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Influence of Chemical Diversity in Determining Lichen Communities Structure along an Altitudinal Gradient in the Chopta Tungnath, Western Himalaya

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Abstract

In recent years there has been growing interest in the study on lichen diversity with relation to altitudinal gradient and anthropogenic disturbances, as changes in lichen community composition may indicate air quality and microclimatic changes. The altitudinal data of species diversity and its subsequent changes with respect to time and space may provide vital information regarding impact of air pollution and/or climate change at regional or global scales. Chopta-Tungnath and adjoining areas of Garhwal Himalaya provide habitat and ecological variation with range of altitude lying between 300 to 3000 m. Out of the 116 species of lichens known from the studied area, the highest species diversity was observed between altitudes 1800 to 2100 m. Lichen communities occurring between 600–1800 m were dominated by members of Physciaceae, while Parmeliaceae were most common above 1800 m. Altitude beyond 2100 m experiences high precipitation, varying temperature conditions and increased incident UV radiation, which are responsible for controlling the variability in lichen diversity to a great extent in the region. The diversity of secondary metabolites in lichen species and consequent changes in species composition at various altitudes indicate the association of secondary chemicals in conferring the lichens resistance to biotic and abiotic stresses. The correlations of lichen diversity, secondary metabolites and the altitudes at which the lichens are growing, present suggestive role of secondary metabolites in determining species composition and sustainability in different environmental conditions.

1. Introduction

Lichens are a unique group of symbiotic organisms consisting of algae and fungi, having cosmopolitan distribution. To a great extent, lichen diversity within an area is largely determined by altitudinal gradient along with the microclimatic factors including light intensity, temperature, precipitation and pollutants (Bruun *et al*., 2006; Giordani and Incerti, 2008; MacDonald *et al*., 2013). It has been observed that lichen species with high concentrations of secondary chemicals inhabit more light exposed areas in comparison to species having lower concentration of the compounds (Gauslaa and Solhaug, 2004). Depending on the altitude and ambient environmental conditions, these secondary metabolites (mainly cortical compounds) play a pivotal role in protecting the lichens from the harmful effects of intense irradiance, pollution load and other biotic and abiotic factors (Bjerke and Dahl, 2002).

Synthesis of secondary metabolites is known to involve high level of metabolic cost (Rundel, 1978). Waring (2008) reported increase in depside concentrations in lichens in response to increasing light exposure, suggesting that these compounds may have a photo-protective role. Secondary compounds present in lichens are also known to form complexes with pollutants mainly metal ions extra cellular thereby preventing the delicate thallus from harmful effects of pollutants (Hauck and Huneck, 2007).

As mentioned earlier that lichen and its secondary metabolite composition are strongly affected by microclimatic changes, as certain species are able to produce secondary metabolite compounds while others cannot, hence the chemical diversity of protecting compounds is expected to differ among lichen communities along altitudinal gradient. Consequently, the correlation of lichen diversity, secondary metabolites and altitudes where lichens occur, could provide better understanding of changes in lichen diversity in relation to climate change and/or anthropogenic pressure. Thus the present study aims to investigate lichen community composition, secondary metabolite variation diversity and the potential role of secondary metabolites in lichens in relation to altitude and ecological conditions in the Chopta-Tungnath region of Garhwal Himalaya, Uttarakhand.

2. Materials and Methods

Chopta-Tungnath is one of the interesting bioregions in Garhwal Himalayas as it provides suitable natural (high alpine vegetation) and anthropogenic conditions (minimum pollution) for studying lichen community structure change with respect to altitude. Although earlier collections have been made from the forest area of Chopta-Tungnath (Kumar and Upreti, 2008), still the area is relatively unexplored, particularly the high altitude areas in and around Madhyamaheshwar, Deoria Taal and Anusuiya Devi track.

A total of 33 sites located at different altitudes ranging from 300 to 3000 m were sampled for lichen diversity (Fig. 1). Approximate site locations were pre-selected in a square grid of 10 m^2. Criterion for collection of specimens was according to Pinho *et al.* (2004). At each site, 10 trees were surveyed to explore the lichen diversity and nearly 150 trees were sampled. The sampled trees fulfilled certain requisites: a. trunk more than 35 cm in diameter, b. trunk inclination less than 75° (15° deviation from vertical), and c. apparently healthy. Quadrates of 15 cm^2 were placed between 1-1.5 m above the ground.

During the field survey in Chopta-Tungnath region including Madhyamaheshwar, Deoria Taal and Anusuiya Devi track more than 500 lichen specimens were collected which were dried and preserved in the lichen herbarium of CSIR-National Botanical Research Institute (LWG). The specimens were identified by studying their morphology, anatomy and chemistry following recent literature on lichens by Awasthi (1988, 1991, 2007) and Divakar and Upreti (2005). Spot tests were performed by using 5% potassium hydroxide solution (K), calcium hypochlorite (C) and *para-*

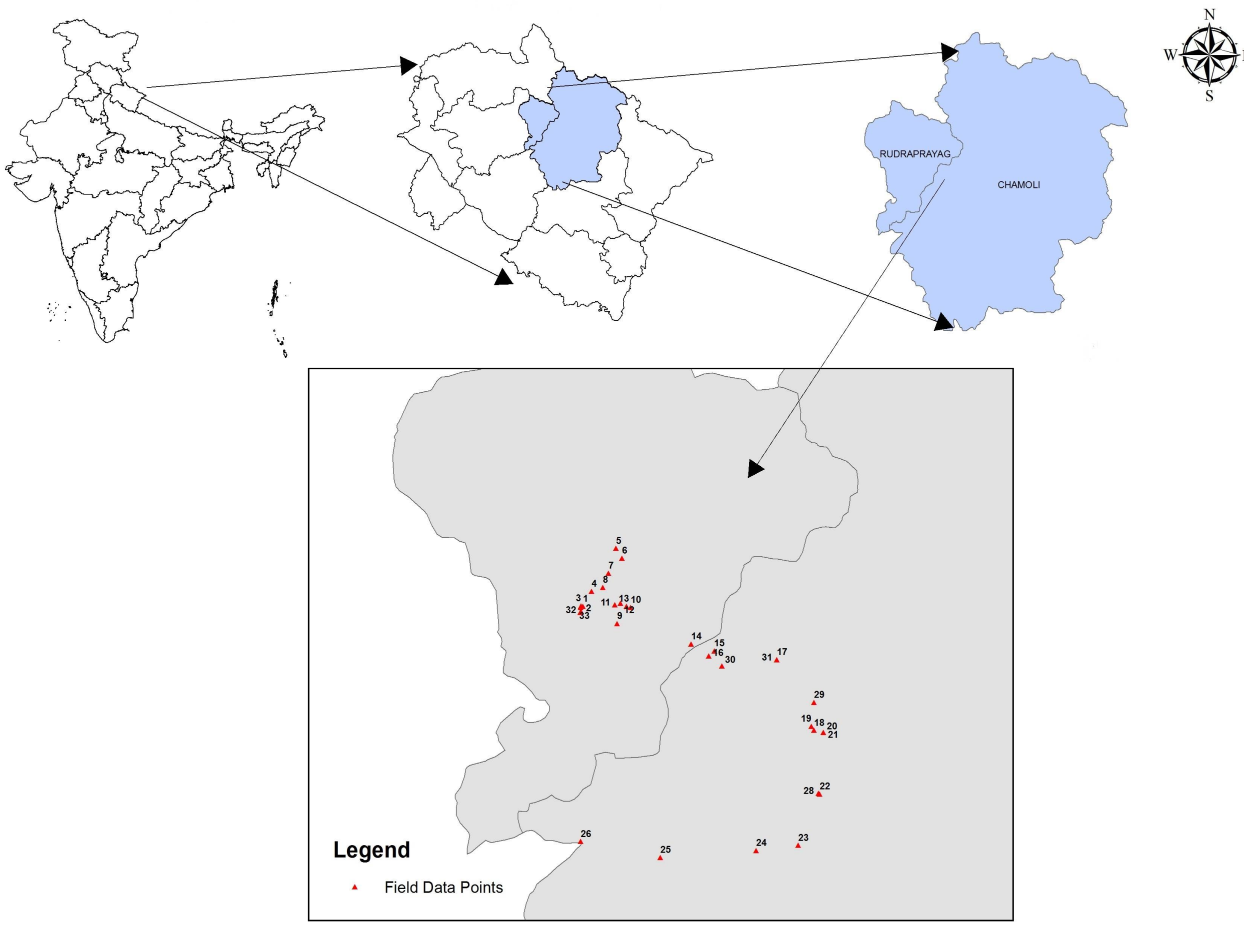

Fig. 1: Study area covering range of altitudes in Rudraprayag and Chamoli districts of Utarakhand (India)

phenylene diamine (PD), while Thin Layer Chromatography (TLC) was carried out following the method of Orange *et al.* (2001).

2.1. Statistical analysis

All the graphs and correlation coefficients have been done using MS EXCEL.

3. Result

One hundred and sixteen lichen taxa belonging to 46 genera and 22 families (Table 1), collected from 33 sites located at different altitudes from 300 to 3000 m from the Chopta-Tungnath region of Garhwal Himalaya, represents the lichen diversity of that region. Results

Table 1: Lichen diversity at different altitudes ranging from 300–3000 meter in and around Ukhimath, Madhyamaheshwar, Chopta-Tungnath, Deoria Taal and Anusuiya Devi area of Garhwal Himalaya

CANDLEARIACEAE	
1	*Candelaria concolor* (Dicks.) Stein.
2	*C. indica* (Hue) Vain.
CALICIACEAE	
3	*Amandinea punctata* (Hoffm.) Coppins & Scheid.
	CHRYSOTHRIACEAE
4	*Chrysothrix chlorina* (Ach.) Laundon
	CLADONIACEAE
5	*Cladonia awasthiana* Ahti & Upreti
6	*C. fruticulosa* Kemp.
7	*C. furcata* (Huds.) Schard
COLLEMATACEAE	
8	*Collema* sp.
9	*C. subnigrescens* Degel.
10	*Leptogium delavayi* Hue
11	*L. furfuraceum* (Harm.) Sierk
12	*L. pedicellatum* P.M. Jørg.
13	*L. phyllocarpum* (Pers.) Mont***
14	*L. askotense* D.D. Awasthi
GRAPHIDACEAE	
15	*Graphis glaucescens* Feé
16	*G. lineola* Ach.
17	*G. arecae* Vain.
18	*G. nematoides* Leight.
19	*G. pinicola* Zahlbr.
20	*G. platycarpa* Esch.
21	*G. scripta* (L.) Ach.
22	*G. tenella* Ach.
23	*G. xanthospora* Müll. Arg.
24	*G. parilis* Kremp.
25	*Phaeographis* sp.
LECANORACEAE	
26	*Lecanora interjecta* Müll. Arg.
27	*L. tropica* Zahlbr.
28	*L. chlarotera* Nyl.
29	*L. alba* Lumbsch
30	*L. achroa* Nyl.
31	*L. flavidofusca* Müll. Arg.
32	*L. fimbritula* Stirt.
33	*L. intumescense* (Rabenh.) Rabenh.
34	*L. japonica* Müll. Arg.
35	*L. caesiorubella* Ach.
36	*Lecidella* sp.
LICHEN IMPERFECTII	
37	*Lepraria lobificans* Nyl.
LOBARIACEAE	
38	*Lobaria retigera* (Bory.) Trev.
PARMELIACEAE	
39	*Bulbothrix setschwanensis* (Zahlbr.) Hale
40	*B. isidiza* (Nyl.) Hale
41	*Canoparmelia texana* (Tuck.) Elix & Hale
42	*Cetrelia pseudolivetorum* (Asahina) W.L. Culb. & C.L. Culb.
43	*C. cetrarioides* (Del ex Dubey) W.L. Culb. & C.L. Culb.
44	*Cetreliopsis rytidocarpa* (Mont. & v. D. Bosch) M.J. Lai
45	*Everniastrum cirrhatum* (Fr.) Hale
46	*Flavoparmelia caperata* (L.) Hale
47	*Hypotrachyna awasthii* Hale & Patw.
48	*H. exsecta* (Taylor) Hale
49	*Myelochroa aurulenta* (Tuck.) Elix & Hale
50	*M. metarevoluta* (Asahina) Elix & Hale
51	*M. subaurulenta* (Nyl.) Elix & Hale
52	*Parmelinella wallichiana* (Taylor) Elix & Hale
53	*Parmotrema thomsonii* (Stirt.) A. Crespo, Divakar & Elix
54	*P. austrosinensis* (Zahlbr.) Hale
55	*P. nilgherrense* (Nyl.) Hale
56	*P. melanothrix* (Mont.) Hale
57	*P. praesorediosum* (Nyl.)Hale
58	*P. reticulatum* (Taylor) Choisy
59	*P. tinctorum* (Nyl.) Hale
60	*Punctelia subrudecta* (Nyl.) Krog
61	*Xanthoparmelia conspersa* Hale
62	*Canoparmelia ecaperata* (Müll. Arg.) Elix & Hale
63	*C. texana* (Tuck.) Elix & Hale
64	*Usnea aciculifera* Vain.
65	*U. orientalis* Mot.
PELTIGERACEAE	
66	*Peltigera polydactylon* (Neck.) Hoffm.
67	*P. rufescens* (Weiss) Humb.

PERTUSARIACEAE
68 *Ochrolechia rosella* (Müll. Arg.) Vers.
69 *Pertusaia leucosora* Nyl.
70 *P. albescense* (Huds.) Choisy & Wern.
71 *P. leucostoma* (Bernh.) A. Massal.
72 *P. composita* Zahlbr.
73 *P. himalayensis* D.D. Awasthi & P. Srivastava
74 *P. quassiae* Feé
75 *P. melastomella* Nyl.
76 *P. alpina* Hepp.
77 *P. pertusa* (Weigel) Tuck
PHLYCTIDACEAE
78 *Phlyctis subhimalayensis* S. Joshi & Upreti
PHYSCIACEAE
79 *Dirinaria aegialata* (Afz. In Ach.) Moore
80 *Heterodermia albidiflava* (Kurok.) D.D. Awasthi
81 *H boryi* (Feé) Kr.P. Singh & S. Singh
82 *H diademata* (Taylor) D.D. Awasthi
83 *H. japonica* (Sato) Swinsc. & Krog.
84 *H. obscurata* (Nyl.) Trevis.
85 *H. speciosa* (Wulf.) Trevis.
86 *Hyperphyscia adglutinata* var. *adglutinata* (Flöerke) Mayerh. & Poelt
87 *H. isidiata* Moberg
88 *H. adglutinata* var. *pyrithrocardia* (Müll Arg) D.D. Awasthi
89 *Phaeophyscia hispidula* (Ach.) Moberg
90 *P. primaria* (Poelt) Tras
91 *P. pyrrophora* (Poelt) D.D. Awasthi & M. Joshi
92 *Physcia dilitata* Nyl.
93 *P. crispa* Nyl.
94 *Pyxine cocoes* var. *prominula* (Stirton) D.D. Awasthi
95 *P. himalayansis* D.D. Awasthi
96 *P. sorediata* (Ach.) Mont.
97 *P. subcinerea* Stirt.
98 *Rinodina sophodes* (Ach.) A. Massal.
PILOCARPACEAE
99 *Micarea excipulata* Coppins**
PYRENULACEAE
100 *Anthracothecium macrosporum* (Hepp) Müll. Arg.
101 *Arthothelium chIodectoides* (Nyl.) Zahlbr.
102 *Pyrenula complanata* (Mont.) Trevis.
103 *P. macrospora* (Degel.) Coppins & P. James**
104 *P. submastophora* A. Singh & Upreti
105 *P. mastrophoroides* (Nyl.) Zahlbr.
106 *P. oculata* A. Singh & Upreti
RAMALINIACAE
107 *Bacidia fusconigrescens* (Nyl.) Zahlbr.
108 *Ramalina conduplicans* Vain.
109 *Ramalina hossei* Vain.
STEREOCAULACEAE
110 *Stereocaulon* sp.
111 *S. foliolosum* Nyl.
THELOTREMATACEAE
112 *Diploschistis actinostomus* (Pers. In Ach.) Zahlbr.
TILOSCHISTACEAE
113 *Caloplaca cupulifera* (Vain.) Zahlbr.
114 *C. parviloba* Wetmore
115 *C. subsoluta* (Nyl.) Zahlbr.
VERRUCARIACEAE
116 *Dermatocarpon vellereum* Zsaschke

** New record for India *** New addition for Uttarakhand

indicate that altitudinal gradient has noticeable effect on the lichen diversity pattern: lower altitudes have poor lichen diversity, while altitudes between 1800-2100 m exhibit highest lichen diversity, signifying influence of microclimatic condition on lichen diversity. The altitude above 2100 m shows the abundance dominance of Parmelioid lichens and also exhibit presence of exclusive terricolous and cyanolichens taxa.

Since, there is dynamic shift of microclimate and pollution load across altitudinal gradient, hence the distribution and diversity of lichen communities at the present site represent a specific pattern while moving from lower altitude to higher altitude.

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 altitude climate seems to favour growth of lichens but the incident solar radiation acts as a limiting factor and hence led to decline in the diversity as the altitude increases. The polynomial model (Fig. 2) for lichen diversity with altitude indicates a convex shape with a maximum diversity at 2100 m. Results are in accordance with the finding of Grytnes *et al.* (2006) as the species diversity exhibit gradual increasing trend with altitude up to 2100 m indicating the impact of microclimatic conditions and forest cover on species composition.

Both lower and higher altitudes of the study area exhibit distinct lichen community composition. The communities at lower altitudes comprised of species of *Candelaria, Chrysothrix, Graphis* and *Phaeophyscia*. Species of lichen genera *Candelaria* and *Phaeophyscia* indicate nutrient enriched habitat whereas areas populated with *Graphis* species indicate an open, exposed and regenerated forest. Species of *Chrysothrix* are pioneer lichens to invade coniferous trees (*Pinus roxburghii*) in the lower Himalayan region after forest fire. On the other hand, high altitude exhibits prevalence

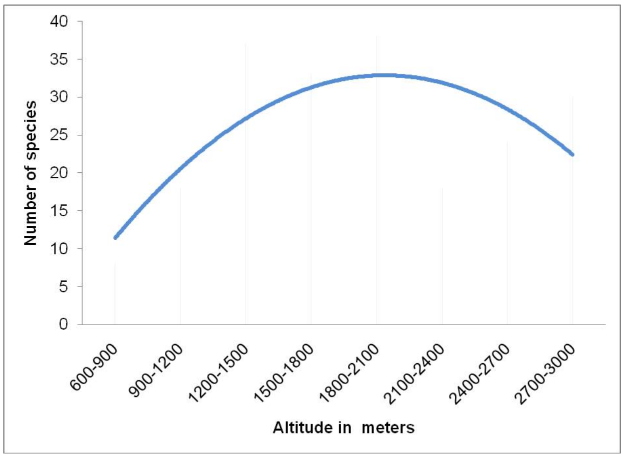

Fig. 2: Relationship between lichen diversity and altitude: polynomial regression line indicating increasing trend in lichen diversity till 2100 m, indicating optimal conditions for lichen growth

of Parmelioid and Cyanophycean communities which signify fairly good air quality and minimum human disturbance.

The diversity pattern of the members of lichen family Parmeliaceae and Physciaceae visibly indicates that they populate different habitats due to their sensitive to moderate pollution tolerance and toxitolerant nature respectively (Fig. 3). The high proportion of members of Physciaceae at altitude between 600–1800 m may be attributed to the presence of chemicals which are competent of sequestering the pollutants while at higher altitude the species having substances such as atranorin, salazinic acid and lecanoric acid, widely known for their UV protecting and antioxidant potential grow luxuriantly (Fig. 4). In the present study correlation of lichen diversity with secondary metabolites (Table 2) provides insight into

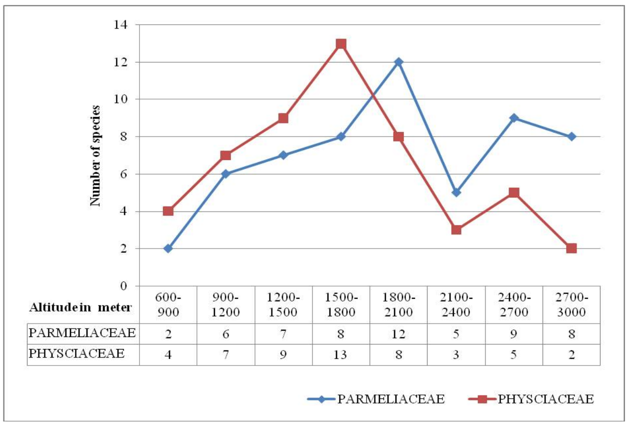

Fig. 3: Comparative distribution of lichen families Parmeliaceae and Physciaceae at different altitudes

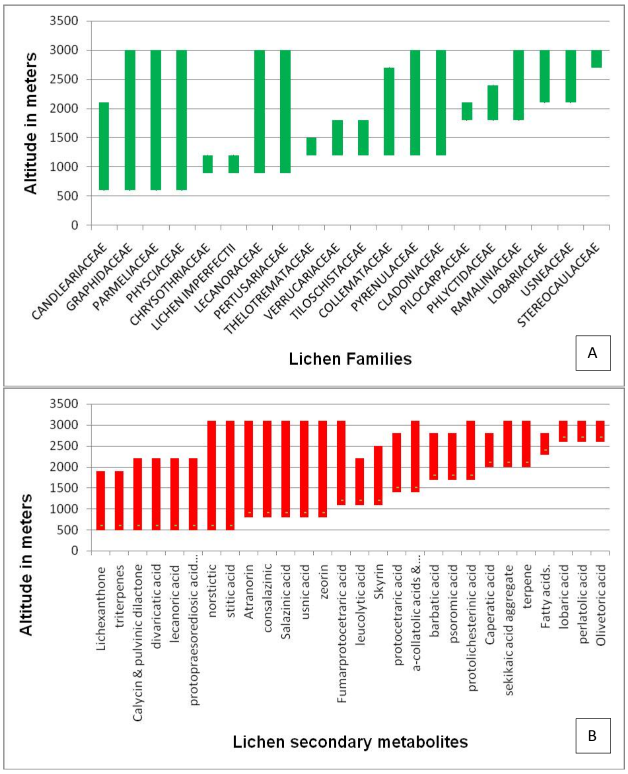

Fig. 4: Range of distribution of (A) lichen families and (B) their corresponding chemical diversity at various altitudes in Chopta-Tungnath, Garhwal Himalaya

Table 2: Correlation coefficient showing influence of chemical diversity on lichen diversity at an altitude ranging between 300-3000 m

Secondary metabolites	Correlation coefficient
Atranorin	**0.6770**
Calycin and pulvinic dilactone	-0.2543
Caperatic acid	-0.2768
Consalazinic	**0.6771**
Divaricatic acid	0.1368
Fumarprotocetraric acid	**0.8664**
Lecanoric acid	0.1368
Lichexanthone	-0.1766
Lobaric acid	0.1621
Olivetoric acid	0.1621
Protolichesterinic acid	0.1766
Protopraesorediosic acid and Praesorediosic acid	0.1368
Salazinic acid	**0.6771**
Sekikaic acid aggregate	-0.1019
Skyrin	**0.5803**
Terpene	-0.1368
Triterpenes	-0.1766
Usnic acid	**0.5681**
Zeorin	**0.6771**

Bold shows significant positive correlation the plausible role of secondary metabolites in determining species composition. Species rich in broad spectrum properties like atranorin, fumarprotocetraric acid, usnic acid and salazinic acid are having significant positive correlation with the lichen diversity which is further substantiated by its presence of lichen species containing secondary compounds in vast range of altitudes. Calycin, lichexanthone, sekikiac acid aggregate and triterpene are negatively correlated with lichen diversity as the compounds are restricted to specific altitudes and perform particular function like pollution sequestration and/or antioxidants/photo-protectants.

4. Discussion

The richness and diversity of photo-protective secondary compounds are known to be elevated in concentration with more exposed environmental conditions (Waring, 2008). Hence chemical diversity at higher altitude with more exposed environmental conditions can be attributed to a more chemo diverse community structure which is justified by the presence of compounds known to provide light resistance and oxidative stress conditions (Xanthone and Anthraquinone) or are exclusive to lichens (Depsides, Depsidones, Dibenzofurans) (Shukla *et al.*, 2015a). In contrast, lichen species at lower altitudes contain higher concentration of calycin, terpene and lichexanthone, which play major role in metal chelation and geochemical weathering of substratum. At higher altitude protecting chemicals quench the UV radiation, due to the presence of free hydroxyl groups and a resonating benzene ring that facilitate electronic transitions (Shukla *et al.*, 2015b).

Thus defensive chemicals seem to cover varying altitudes despite the fact that their major role at a range of altitude and microclimate differs. Ecological role of lichen substance have been classified into three groups; light-screening compounds, chemical weathering compounds, allelopathic compounds, (including antibiotic compounds) which are directly linked with the environmental and/or anthropogenic stress present at the study site (Rundel, 1978). Since lichens lack protective cuticle, consequently secondary metabolites present extracellularly (extrolites) are considered to afford screening from harmful radiation in the alpine and temperate ecosystem (Gauslaa and Solhaug, 2004). Environmental variables and anthropogenic pressure differ with the rising altitude. Therefore, while examining differences in lichen diversity it is important to consider that lichen secondary compounds may have multiple functions (Waring, 2008), which might partly explain the variation in lichen diversity with the altitudinal rise.

The present finding specifies the view that with increasing altitude, microclimate and/or air quality changes determines lichen community structure by providing a selective pressure that favours abundance of those species which are able to synthesise protective compounds. This can be justified by the fact that the cosmopolitan lichen genus *Xanthoparmelia* has more than 40 chemosyndromes which depends upon the ecological conditions and thus underlines the importance of chemical diversity as an adaptive strategy of the lichens across altitudinal gradient. Variations in chemical diversity actually mirror physiological, ecological, and even evolutionary responses to change in the environment and climate (Stocker-Wörgötter, 2015).

The major factor governing the community structure in mountain ecosystem is altitude (including slope, aspect and elevation), since resultant dispersal followed by accumulation of pollutants and microclimate is dependent on altitude. The impact of pollutants and variable microclimatic conditions (*viz.* temperature, humidity and rainfall) further respond to extrolites present, as evident by the good chemical diversity and range of protective chemicals shifting at various altitudes.

5. Conclusion

The study thus provides pattern of major shifts in lichen communities along altitudinal gradient in Western Himalaya, as well as correlation with secondary metabolite profile. Study also underlines the plausible role of secondary metabolites in affording high sustainability of lichens at range of altitudes. More researches are required to be carried out to get a better understanding of chemo diversity affecting community dynamics in response to ecological condition of the study area.

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