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Research article

Elevational controls of lichen communities in Zanskar valley, Ladakh, a Trans Himalayan cold desert

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Abstract: Elevation linked climatic factors such as temperature, moisture, radiation and precipitation delimit the distribution of organisms. Effect of elevation was studied on lichen diversity in seven spatially separated sites of Zanskar valley, in Ladakh region of Indian Himalayan state of Jammu and Kashmir. The study revealed presence of 24 species, of lichens in the valley belonging to 12 genera and 10 families. Microlichens (crustose, placodioid, squamulose) were the dominant growth forms in all the studied sites. *Acarospora badiofusca* and *Xanthoria elegans* were the most common species in the valley. The study revealed presence of one new record for the state (*i.e. Endocarpon pallidum*) and there new *Toninia* species to the lichen flora of India. Principal component analysis (PCA) of sites and further two tailed bivariate correlational analysis concluded the determinable influence of elevation on the lichen diversity of the valley.
Keywords: Correlation - Elevation - Himalaya - Lichens - PCA - Zanskar.

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INTRODUCTION

The diversity and distribution pattern of organisms is strongly influenced by environmental variables such as elevation, topography, moisture, temperature, precipitation, exposure to radiation and substrate attributes (*i.e.* stability, nutrients, and chemistry) (John & Dale 1990, Eldridge & Tozer 1997, Belnap & Gillette 1998, Ponzetti & McCune 2001, Körner 2003). Among various environmental variables elevation gradient is among the most influencing, which through associated effects on atmospheric temperature, humidity, pressure and precipitation influence the distribution dynamics of plant and animals (Vetaas & Grytnes 2002, Bhattarai *et al*. 2004, McCain 2004, Grau *et al*. 2007, Baniya 2010, Baniya *et al*. 2012).

Lichens, one of the most successful symbiotic associations of a fungus, a green and/ or blue green alga, are known to inhabit nearly all the terrestrial domains of the planet (Galloway 1992). Though habitat range of lichens is influenced by multi-scale environmental variables (Lalley *et al*. 2006), elevation is a key variable which influences the diversity and distribution patterns of lichens (Bruun *et al*. 2006, Pinokiyo *et al*. 2008, Baniya *et al*. 2010, Huang 2010, Baniya *et al*. 2012, Rai *et al*. 2012).

Himalayan habitats, rich in diversity of lichens, harbour definite pattern of lichen growth form distribution-dominated by foliose lichens at lower to mid-elevations, fruticose-dimorphic lichens at subalpine elevations and predominantly crustose along with their sub-growth forms- squamulose and placoid in alpine habitats with low precipitation (Upreti 1998, Singh & Sinha 2010, Kumar *et al*. 2012).

Ladakh, the north most region of the Indian Himalaya, is characterized by mountainous topography, and subzero harsh climate. Rocks and soil are the most preferred habitats for lichens of the region (Negi & Upreti 2000).Except the enumeration of 21 species of lichens from Hemis National Park, by Negi & Upreti (2000) and 36 species of lichens by Kumar *et al*. (2012), no records of lichens are available from this region.

In the present study we describe the lichen diversity of seven sites of Zanskar valley, situated in west Ladakh, in the state of Jammu and Kashmir, India with reference to elevational gradients.

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MATERIAL AND METHODS

Study area

Zanskar, a sub district/ tehsil of the Kargil district, lies in the eastern half of the Indian state of Jammu and Kashmir (Fig. 1). The Zanskar valley lies south west to Zanskar mountain range which separates Zanskar from Ladakh. Geologically, the Zanskar Range is part of the Tethys Himalaya, an approximately 100-km-wide synclinorium formed by strongly folded and imbricated, weakly metamorphosed sedimentary series. The average height of the Zanskar mountain range is about 6,000 m.

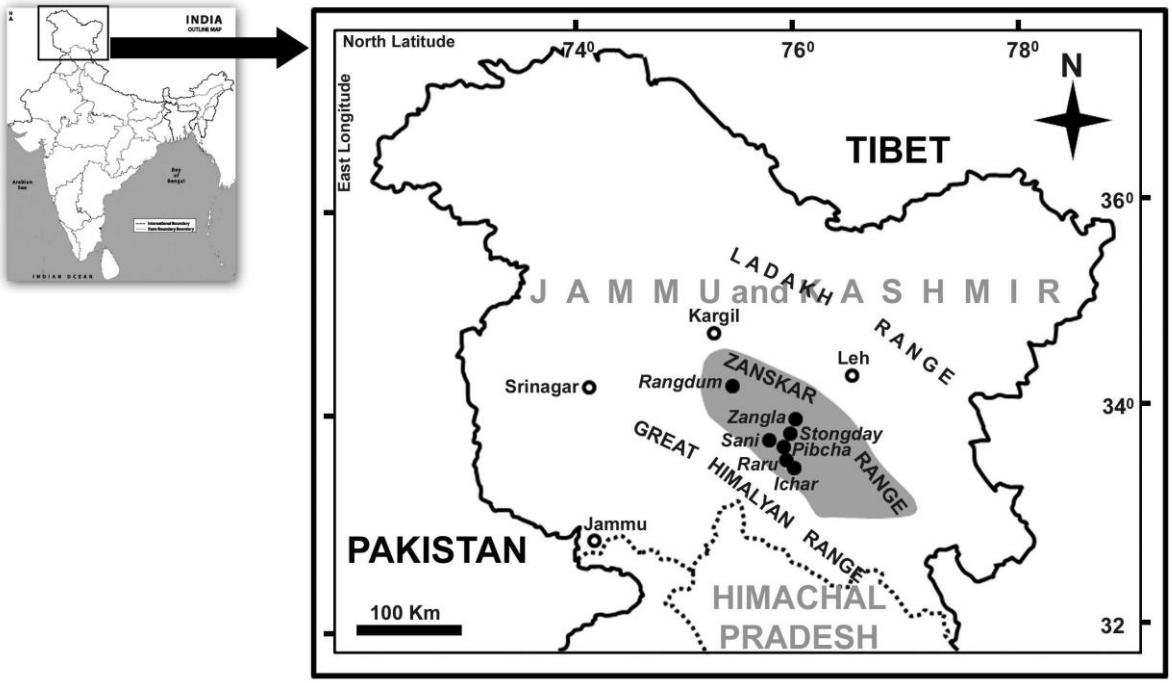

Figure 1. Location map of study sites in Zanskar valley.

Zanskar valley covers an area of some 7,000 square kilometers, at a height ranging from 3,500 and 7,000 metres. The Valley consists of the area lying along the two main branches of the Zanskar River, Doda and Lungnak (formed by two tributaries Kargyag and Tsarap river). The easiest approach is from Kargil through the Suru valley. These topographical features makes access to Zanskar difficult from all sides. Communication with the neighboring areas is maintained across mountain passes or along the Zanskar river when frozen.

The climate of Zanskar valley is extremely dry and cold. Annual precipitation is only around 100 mm / year and humidity is very low. In this region, above 3,000 meters elevation, winters are extremely cold. The average January temperature of the valley is -20°C which drops as low as -40°C.

The vegetation of Zanskar mainly consists of alpine and tundra plant species, which are mainly confined on the upper slopes which receive more precipitation. Many species of *Hippophae*- the sea-buckthorns are found in the region with minimal soil humidity. The alpine meadows are covered with edelweiss (*Leontopodium alpinum*). Landuse by the local human population is mainly semipastoral agriculture based on livestock grazing and agriculture. Cultivated crops including barley, lentils, and potatoes which are grown by farmers at the lower elevations. At higher elevation livestock are major source of livelihood. Domesticated animals consists of yak, dzo, sheep, horse, and dog. The wildlife in Zanskar is represented by marmot, bear, wolf, snow leopard, kiang, bharal, alpine ibex, wild sheep and goats, and the lammergeyer (*Bearded vulture*).

The study was conducted in seven sites of Zanskar valley- Pibcha, Rangdum, Ichar, Sani, Raru, Stongday and Zangla (Table 1) in order to assess the lichen diversity of the valley along elevation gradients. The sites covered the elevational range of 3571–4001 m above mean sea level.

Lichen sampling and identification

Lichens were collected from seven localities of Zanskar valley (Table 1) using random sampling from all the available relevés. In all the sampling sites the land use was semipastoral. The sampling was done on the basis of morphospecies or recognizable taxonomic units (RTUs), identified based on morphological differences,

irrespective of their association with individuals of other taxa (Negi 2000). All the lichen RTUs were reported from rocks.

Table 1. Sampling sites and their geomorphic and land use attributes in Zanskar valley.

S No.	Localities	Altitude (m)	Coordinates	Land use
1.	Pibcha	3756	N 33°23.596' E 76°55.988'	Semipastoral
2.	Rangdum	4006	N 34°03.165' E 76°20.772'	Semipastoral
3.	Ichar	3774	N 33°18.129' E 76°59.901'	Semipastoral
4.	Sani	3572	N 33°30.020' E 76°48.932	Semipastoral
5.	Raru	3728	N 33°19.662' E 76°57.545'	Semipastoral
6.	Stongday	3571	N 33°31.356' E 76°58.894'	Semipastoral
7.	Zangla	3573	N 33°39.769 E 76°59.316'	Semipastoral

The lichen samples collected were examined and identified in the lichenology laboratory of the CSIR-National Botanical Research Institute, Lucknow, Uttar Pradesh, India. 100% of the lichen RTUs were identified taxonomically upto species level using a stereomicroscope, light microscope (morpho-anatomically) and, chemically with the help of spot tests, UV light and standardized thin-layer chromatography (Elix & Ernst-Russel 1993, Orange *et al*. 2001). The species were authenticated using relevant keys and monographs (Awasthi 1991, Divakar & Upreti 2005, Awasthi 2007).The voucher specimens were deposited at the lichen herbarium (LWG), National Botanical Research Institute (CSIR-NBRI), Lucknow, India.

Data analysis

Lichen assemblage of all the 7 sites was quantitatively analyzed for frequency, with reference to lichen richness, species and growth form diversity, in each site. RTUs collected from each site were considered as measure of total lichen richness (Negi 2000), whereas number of species was considered as measure of species diversity in sites (Pinokiyo 2008, Rai *et al*. 2012). An indirect gradient ordination method, principal component analysis (PCA), was used to summarize the compositional differences between the sites (Pinokiyo *et al*. 2008, Rai *et al*. 2012). Pearson's correlation coefficients were calculated to compare explanatory variable (*i.e.* elevation) and response variables (PCA axis score, total lichen diversity, lichen species diversity and growth form diversity) (Rai *et al*. 2012). The absolute constancy of each species in the study was calculated as the number of sites in which the given species was present (Mueller-Domdois & Ellenberg 1974, Rai *et al*. 2012). Except PCA and cluster analysis, which were performed using multivar option in PAST 2.17c (Hammer *et al*. 2001), all other statistical analysis were made using IBM SPSS Statistics 20.

RESULTS

Average community structure and patterns

The terricolous lichen assemblage recorded from the 7 sites in the Zanskar valley consisted of 24 species belonging to 12 genera, ten families and four growth forms (*i.e.* crustose, placodioid, squamulose and, foliose) (Table 2). All the studies sites exhibited dominance of the species of lichen family *Lecanoracea* (8 spp.), followed by *Acarosporaceae*, *Catillariaceae* and *Candelariaceae* (3 spp. each) (Table 2). Among the species recorded *Acarospora badiofusca* and *Xanthoria elegans* were the most common lichens (present in 6 sites) (Table 2). The study revealed one addition (*Endocarpon pallidum*) to lichens for Jammu & Kashmir state and recorded three new species of *Toninia* for India (Table 2).

The lichen communities on all the study sites surveyed were dominated by microlichens (*i.e.* squamulose and crustose) (Table 2, Fig. 2B). Though no significant relationship was found between number of species and elevation, a significant linear relationship was observed between total lichen diversity (RTUs frequency) and elevation, where a gradual decrease in lichen diversity was observed with decrease in elevation (Table 2, Fig. 2A).

Principal community determinants

Principal component analysis:

The dominant and co-dominant lichens differed within seven sites of Zanskar valley indicating distinct lichen assemblages in different sites (Table 2), which was also confirmed by PCA (Fig. 3).

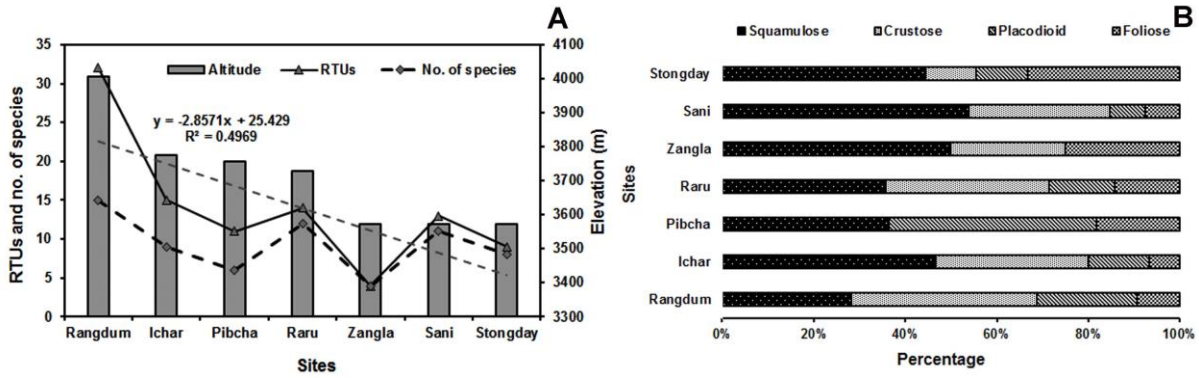

Figure 2. A, Total lichen diversity along elevation gradient, with reference to RTUs recorded from the seven sites of Zanskar valley; **B,** Percentage lichen growth form composition recorded in the seven sites of Zanskar valley. Sites are arranged along decreasing elevation gradient.

The PCA analysis required 6 components (axis) to account for 100% variation in the data set. The first three axis of PCA explained 85.8% of variance, and each axis explained 58.3, 15.1 and 12.4%, respectively. The first two axes explaining 73.4% of variance were considered for further correlation studies.

PCA analysis resulted in preferential clustering of seven sites of Zanskar valley. Zangla, Stongday, Raru and Pibcha though mapped in the same quarter of the PCA ordination plot, their relative clustering was governed by proportional difference of growth forms in each site (Fig. 2B, 3; Table 2). Znagla and Stongday clustered along due to dominance of squamulose growth forms in both sites. Raru and Pibcha mapped apart due to almost equal proportion of squamulose and crustose growth forms in Raru and absence of placodioid growth forms in Pibcha (Fig. 2B, 3; Table 2). PCA ordination showed similar differential proportion of crustose and, squamulose growth forms in rest of the sites (Fig. 2B, 3; Table 2).

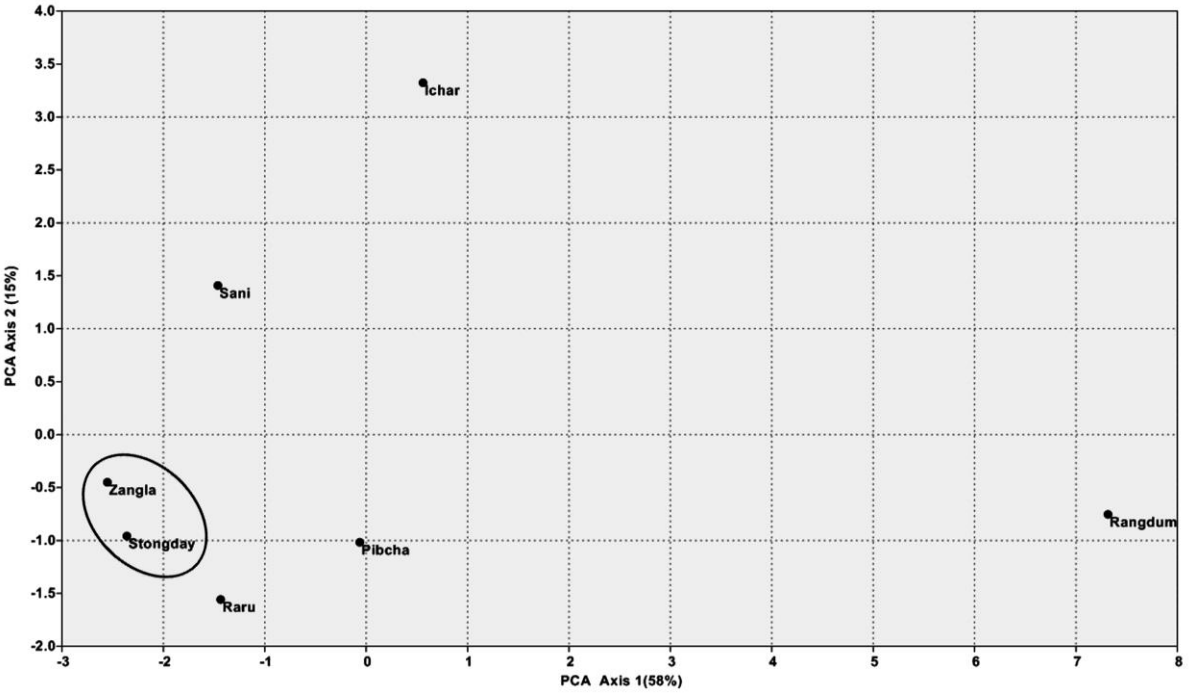

Figure 3. PCA ordination plot of 7 study sites of Zanskar valley.

Correlation analysis:

PCA 1 was found significantly correlated to total lichen diversity, elevation, and growth forms- curstose and placodioid, indicating their primary influence in differentiating lichen communities in Zanskar valley (Table 3). Total lichen diversity was correlated with lichen species diversity, elevation, and diversity specific growth forms (*i.e.* squamulose, crustose, and placodioid). Elevation was correlated with total lichen diversity and diversity of crustose and placodioid growth forms, indicating specific controls of elevation on lichen communities.

Table 2. Lichen diversity recorded in different sites of Janskar valley, Ladakh, Jammu & Kashmir.

S No.	Species	Family	Growth form	Pibcha*	Rangdum*	Ichar*	Sani*	Raru*	Stongday*	Zangla*	Consistency
1.	*Acarospora badiofusca* (Nyl.) Th. Fr.	*Acarosporaceae*	Squamulose	D2 (2)	2	D2 (2)	1	0	D1 (2)	1	6
2.	*Acarospora strigata* (Nyl.) Jatta	*Acarosporaceae*	Squamulose	0	0	1	0	D2 (2)	0	0	2
3.	*Aspicilia maculata* (H. Magn.) Oxner	*Megasporaceae*	Crustose	0	D3 (3)	D1 (4)	D1 (2)	1	0	0	4
4.	*Candelariella aurella* (Hoffm.) Zahlbr.	*Candelariaceae*	Crustose	0	0	0	0	1	1	1	3
5.	*Candelariella grimmiae* Poelt & Reddi	*Candelariaceae*	Squamulose	0	1	1	0	0	1	1	4
6.	*Candelariella vitellina* (Ehrh.) Müll. Arg	*Candelariaceae*	Squamulose	0	0	1	0	0	0	0	1
7.	[A] *Endocarpon pallidum* Ach.	*Verrucariaceae*	Squamulose	0	1	0	0	1	1	0	3
8.	*Lecanora frustulosa* (Dicks.) Ach.	*Lecanoraceae*	Placodioid	D2 (2)	0	0	1	1	0	0	3
9.	*Lecanora garovaglii* (Körb.) Zahlbr.	*Lecanoraceae*	Placodioid	D1 (3)	D1 (7)	D2 (2)	0	1	0	0	4
10.	*Lecanora muralis* (Schreb.) Rabenh.	*Lecanoraceae*	Placodioid	0	0	0	0	0	1	0	1
11.	*Lecidella alaiensis* (Vain.) Hertel	*Lecanoraceae*	Crustose	0	1	0	0	0	0	0	1
12.	*Lecidella enteroleucella* (Nyl.) Hertel	*Lecanoraceae*	Crustose	0	1	0	0	0	0	0	1
13.	*Lecidella stigmatea* (Ach.) Hertel & Leuck.	*Lecanoraceae*	Crustose	0	1	0	1	D1 (3)	0	0	3
14.	*Physcia gomukhensis* D.D. Awasthi & S.R. Singh	*Physciaceae*	Foliose	1	1	0	0	1	1	0	4
15.	*Pleopsidium flavum* (Bell.) Körb	*Acarosporaceae*	Crustose	0	0	0	1	0	0	0	1
16.	*Rhizocarpon disporum* (Naeg. ex Hepp.) Müll. Arg.	*Rhizocarpaceae*	Crustose	0	D2 (4)	0	0	0	0	0	1
17.	*Rhizocarpon geographicum* (L.) DC. in Lam. & DC.	*Rhizocarpaceae*	Crustose	0	3	0	0	0	0	0	1
18.	*Rhizoplaca chrysoleuca* (Sm.) Zopf	*Lecanoraceae*	Squamulose	1	1	0	1	1	1	0	5
19.	*Rhizoplaca melanopthalma* (DC.) Leuckert & Poelt	*Lecanoraceae*	Squamulose	1	2	D2 (2)	D1 (2)	0	0	0	4
20.	*Rinodina straussii* J. Steiner	*Physciaceae*	Crustose	0	0	1	0	0	0	0	1
21.	[B] *Toninia* sp.1	*Catillariaceae*	Squamulose	0	2	0	1	1	0	0	3
22.	[B] *Toninia* sp.2	*Catillariaceae*	Squamulose	0	0	0	1	0	0	0	1
23.	[B] *Toninia* sp.3	*Catillariaceae*	Squamulose	0	0	0	1	0	0	0	1
24.	*Xanthoria elegans* (Link) Th. Fr.	*Teloschistaceae*	Foliose	1	2	1	1	1	1	1	6
	Species richness (no. of species recorded)			6	15	9	11	12	8	4	
	Lichen diversity (frequency of RTUs recorded)			11	32	15	13	14	9	4	

D1 dominant species within macrohabitat, D2 primary co-dominant species within macrohabitat.
[A] New record (s) for Jammu & Kashmir; [B] New records for India.
*Lichen diversity is reported as frequency of recognizable taxonomic units (RTUs) recorded in each site.

DISCUSSIONS

The Ladakh region of Jammu and Kashmir, India is a Trans Himalayan desert which receives minimal precipitation due to its location in the rain shadow region of Indian monsoon. The Zanskar valley, like majority of Ladakh receive most of its moisture through winter snow fall, occasional rainfall and cloud burst events (Strzepek & Smith 1995). The dominance and low species turnout of crustose, squamulose and placodioid growth forms in Zanskar valley is in accordance to other such trans Himalayan habitats (Baniya 2010, Baniya *et al.* 2012, Kumar *et al.* 2012), which can be attributed to decreasing soil cover, low atmospheric humidity and poor substrate nutrients (carbon and nitrogen) at higher elevations (Baniya 2010). The clustering of some sites (*i.e.* Zangla and Stongday) was due to alike lichen growth form composition, which was characterized by the presence and similar proportion of crustose, placodioid, squamulose and foliose growth forms. The peculiar dominance of microlichens in the Zanskar valley is similar studies to such studies done in the region of Leh (Kumar *et al.* 2012). Higher total lichen (RTUs collected) and species (no. of species collected) diversity in the sites with higher elevation can be attributed to relative higher precipitation received at these elevations (*i.e.* 3500–4006 m).

Table 3. Pearson's correlation coefficients between PCA axes and selected variables (significant correlations are tagged).

	PCA1	PCA2	SD	LD	Al	Sq	Cr	Pl	Fo
PCA1	1								
PCA2	0.000	1							
SD	0.680	-0.003	1						
LD	0.953**	0.008	0.868*	1					
Al	0.937**	-0.051	0.630	0.894**	1				
Sq	0.742	0.365	0.883**	0.865*	0.687	1			
Cr	0.883**	0.071	0.878**	0.949**	0.806*	0.916**	1		
Pl	0.881**	-0.243	0.514	0.812*	0.906**	0.451	0.624	1	
Fo	0.174	0.124	0.402	0.305	0.191	0.223	0.076	0.399	1

SD, Species diversity (no. of spp.); *LD* Lichen diversity (frequency of RTUs); *Alt*, Altitude; *Sq*, Squamulose; *Cr*, Crustose; *Pl*, Placodioid; *Fo*, Foliose

* Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).

CONCLUSION

Lichen constitute a major component of flora of cold desert in trans Himalaya (Baniya 2010), and their growth forms are known to be good indicators of habitat heterogeneities in Himalayan habitats (Baniya *et al.* 2012, Rai *et al.* 2012). Present study revealed a considerable lichen diversity in Zanskar valley, influenced by elevation linked climatic factors. The findings here by elucidate the yet less explored lichen biodiversity of Ladakh, and can act as base line data for further lichenological researches in the region.

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