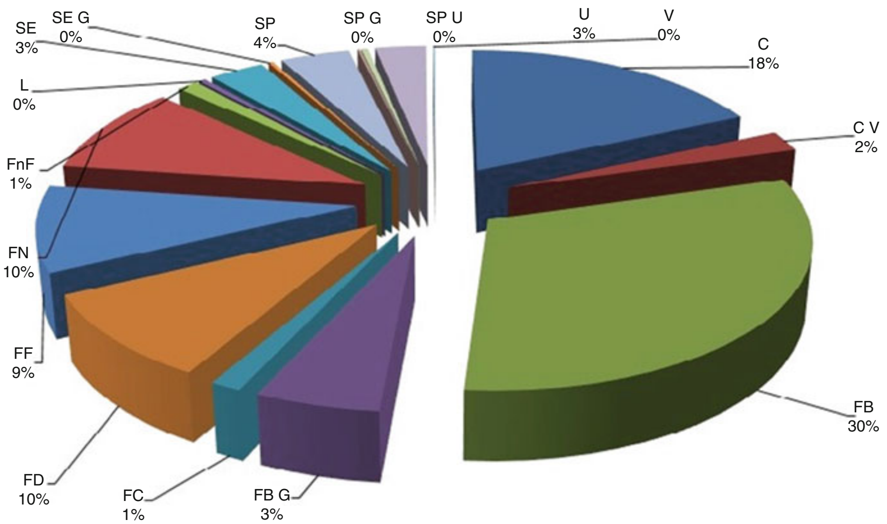

Fig. 13.2 Growth form of lichens represents the number of species found growing in Indian Alpine Himalayan areas. *C*: Crustose; *CV*: Crustose Verricouse; *FB*: Foliose with broad lobes; *FB G*: Foliose with broad lobes Gelatinous; *FC*:Foliose with canaliculate; *FD*: Fruticose dimorphic; *FF*: Fruticose filamentous; *FN*: Foliose with narrow lobes; *FnF*: Fruticose non-filamentous; *L*: Leprose; *SE*: Squamulose effigurate; *SE G*: Squamulose effigurate Gelatinous; *SP*: Squamulose peltate; *SP G*: Squamulose peltate Gelatinous; *U*: Umbilicate; *V*: Verricouse

(Stanton and Horn 2013; Stanton 2015). Fruticose growth forms, being pendulous from twigs in well-lit higher elevations have the advantage of being able to use light from all directions better than foliose lichens which can maximize the harvest of more or less unidirectional light (Gauslaa et al. 2009). Moreover, the dissected fruticose lichens have a high surface area to volume ratio, making them more closely coupled to ambient atmosphere than flat foliose lichens, and absorb moisture more readily from air, that results in their greater frequency in open sites (Baniya et al. 2009).

Lichens growing at higher elevations have abundance of hair like structures (rhizines) on their lower side. Rhizines act as reservoir and trap the atmospheric moisture for longer period. As altitude increases, the precipitation decreases thus the presence of rhizines helps in obtaining the scarce water that lichens need for photosynthesis (Stanton and Horn 2013). Lichens growing in open sites, where there is a higher intensity of light and low humidity, rhizines play vital role in absorbing moisture for lichens to survive in microhabitats. The higher frequency of cyanolichens was reported between the altitudes 2500–3000 m. The occurrence of cyanolichens related to the fact that these lichens require high humidity and low luminosity conditions in montane forests, especially in the forest interior (Soto-Medina and Londoño 2015). On the other hand, at low elevations, higher temperature reduces the presence of cyanolichens, whereas at high elevations there is a high intensity of light and low forest cover, which is a limiting factor for cyanolichens in the area.

13.4.3 Substrate Specificity

The colonization of lichen thalli is certainly one of the more apparent effects of difference in substrate texture. Lichen spores can get trapped and begin to develop on rough surface more easily than smooth surface. The types of substrata play an important role in distribution of different lichen species in the area. In this study, lichens growing on barks dominate with 233 species followed by 184 species growing over rocks and 48 species on soils. However, 190 species share two different substratum (Bark and Rock), 58 species share three types of substrates (Bark, Rock and Soil) while 8 species commonly grow on all available substrates. The study area revealed dominance of corticolous (32%) followed by saxicolous, terricolous and muscicolous with 25%, 7% and >1%, respectively (Fig. 13.3). The lower altitudes around <3000 m are dominated by a variety of phorophytes, which provide excellent substratum to a number of lichen taxa to colonize. However, in higher altitudes (>3000 m) mostly devoid of phorophytes and presence of exposed rocks represented the lesser number of epiphytic lichens in the area. In this study, most of the corticolous lichens reported are from lower and middle altitudes as compared to higher elevation.

All the IHR states exhibit the dominance of corticolous lichens in lower and middle altitudes region followed by foliiocolous and muscicolous. However, saxicolous lichens dominated at higher altitudes because of the presence of exposed

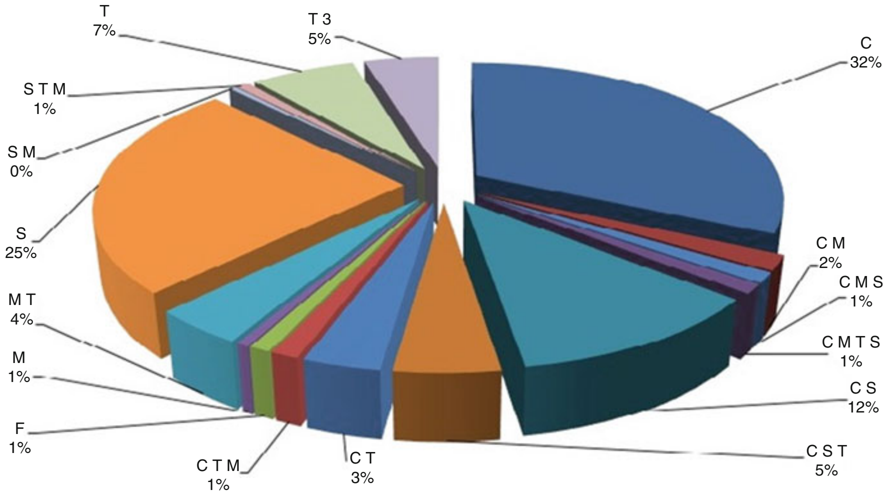

Fig. 13.3 Substratum of lichens represents the numbers of species found growing in Indian Alpine Himalayan regions. *C*: Corticolous; *CM*: Corticolous, muscicolous; *CMS*: Corticolous, muscicolous, saxicolous; *CMTS*: Corticolous, muscicolous, terricolous, saxicolous; *CS*: Corticolous, saxicolous; *CST*: Corticolous, saxicolous, terricolous; *CT*: Corticolous, terricolous; *CTM*: Corticolous, terricolous, muscicolous; *F*: Foliicolous; *M*: muscicolous; *MT:* Muscicolous, terricolous; *S*: Saxicolous; *SM:* Saxicolous, muscicolous; *STM:* Saxicolous, terricolous, muscicolous; *T*: Terricolous; *TS:* Terricolous, saxicolous

rocks, stones, boulders and lack of big trees. Members of lichen families Teloschistaceae, Cladoinaceae, Stereocauloiaceae, and some species of Lecanoraceae colonize most of the exposed rocks and boulders and soil over rocks or soil in open places at high altitudes. It is reported that at higher altitudes, climate seems to favour growth of lichens but the incident solar radiation acts as a stress factor leading to decline in the diversity as the altitude increases. Similar to the finding of Grytnes et al. (2006), the species diversity exhibited gradual increasing trend with increasing altitude, indicating the impact of microclimatic conditions and forest cover on species composition, which declined with further increase in altitudes.

13.4.4 Community Characterization

The increasing altitude, microclimate and/or air quality changes determine lichen community structure in the area. Both higher and lower altitudes of the study area exhibit distinct lichen community composition. Parmeliod community with 25% exhibits dominance in the area followed by Lecanorioid, Dimorphic, Physcioid and Usnioid represented by 12%, 10%, 9% and 8% respectively (Fig. 13.4).

The communities at lower altitudes comprised of species of the genera *Candelaria*, *Chrysothrix, Physcia* and *Phaeophyscia*, which indicates nutrient

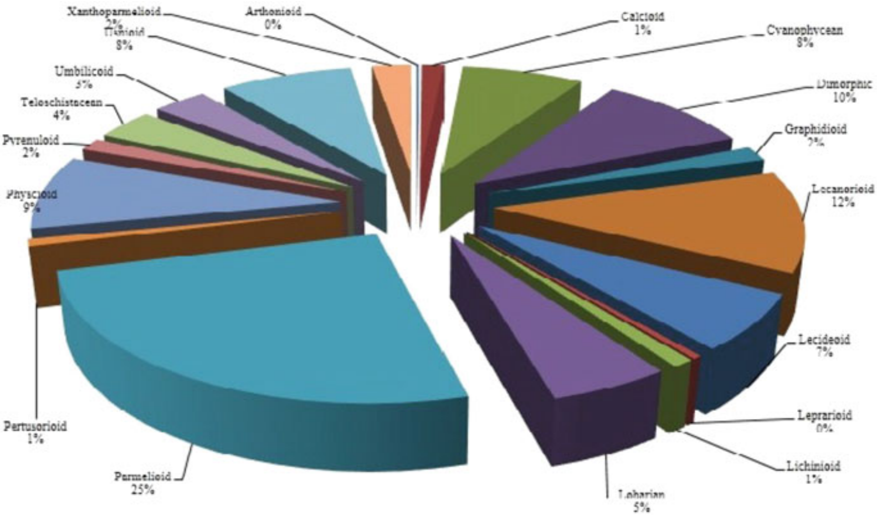

Fig. 13.4 Cumulative lichen communities representation in Indian Alpine Himalayan regions

enriched habitat whereas species of *Graphis* indicate an exposed and regenerated forest. As for as characterization of lichen indicator communities in both the Himalaya regions is concerned we have fascinating results. Most of the lichen communities were found dominating in Western Himalaya (WH) as compared to alpines of Eastern Himalaya (EH). The Parmelioid, Dimorphic, Graphidioid, Usnioid and Pyrenulioid were predominant in EH whereas, Lecanorioid, Cyanophycan, Lobarian, Lecidioid, Teloschistacean, Umbilicoid, Physcioid and Xanthoparmelioid were dominating in WH (Fig. 13.5). The lower altitudes usually have few lichens except in moist places. The lichen vegetation changes as the altitude increases, and the smooth bark mostly supports the crustose lichens belonging to species of lichen genera *Pyrenula*, *Calcioid, Graphis, Lecanora, Pertusaria, Verrucaria* and *Arthonia* but do not support the growth of foliose lichens as spores of bigger lichens get washed off from smooth surfaces in the EH (Sinha and Jagadeesh Ram 2014).

However, the alpine zone (3200–4500 m) between the treeline and permanent snow line is dominated by grassy meadows, locally called 'Bugyals' in the Himalaya. In terms of herbaceous species diversity, this is the richest zone, harbouring a number of plants. This vegetation is composed of tall forbs, mixed herbaceous formations, *Danthonia* grasslands and *Kobresia* sedge, with several intermixed cushionoid species, and is often lined by scrubs. Majority of the lichen species of genera *Cladonia*, *Fuscopannaria, Canoparmelia, Heterodermia, Hypogymnia, Lethariella, Melanelia, Melanelixia, Melanohalea, Myelochroa, Nephromopsis, Parmotrema, Remototrachyna, Xanthoparmelia* and some members of family Teloschistaceae prefer to grow at base of Bugyal vegetation along with mosses and small *Rhododendron* trees. The species of the above genera, not

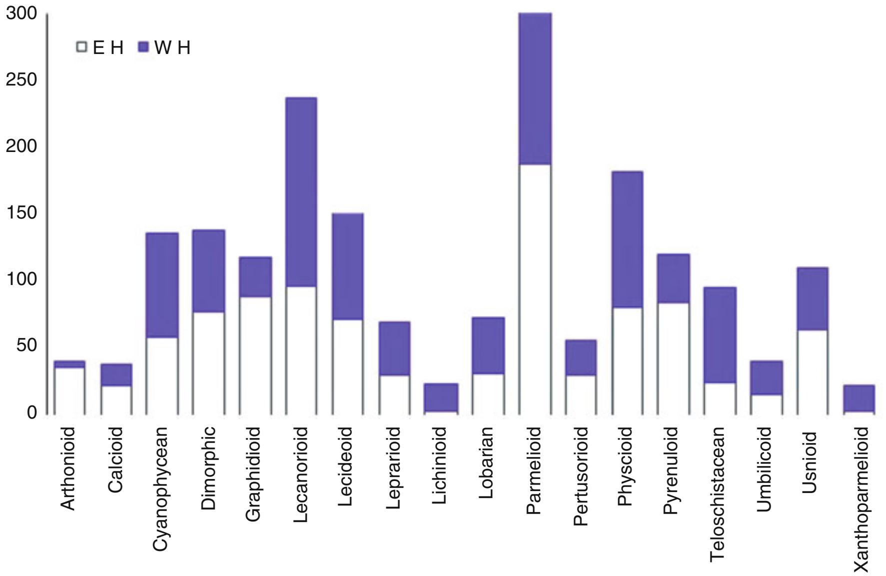

Fig. 13.5 Comparative assessment of lichen communities in Eastern Himalaya (EH) and Western Himalaya (WH)

supported by the exposed rock beyond treeline hence these grow luxuriantly in Bugyals. Rawat (2005) indicated that the Bugyal vegetation is high in the Western Himalaya. The Western Himalaya largely supports drought-resistant and cold-loving plants belonging mostly to Coniferae, Fabaceae, Asteraceae, Poaceae, Rosaceae, while in high altitudes, the landscape is dominated by species of *Abies, Cedrus, Picea, Pinus, Quercus, Rhododendron* and the treeline formed by *Betula utilis*. The landscape tree species, mostly support the growth of foliose and fruticose lichens. Those tree species have bark shedding nature do not favour the lichen growth, such as *Betula utilis*, which favours only the growth of some limited species of *Parmotrema, Flavoparmelia* at base and *Usnea* at twigs.

It is well known that the changes in temperature and precipitation have influenced phenology as well as diversity of plants in different parts of the Himalaya, and climate change in Himalaya may alter phenology, diversity at both individual species and community levels (Xu et al. 2009). According to Shrestha et al. (2012), the Himalaya has warmed by 1.5 °C from 1982 to 2006, at an average rate of 0.06 °C/year but the rate of warming varies across seasons and ecoregions. The greatest increase of 1.75 °C is observed in winter with an average increase of 0.07 °C/year whereas the least increase of 0.75 °C, is in summer, and an average increase is 0.03 °C/year. Average annual precipitation has increased by 163 mm (6.52 mm/year) during the 25 years period. However, the warming trend reported previously in the Himalaya was 0.04 °C/year in the Western Himalaya (Kumar et al. 2009) and 0.03 °C/year in the Eastern Himalaya (Sharma and Tsering 2009). Furthermore, both increasing and decreasing trends in Eastern Himalaya (Sharma et al. 2000), and decreasing trends in Western Himalaya (Kumar et al. 2009) have been reported for precipitation. The variability in abiotic components may lead to qualitative and quantitative variations in diversity and luxuriance of lichen species in the area.

The Eastern Himalaya, on the contrary, has cool, humid and semi-oceanic climate, with the vegetation characterized by the abundance of *Rhododendrons* and the remnants of *Podocarpus*, followed by tree ferns, *terminalias*, oaks, laurels and bamboos to support the growth of epiphytes orchids, ferns, bryophytes and lichens (Chowdhery 2008). Most of the tree species have smooth bark, favour only crustose growth form of lichens in the area (Sinha and Jagadeesh Ram 2014). Crustose lichen distribution patterns have their affinity for smoother bark. The bark condition of younger trees is often smoother which may allow these lichens to successfully attach to the substrate and grow compared with older trees bark which are rougher with numerous cracks, largely preventing these species from expanding. Whereas the foliose lichen species adhere closely to loosely to the substratum which may be adapted to survive in diverse water moisture stresses in different microhabitats and mostly prefer to grow on rough surface. Furthermore, the fruticose lichens grow up to trunk and twig in open canopy and adapt to survive in low precipitation (McCune et al. 1997).

In this study, following communities occur indicating the surrounding environment.

1. **Arthonioid community:** The species of lichen genera *Arthonia* and *Cryoptothecia* represent the Arthonioid community. Arthonioid community is present only at lower altitudes and prefers to grow on bark and leaves. The Arthonioid community is predominant in WH and shows increasing trend up to 3000 m altitudes (Fig. 13.6a). It clearly indicates that the area is moist with high humidity, especially at lower altitudes.
2. **Calcioid community:** The Calcioid community is composed of the species of lichen genera *Acroscyphus, Baculiferea, Calicium, Dibaeis, Diplotomma, Chaenotheca, Aderkomyces, Icmadophila* and *Bunodophoron*. The community prefers to grow on dead wood, bark, twigs at an altitudes up to 3000 m in both the Himalayan regions but the dominance is observed in EH (Fig. 13.6a). It indicates that the ecological contiguity of the aged forests tend to provide a wide variety of suitable substrates and microenvironments that provide favourable illumination conditions with high atmospheric humidity.
3. **Cyanophycean community:** The species of lichens genera *Coccocarpia, Collema, Leptogium, Pseudocyphellaria, Nephroma, Peltigera, Fuscopannaria, Pannaria* and *Solorina* represent the Cyanophycean community. The Cyanophycean lichens constitute a separate group of lichens having Cyanophycean algae either alone (bipartite) or along with a green primary photobiont (tripartite) and prefers to grow between lower altitudes and shows decreasing trend with increasing altitudes. The maximum dominance is observed in WH in comparisons to EH (Fig. 13.6b) as they are an exclusive group of lichens having capability of nitrogen fixation, enriching the substrate and playing an important role in nutrient cycling of the ecosystem. It indicates

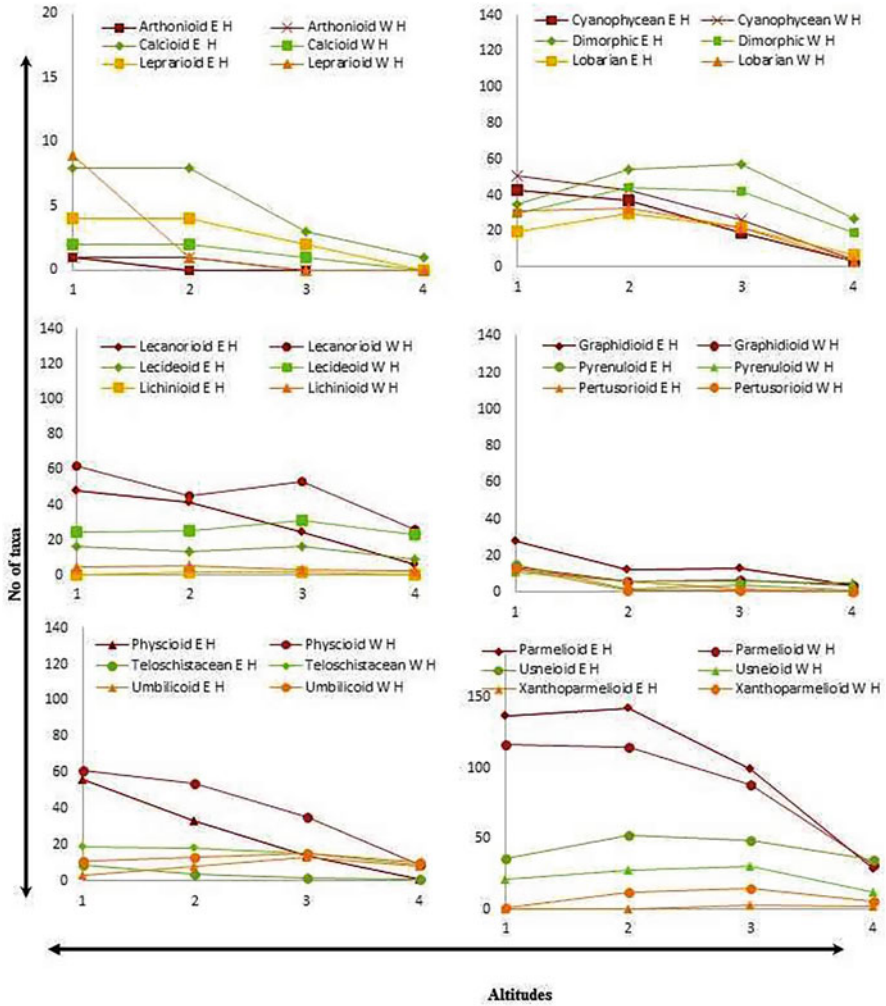

Fig. 13.6 Individual community assessment in EH and WH at different altitudinal gradients 1. 2500–3000 m, 2. 3000–3500 m, 3. 3500–4000 m, 4. 4000–4500 m

the forest age and continuity of forest ecosystem function. However, presence of the community indicates the humus rich soil, shift of the species habitat and loss of moisture in the respective substratum.

4. **Dimorphic community:** The Dimorphic community is composed of the species of lichen genera *Baeomyces, Cladia, Cladonia, Dibaeis, Siphula, Thamnolia* and *Stereocaulon*. The species found growing on soil, rock and sporadically along with mosses at an altitude between 3000 and 4000 m in both EH and WH

(Fig. 13.6b). However, the maximum dominance is observed in EH. The presence of dimorphic community in the area indicates undisturbed soil ecosystem.

5. **Graphidioid community:** The Graphidioid community is made up of the species of lichen genera *Diploschistes, Graphis, Phaeographis, Thecaria* and *Opegrapha.* The community growing at lower altitudes indicates open, thinned-out forest, presence of smooth bark trees and the area devoid of moisture. This community is dominat in EH and shows dominance with decreasing altitudes in both the Himalayan regions (Fig. 13.6d).
6. **Lecanorioid community:** The community is composed of the species of the lichen genera *Acarospora, Pleopsidium, Dimelaena, Candelaria, Candelariella, Coenogonium, Lecanora, Lecidea, Protoparmeliopsis, Rhizoplaca, Aspicilia, Lobothallia, Mycoblastus, Ochrolechia, Phyllopsora, Tephromela, Placopsis, Trapelia* and *Trapeliopsis.* This community prefers to grow on bark and rock at lower altitudes but *Protoparmeliopsis, Rhizoplaca* and *Aspicilia* are found growing over rocks at higher altitudes as well. The community indicates windy and well-illuminated environmental conditions. The Lecanorioid community is more common in WH and showing increasing trend from 4000 m altitudes (Fig. 13.6c).
7. **Lecideoid community:** This community is composed of species of the lichen genera *Buellia, Catillaria, Haematomma, Lecidea, Lecidella, Lecidoma, Porpidia, Megalaria, Megalospora, Lasioloma, Lopadium, Psora, Mycobilimbia, Toninia* and *Rhizocarpon.* The community members show their dominance in WH and abundance increases with increasing altitude (Fig. 13.6c). Some of the species of this community have bright coloured thallus indicating exposed and well illuminated area. The community members are more resistant against coldness and they are widely used in the lichenometric studies in alpine area.
8. **Leprarioid community:** The community represents the species of *Chrysothrix, Leprocaulon, Lepraria*and found growing at lower altitudes, and the dominance of this community decreases with increasing altitude. The maximum diversity is observed in EH (Fig. 13.6a). The community appears first after forest fires.
9. **Lichinioid community:** The community is found growing mostly on rock, lime plaster at lower altitudes. Several species of lichen genera *Lichinella, Peccania, Peltula* and *Endocarpon* represent the community. The Lichinioid community indicates dry desert habitat (devoid of moisture) and presence of medium to higher temperature in the area. The members of Lichinioid community show their dominance in WH and their dominance increases with increasing altitude (Fig. 13.6c).
10. **Lobarian community:** The community is composed of species of lichen genera *Dendriscosticta, Lobaria, Sticta, Peltigera* which are found growing at an altitude of 3000–4000 m in both EH and WH, but dominance is maximum in WH (Fig. 13.6b). The community indicates moist shady forest, productive forest and long forest continuity. The community is a good indicator of anthropogenic disturbance in the forest. The members of this community clearly indicate the presence of moisture in the area. If species of this community were found

growing on soil in past and currently growing on tree trunks or rocks, this escape indicates drying of soil (loss of moisture in the substratum). The periodical data about change of substrate by community are a good indicator of climate change.

11. **Parmelioid community:** The parmelioid community is composed of species of lichen genera *Allocetraria, Arctoparmelia, Bulbothrix, Canomaculina, Canoparmelia, Cetraria, Cetrariopsis, Cetrelia, Cetreliopsis, Evernia, Flavocetraria, Flavocetrariella, Flavoparmelia, Flavopunctelia, Hypogymnia, Hypotrachyna, Lethariella, Melanelia, Melanelixia, Melanohalea, Menegazzia, Montanelia, Myelochroa, Nephromopsis, Nipponoparmelia, Oropogon, Parmelia, Parmelina, Parmelinella, Parmelinopsis, Parmotrema, Platismatia, Punctelia, Relicinopsis, Remototrachyna, Rimelia, Tuckermannopsis, Tuckneraria* and *Vulpicida.* The community is found growing on diverse substrata and shows increasing trend with decreasing altitude. The maximum dominance is observed in EH as compared to WH (Fig. 13.6f). The community indicates thinned-out forest with more light, moist condition and lower to medium precipitation in the area.
12. **Pertusorioid community:** Mostly the species of *Pertusaria* represent the community and prefers to grow on rough bark and rarely on rock at lower latitudes. This community indicates well-illuminated environmental conditions, old tree forest, exposed to good winds. The members of Pertusorioid community were found dominating in EH and showed increasing trend with decreasing altitudes in both the Himalayan regions (Fig. 13.6d).
13. **Physcioid community:** The physcioid community is composed of the species of lichen genera *Rinodina, Anaptychia, Heterodermia, Hyperphyscia, Phaeophyscia, Physcia, Physconia* and *Pyxine*. The community members prefer to grow on bark, twigs and some time on rocks at lower to middle altitudes. This community is well known for pollution tolerance and their presence indicates a nitrophilous environment. The members of Physcioid community are dominant in WH but as far as the altitudinal distribution is concerned, it decreases with increasing altitude (Fig. 13.6e).
14. **Pyrenuloid community:** The community is composed of species of the lichen genera *Anisomeridium, Porina, Pyrenula, Lithothelium, Staurothele* and *Verrucaria*. This community prefers to grow on smooth bark at lower latitude and some species are found growing on higher altitudes on stable rock also. At lower altitudes, the community indicates the young and regenerated forest. However, the presence of *Staurothele, Verrucaria* on higher altitudes indicates the stable substratum and open area. Mostly this community is found in EH as compared to WH. However the community shows its dominance with decreasing altitudes (Fig. 13.6d). The community members prefer to grow on smooth bark substratum in comparison to rough bark.
15. **Teloschistacean community:** The community composed of the species of lichen genera *Calogaya, Caloplaca, Flavoplaca, Ioplaca, Oxneria, Rusavskia, Squamulea, Teloschistes, Variospora* and *Xanthoria* found growing on barks and rocks. Members of the Teloschistacean community is more common in WH as compared to EH (Fig. 13.6e). Dominance of this community increases with

increasing altitude. The colour of the thallus is mostly orange, brown and yellow due to presence of cortical pigment to protect algae inside against stress. The community indicates high UV irradiance in the area.

16. **Umbilicoid community:** The community grows in higher altitudes and shows increasing dominance with increasing altitude. This community is composed of species of lichen genera *Glypholecia, Lasallia, Umbilicaria, Catapyrenium, Dermatocarpon* and *Normandina.* This community is mostly found in WH as compared to EH (Fig. 13.6e). The presence of members of this community indicates the stable rock substratum along with high UV irradiance and low temperature.
17. **Usneioid, Alectoroid community:** The community is composed of the species of lichen genera *Alectoria, Bryoria, Sulcaria, Usnea* and *Ramalina*. This community is found growing on bark, twigs and rarely on rocks and shows increasing dominance with increasing altitude (Fig. 13.6f). The maximum dominance is reported in EH in comparison to WH. Most of the species of this community are pendulous thread like and indicate old forest and better air quality. This community is most sensitive to anthropogenic activities. However, increase in the pollution level causes disappearance of the species of this community.
18. **Xanthoparmelioid community:** Community is a group of species of a single lichen genus *Xanthoparmelia* found growing on higher altitudes between 3500 and 4500 m in both the Himalayan regions (Fig. 13.6f). The maximum dominance is observed in WH in comparison to EH. They grow luxuriantly over rocks along with mosses and rarely on barks. The presence of the community in the area indicate stable productive landscape and high UV radiation and the area being devoid of pollution.

The high altitude exhibits dominance of Parmelioid, Usnioid and Cyanophycean communities, which indicates fairly good air quality and minimum human disturbance. The change in microclimatic condition and pollution load across an altitudinal gradient determines the distribution and diversity of lichen communities with a specific pattern. The lower altitudes that are more easily accessible to the humans have poor lichen diversity, while higher altitudes being pristine exhibit rich lichen diversity. At higher altitude climate seems to favour growth of lichens but the higher UV radiation acts as a stress factor and may lead to decline in the diversity. The results correspond to the findings of Colwell and Lees (2000); Zapata et al. (2005) who also suggested that as we go up in altitudinal range there are strong barriers and consequently peak richness occurs in the middle (hump shaped curve). It is also reported that lichen species that are bright in colour belong to Xanthoparmeliod, Teloschistacean communities which dominate in the higher altitudes.

The fruticose and dimorphic growth form communities, in well-lit higher elevations, have the advantage to use light from all directions better than foliose lichens, thus maximizes the harvest of more or less unidirectional light (Gauslaa et al. 2009). The environmental filtering processes are occurring at low and high elevations, which can be explained by the extreme climatic conditions of the sites: high altitudes have low temperature, a strong temperature variation (high temperatures in day and low temperatures at night) and low average precipitation, which favours the presence of macro-lichen species (mainly fruticose) with few common features. On the other hand, lower altitudes with high temperatures and precipitation, which are a favourable environment only for crustose or filamentous lichens and some micro-foliose and squamulose that can survive in high humidity conditions. In this way, altitudinal extremes seem to be strong barriers for functional variation of lichens. The middle elevations have has balanced abiotic/biotic factors, which explains the greater diversity of lichens in this zone (Mayfield and Levine 2010; Prieto et al. 2017).

According to Ellis (2019), the species shows migration when anthropogenic activities increase in the area. The species can shift to a suitable climate space through lichen dispersal and establishment dynamics. On one hand, species may adapt to climate change and survive against anthropogenic disturbance by developing several functional traits. On other hand, lichens may acclimate to the changing climate space physiologically. The species produces some cortical pigments to acclimatize the species in the stressed environment. However, the habitat quality also plays an important role in relation to lichen diversity. The microclimate of the area also plays an an important factor to maintain habitat quality for survival of the species. These underlying factors *vis-à-vis* community study are important to understand the climate-driven fate of sensitive alpine ecosystems of Himalaya.

13.5 Conclusion

The study clearly brings out that Western Himalaya (WH) is richer as compared to Eastern Himalaya (EH) in terms of lichen indicator communities. The lichen community as well as the species show climate-related thresholds and is likely to be useful for targeting monitoring efforts. The status of present lichen bioindiactor communities (genus/species) at different altitudinal gradient can be used as the baseline data for carrying out future climatic change and environmental monitoring studies in different states of Indian Himalayan regions. More researches are required to be carried out to get a better understanding of community dynamics in response to ecological condition of the area. It is further emphasized that there is a need to develop a biomonitoirng programme of the country in terms of data repository for future studies.

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