Botanica Orientalis – **Journal of Plant Science** (2011) **8:** 16–23 ISSN 1726-6858
doi: http://dx.doi.org/10.3126/botor.v8i0.5554

http://www.nepjol.info/index.php/BOTOR

Research

Terricolous lichens as indicator of anthropogenic disturbances in a high altitude grassland in Garhwal (Western Himalaya), India

Himanshu Rai[1,2*], Roshni Khare[1,2], Rajan Kumar Gupta[1] and Dalip Kumar Upreti[2]

[1]*Department of Botany Pt. L.M.S. Government Post Graduate College, Rishikesh (Dehradun), Uttarakhand, Pin-249201, India;*
[2]*Lichenology Laboratory, National Botanical Research Institute, CSIR, Lucknow, Uttar Pradesh-226001, India*

Abstract

Lichens are known to be more sensitive indicators of ecosystem functioning and disturbances than any other cryptogams and vascular plant communities. Himalayan habitats, despite their stressed climates, harbor some of the unique biodiversity of the region, vital for overall ecosystem functioning and stability. Lichens, due to their desiccation tolerance, are able to survive in high altitude habitats and evolved into diverse categories and functional groups. Present study examines the terricolous lichen community in Chopta-Tungnath temperate-alpine grassland of Garhwal Himalaya, in order to identify potential elements (species/growth form) as indicator of anthropogenic disturbances. Terricolous lichens were sampled from twelve sites distributed in three stratified macrohabitats, along increasing altitudinal gradient. A total of twenty soil lichen species belonging to ten genera, six families and four morphological groups (i.e. leprose, foliose, dimorphic and fruticose) were identified. Terricolous lichen diversity was negatively correlated (r = 0.70; p<0.05) with altitude. Among the four growth forms, fruticose growth form was indicator of grazing disturbance, distinguishing low grazed high altitude (3400-4001 m asl) areas with highly grazed low altitude (2700-3000 m asl) to mid altitude (3000-3400 m asl) areas. Terricolous lichen diversity in the study area was found constrained by vascular plants at lower altitudes, human-related impacts (tourism and livestock grazing induced trampling) at mid-altitudes and habitat characteristics (low soil cover) at higher altitudes.

Key-words: anthropogenic impact, Garhwal Himalaya, grazing, lichens diversity.

Introduction

Lichens, a symbiotic amalgamation between a fungus (mycobiont) and an alga (phycobiont) or cyanobacteria (cyanobiont), are among the most significant indicators of ecosystem functioning as they are more sensitive towards habitat alteration and climate change than other cryptogams and vascular plant forms (Wolseley *et al*. 1994; Herk *et al*. 2002, Bokhorst *et al*. 2007; Saipunkaew *et al*. 2007). Soil inhabiting terricolous lichens are good indicator of ecosystem functioning (Will-Wolf *et al.* 2002) and their requirement of greater environmental stability make them highly sensitive indicators of overall ecosystem functioning and various environmental disturbances (Grabherr 1982; Eldridge and Tozer 1997; Scutari *et al*. 2004; Lalley and Viles 2005; Lalley *et al*. 2006).

India is a rich centre of lichen biodiversity, harboring nearly 15% of total global lichen flora (Singh and Sinha 1997; Upreti 1998). Terricolous lichens constitute about 9% of total lichen species recorded from India and their distribution ranges from temperate (1500-3000 m asl) to alpine (≥3000 m asl)

**Correspondence*,
e-mail: himanshurai08@yahoo.com, Tel: +91 9415462755.

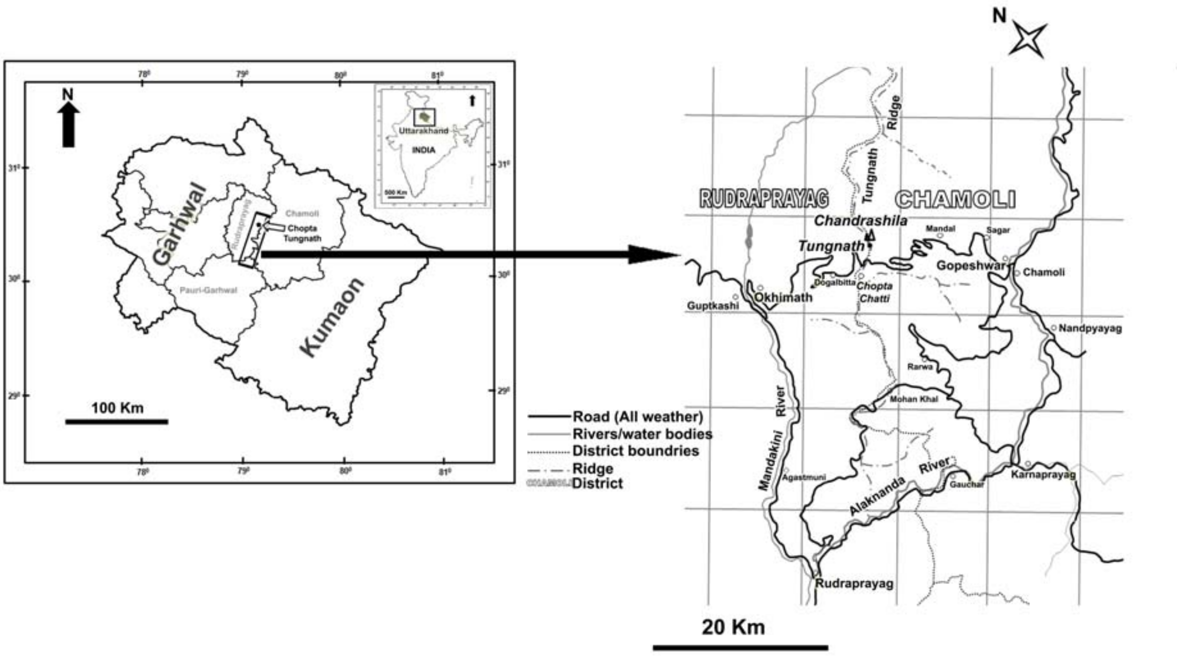

Figure 1. Location map of the study area.

habitats of the Himalayas. Major distribution of terricolous lichens in Himalaya is confined to alpine pastures locally known as *Bugyals*. There have been various monographic, revisionary and floristic studies on lichens for last five decades (Awasthi 1988, 1991, 2007; Upreti and Büdel 1990; Upreti and Negi 1998). However, community level investigations have recently begun but there is still lack of consideration of terricolous lichens as an indicator group (Negi and Gadgil 1996; Negi 2000 a, b; Negi and Upreti 2000; Pinokiyo *et al*. 2008). Grazing, tourism and unconstrained forest management are affecting the overall biodiversity of the Himalayan habitats. The main threats applicable to biodiversity, in general, are also true for lichens e.g., habitat degradation, fragmentation and loss, over exploitation, species invasions and climate change (Scheidegger and Werth 2009). Lichen population in the Indian Himalayas is threatened by uncontrolled livestock grazing, over exploitation and habitat destruction.

There are some sporadic studies on climate change and grazing pressures in Indian Himalayan temperate and alpine habitats, but they lack any reference of lichens (Nautiyal *et al*. 2004). In the present study, distribution of terricolous lichens in a temperate-alpine habitat of Garhwal Himalayas is analysed along an altitudinal gradient to assess their indicator capability for habitat disturbances.

Materials and Methods

STUDY AREA

Chopta-Tungnath lies between 30°28’39"– 30°29’51" N latitude and 79°12’9" to 79°13’21" E longitude in the Garhwal Himalayas of Rudraprayag district, Uttarakhand (Figure 1). The area is famous for the holy shrine of Tungnath, situated at the top of the ridge dividing Mandakini and Alaknanda rivers (Figure 1).

The shrine and associated alpine grassland lies about 2 km below the Chandrashila Peak (4,001 m asl). The landscape is typically mountainous, with moderate to steep slopes (30-60°) and elevation ranging from 2700 m to 4001 m asl. The topography of the area comprises of ridges of exposed rocks and patches of flat alpine grassland. The crust of the area is made up of crystalline and metamorphic weathering bedrock with sedimentary deposits formed during the Paleozoic. Soils in the area are of coarse textured loam or sandy loam at lower altitudes and sandy at higher altitudes, well drained and acidic (pH 4.0-5.5) (Sundriyal 1992).

Climate of the area is characterised by heavy frost, blizzards and hailstorm most of the months of the year. Precipitation occurs in the form of snow, hail, heavy rains and showers during the year. The snowfall occurs from

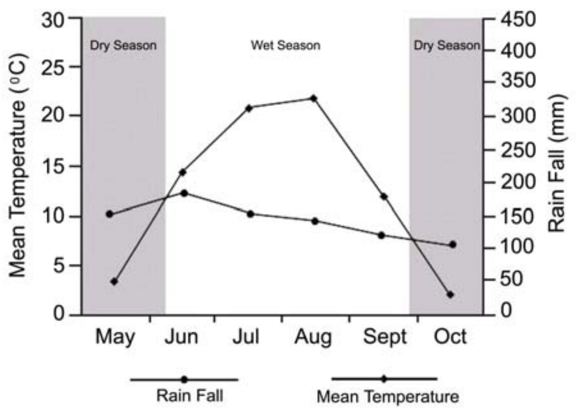

Figure 2. Pluviothermic diagram showing wet and dry months at Tungnath (redrawn from Nautiyal *et al*. 2001).

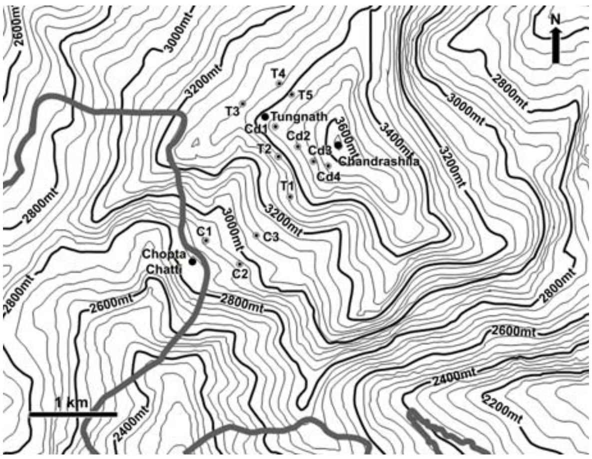

Figure 3. Terrain map of the study area showing the location of sampling sites. Contour interval is 200 mt. Map prepared using Google maps India 2010 (refer Table 1 for abbreviations).

November to April. Snowmelt occurs during April and May, providing an abundance of soil water prior to the monsoon period. Maximum rainfall is recorded in July-August (Figure 2) (Nautiyal *et al*. 2001). The maximum monthly temperature in the area varies from 19°C to 37°C in the months of May to October, while the minimum temperature as low as –15°C is recorded at the alpine grasslands during the months of December to February (Negi 2000 a). The higher plant vegetation of the study area is broadly classified as temperate mixed oak and coniferous forests through subalpine forest to alpine scrub or grassland along the altitude gradient (Gadgil and Meher-Homji 1990).

The land use by the local human population is mainly confined to semipastoral mode of agriculture based mainly on livestock grazing, agriculture, and forest produce (fodder and fuel) collection from the oak–rhododendron woodlands. In addition, land around the Tungnath shrine and at Chopta is occupied for religious purpose during the pilgrimage season. Livestock grazing activities peaks during summer (May–October). About 4000–5000 sheep and goats, 50–70 buffalos and 30–40 horses and mules reach in the alpine pastures each year exerting heavy grazing pressure (Nautiyal *et al*. 2004).

FIELD METHODS AND DATA RECORDING

Sampling of terricolous lichens was done along the bridle path from Chopta to Chandrashila summit and in the alpine flat pastures in between, employing the stratified random sampling method (Greig-Smith 1983; Krebs 1989). The landscape was stratified into three macro-habitats, based on dominant vegetation along the elevation gradient (Table 1): (i) Oak-Rhododendron mixed forest (ORMF, altitudinal range 2700-3000 m asl); (ii) Rhododendron-rich middle altitude subalpine forest (RMSF, altitudinal range 3000-3400 m asl); (iii) Higher altitude alpine grassland (HAGL, altitudinal range 3400-4001 m asl) (Table 1). These macro-habitats were further delimited by gradients of geomorphology and anthropogenic disturbances (Table 1).

A total of twelve sites were selected from three macro-habitats (Table 1, Figure 3). As the study area is subjected to frequent trampling by grazing livestock, native human population and tourists' movement, site selection was constrained by the availability of lichen-rich patches in the landscape.

Narrow frequency grid of 10 cm × 50 cm, divided into five sampling units of 10 cm × 10 cm each was used for lichen sampling (Scheidegger *et al*. 2002). Three such grids were laid at each of the sampling sites, thus total fifteen 10 cm × 10 cm sampling units were laid at each sampling site. Elevation was measured with a GPS (Garmin GPS 76S).

Collected lichen samples were examined and identified at Lichenology Laboratory, 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; Saag *et al*. 2009) and chemically with the help of spot tests, UV light and standardized thin-layer chromatography (Elix *et al*. 1993;

Table 1. Stratification of Chopta-Tungnath landscape based on dominant vegetation along the elevation gradient.

Macro-habitat	Altitude range (m asl)	Sites	Grazing Pressure (Tr)	Characteristic vegetation	Geomorphic features	Anthropogenic disturbances
Oak-Rhododendron mixed forest (ORMF)	2700-3000	C1,	0	Dominate vegetation of *Quercus semecarpifolia* forming the upper vegetational strata followed by *Rhododendron* spp. forming the lower story of vegetational strata.	Temperate topography with steep increase in altitude; forest floor covered with litter; rich in soil cover; flat pastureland less than of mid-altitudes.	Base camp for tourist; with about 20-30 human settlements; open grass land area; initiation of grazing pressure.
		C2	1			
		C3	0			
Rhododendron rich middle altitude subalpine forest (RMSF)	3000-3400	T1	4	Dominate vegetation of *Rhododendron arboreum* and *Rhododendron campanulatum*, along with isolated stands of *Quercus semecarpifolia* and few *Abies pindrow* and *Taxus baccata* trees.	Subalpine topography with increasing rock cover; moderate rise in slope; less litter on floor; adequate soil cover and flat plains for flourished growth of grassland vegetation resulting in highest concentration of flat pasturelands.	En route 2-5 human settlements and about 6-8 human settlements at the Tungnath shrine; maximum concentration of grazing livestock; maximum trampling due to grazing and tourist' movement
		T2	5			
		T3	8			
		T4	7			
		T5	3			
Higher altitude alpine grassland (HAGL)	3400-4001	Cd1	2	Dominate vegetation of herb species of *Anemone*, *Potentilla*, *Aster*, *Geranium*, *Meconopsis*, *Primula* and *Polemonium*, and scattered pockets of shrubs of *Rhododendron anthopogon* and *Juniperus* species.	Open alpine grassland with massive exposed boulders; land-slide dominant area with very scarce soil cover.	Human settlements absent; grazing pressure minimum due to absence of flat pasturelands; trampling due to tourists' movement
		Cd2	1			
		Cd3	0			
		Cd4	0			

Orange *et al*. 2001). Specimens were deposited at the lichen herbarium (LWG), National Botanical Research Institute (NBRI), Lucknow, Uttar Pradesh, India. Data regarding to lichen species richness at all collection sites of three macro-habitats and their growth form diversity were documented carefully. Livestock grazing was considered as the parameter of anthropogenic disturbance and number of heard recorded at each sampling site was taken as its measure (Table 1).

DATA ANALYSIS

Terricolous lichen assemblage was quantitatively analysed for frequency, species richness (number of species) and growth form diversity in each site (Curtis and McIntosh 1950; Pinokiyo *et al*. 2008; Rai *et al* 2011). Pearson's correlation coefficients were calculated between altitude, species richness and growth form diversity of terricolous lichen community using SPSS version 17 (known as Predictive Analytics Software, PASW).

Results

AVERAGE COMMUNITY STRUCTURE AND PATTERNS

Terricolous lichen assemblages recorded from the twelve sites in the Chopta-Tungnath landscape consisted of total 20 species belonging to ten genera and five families (Table 2). Terricolous lichens were found in 57 out of the 180 sampling units laid (Table 2). There were substantial differences in

Table 2. Frequency and richness of terricolous lichen species recorded in the sampling sites* of three macro-habitats† in Chopta-Tungnath landscape.

Species	Family	Morphological‡ group	ORMF†			RMSF†					HAGL†			
			Sites*											
			C1	C2	C3	T1	T2	T3	T4	T5	Cd1	Cd2	Cd3	Cd4
Bryoria confusa	Parmeliaceae	Fr	–	–	x	x	–	–	–	–	–	–	–	–
Cetrelia olivetorum	Parmeliaceae	Fo	x	–	–	–	–	–	–	–	–	–	–	–
Cladonia cartilaginea	Cladoniaceae	Dm	–	–	–	–	–	–	x	–	–	–	x	–
Cladonia coccifera	Cladoniaceae	Dm	–	–	–	–	D2 (26.67)	D2 – (26.67)	x	–	–	D2 (13.33)	–	–
Cladonia furcata	Cladoniaceae	Fr	–	–	–	x	–	–	x	–	–	–	–	–
Cladonia pyxidata	Cladoniaceae	Dm	D1 (26.67)	–	D3 (13.33)	–	–	D1 (33.33)	–	–	–	D2 (13.33)	x	–
Cladonia scabriuscula	Cladoniaceae	Dm	–	–	–	–	–	–	–	–	x	–	–	–
Cladonia subulata	Cladoniaceae	Dm	–	–	D3 (13.33)	–	–	–	–	–	–	–	–	–
Everniastrum cirrhatum	Parmeliaceae	Fo	x	–	–	x	–	–	–	–	–	–	–	–
Heterodermia hypocaesia	Physciaceae	Fo	–	–	D2 (20)	x	–	–	–	–	–	–	–	–
Heterodermia obscurata	Physciaceae	Fo	–	–	–	–	–	–	–	–	–	–	–	x
Lepraria caeseoalba var. *groenlandica*	Stereocaulaceae	Lp	x	–	–	–	–	–	–	–	–	–	–	–
Lepraria neglecta	Stereocaulaceae	Lp	D3 (13.33)	–	x	–	–	–	D3 (13.33)	–	–	–	–	–
Melanelia stygia	Parmeliaceae	Fo	–	–	–	–	–	–	–	–	–	–	–	x
Physconia grisea	Physciaceae	Fo	–	–	–	–	–	–	–	–	–	–	–	x
Ramalina hossei	Ramalinaceae	Fr	x	–	–	–	–	–	–	–	–	–	–	x
Stereocaulon alpinum	Stereocaulaceae	Fr	x	–	–	–	–	–	–	X	–	–	–	x
Stereocaulon foliolosum var strictum	Stereocaulaceae	Fr	D3 (13.33)	D3 (13.33)	–	–	–	–	x	–	–	D1 (20)	x	–
Stereocaulon massartianum	Stereocaulaceae	Fr	–	x	–	–	–	–	–	–	–	–	–	–
Stereocaulon pomiferum	Stereocaulaceae	Fr	x	–	–	–	–	–	–	–	–	–	–	–
Sampling units with soil lichens			11	3	8	2	4	9	5	1	1	6	3	4
Species richness (no of species per site)			9	2	5	4	1	2	5	1	1	3	3	5

* Sites: see Table 1 for detail; x = species present in the site with low frequency, D1 = dominant species within macro-habitat, D2 = primary co-dominant species within macro-habitat, D3 = secondary co-dominant species within macro-habitat, values in parentheses are frequency of species for each site.

‡ Morphological group: Lp = leprose, Fo = foliose, Fr = fruticose, Dm = dimorphic.

† Macro-habitats: ORMF = Oak-rhododendron mixed forest, RMSF = rhododendron-rich middle altitude subalpine forest, HAGL = higher altitude alpine grassland.

species constitution and abundance between various sites (Table 2). Among the three macro-habitats, the sites in lower altitude (ORMF , 2700-3000 m asl) macro-habitat harbored the larger number of species than the sites in mid- (RMSF, 3000-3400 m asl) and high altitude (HAGL, >3400 m asl) macro-habitats (Table 2, Figure 4). Cladoniaceae and Stereocaulaceae were the dominant families, followed by Parmeliaceae, Pysciaceae and Ramalinaceae (Table 2). Four growth forms: leprose, foliose, fruticose and dimorphic (squamules as primary thallus bearing erect fruticose body as secondary thallus) were encountered in the terricolous lichen community of the landscape (Table 2).

Terricolous lichen species showed restricted distribution. Majority of sampling units consisted of single lichen species per unit. Only three species, *Cladonia coccifera*, *Cladonia pyxidata* and *Stereocaulon foliolosum* occurred in five sites; whereas twelve species (60%) were confined to single site (Table 2). *Cladonia scabriuscula* was recorded exclusively from one site, in high altitude macrohabitat (HAGL).

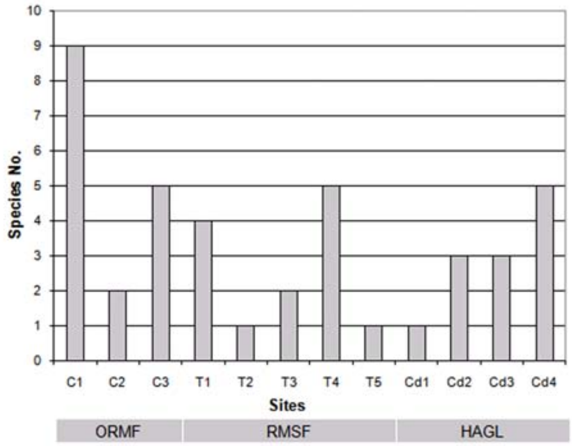

Figure 4. Soil lichen species richness (number of species) of all sites, arranged according to macrohabitats (refer Table 1 for abbreviations).

CORRELATION ANALYSIS

There was significant negative relationship between terricolous lichen species richness and altitude (r = –0.700; p< 0.05), indicating a gradual decrease in terricolous lichen species richness with increasing altitude (Table 3). Species richness of leprose (r = –0.585; p< 0.05) and fruticose (r = –0.808; p< 0.01) growth forms were also found negatively correlated with altitude (Table 3). Anthropogenic disturbance, recorded as number of livestock heard at each sampling sites (Table 1), was significantly correlated with richness of dimorphic growth forms (r = –0.641; p< 0.05), but with richness of other growth forms the relationship was not significant (Table 3).

Discussion

High altitude ecosystems and associated vegetation are usually considered as fragile and sensitive to human impacts (Grabherr 1982). Although soil is the major substrate for terricolous lichen growth in the Chopta-Tungnath, the landscape harbors fewer lichen species than the rock and wood relevés (Negi 2000a). This disparity can be attributed to the instability of the terrestrial niche due to anthropogenic pressures, like livestock grazing (Motiejûnaitë and Faùtynowicz 2005). The gradual decrease of terricolous lichen species richness in the study area is determined both by grazing pressure, which initiates from lower altitude macro-habitat (ORMF, 2700-3000 m asl) and maximizes in mid-altitude macro-habitat (RMSF, 3000-3400 m asl) and by decreasing soil cover, which becomes limiting factor at higher (HAGL, >3400 m) altitudes. The terricolous lichen assemblages of Chopta-Tungnath are highly influenced by altitudinal gradient as reflected by correlation analysis. Among the growth forms recorded, leprose and fruticose growth forms showed negative relationship with altitude and were indicative of habitat heterogeneity. Dimorphic growth form, due to their negative relationship with grazing pressure (number of livestock heard), emerged as indicator of grazing-induced trampling as also reported by Grabherr (1982).

The temperate alpine meadows of Garhwal Himalaya harbor most of the open grasslands which are subjected to high grazing pressures. Terricolous lichens in this study proved an appropriate bioindicators of grasslands in the region. The study differentiates leprose and fruticose growth forms as indicator of habitat heterogeneity, and dimorphic growth forms as indicator of grazing pressure.

These findings validate the role of terricolous lichens as indicators of habitat conditions in Himalayan grasslands, and can be used to calibrate various anthropogenic pressures. Alpine grasslands of the region are key component for the sustainable existence of livestock. Management practices must

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

	Alt	SPN	Lp	Fo	Dm	Fr
Alt	1					
SPN	-0.700*	1				
Lp	-0.585*	0.554	1			
Fo	-0.251	0.086	0.369	1		
Dm	-0.025	0.001	0.182	-0.107	1	
Fr	-0.808**	0.535	0.661*	0.344	-0.166	1
Tr	0.269	-0.214	0.151	-0.302	-0.641*	-0.35

*Correlation is significant at the 0.05 level (2-tailed).

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

Variatbles: Alt = altitude, SPN = total number of species of terricolous lichens, Lp = species richness of leprose growth form, Fo = species richness of foliose growth form, Dm = species richness of dimorphic growth form, Fr = species richness of fruticose growth forms, Tr = number of livestock heard recorded at each sampling site.

be focused to reduce the grazing pressures on these grasslands and on their sustainable utilization. Though the finding presented here are from a relatively small area, the study points towards representative, region-specific monitoring importance of terricolous lichens for the development of appropriate conservation and management strategies for alpine grasslands.

Acknowledgements

Authors are grateful to the Director, National Botanical Research Institute, Lucknow and University Grant Commission, India for providing necessary laboratory facilities and financial assistance. This research is dedicated to late Dr. D.D Awasthi (28 Sept. 1922-21 Aug. 2011), a pioneer lichenologist, whose works laid foundation for systematic lichenological research in the Indian subcontinent.

References

Ahti T. 2000. *Cladoniaceae*. Flora Neotropica Monograph 78. The New York Botanical Garden Press, New York, USA.

Awasthi D.D. 1988. A key to the macrolichens of India and Nepal. *Journal of the Hattori Botanical Laboratory* 65: 207–302.

Awasthi D.D. 1991. A key to the microlichens of India, Nepal and Sri Lanka. *Bibliotheca Lichenologica* 40: 1–337.

Awasthi D.D. 2007. *A Compendium of the Macrolichens from India, Nepal and Sri Lanka*. Bishen Singh Mahendra Pal Singh, Dehradun, India.

Bokhorst S., Huiskes A., Convey P. and Aerts R. 2007. The effect of environmental change on vascular plant and cryptogam communities from the Falkland Islands and the Maritime Antarctic. *BMC Ecology* 7: 15 [online] URL: http://www.biomedcentral.com/content/pdf/1472-6785-7-15.pdf.

Curtis J.T. and McIntosh R.P. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* 31: 434–455.

Eldridge D.J. and Tozer M.E. 1997. Environmental factors relating to the distribution of terricolous bryophytes and lichens in semi-arid eastern Australia. *The Bryologist* 100: 28–39.

Elix J.E. and Ernst-Russel K.D. 1993. *A Catalogue of Standardized Thin Layer Chromatographic Data and Biosynthetic Relationships for Lichen Substances*. 2nd edn. Australian National University, Canberra, Australia.

Gadgil M. and Meher-Homji V.M. 1990. Ecological diversity. In: *Conservation in Developing Countries: Problems and Prospects* (J.C. Daniel and J.S. Serrao, eds.), pp.175–198. Bombay Natural History Society, Bombay, India.

Grabherr G. 1982. The impact of trampling by tourists on a high altitudinal grassland in the Tyrolean Alps, Austria. *Vegetatio* 48: 209–217.

Greig-Smith P. 1983. *Quantitative Plant Ecology*. 3rd edition. Blackwell, London, UK.

Herk van C.M., Aptroot A. and Dobben van H.F. 2002. Long-term monitoring in the Netherlands suggests that lichens respond to global warming. *The Lichenologist* 34: 141–154.

Krebs C.J. 1989. *Ecological Methodology*. Harper and Row, New York, USA.

Lalley J.S. and Viles H.A. 2005. Terricolous lichens in the northern Namib desert of Namibia: distribution and community composition. *The Lichenologist* 37: 77–91.

Lalley J.S., Viles H.A., Henschel J.R. and Lalley V. 2006. Lichen-dominated soil crusts as arthropod habitat in warm deserts. *Journal of Arid Environments* 67: 579–593.

Motiejûnaitë J. and Faùtynowicz W. 2005. Effect of land-use on lichen diversity in the transboundary region of Lithuania and northeastern Poland. *Ekologija* 3: 34–43.

Nautiyal M.C., Nautiyal B.P. and Prakash V. 2001. Phenology and growth form distribution in an alpine pasture at Tungnath, Garhwal, Himalaya. *Mountain Research and Development* 21: 168–174.

Nautiyal M.C., Nautiyal B.P. and Prakash V. 2004. Effect of grazing and climatic changes on alpine vegetation of Tungnath, Garhwal Himalaya, India. *The Environmentalist* 24: 125–134.

Negi H.R. 2000a. On the patterns of abundance and diversity of macrolichens of Chopta-Tungnath in Garhwal Himalaya. *Journal of Biosciences* 25: 367–378.

Negi H.R. 2000b. Species richness and turnover of moss communities in western parts of Nanda Devi Biosphere Reserve. *International Journal of Ecology and Environmental Sciences* 26**:** 1–18.

Negi H.R. and Gadgil M. 1996. Patterns of distribution of macrolichens in western parts of Nanda Devi Biosphere Reserve. *Current Science* 71: 568–575.

Negi H.R. and Upreti D.K. 2000. Species diversity and relative abundance of lichens in Rumbak catchment of Hemis National Park in Ladakh. *Current Science* 78: 1105–1112.

Orange A., James P.W. and White F.J. 2001. *Micro-chemical Methods for the Identification of Lichens*. British Lichen Society, London, UK.

Pinokiyo A., Singh K.P. and Singh J.S. 2008. Diversity and distribution of lichens in relation to altitude within a protected biodiversity hot spot, north-east India. *The Lichenologist* 40: 47–62.

Rai H., Upreti D.K. and Gupta R.K. 2011. Diversity and distribution of terricolous lichens as indicator of habitat heterogeneity and grazing induced trampling in a temperate-alpine shrub and meadow. *Biodiversity and Conservation* (in press). DOI 10.1007/s10531-011-0168-z.

Saag L., Saag A. and Randlane T. 2009. World survey of the genus *Lepraria* (*Stereocaulaceae*, lichenized Ascomycota). *The Lichenologist* 41: 25–60.

Saipunkaew W., Wolseley P.A., Chimonides P.J and Boonpragob K. 2007. Epiphytic macrolichens as indicators of environmental alteration in northern Thailand. *Environmental Pollution* 146: 366–374.

Scheidegger C. and Werth S. 2009. Conservation strategies for lichens: insights from population biology. *Fungal Biology Reviews* 23: 55–66.

Scheidegger C., Groner U., Keller C. and Stoffer S. 2002. Biodiversity assessment tools: lichens. In: *Monitoring with Lichens: Monitoring Lichens* (P.L. Nimis, C. Scheidegger and P.A. Wolseley, eds.), pp. 459–365. Kluwer Academic Publishers, Dordredht, Netherlands.

Scutari N.C., Bertiller M.B. and Carrera A.L. 2004. Soil-associated lichens in rangelands of north-eastern Patagonia. Lichen groups and species with potential as bioindicators of grazing disturbance. *The Lichenologist* 36: 405–412.

Singh K.P. and Sinha G.P. 1997. Lichens. In: *Floristic Diversity and Conservation Strategies in India, Vol. 1 Cryptograms and Gymnosperms* (V. Mudgal and P.K. Hajra, eds.), pp. 195–234. Botanical Survey of India, New Delhi, India.

Sundriyal R.C. 1992. Structure, productivity and energy flow in an alpine grassland in the Garhwal Himalaya. *Journal of Vegetation Science* 3: 15–20.

Upreti D.K. 1998. Diversity of lichens in India. In: *Perspectives in Environment* (S.K. Agarwal, J.P. Kaushik, K.K. Kaul and A.K. Jain, eds.), pp. 71–79. APH Publishing Corporation, New Delhi, India.

Upreti D.K. and Büdel B. 1990. The lichen genera *Heppia* and *Peltula* in India. *Journal of the Hattori Botanical Laboratory* 65: 279–248.

Upreti D.K. and Negi H.R. 1998. Lichen flora of Chopta-Tungnath, Garhwal Himalayas, India. *Journal of Economic and Taxonomic Botany* 22: 273–286.

Will-Wolf S., Esseen P.A. and Neitlich P. 2002. Methods for monitoring biodiversity and ecosystem function. In: *Monitoring with Lichens: Monitoring Lichens* (P.L. Nimis, C. Scheidegger and P.A. Wolseley, eds.), pp. 147–162. Kluwer Academic Publishers, Dordredht.

Wolseley P.A., Moncrieff C. and Aguirre-Hudson B. 1994. Lichens as indicators of environmental stability and change in the tropical forests of Thailand. *Global Ecology and Biogeography Letters* 4: 116–123.