# The Influence of Water Variables on the Distribution of Terricolous Lichens in Garhwal Himalayas

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## Introduction

An organism occurs in a characteristic, limited range of habitats and within this range they are found to be most abundant indicating their specific environmental optimum (Körner 2003). The distribution of organisms is strongly influenced by factors such as elevation, precipitation, moisture, temperature, and nutrients in the substratum (Huang 2010). Mountain regions encapsulate broad elevational ranges covering large gradients of geological, topographical and climatic diversity, and thus host greater biodiversity than the surrounding lowlands (Körner 2003). Himalayan habitats due to their temperate-alpine climate, coupled with plenty of monsoon, are able to retain sufficient amount of water content. The water retention is either in the form of moisture in ambient air or as daily rainfall through orographic precipitation at mid to higher altitudes (3000-3400m).

Lichen, a mutualistic association of a fungus (mycobiont) and a green (phycobiont) and/ or blue green algae (cyanobiont) are known to be one of the most successful symbionts in nature (Galloway 1992). Nearly 40 genera of algae and cyanobacteria have been reported as photobionts in lichens (Tschermak-Woess 1988; Büdel 1992; Friedl & Büdel 2008; Honegger 2008). About 85% of lichen-forming fungi associate with green algae (often referred to as ***chlorolichens***; Ahmadjian 1993), about 10% with ***cyanobacteria*** (cyanolichens; Ahmadjian 1993) while about 4% form an association simultaneously with both type of photobionts (Friedl & Büdel 2008). Among the cyanobacteria containing lichen species, 10% are ***bipartite*** (having cyanobacteria as the only photosynthetic partner) and are 3-4% ***tripartite*** (having both green algae and cyanobacteria) (Rai & Bergman 2002) (Figure 3). In tripartite cyanolichens the cyanobacteria is restricted to a special gall like external or internal structure called cephalodia, in which the fungal partner creates microaerobic conditions to facilitate cyanobacterial nitrogen fixation (Honegger 2001; Rikkinen 2009).

***Terricolous lichens*** being a habitat specialist inhabits areas where abiotic stresses such as aridity, low nutrient content, highly acidic pH and greater salt content, which prohibit the establishment of higher plants (Hachfeld 2000; Belnap *et al.* 2001; Scheidegger & Clerc 2002). Terricolous cyanolichens and chlorolichens respond differently to various source of water (Lange 2003). The chlorolichens are able to achieve net photosynthetic carbon gain through water vapour uptake alone, whereas cyanolichens need liquid water for positive net photosynthesis (Lange 2003). The ability of chlorolichens to use water vapour for photosynthetic productivity favours their existence over cyanolichens in areas with low precipitation and elevated air humidity (Lange 2003).

India is a rich centre of lichen biodiversity, harboring nearly 14% (2303 species of total 13,500 species worldwide) of the global lichen flora (Singh & Sinha 2010). Terricolous lichens constitute about 9% of total lichen species recorded from India and their distribution ranges from temperate (1500-3000 m) to alpine regions (>3000 m) (Rai *et al.* 2011, 2012). The terricolous lichens by virtue of their occurrence on soil experience a direct influence of environmental variables, competition with other ground vegetation and anthropogenic pressures and hence they act as suitable indicators of micro-climatic conditions of habitats in Himalaya (Laley *et al.* 2006; St. Clair *et al.* 2007, Rai *et al.* 2011, 2012). Here we report the distribution of terricolous lichens in Garhwal Himalayas, with reference to water variables such as precipitation and moisture, along altitudinal gradient (2650 to 4441 m).

## Materials and Methods

***Study area:*** The study was conducted in three sites situated in the Garhwal region of Uttarakhand Himalayas, namely in Khirsu (distt. Pauri), Chopta-Tungnath (distt. Rudraprayag) and Gangotri-Gomukh (distt. Uttarkashi) (Fig.1). The three sites situated at increasing altitudinal gradients, were characterised by different sets of multiscale environmental variables (i.e. precipitation, relative humidity and temperature) (Table 1).

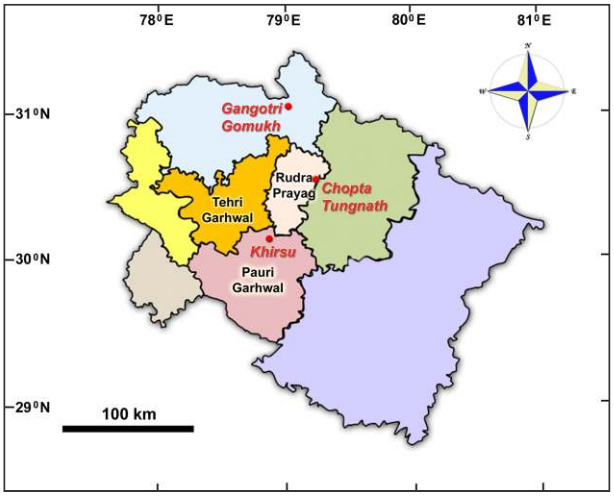


**Fig.1:** Location map of the studies sites in Garhwal Himalayas.

**Field methods and data recording:** Sampling of terricolous lichens was carried out during 2008 to 2011. A random stratified sampling method was employed

**Table1:** Taxonomical and diversity attributes of terricolous lichen species recorded in the three study sites and their multiscale environmental variables attributes in Garhwal Himalayas

| Species | Family | Growth form* | Photo-biont** | Sites‡ Khirsu | Chopta-Tungnath | Gangotri-Gomukh |
|---|---|---|---|---|---|---|
| *Bryoria confusa* | Parmeliaceae | Fr | Gr | - | 3.1 | - |
| *Cetrelia olivetorum* | Parmeliaceae | Fo | Gr | - | 1.6 | - |
| *Cladonia cartilaginea* | Cladoniaceae | Cd | Gr | - | 3.1 | - |
| *C. chlorophaea* | Cladoniaceae | Cd | Gr | - | - | 4.5 |
| *C. coccifera* | Cladoniaceae | Cd | Gr | - | 15.6 | - |
| *C. coniocraea* | Cladoniaceae | Cd | Gr | - | - | 1.2 |
| *C. fimbriata* | Cladoniaceae | Cd | Gr | - | - | 5.9 |
| *C. fruticulosa* | Cladoniaceae | Cd | Gr | 3.7 | - | 3.5 |
| *C. furcata* | Cladoniaceae | Fr | Gr | - | 3.1 | - |
| *C. ochrochlora* | Cladoniaceae | Cd | Gr | - | - | 5.9 |
| *C. pyxidata* | Cladoniaceae | Cd | Gr | - | 20.3 | 25.9 |
| *C. rangiferina* | Cladoniaceae | Cd | Gr | - | - | 3.5 |
| *C. scabriuscula* | Cladoniaceae | Cd | Gr | 48.2 | 1.6 | - |
| *C. squamosa* | Cladoniaceae | Cd | Gr | - | - | 4.5 |

| Species | Family | Growth form* | Photo-biont** | Sites‡ | | |
|---|---|---|---|---|---|---|
| | | | | Khirsu | Chopta-Tungnath | Gangotri-Gomukh |
| *C. subradiata* | Cladoniaceae | Cd | Gr | 14.8 | - | 11.8 |
| *C. subulata* | Cladoniaceae | Cd | Gr | - | 3.1 | - |
| *Evernia mesomorpha* | Parmeliaceae | Fr | Gr | - | - | 1.2 |
| *Everniastrum cirrhatum* | Parmeliaceae | Fo | Gr | - | 3.1 | 1.2 |
| *Flavoparmelia caperata* | Parmeliaceae | Fo | Gr | - | - | 1.2 |
| *Flavopunctelia soredica* | Parmeliaceae | Fo | Gr | - | | 1.2 |
| *Heterodermia hypocaesia* | Physciaceae | Fo | Gr | - | 6.3 | - |
| *H. obscurata* | Physciaceae | Fo | Gr | - | 1.6 | - |
| *H. pseudospeciosa* | Physciaceae | Fo | Gr | 11.1 | - | - |
| *Hypogymnia enteromorpha* | Physciaceae | Fo | Gr | - | - | 1.2 |
| *Hypotrachyna adducta* | Parmeliaceae | Fo | Gr | - | - | 1.2 |
| *H. crenata* | Parmeliaceae | Fo | Gr | 6.9 | - | - |
| *Lepraria caeseoalba* | Stereocaulaceae | Lp | Gr | - | 1.6 | - |
| *L.lobificans* | Stereocaulaceae | Lp | Gr | 9.3 | - | - |
| *L. neglecta* | Stereocaulaceae | Lp | Gr | - | 7.8 | - |
| *Melanelia stygia* | Parmeliaceae | Fo | Gr | - | 1.6 | - |
| *Melanelixia villosella* | Parmeliaceae | Fo | Gr | - | - | 1.2 |
| *Parmelia sulcata* | Parmeliaceae | Fo | Gr | - | - | 2.4 |
| *Peltigera praetextata* | Peltigeraceae | Fo | Bg2 | - | 14.1 | 7.1 |
| *P. rufescens* | Peltigeraceae | Fo | Bg2 | - | 20.5 | 7.1 |
| *Phaeophyscia hispidula* | Physciaceae | Fo | Gr | 9.3 | - | - |
| *Physconia detersa* | Physciaceae | Fo | Gr | - | - | 1.2 |
| *P. grisea* | Physciaceae | Fo | Gr | - | 1.6 | - |
| *Ramalina hossei* | Ramalinaceae | Fr | Gr | - | 3.1 | - |
| *Rhizoplaca chrysoleuca* | Lecanoraceae | Fo | Gr | - | - | 3.5 |
| *R. melanophthalma* | Lecanoraceae | Fo | Gr | - | - | 2.4 |
| *Stereocaulon alpinum* | Stereocaulaceae | Fr | Bg3 | - | 4.7 | 7.1 |
| *S. foliolosum* | Stereocaulaceae | Fr | Bg3 | - | 14.1 | 4.5 |
| *S. massartianum* | Stereocaulaceae | Fr | Bg3 | - | 1.6 | 7.1 |
| *S. pomiferum* | Stereocaulaceae | Fr | Bg3 | - | 1.6 | - |
| *Xanthoparmelia terricola* | Parmeliaceae | Fo | Gr | - | - | 1.2 |

| | | | |
|---|---|---|---|
| Species richness (no. of species) | 7 | 22 | 26 |
| Chlorolichen (%) | 100 | 72.78 | 0.8 |
| Cyanolichens (%) | 0 | 27.3 | 19.2 |
| Average altitudinal (m) | 2650 | 3351 | 4442 |
| Average annual precipitation (mm) | 145 | 260 | 165 |
| Average annual relative humidity (%) | 60 | 62 | 55 |
| Annual maximum temperature (°C) | 28 | 18.6 | 7 |
| Annual minimum temperature (°C) | 7.0 | 4.5 | 2.5 |

*Lp= leprose, Fo= foliose, Fr= fruticose, Cd =compound; ** Gr= green algal photobiont, Bg= blue green algal photobiont; Bg2= bipartite, Bg3= tripartite; ‡ the value are percentage frequency distribution of terricolous lichens in each site.

(Greig-Smith 1983; Krebs 1989; Rai *et al.* 2012). Lichen samples were collected in open areas subject to minimal tree canopy effects (Reimann *et al.* 1999). As the study area is subjected to frequent trampling by grazing livestock, the site selection was constrained by the availability of lichen rich patches in the landscape (Rai *et al.* 2012). Data on macroscale environmental variables (average temperature, relative humidity and precipitation) were arranged from published data by Indian meteorological department and General Survey of India. Elevation was measured with a hand-held GPS unit (Garmin GPSMAP® 76S™). Data regarding to lichen species and growth form diversity at all the three collection sites were documented carefully.

***Lichen identification:*** Collected lichen samples were air dried at room temperature and identified at Lichenology Laboratory, CSIR-National Botanical Research Institute, Lucknow, Uttar Pradesh, India. Lichens were identified at the species level using a stereomicroscope and light microscope morpho-anatomically, using relevant keys and monographs (Ahti 2000; Awasthi 2007; McCune and Rosentreter 2007; Rosentreter *et al.* 2007; Saag *et al.* 2009) and chemically with the help of spot tests, UV light and standardized thin-layer chromatography (Elix and Ernst-Russel 1993; Orange *et al.* 2001). Representative specimens were deposited at the lichen herbarium (LWG) of CSIR-National Botanical Research Institute, Lucknow.

***Data analysis:*** Terricolous lichen assemblage was quantitatively analysed for percent frequency, with reference to species diversity and chlorolichens as well as cyanolichens at each site (Curtis and McIntosh 1950; Pinokiyo et al. 2008, Rai *et al.* 2012). An indirect gradient ordination method, principal component analysis (PCA), was used to summarise the compositional differences between the sites (Gauch 1982; ter Braak and Prentice 1988; Pinokiyo *et al.* 2008). Pearson's correlation coefficients were calculated to compare explanatory variables (i.e. altitude, temperature, relative humidity and precipitation) and response variables (PCA axis score, chloro- and cyanolichen species richness) (Pinokiyo *et al.* 2008, Rai *et al.* 2012). Except PCA, which was performed using multivar option in PAST Ver. 2.17b (Hammer *et al.* 2001; Barluenga *et al.* 2006; Rai *et al.* 2012), all other statistical analysis were carried using IBM® SPSS® Statistics ver. 20.

## Results

**Average community structure and patterns:** The terricolous lichen assemblage recorded from the three sites in Garhwal Himalayas consisted of 45 species belonging to 21 genera and seven families (Table 1). A gradual decrease in species diversity (no. of species) was observed with increasing altitude. Cladoniaceae and Parmeliaceae were the dominant families, followed by Physciaceae, Stereocaulaceae, Peltigeraceae and Ramalinaceae. Four lichen growth forms; leprose, foliose, fruticose and compound (squamules as the primary thallus bearing erect fruticose podetia) (Rai *et al.* 2012) were encountered. Though green algae containing chlorolichens were dominant, two species of bipartite cyanolichen *Peltigera* and four species of tripartite cyanolichen *Stereocaulon* were also recorded. Increase in cyanolichen species was observed with increasing altitude, coupled with increase in precipitation and decrease in relative humidity and temperature.

***Principal community determinants:*** The PCA analysis required 2 components (axis) to account for 100% variation in the data set (Fig. 2). The first axis of PCA explained 82.6% of variance, where as second axis explained 17.4% variance in the data set. PCA showed that among the three sites studies while, Chopta-Tungnath and Gangotri-Gomukh share similarity in terricolous lichen community, driven by a significant cyanolichen dominance in the sites, total absence of cyanolichens in Khirsu mapped it away from the other two sites, in the ordination matrix (Fig. 2). PCA axis 1 was significantly correlated with altitude and precipitation, indicating their primary influence in differentiating soil lichen communities (Table 2). PCA axis 2 was significantly correlated to minimum temperature and diversity of chlorolichens as well as cyanolichens, indicating a secondary influence of these photobiont functional groups in differentiating the lichen communities (Table 2).

Taking statistically significant correlations among variables into account, altitude, was negatively

**Table 2:** Pearson's correlation coefficients between PCA axes and selected variables (significant correlations are tagged)

| | PCA1 | PCA2 | Alt | Ppt | TMn | TMx | Rh | ClL |
|---|---|---|---|---|---|---|---|---|
| Alt | 0.733a | -0.680 | | | | | | |
| Ppt | 0.708b | 0.706 | 0.038 | | | | | |
| TMn | -0.848 | 0.530a | -0.982 | -0.226 | | | | |
| TMx | -0.775 | 0.632 | -0.998 a | -0.103 | 0.992 | | | |
| Rh | 0.433 | 0.901 | -0.295 | 0.943 | 0.111 | 0.233 | | |
| ClL | -0.981 | -0.192[a] | -0.588 | -0.831[a] | 0.730 | 0.639 | -0.599 | |
| CyL | 0.981 | 0.192[a] | 0.588 | 0.831[a] | -0.730[a] | -0.639 | 0.599 | -1.000[b] |

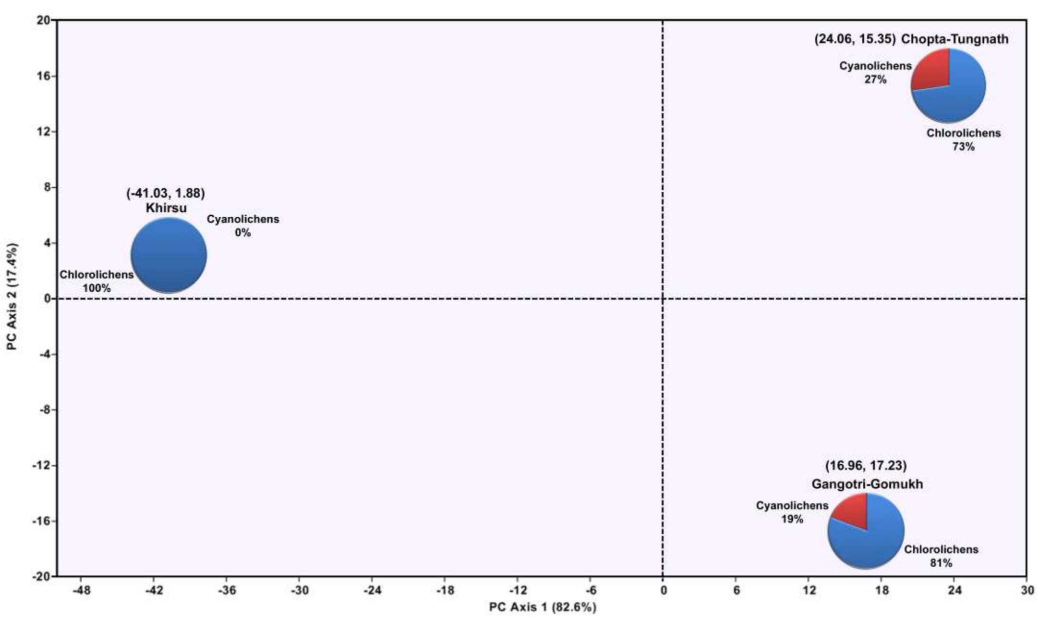


**Fig 2:** PCA ordination plot of three terricolous lichen study site data, with superimposed pie-plots depicting percentage sharing of chlorolichens and cyanolichens at each site, values in parentheses are PC axis scores for axis 1 and 2, respectively.


**Fig.3** Some prominent terricolous lichens of Garhwal Himalayas: Cyanolichens, A. *Stereocaulon foliolosum* (Tripatite), **B.** *Pletigera praetextata* (Bipartite); Chlorolichens, **C.** *Cladonia subradiata*, **D.** *Flavoparmelia caperata*.

correlated with maximum annual average temperature. Among the other explanatory variables, mean annual average precipitation was positively correlated with cyanolichen diversity but negatively correlated with chlorolichens diversity. Minimum annual mean temperatures as well as chlorolichen diversity were negatively correlated with cyanolichen diversity in Garhwal Himalayas.

## Discussion

Abiotic factors play a determining role in defining the functional niche of organisms. In temperate alpine habitats the stress-gradients produced by the abiotic factors influence the co-occurrence and segregation of various functional groups (i.e. chlorolichens and cyanolichens) of vegetation (Maestre *et al.* 2009). The absence of cyanolichens in low altitude sites (Khirsu) and their increase in high altitude sites (Chopta-Tungnath & Gangotri-Gomukh) due to lower precipitation at Khirsu, which is the major source of liquid water cyanolichens require for their active physiology (Lange 2003).

The correlation of ordination data (PCA axis scores) with precipitation and altitude depicts their determining role in soil lichen community of the region. The clear differentiation of terricolous lichens into chlorolichen and cyanolichen functional groups, along gradients of precipitation and altitude is in accordance with the physiological needs of hydration by the two groups respectively (Lange 2003). Further the dominance of terricolous lichen species *Cladonia* and *Stereocaulon* can be attributed to their tolerance to wind exposure and abrasion by ice particles (Sheard 1968).

## Conclusion

As the photosynthesis and respiration of soil lichens are dependent by the degree of hydration it also decides their habitat preferences. This study specifically indicates habitats most suitable for both the photobiont functional groups of terricolous lichens found in the Garhwal Himalayas. As terricolous cyanolichens are the most important component of carbon-nitrogen cycling in soil crusts of alpine habitats such as Himalayas (Elbert *et al.* 2012), the findings can be used for conservation and management of these biodiversity rich habitats.

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*At Renukoot : Life, rocks and water (Photo credit : Sanjay Singh)*