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RESEARCH ARTICLES

Establishment of GLORIA sites in Indian Himalayan Region: diversity and distribution of lichens

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Abstract
Alpine ecosystems are important monitoring targets for examining climate-induced changes in biodiversity components. In this context, by following the protocol of the Global Observation Research Initiative in Alpine environments, two target regions (TR) were established in the mountainous regions of the Chaudans and Byans valleys of Uttarakhand. Lichens along with some vascular plants dominate alpine ecosystems and are known to play a pivotal role in ecosystems. Lichens are well known bioindicators of climatic conditions, hence the present study is focused on lichen diversity and distribution in selected TRs. We established 08 (04 in each TR) summits (covering different alpine zones from treeline to nival belt). The data sets regarding species richness, distribution, frequency, cover etc. were generated. We reported 30 species belonging to 25 genera and 17 families collected at eight alpine mountain summits in TR—I and II. With plans to monitor and resurvey at five-year intervals, the sites established in this project document current lichen species composition, and allow for a long-term assessment of changes in biodiversity attributable primarily to changes in climate. The dataset generated can be compared with the datasets of other high-altitude regions of the globe.

Keywords Biodiversity · Alpine zone · GLORIA · Himalaya · Long-term monitoring

Abbreviations

GLORIA	Global Observation Research Initiative in Alpine environments
TR	Target regions
IHR	Indian Himalayan Region
KSLCDI	Kailash Sacred Landscape Conservation and Development Initiative
KSL	Kailash Sacred Landscape
ICIMOD	International Center for Integrated Mountain Development
N, S, E and W	North, South, East and West
HSP	Highest summit point HSP
SASs	Summit area sections
m	Meter
cm	Centimeter
r!	Very rare (one or a few individuals)
r	Rare (some individuals at several locations, can hardly be overlooked in a careful observation)
s	Scattered (widespread within the section, species cannot be overlooked, but the presence is not obvious at first glance)
c	Common (occurring frequently and widespread within the section, presence is obvious at first glance)
d	Dominant (very abundant)
PCA	Principal Component Analysis

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Introduction

The alpine regions due to their location at high altitudes, experience low temperature conditions, and are hence, generally considered sensitive to climate warming (Price and Barry 1997). These regions are known to exhibit unique floristic as well as faunal biodiversity. Due to their low ecological complexity and low impact of biotic factors, alpine vegetation is more dependent on climatic factors (macro and micro). Besides this the impact of human land use is negligible or very less significant in most of the alpine regions of the globe, except in some of the alpine regions of the Himalaya where pastoralism is a major land use practice during the summer seasons. During the last few years, researchers have experienced an increasingly wider interest in relation to environmental variables, specifically, some of them centered on growing lichen rates and environmental conditions such as humidity, temperature or precipitation along with altitude (Sancho and Pintado 2004; Hawksworth et al. 2005; Upadhyay et al. 2018; Bisht et al. 2020; Nanda et al. 2021). The lichens are long living organisms, unlike the other plants they lack the presence of a protective layer i.e., cuticle on their body surface, this makes them enable to accumulate environmental pollutants directly into their bodies, and makes them important bioindicators of environmental sensitivity. Under the current climate change scenario, the lichen diversity of the alpines is also getting distorted. The shifting of lichen species from tropical to higher temperate regions under the influence of global warming has been observed in many parts of the globe (Aptroot 2009). In relation to this, many of these scientific investigations are nowadays focused on the current global warming process, emphasizing the sensitivity of high mountain zones towards environmental warming (Theurillat 1995; Pauli et al. 1996; Körner 2002; Grabherr et al. 2001, 2010; Dullinger et al. 2007) where the study of lichens has appeared as an interesting option (McCune 2000; van Herk et al. 2002; Scheidegger et al. 2002; Vittoz et al. 2010; Upadhyay 2017; Bisht 2018; Bisht et al. 2018a, b).

Based on this, the alpine regions of IHR appear to be suitable areas where the study of global warming through lichens could be an interesting alternative as yet unconsidered. It includes prominent peculiarities such as its geographical location, type of climate, high floristic biodiversity and endemism rate which mark its importance at national and international level (Dhar 2000; Gairola et al. 2015; Chandra Sekar et al. 2017). But despite its importance, not a single project has been developed on this aspect. The lack of standardized long-term ecological observations within this region provided the stimulus for running a popularly known, GLORIA project (http://www.gloria.ac.at) which consists of a global network of monitoring sites (known as TR) coordinated by the University of Vienna Institute of Ecology and Conservation Biology.

GLORIA focuses on monitoring changes in species richness (number of species), species composition (loss or gain of individual species), patterns of vegetation (changes in % cover), soil temperatures of microhabitats, and snow cover (indirectly through temperature measurements) in alpine environments to monitor climate change impact on alpine vegetation. A field manual with simple and cost-effective protocols prepared by Pauli et al. (2004) encouraged numerous researchers to establish and regularly monitor GLORIA TRs. Observations from TRs worldwide are being compiled by the GLORIA coordination office and are available for analysis by the scientific community, and these results offer an interesting opportunity to investigate species-richness patterns along the subalpine-nival elevation gradient. Currently more than 50 countries are participating in the program and 135 active GLORIA TRs (http://www.gloria.ac.at), including the two TRs described here in have been established in alpine regions across the globe (accessed on 02/02/2021).

The aim of our paper was to use the GLORIA protocol to establish long-term alpine vegetation TRs in India and under the KSLCDI project, in the year 2014–2015, eight monitoring summits on the upper area of the Pithoragarh district [KSL, part of India], Uttarakhand (TR: IN-CHU and IN-BYN) were established. Pithoragarh was chosen because it falls under the project implementation area of KSLCDI and has a vast altitudinal range (< 500 to > 6000 m asl) and provides a suitable geographical region for the growth of several different lichen communities in West Himalaya and is well explored for the floristic studies of lichens since decades (Upreti et al. 2001, 2002; Pant 2002; Joshi et al. 2008a, b; Mishra 2012, Mishra and Upreti 2016; Joshi et al. 2016, 2018a, b; Upadhyay 2017; Bisht et al. 2019).

For the first time the present study is focused to generate the data according to a globally accepted protocol so that these data sets can be monitored and compared with the datasets of other regions of the globe in the future and can be helpful in understanding the response of lichen taxa to climate change. Presently, the study is designed to describe the present state of the lichen layer at the study sites and (ii) identification of factors responsible for the observed pattern. With plans to monitor and resurvey our newly established GLORIA sites at five year intervals, the baseline data collected during the establishment of monitoring sites in target regions will provide an opportunity for assessment of any changes in biodiversity that may be related to changes in climate.

Materials and methods

Study area

The study was conducted in the alpine regions of the Pithoragarh district of Uttarakhand. The district falls under the Kumaun Division of Uttarakhand state and is spread over an area of 6826.35 Km^2. This region shows great variability in geological and physiographic forms. It represents the three major physiographic zones of the Himalaya viz. the Trans-Himalaya, the Greater Himalaya and the Lesser Himalaya. The diverse physiographic features of the landscape provide opportunities to exhibit the richness, representativeness, and uniqueness of biodiversity components. The south-western part of Pithoragarh is hot and semi-arid in nature while a few valleys in the central part are lush green and humid. The upland, glaciated valleys viz., Byans, Chaudans, Darma, and Malla Johar, have quite extensive alpine scrub and meadows. The western part is formed by the mountain basins of eastern Ramganga. Likewise, the Great Pancha-Chuli range, running south-east divides the basins of Gori from those of Darma Ganga (eastern Dhauli). Kuti Yangti, Dhouliganga, Goriganga, Ramganga (East), Kali/Sharda and Saryu are the major river systems of this region. This region is also of great religious importance due to its location on the sacred tract of Mt. Kailash. The ICIMOD has designated Pithoragarh as the Indian part of KSL; which is a trans-boundary landscape covering a large region of about 31,175 km^2 around Great Mt. Kailash in China, India and Nepal (Zomer and Oli 2011). This region is also home to several high mountain peaks, lakes, pastures, meadows, forests, groves etc. that are associated with spiritual, cultural and religious beliefs. 132 sacred natural sites, including 77 sacred groves, 27 sacred forests (area larger than 2 hectare each), 18 wetlands and 10 pastures have been documented in this region (Negi 2010). The region is bestowed with varied vegetation types ranging from tropical moist deciduous to alpine vegetation. More than 50% of the geographical area of Pithoragarh falls under the alpine zone hence this region harbors rich alpine lichen diversity and provides scope for GLORIA to be executed in its alpine regions. The alpine regions of the Chaudans and Byans Valleys were selected to conduct the study. Both valleys are located in the Dharchula block of Pithoragarh district. The Chaudans Valley represents monsoon influenced greater Himalayan conditions while the Byans Valley shows trans-Himalayan cold desert conditions.

Methodology

The study was conducted in July 2014 and October, 2015 in TR—I and TR—II respectively. The GLORIA—Field Manual of Multi Summit Approach (Pauli et al. 2004, 2011) was followed to conduct the study. The observation site, known as the TR consisted of four summits, exposed to the same regional macroclimate, along an altitudinal gradient from above the natural tree line ecotone up to the uppermost vegetation zone (Table1). Special care was taken while selecting the summits because in the alpine meadows of Pithoragarh, pastoralism is a major land use practice during the summer season. And to check the cattle induced dispersal of plant material from one place to another, the study was conducted in grazing free summits. To identify the grazing free summits negotiations were made with the local herders because herders follow a particular path for grazing.

At each TR, summit was defined as a polygon with four corners, at each point of the compass (N, S, E and W) and at an altitude difference of 5 m form the HSP and a lower area extending from 5 vertical meters below summit to 10 vertical meters below summit (Fig. 1). Intersection lines from the HSP to the directions NE, SE, SW and NW resulted in eight SASs (four upper and four lower ones). At each of the main geographical (cardinal) direction, down 5 m vertical elevation from the HSP, either on the left or on the right side of the principal measurement line, depending on the nature of the terrain and habitat, a permanent 3 m × 3 m quadrat cluster was established. Each cluster was divided into nine

Table 1 Geographical attributes of the two Target Regions

Target region (code)	Summit name	Summit code	Altitude (m asl)	Latitude (N)	Longitude (E)
Target region—I Chaudans valley (IN-CHU)	Bhairav Ghati	BHT	3773	30° 02.782′	80° 39.122′
	Kharangdhang	KHA	3881	30° 02.927′	80° 39.320′
	Ganglakhan	GAN	4060	30° 03.113′	80° 39.951′
	Shekuakhan	SKN	4266	30° 03.783′	80° 39.927′
Target region—II Byans valley (IN-BYN)	Shyang	SHY	3999	30° 18.573′	80° 45.830′
	Kuti	KUT	4038	30° 18.336′	80° 45.528′
	Chaga	CHA	4062	30° 18.615′	80° 45.951′
	Eurong	EUR	4154	30° 18.645′	80° 46.165′

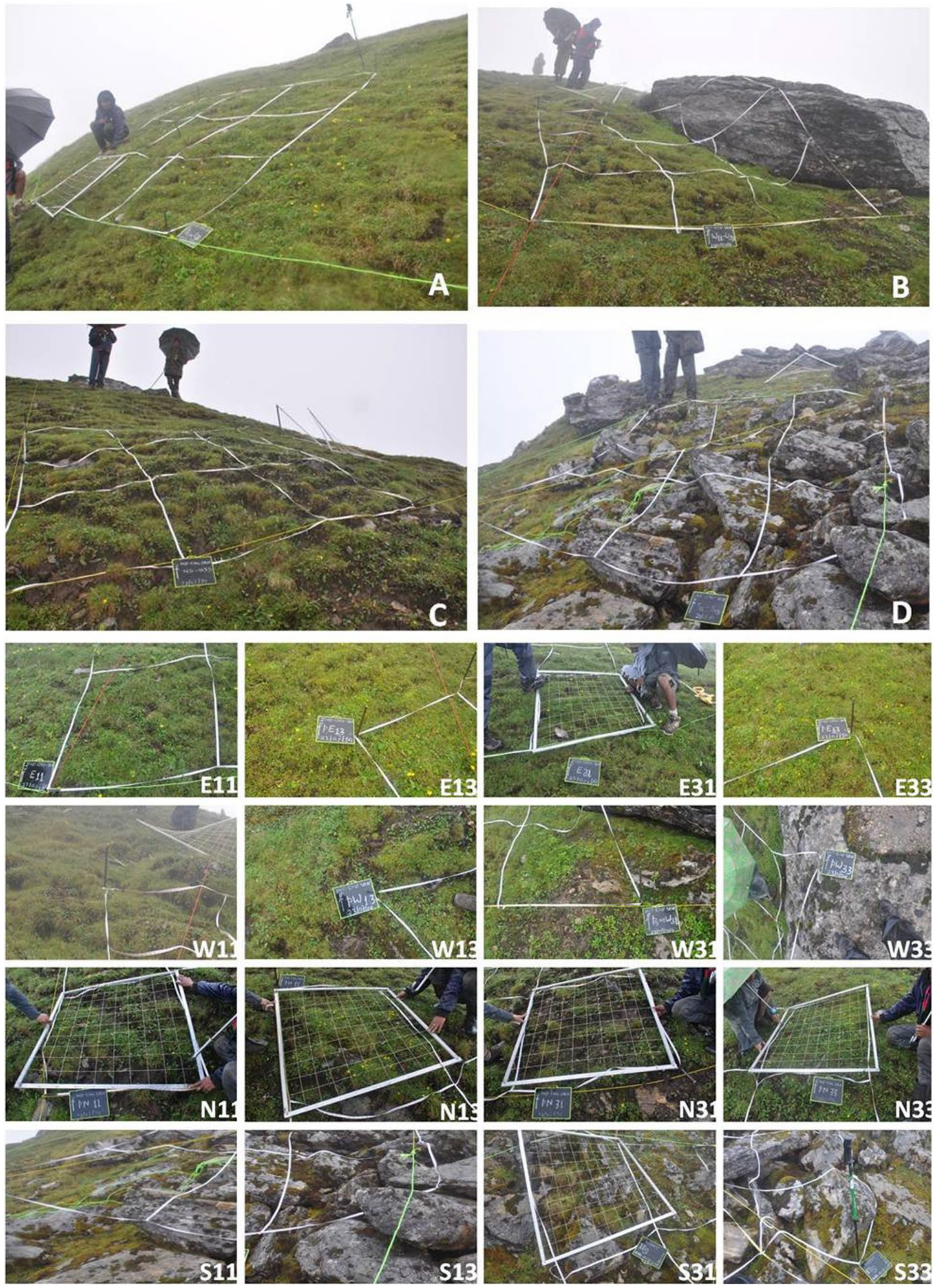

Fig. 1 Set up of a GLORIA summit at SKN summit: 3 m × 3 m Quadrat Cluster, **A** East, **B** West, **C** North, **D** South and 16, 1m^2 quadrats

1 m × 1 m quadrats. The four 1 m × 1 m quadrats (in total 16 on each summit) at the corners of each 3 m × 3 m grids were used for lichen sampling, while the middle quadrat was used for placing soil temperature data loggers, buried 10 cm under the soil surface.

In each summit, sampling was made by measuring the percent cover of each lichen taxa in 16 permanent quadrats (1 m × 1 m) and in the eight SAS lichen species richness was documented along with the visual estimation of the abundance of lichen taxa. The abundance was divided into five categories (r!, r, s, c and d). Summits were well demarcated by inserting iron nails into the soil so that the site could be relocated with the help of a metal detector to continue future monitoring. Detailed sampling of lichen species within each quadrat and SAS provided a baseline for detecting changes in species diversity and composition. A total of 32 (16 per TR) soil temperature loggers (Geo Precision M-Log 5W and Rotronic Log-PT 1000-RC) were buried 10 cm in the soil in both TRs to record the soil temperature over time. In each summit, species data were recorded at different sections of the summit: (1) 8 SASs (= 4 subdivisions of the 5-m summit area and 4 subdivisions of the 10-m SA, representing four cardinal compass directions); (2) four quadrat clusters; and (3) 16, 1 m × 1 m quadrats. The percentage of soil and rock cover within each 3 m × 3 m quadrat cluster was also recorded. Photographs were also taken of all elements of the sampling design to aid in relocating boundary markers and for the purpose of photo monitoring.

Lichen identification and statistical analysis

Lichen specimens were collected at each of the eight peaks at the GLORIA site. For the floristic data a visual inventory of the area was done to find the main taxa with the help of a magnifying glass (20 ×). With the intention of avoiding misidentification with some problematic species, samples in neighbouring zones were taken to be analysed later in the laboratory. All vouchers were examined morphologically, anatomically and chemically using published floras (Orange et al. 2001; Divakar and Upreti 2005; Awasthi 1991, 2007) and deposited in the personal herbarium of Dr. Yogesh Joshi (YJ).

The ordination method (multivariate analysis) i.e. Principal Component Analysis (PCA) was performed using the species quantitative data recorded from each sites broads and sub-sites in different aspects using Past version 3.0 software (Hammer et al. 2001). It is a widely used statistical technique that can reduce the dimension and extract important information from confusing data sets. In the present study, it was performed to group the species having similar composition and to find out the component (here species) which have the maximum variance within the data set.

Results

The GLORIA summits established in the Byans and Chaudans valleys target regions (TR—I and TR—II respectively) ranged from 3773 to 4266 m asl. A total of 30 lichen species belonging to 25 genera and 17 families were inventoried during establishment of India's eight GLORIA summits. A summary and breakdown of the number of lichen species, their percent cover and abundance was inventoried in 3 m × 3 m Quadrat Cluster, 5-m Summit Area Section and 10-mSummit Area Sections in different aspects of all the eight summits of both the TRs and is represented in Table 2, 3, Supplementary Table 1 to 4 and shown in Figs. 2 and 3.

In TR—I, 23 species were inventoried and the most dominant species overall in terms of cover were *Aspicilia calcarea* at 0.60%, *Diploschistes scruposus* at 0.14%, *Peltigera polydactylon* 0.07%, *Umbilicaria indica* at 0.06%, *Lecanora muralis* 0.04%, *Lobaria retigera* at 0.03% *Lecanora indica* at 0.02%, *Cladonia coccifera* and *Thamnolia vermicularis* at 0.01%. The most widespread species in terms of how many summits they occurred in were *Aspicilia calcarea* and *Rhizocarpon geographicum* all at 100%, followed by *Caloplaca cinnabarina*, *Cladonia coniocraea*, *Diploschistes scruposus*, *Lecanora muralis*,

Table 2 Number of lichen taxa in each summit and percent cover of rock and soil in the 3 m × 3 m quadrat clusters of all summits in the two target regions

Target region	Summit name	Substrate Cover (%)				Lichen taxa		
		Rock	Soil	Vegetation cover on soil (%)	Dominant plant species	Species	Genera	Families
Target Region—I	Bhairav Ghati	1.4	98.6	83.18	*Danthonia cachemyriana*, *Kobresia nepalensis*, *Jurinea dolomea*	11	11	11
	Kharangdhang	0.0	100.0	94.31	*Oxygraphis polypetala*, *Geranium wallichianum*, *Trachydium roylei*	7	7	7
	Ganglakhan	0.5	99.5	91.18	*Trachydium roylei*, *Kobresia nepalensis*, *Potentilla cuneata*	12	9	9
	Shekuakhan	29.0	71.0	63.56	*Potentilla cuneata*, *Kobresia nepalensis*, *Geum elatum*	18	14	13
Sub total		7.72	92.27	83.05		– 23	19	14
Target Region—II	Shyang	39.0	61.0	49.58	*Danthonia cachemyriana*	19	18	14
	Kuti	5.0	95.0	54.53	*Danthonia cachemyriana*, *Juniperus indica*	13	12	10
	Chaga	1.0	99.0	48.89	*Danthonia cachemyriana*, *Juniperus indica*, *Potentilla cuneata*	11	11	10
	Eurong	25.0	75.0	59.86	*Danthonia cachemyriana*, *Juniperus indica*, *Potentilla cuneata*	15	13	12
Sub total		17.50	82.50	53.21		– 26	23	15
Total		12.61	87.39	68.13		– 30	25	17

Table 3 Diversity and distribution of lichens in eight summits of two Target Regions

S. no	Lichen taxa	Family	Target region—I				Target region—II				Frequency (%)
			BHT	KHA	GAN	SKN	SHY	KUT	CHA	EUR	
1	*Aspicilia calcarea* (L.) Sommerf	Megasporaceae	+	+	+	+	+	+	+	+	100.0
2	*Caloplaca cinnabarina* (Ach.) Zahlbr	Teloschistaceae	+	−	+	+	+	+	−	+	75.0
3	*C. flavovirescens* (Wulfen) Dalla Torre and Sarnth	Teloschistaceae	−	−	−	−	−	−	−	+	12.5
4	*Cetraria islandica* (L.) Ach	Parmeliaceae	−	−	−	−	+	+	+	+	50.0
5	*Cladonia coccifera* (L.) Willd	Cladoniaceae	−	−	+	+	−	−	−	−	25.0
6	*C. coniocraea* (Flörke) Spreng	Cladoniaceae	+	−	+	+	−	−	−	−	37.5
7	*C. corniculata* Ahti and Kashiw	Cladoniaceae	−	−	+	+	+	+	−	−	50.0
8	*C. pyxidata* (L.) Hoffm	Cladoniaceae	−	−	−	+	+	−	+	−	37.5
9	*Cryptothecia lunulata* (Zahlbr.) Makhija and Patw	Arthoniaceae	−	−	−	+	+	−	−	+	37.5
10	*Dermatocarpon miniatum* (L.) W. Mann	Verrucariaceae	+	−	−	−	+	+	−	−	37.5
11	*Dimelaena oreina* (Ach.) Norm	Caliciaceae	+	−	−	−	+	−	−	−	25.0
12	*Diploschistes scruposus* (Schreb.) Norman	Thelotremataceae	+	−	+	+	−	−	−	+	50.0
13	*Dirinaria applanata* (Fée) D.D. Awasthi and M.R. Agarwal	Caliciaceae	−	−	+	−	−	−	−	−	12.5
14	*Endocarpon pusillum* Hedw	Verrucariaceae	−	−	−	−	−	−	+	+	25.0
15	*Lecanora indica* Zahlbr	Lecanoraceae	−	−	−	+	+	+	−	+	50.0
16	*L. muralis* (Schreb.) Rabenh	Lecanoraceae	+	−	+	+	−	+	−	+	62.5
17	*Lepraria isidiata* (Llimona) Llimona & A. Crespo	Stereocaulaceae	−	−	+	−	+	−	+	−	37.5
18	*Lobaria retigera* (Bory) Trev	Lobariaceae	+	+	−	+	−	−	−	−	37.5
19	*Peltigera polydactylon* (Neck.) Hoffm	Peltigeraceae	+	+	−	+	+	+	+	−	75.0
20	*Physcia caesia* (Hoffm.) Fürnr	Physciaceae	−	−	−	−	+	−	+	−	25.0
21	*Pleopsidium flavum* (Bell.) Körb	Acarosporaceae	−	−	−	−	+	−	−	+	25.0
22	*Pyxine cocoes* (Sw.) Nyl	Caliciaceae	−	−	−	−	+	−	+	−	25.0
23	*Rhizocarpon geographicum* (L.) DC	Rhizocarpaceae	+	+	+	+	+	+	+	+	100.0
24	*Rhizoplaca chrysoleuca* (Sm.) Zopf	Lecanoraceae	−	+	−	+	−	+	+	+	62.5
25	*Stereocaulon foliolosum* var. strictum (C. Bab.) I.M. Lamb	Stereocaulaceae	−	+	+	+	+	+	+	+	87.5
26	*Thamnolia vermicularis* (Sw.) Ach	Icmadophilaceae	−	−	−	+	−	−	−	+	25.0
27	*Umbilicaria indica* Frey	Umbilicariaceae	−	+	+	+	+	+	−	−	62.5
28	*Verrucaria acrotella* Ach	Verrucariaceae	−	−	−	+	−	−	−	+	25.0
29	*Xanthoparmelia mexicana* (Gyeln.) Hale	Parmeliaceae	+	−	−	−	+	−	−	−	25.0
30	*Xanthoria elegans* (Link) Th. Fr	Teloschistaceae	−	−	−	−	+	+	−	−	25.0
Total			11	7	12	18	19	13	11	15	

BHT Bhairav Ghati, *KHA* Kharangdang, *GAN* Ganglakhan, SKN Shekuakhan, *SHY* Shyang, *KUT* Kuti, *CHA* CHAGA, *EUR* Eurong, (+) present, (−) absent

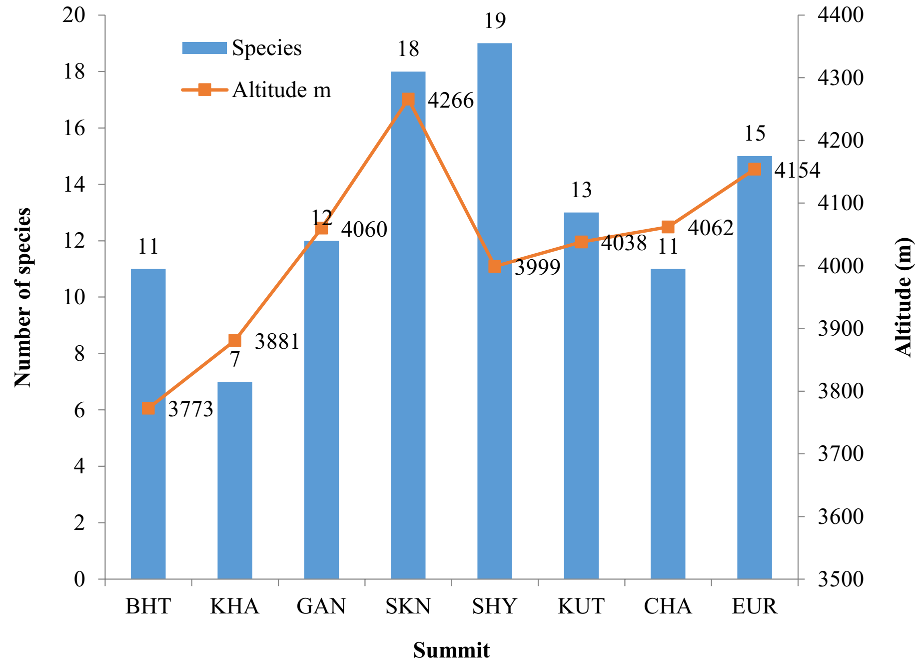

Fig. 2 Lichen species richness in eight summits of the two Target Regions

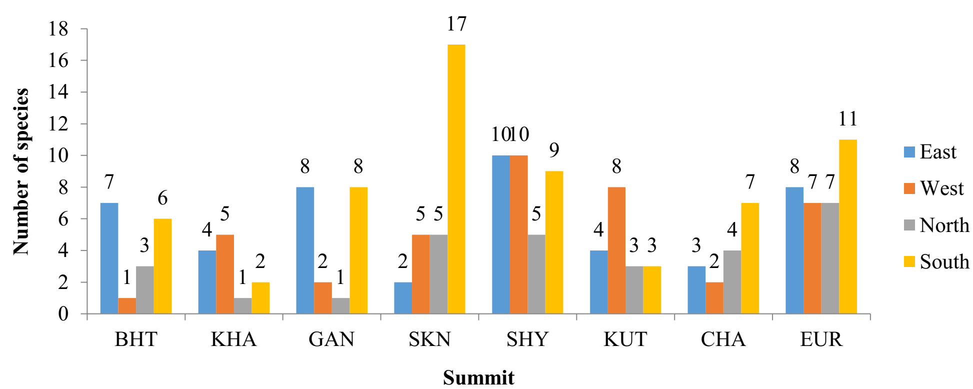

Fig. 3 Number of species in different aspects of the 8 summits of two Target Regions

Lobaria retigera, Peltigera polydactylon, *Stereocaulon foliolosum*, *Umbilicaria indica* all at 75%, *Cladonia coccifera, C. corniculata, Rhizoplaca chrysoleuca* all at 50%, *Cladonia pyxidata, Cryptothecia lunulata, Dermatocarpon miniatum, Dimelaena oreina, Dirinaria applanta, Lecanora indica, Lepraria isidiata, Thamnolia vermicularis, Verrucaria acrotella, Xanthoparmelia mexicana* all at 25%, while *Caloplaca flavovirescens, Cetraria islandica, Endocarpon pusillum*, *Physcia caesia, Pleopsidium flavum, Pyxine cocoes* and *Xanthoria elegans* were absent in this region. Out of the four summits of TR—I maximum species richness was recorded in the highest summit viz. SKN (18) followed by GAN (12) the 2nd highest summit, BHT (11) the lowest summit and KHA (7) the 2nd lowest summit while in case of TR—II SHY (19) the lowest summit showed maximum diversity followed by EUR (15) the highest summit, KUT (13) the 2nd lowest summit and CHA (11) the 2nd highest summit (Tables 3, Supplementary Table 3–4, Fig. 2).

In TR II, 26 species were inventoried and the most dominant species overall in terms of cover were *Rhizocarpon geographicum* at 0.15%, *Aspicilia calcarea* and *Cetraria islandica* at 0.04%, *Caloplaca cinnabarina* at 0.03%, *Lecanora indica* and *Stereocaulon foliolosum* at 0.02%. The most widespread species in terms of how many SASs they occurred in were *Aspicilia calcarea, Cetraria islandica*, *Rhizocarpon geographicum* and *Stereocaulon foliolosum* all at 100%, followed by *Caloplaca cinnabarina*, *Lecanora indica, Peltigera polydactylon* and *Rhizoplaca chrysoleuca* all at 75%, *Cladonia corniculata, C. pyxidata, Cryptothecia lunulata, Dermatocarpon miniatum, Endocarpon pusillum*, *Lecanora muralis*, *Lepraria isidiata, Physcia caesia, Pleopsidium flavum, Pyxine cocoes*, *Umbilicaria indica* and *Xanthoria elegans* all at 50%, *Caloplaca flavovirescens*, *Dimelaena oreina, Diploschistes scruposus*, *Thamnolia vermicularis, Verrucaria acrotella* and *Xanthoparmelia mexicana* all at 25%, while *Cladonia coccifera, C. coniocraea, Dirinaria applanta* and *Lobaria retigera* were absent in this region.

In a nut shell, percent cover study of lichen taxa in 1 m × 1 m quadrats (Supplementary Table 5) indicates that *Aspicilia calcarea* exhibited maximum cover viz. 0.33% (avg.) in all the 128 studied 1 m × 1 m quadrats, followed by *Diploschistes scruposus* and *Rhizocarpon geographicum* (0.08%), *Peltigera polydactylon* and *Umbilicaria indica* (0.04%), *Lecanora indica* and *L. muralis* (0.03%), *Caloplaca cinnabarina, Cetraria islandica* and *Lobaria retigera* (0.02%) and *Cladonia coccifera, Cryptothecia lunulata, Stereocaulon foliolosum, Thamnolia vermicularis* and *Verrucaria acrotella* (0.01%).

Nineteen species were common to both target regions. Four species viz. *Cladonia coccifera*, *C. coniocraea*, *Dirinaria applanata* and *Lobaria retigera* were recorded only in TR—I while 7 species *Caloplaca flavovirescens*, *Cetraria islandica*, *Endocarpon pusillum*, *Physcia caesia*, *Pleopsidium flavum*, *Pyxine cocoes* and *Xanthoria elegans* were specific to TR—II. In totality *Aspicilia calcarea* and *Rhizocarpon geographicum* showed maximum frequency i.e. 100% while *Caloplaca flavovirescens* and *Dirinaria applanata* showed minimum frequency i.e. 12.5%.

In 3 m × 3 m quadrat cluster of all the aspects of 4 summits of TR—I soil contributed 92.27% and rock contributed 7.72% of substrate cover, while in the case of TR—II, soil and rock contributed 82.50% and 17.50% respectively as substrate cover (Table 2). Eight species viz. *Cetraria islandica*, *Cladonia coccifera*, *C. coniocraea*, *C. corniculata*, *C. pyxidata*, *Lobaria retigera*, *Peltigera polydactylon* and *Thamnolia vermicularis* were confined to soil only, while the remaining were confined to rock, except *Stereocaulon foliolosum* which was growing both on soil and rock.

The multivariate analysis (PCA) grouped species of whole dataset into two main groups/ cluster of lichen communities in site-1 (Fig. 4). The PCA loading of all species shows that PC-1 explained 25.69% and PC-2 explained 15.99% of the variability in lichen communities (Supplementary Table 6). The group one is comprised of 18 species: A (*Aspicilia calcarea*), C1 (*Caloplaca cinnabarina*), C2 (*Cladonia coccifera*), C3 (*C. coniocraea*), C5 (*C. pyxidata*), C6 (*Cryptothecia lunulata*), D3 (*Diploschistes scruposus*), L1 (*Lecanora indica*), L2 (*L. muralis*), L3 (*Lepraria isidiata*), L4 (*Lobaria retigera*), P (*Peltigera polydactylon*), R1 (*Rhizocarpon geographicum*), R2 (*Rhizoplaca chrysoleuca*), S (*Stereocaulon foliolosum*), T (*Thamnolia vermicularis*), U (*Umbilicaria indica*) and V (*Verrucaria acrotella*), while the small group (group two) comprised only 5 species: C4 (*C. corniculata*), D1 (*Dermatocarpon miniatum*), D2 (*Dimelaena oreina*), D4 (*Dirinaria applanata*) and X (*Xanthoparmelia mexicana*). These two groups have similar species composition and overall distribution in terms of the numerical dataset.

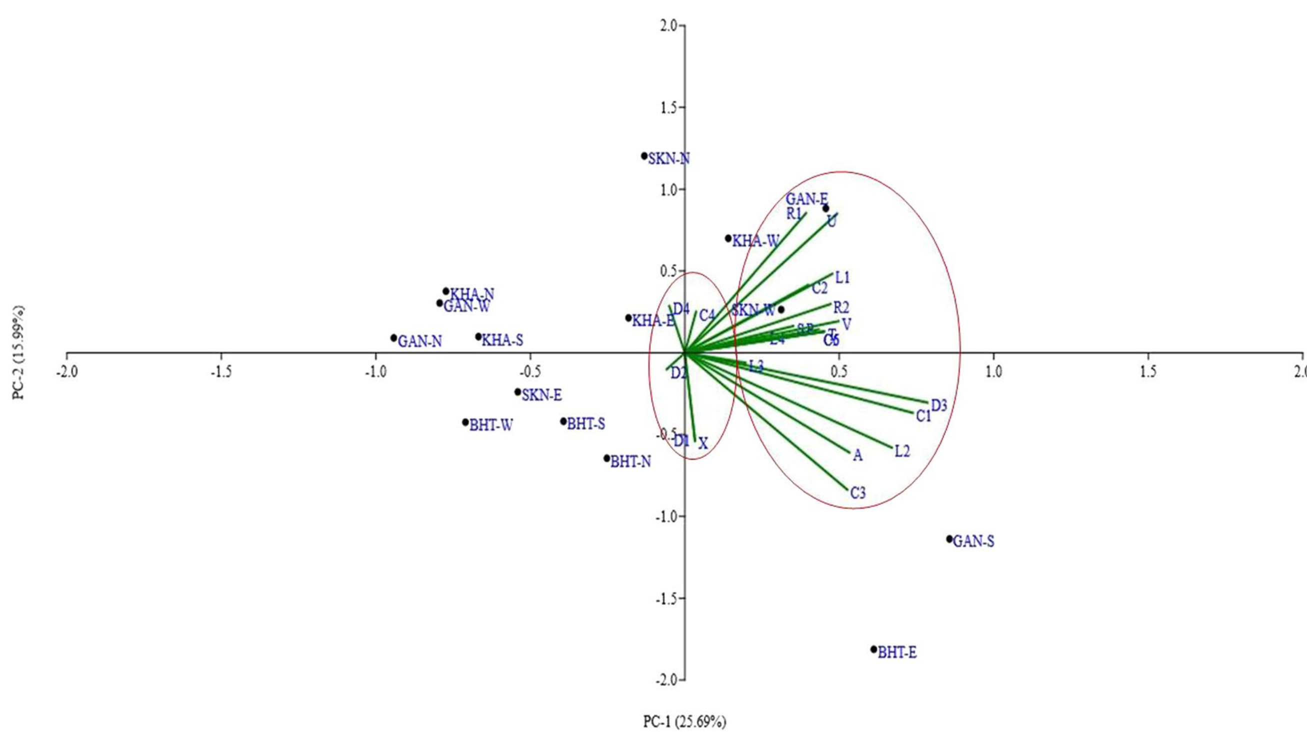

Fig. 4 Principal component analysis (PCA) for TR-I

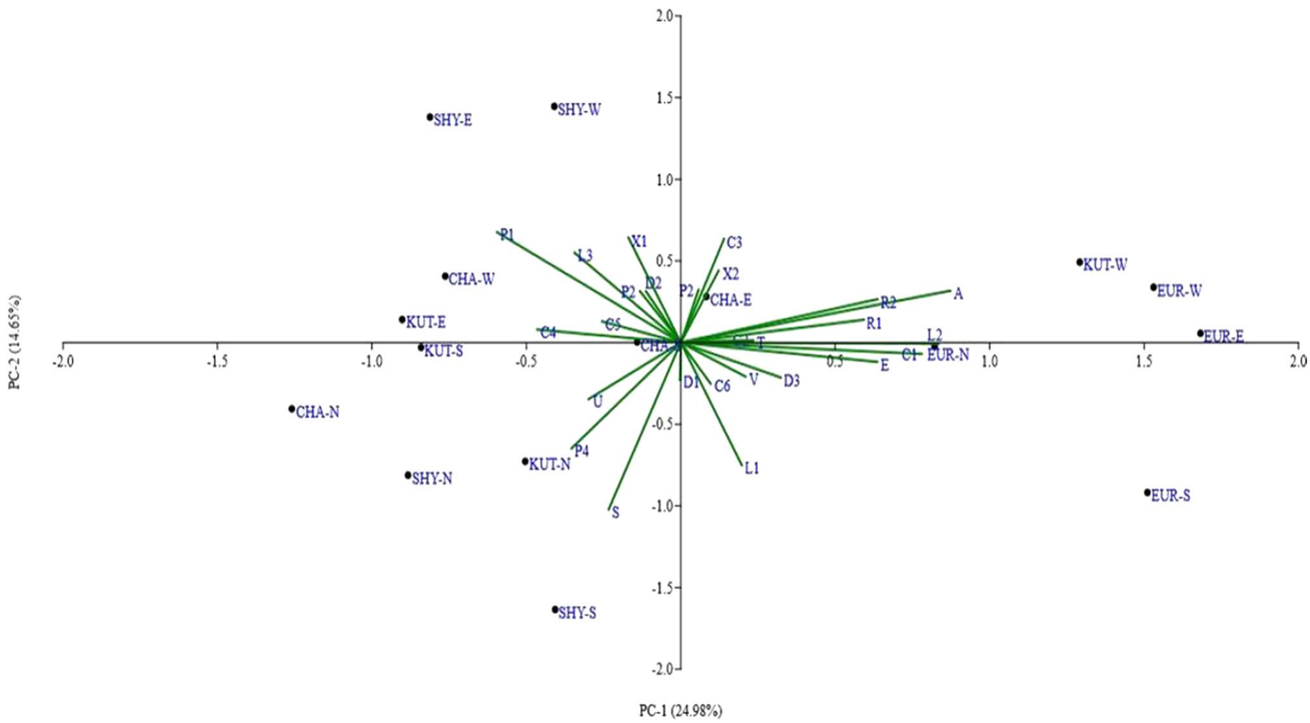

Fig. 5 Principal component analysis (PCA) for TR-II

In site-2 the PCA analysis grouped the species of the whole dataset into two main clusters of lichen species, with three species appearing as outliers (Fig. 5). The PCA loading of all species shows that PC-1 explained 23.98% and PC-2 explained 14.65% variability in lichen communities (Supplementary Table 7). The PCA biplot shows that species P1 (*Peltigera polydactylon*) followed by A (*Aspicilia calcarea*) and S (*Stereocaulon foliolosum*) were at the farthest distance from the main groups. Here these three outlier species are mainly considered the principal components. The principal components are basically those vectors that are not linearly correlated and have the most variance within the data. The main group comprised all 23 lichen species, which indicates the similarity between the species in their composition and distribution within site-2.

Discussion

Every taxon may not respond to climate change in a same way. A particular climatic condition may be quite favorable for some while at the same time it may be unsafe for others. If climate warming prevails and forces the species to shift upwards; the cold adapted species inhabiting the mountain summits will not get any further space to move upward and may be on the edge of disappearing in the near future. The temperature loving species may replace the cold adapted species and dominate the high mountain summits.

The present study provides baseline datasets regarding the diversity and distribution of lichens in different summits of the TRs. Though the lichen diversity was relatively low at the TRs (30), as compared to the alpine regions of the Munsiyari region of Pithoragarh district (232 species, Joshi 2010), this overall diversity at the GLORIA site is possibly due to the rocky substrates and poorly developed soils that are present at these sites. 12 species viz. *Cetraria islandica*, *Cladonia coccifera*, *Cladonia coniocraea, Cladonia pyxidata, Dimelaena oreina, Lecanora muralis*, *Lobaria retigera*, *Physcia caesia*, *Rhizocarpon geographicum*, *Rhizoplaca chrysoleuca*, *Thamnolia vermicularis* and *Xanthoria elegans* have already been included in the 402 lichen taxa of GLORIA database (as on 02/02/2021). The remaining 18 taxa in the present study are likely to be the first to be reported in a GLORIA Target Region.

At first glance, we cannot observe a clear pattern between species richness and altitudinal gradient at the total summit or exposure level (Table1) the role of aspect also seems to be negligible in the distribution of lichens (Fig. 4). But, besides altitude and aspect, substrate was found to play a major role in distribution of lichen species. Rock came out as an excellent host for lichen diversity. Summits having more rock cover revealed higher species richness than summits having more soil cover. All eight summits of both TRs being beyond the tree line were devoid of the woody substrate; although there were shrubs of *Juniperus communis* and *J. indica* in TR—II but they were devoid of lichens. Most of the species were growing under sunlight but *Thamnolia vermicularis* a medicinally important lichen taxon was found growing only under the boulders in the shady places in both the TRs and was found only on the highest summits of both the TRs.

In the 5 m and 10 m SASs of each aspect of the four summits of TR—I, *Aspicilia calcarea* and *Rhizoplaca chrysoleuca* showed common abundance (c); *Cladonia coccifera*, *Cladonia coniocraea*, *Lobaria retigera*, *Peltigera polydactylon*, *Rhizocarpon geographicum* and *Stereocaulon foliolosum* showed scattered abundance (s); *Caloplaca cinnabarina*, *Cladonia corniculata*, *Cladonia pyxidata*, *Cryptothecia lunulata*, *Dermatocarpon miniatum*, *Dimelaena oreina*, *Diploschistes scruposus*, *Lecanora indica*, *Lecanora muralis, Lepraria isidiata* and *Verrucaria acrotella* Showed rare abundance (r); *Dirinaria applanata* and *Xanthoparmelia mexicana* showed very rare abundance (r!) (Supplementary Table 4), while in TR—II *Aspicilia calcarea*, *Caloplaca cinnabarina* and *Cetraria islandica* showed scattered abundance (s); *Rhizocarpon geographicum* showed dominant abundance (d); *Caloplaca flavovirescens, Cladonia corniculata*, *C. pyxidata, Dimelaena oreina*, *Endocarpon pusillum*, *Lecanora indiaca*, *Peltigera polydactylon*, *Rhizoplaca chrysoleuca* and *Stereocaulon foliolosum* showed rare abundance (r); *Cryptothecia lunulata*, *Dermatocarpon miniatum*, *Diploschistes scruposus*, *Lecanora muralis*, *Lepraria isidiata*, *Physcia caesia*, *Pleopsidium flavum*, *Pyxine cocoes*, *Thamnolia vermicularis*, *Xanthoparmelia mexicana* and *Xanthoria elegans* showed very rare abundance (r!) (Supplementary Table 5).

Conclusion

No conclusive trends in species numbers were evident from our baseline data. However, the base line data sets recorded at the species level are of great significance for monitoring the climate change induced changes in species composition. Establishment of the IN-BYN and IN-CHU target regions provides baseline observations that will be important to document and assess the long-term vulnerability of high mountain ecosystems in the Indian Himalayan Region (IHR). These TRs will be monitored regularly at intervals of five years and the datasets would give information about the changes taking place in diversity and distribution of lichens, changes in community structure and the change in soil temperature over time. The datasets may help in understanding the response of lichens to climate change over time; revealing the lichen taxa or communities that are thriving and those are suffering under the influence of climate change. Monitoring for a considerable period of time may help in identifying the taxa that are suffering and are at the edge of extinction from the mountain summits so that steps can be taken for conservation of those taxa.

In addition, the datasets generated during this study will be submitted to the GLORIA network, so that they can be compared with the datasets from other parts of the globe and will help in understating the responses of lichen taxa to the changing climatic conditions in different geographical regions of the earth.

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Data availability All data of lichens based on the GLORIA sites that support the findings of this study are included within this paper and its Supplementary Information files.

Declarations

Conflict of interest The authors do not have any conflict of interest.

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