RESEARCH ARTICLE

Lichenometry to Predict the Age of Substratum at Indian Alpine Himalayan Area in Climate Change Perception

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Abstract

The growth of circular lichen thalli on permanent substrate is widely used to measure the age of exposure of the substratum for long periods of time. The measurement of lichen thallus diameter and its correlation with the age of the substratum by geographers has applications in pollution monitoring and climate change studies. In addition, frequency size investigation can provide minimum dates for constructions built of lichen-covered materials, like walls, iron poles, graveyard stones, and monuments. The lichenometry is able to measure the minimum age of substrata even in less than 500 years of exposure. We provide a comparative assessment of lichenometry in Indian Himalayan sites together with comparative global data. We document the growth rate of *Xanthoria elegans*, a native placoidiod lichen, at 0.108 to 0.225 mm per month from Jammu & Kashmir. The purpose of this communication is to present the current eminence of lichenometry studies in the area and their future prospect.

Keywords: Lichenometry, Marginal growth, Indirect and Direct measurement, Climate change.

Highlights

- The novelty of the present work is, to compile all the lichenometry data of the Indian Himalayas and their comparative assessment with world data.
- Advanced methods for lichenometry are delivered.
- A list of future lichenometric species is provided.
- Further to provide baseline data for prognostic analysis in terms of climate change scenario in the alpine areas of the Indian Himalayas.

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Introduction

Lichens have many characteristics by which they can be considered as one of the best materials for carrying out environmental pollution monitoring and climate change studies. Due to their higher sensitivity against microclimate changes, lichen communities very quickly predict the climate and environmental changes in a particular area within a short duration of one or two decades.

It is well known that future prognostications on global temperature suggest more rapid warming in three poles, basically Antarctica, the Arctic and the Himalayas. Therefore, it is expected that, the signals of global climate change can be more pronounced in these regions. The presence of lichens in the coldest regions and their sensitivity makes them unique and effective indicator communities among various plant groups. Certain ecological and physiological traits, a delicate symbiotic association between the lichen partners, increased metabolic rate especially when moist, the lack of vascular system, absence of root system and poikilohydric nature make them sensitive against environmental perturbation. The slow-growing nature, differential growth rates of various species and their longevity particularly suites them to be used for this purpose. Numerous studies world over have linked lichens to climate change and ecosystem health assessment. Further, lichens are also being utilized to determine the rate of retreat of glaciers and as an important indicator of change and fluctuation in alpine biodiversity through the network of long-term monitoring sites (Armstrong, 2015, 2016; Petersson *et al.* 2021, Winchester, 2023).

Conversely, lichenometry (lichen +metric) encompasses the application of lichen morphology dimensions to appraisal the minimum age of exposure of any substratum. Lichenometry is an extensively applied technique for dating the outward age of substrata and has countless solicitations over more than 70 years comprising the dating of rock faces, boulders, walls, monuments and some time to categorize the nature of forest (Armstrong, 2016; Petersson, *et al.* 2021). Diverse species exhibit numerous colonization-extinction dynamics and prospectively to exhibit long time lags before the establishment of a newly surfaces (Johansson, *et al.* 2013). However, lichen thalli inhabit newly exposed rock faces at altered times, depending particularly on the species and climate of the area. It is reported that the foliose species have little lifespans, conceivably a maximum of 150 years as well as squatter depending on the species and environment of the area (Armstrong and Bradwell, 2011). The crustose species are longer-lived, perhaps ~460 years in a temperate climate (Winchester 1984), ~680 years in the mountains (Larocque and

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Smith, 2004) and 1400–1500 years in the Arctic (Solomina and Calkin, 2003; Young, *et al*., 2009). Benedict (2009) recommended a practical limit at 4000 to 5000 years, but the older surfaces have the possibility of error like aged lichens are likely to have fused with conspecifics or pretentious by antagonism, weathering, microclimate or other environmental changes (Osborn, *et al*. 2015). Whereas in polar areas, thalli of rock-inhabiting lichens *Rhizocarpon* sps., necessary in several decades to inhabit over rock surface. Conversely, in sensible climates, the preliminary colonization times will range from numerous years to more than decades (Benedict, 2009; Hansen, 2010).

Moreover, the leisurely growth and unvarying growth dimension, facilitating in dating the acquaintance time of the rock establishing glacier moraines due to retreat of the glacier can provide the imprecise time of glacier retreat. Conversely, dimension of larger thallus specimens developing on big boulders which are imaginary to be unpretentious by predominant climatic circumstances as well as anthropogenic interventions. The largest lichen is assumed to be the oldest, and its known growth rate can estimate the age of exposure of the substrate. In this regard, the glaciers are documented amongst the most sensitive indicators of changing climate, evolving significantly through climate cooling and retreating during warming climate.

Previously, lichenometry has been widely used to date rock surfaces since its developed by Beschel (1950). However, the number and size of apothecia/perithecia, lobes, and diameter of primary and secondary thallus will be measured as morphologically may be more useful in the present scenario in assessment of changing climate. The lichenometry will be applied on lichen species extensively growing over soil, rock and bark. That is, there is no restriction on substratum as well as growth forms. Lichenometry is predominantly convenient in arctic-alpine environments beyond the tree line where some crustose lichens nurture very slowly and have great longevity (Armstrong, 2004), and somewhere the lack of appropriate organic materials make supplementary dating practices like dendrochronology as well as radiocarbon dating are less suitable.

The hypothesis of the present work is, to compile all the lichenometry data of the Indian Himalayas and their comparative assessment with world data. In this regard, the dimension of *Rhizocarpon geographicum* (crustose lichen) has a known growth rate which is designated to appraisal the age of exposed rocks in glaciers mount tops amongst 3500-4500 m altitude in the Indian Himalayan states of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. However, foliose lichen *Xanthoria elegans* was measured on the known age of substratum to observe the annual growth rate of the species. The further aim is to provide baseline data for prognostic analysis in terms of climate change scenarios in the alpine areas of the Indian Himalayas.

MATERIALS AND METHOD

Space Applications Centre (SAC-ISRO), Ahmedabad, India, has started a long-term monitoring network for climate change assessment around Indian Himalayan regions (IHRs) known as Himalayan Alpine Dynamics Research Initiative (HIMADRI) in the year 2013 and continued till 2022 equally as Studies on Harnessing REmote Sensing for EnvironmenT and CIImate (SHRESTI) agenda. In this agenda, lichens are included as a monitoring tool. To study the establishment and growth of lichen *R. geographicum* to date the exposure of rock facades, on which they found. The diameter of respective lichen thallii was analysed thru the vernier caliper (Fig. 1).

It is well known that the *R. geographicum* reveal a centrifugal slow growth at the rate of 0.2 mm/year (Hansen, 2008). Now in Jammu and Kashmir, the study was conducted in and around the Thajiwas Glacier area of Ganderbal district (N 34″16′25.09″ E 75°17′05.09″ altitude 3100 m). Thajiwas Glacier concealments is approximately 15 to 20 km^2 with numerous passages, shattered near Sonmarg via a wide-ranging glacial stream seriatim in the northern direction over a proglacial valley. A tramp of more than eight km from Sonmarg towards glacier was covered up to 3000 m. Another area was, Aparwat near the Gulmarg area of Baramulla District (N 34°01′53″ E 74°20′49″) was taken for the study. Whereas in Himachal Pradesh, the study area was Chansal Pass of Shimla District (N 31°13.280″ E 77°58.774″). In Uttarakhand, Kumaon Himalaya Pindari glacier area of Bageshwar district (N 30°15.30″ E 79°13′80.2″), Pakhwa (N30°07′36.34″ E79°58′53.15″) Tungnath in Garhwal Himalays (N30°29′20.23″ E79°13′01.24″) were selected for the study.

The eastern Himalayan regions have short elevation variations in both Thangu (N 27°53′54.4″ E 88°32′05.1″) and Gnathang area (N 27°17′40.3″ E 88° 49′57.9″) of Sikkim. Consequently, the dimensions of lichen thalli were documented at 500 m detachment along with three replicates amongst 3000-3500 m altitudinal range. The same was also measured in Arunachal Pradesh, Sela Pass (N 27°30′47.1″ E 92°05′45.0″), Tawang near PTSO lake (N27°38′14.3″, E91°51′35.6″) area.

Conversely, the measurement of *Xanthoria elegans* on the boundary wall (Cement plaster) of the office of the Chief Executive officer, Gulmarg (N34°03′17.03″, E74°24′00.56″ altitude

Fig. 1: Lichenometry **A**. *Rhizocarpon geographicum* **B**. *Xanthoria elegans* **C**. radial growth pattern of *Xanthoria elegans*

Table 1: Worldwide lichenometirc data including Indian studies

Locality, Country	*Area surveyed*	*Search area*	*Method*	*Lichen size range (mm)*	*References*
Antarctic	Former snow patch areas	13 sites	Size-frequency	2.5-28.5	Golledge et al. (2010)
Aparwat, Jammu & Kashmir, India	Exposed rocks slope	2 Km^2	Lichen Size-frequency	1.5-35.1	In this paper
Australia	Archaeological structures		Largest lichen	5.7-74.4	Müller (2005)
Austria	Talus slope	300 boulders	Mean 5 largest % cover	5.1-27.9	Sass (2010)
Bolivian Andes	15 glacier forelands	Blocks, 2678 lichens	Largest lichen	9.0-41.0	Rabatel et al. (2008)
Cascade, Range, USA	Glacier forelands	-	Largest lichen	11.8-50.0	O'Neal & Schoenenberger (2003)
Central Asia USSR	Seismic dislocations	-	Statistical mode		Smirnova & Nikonov (1990)
Chandrashila Uttarakhand, India	Exposed rocks slope	2 Km^2	Lichen Size-frequency	8.5-40.2	In this paper
Chanshal Pass, Himachal Pradesh, India	Exposed rocks slope	2 Km^2	Lichen Size-frequency	21.15-58.8	In this paper
Cumbria, England	Valley floor development	7 zones	Largest lichen	4.0 – 95.0	Harvey et al. (1984)
France	Flood event, 4 rivers	Blocks in riverbeds	Mean 5 largest Size-frequency	0.1-81.0	Gob et al. (2010)
Gulmarg, Baramulla, Jammu & Kashmir, India	Cement wall plaster (known date)	2x20 m	Lichen Size-frequency	2.4-35.1	In this paper
Iceland	Glacier forelands	30 m^2 / site	Largest lichen Size-frequency	19.0-95.0	Bradwell (2009)
Iceland	Rock Glacier	Entire surface	Size-frequency	5.0 to 80.0	Hamilton & Whalley (1995)
Iceland	Proglacial river terrace	Entire surface of each terrace	Mean 5 largest	14.3-67.4	Thompson & Jones (1986)
Lake District, England	Flood event	All deposit measured	Mean 5 largest	10.2-62.5	Johnson & Warburton (2002)
Montenegro	5 cirques	Sites 25 m long, 10 m wide	Mean 5 largest	67.5-142.3	Hughes (2010)
New Zealand	Glacier forelands	10 to 100 m^2	Largest lichen	-	Lowell et al. (2005)
New Zealand	Earthquake blocks rock fall event	-	Largest lichen	0.2-1.0	Bull & Brandon (1998)
Norway	16 glacier forelands	25x8 m/site	Largest lichen Mean 5 largest	14.0-158.0	Matthews (2005)
Norway	Talus slope	100 boulders, 25 sites	Largest lichen Size-frequency	16.6-37.2	McCarroll et al. (2001)
Norway	Lake shoreline	25 m sections 6 sites	Mean 5 largest	59.0-310.0	Matthews et al. (1986)+
Pakhwa, Uttarakhand. India	Exposed rocks slope	2 Km^2	Lichen Size-frequency	10.2-25.8	In this paper
Patagonian Andes	6 glacier forelands	Entire surface each moraine	Largest lichen Size-frequency	6.0-135.0	Garibotti & Villalba (2009)
Pindari, Uttarakhand, India	Glacier forelands	1 Km^2	Largest lichen Size-frequency	15.0-120.0	Joshi & Upreti 2010
Poland	Debris flow	-	Largest lichen	-	Jonasson et al. (1991)
Thangu, Sikkim, India	Exposed rocks slope		Lichen Size-frequency	28.5-53.1	Bajpai et al (2016)
Sweden	Raised beaches	All rocks and surfaces	Largest lichen	19.0-358.0	Broadbent & Bergqvist (1986)

Tawang, Arunachal Pradesh, India	Exposed rocks slope	2 Km^2	Lichen Size-frequency	2.5-51.5	In this paper
Thazwaj, Jammu & Kashmir, India	Glacier forelands	1 Km^2	Lichen Size-frequency	45.5-101.3	Bajpai et al (2016)
Vancouver sland, Canada	2 glacier forelands	-	Largest lichen Mean 5 larges	33.2-97.4	Lewis & Smith (2004)
Volcan Barú, Panama	Annual radial increase	-	Statistical mode	0.2-1.0	Zotz (2017)
New Zealand	slope	-	Largest lichen	21.0-40.0	Bull (2018)

2575mt) was recorded to know the annual growth of the species and will help in future studies. The sample measurement was done on 03 August 2021, and the wall was repaired on August 2014 means, the lichen thalli were colonized between August 2014 to August 2021, i.e., in about a 7-year time period (Fig. 2). Additionally, the meta-analysis of the global lichenometry data was also carried out to correlate the study together with our observations. The documentation and geotagging of other species found in India will be useful for further investigations in the near future for lichenometric purposes.

Results And Discussion

The lichens were surveyed from high alpine areas of Indian Himalayan states, particularly Arunachal Pradesh, Jammu & Kashmir, Himachal Pradesh, Sikkim and Uttarakhand, predominantly for lichenometric study. The diameters of *Rhizocarpon geographicum* at different locations in IHRs were analysed for accompanying initial lichenometric revisions in the area. The worldwide lichenometric data, along with Indian studies, are mentioned in Table 1. In most of the studies, lichen size frequency and largest lichen thallus measurements were applied to check the age of substratum exposure. In most of the studies, the lichen Size-frequency analysis and maximum thallus size are taken to know the age of the substratum. The size of crustose lichens thallus ranges between 0.1 to 358.0 in the world where as in India, it ranges between 1.5 to 120.0 mm.

In the Indian perspective, the diameter of *Rhizocarpon geographicum* thalli, was measured between altitudes of 2800-4500m at various localities of Indian Himalayan regions. However, a study is centered on lichen size/age relationship and lichen species population scattering. It is well known that the big specimens that grow on enormous boulders are imaginary to remain unpretentious through the predominant climatic circumstances as well as anthropogenic interventions. However, it is evident from the present observations Thangu and Kupup area of Sikkim exhibited a normal width range of 28.0-53.0 mm of diameter of thallus lengthwise a distance of 200 at 50 m between 2800 to 3000 m altitudes. The maximum average diameter (48–53 mm) was reported near 2800 m altitudes, i.e., away from the glacier; however, the diameter range 28 to 34.8 mm was found near the glacier (3000 m). The exposed boulder in Kupup and Thangu areas premeditated as 200 m retreated in 100 and 91 years, correspondingly (Bajpai *et al*. 2016).

However, in Thaji, was area of Jammu and Kashmir, the lichen thalli diameter at 2800 m was reported an average diameter of 101.3 mm, whereas 28 to 34.8 mm diameter was reported near the glacier at 3000 m. The observation showed that the retreat in Thajiwas glacier is calculated as 200 m in 279 years. Other localities of Jammu and Kashmir, like Aparwat and Gulmarg, also recorded the diameter as 1.5 to 35.1 and 2.5 to 35.0 mm, respectively, but the frequency of the *Rhizocarpon geographicum* was very low. A similar lichenometric study was earlier done in Uttarakhand and showed that the Pindari glacier retreated at the rate of 1000m in 575 to 600 years (Joshi and Upreti, 2010). Similarly, the establishment of lichen *Rhizocarpon geographicum* is diverse on altered type of rocks premeditated in the Gangotri Glacier area and a 6 to 9 m/year retreat of Chorabari Glacier in Uttarakhand was predicted (Gupta, *et al*. 2014, Mehta, *et*

Fig. 2: Measurement of lichen thallus *Xanthoria elegans* on boundary wall (cement plaster) of the office of Chief Executive officer, Gulmarg, Baramulla District, JandK (N34°03'17.03", E74°24'00.56" altitude 2575mt). **A. and B.** picture of boundary wall (35x4 m), **C and D.** small and large thallus size, **E-H**. Measuring diameter of thalli

al. 2014). Correspondingly, the current observations show the rate of retreat between the range of 18.5 to 20.0 mm/century in the north-western and Western Himalayas. Correspondingly, Tungnath in Garhwal and Pakhwa in Kumaon Himalaya also documented the morphometrics of *R. geographicum* as 8.5 to 40.2 and 10.2 to 25.8 mm, respectively. However, Chansal Pass area of Shimla district in Himachal Pradesh shows a larger thallus of *R. geographicum* as compared with other localities except for Jammu and Kashmir, ranging between 21.15 to 58.8 mm in diameter.

It is well documented that the macro-lichens are relatively fast developing and show a maximum radial growth of 6.5 mm per year as the maximum analyzed values, whereas microlichen *Rhizocarpon geographicum* showed an average growth rate of 12.00 mm per century (Hansen, 2008). Conversely, in the Indian context, *Rhizocarpon geographicum,* both in the eastern as well as in the western Himalayan region, revealed a normal growing rate of 18 ± 2 mm per century. However, the progressive development ranges between 0.1 to 358.0 mm was documented worldwide by several authors (Table 1).

The dissimilarity in growing rates of thallus, fundamentally depends on the environmental influences dominant in the areas. Sympathetically, environmental factors on lichen thallus development is essential in lichenometry for basically two reasons. Firstly, growth rates will analyzed over a comparatively few years, compared with the overall durability of lichens, to recognize how long-term change in climate may have affected radial growth rate under direct lichenometry. In contrast, to understand how local environmental fluctuations accompanying rock nature, aspect, slope, or type of substratum may have differentially affected growth on surfaces of both known and unknown age as in indirect lichenometry assessment (Armstrong, 2015). Similarly, increasing or decreasing radial growth rate largely depends on the site and consequently influences indirect lichenometry (Roof and Werner, 2011).

The majority of lichenometric studies involve a yellow-green crustose genus *Rhizocarpon*, which successfully grows over siliceous rock categories in arctic, subarctic, as well as alpine environments and can survive for as long as more than 10,000 years (Armstrong, 2015). However, forest fire and competition between several foliose growth forms of lichens make the technique less appropriate for forested terrain. The consistency of lichenometric dating will depend on the quality of the calibration curve, thallus size, nature and post-occupational history of the substratum, as well as the ability of the archaeologist to distinguish possible disturbance factors. Other than *Rhizocarpon geographicum,* several more lichens are required to be standardized according to their presence in the area in near future (Table 2). A total of 18 species of lichens were geotagged and widely found growing over Indian Himalayan regions will be useful for future assessment. There is a scope to standardize and identify another species for similar work in the near future.

However, the direct lichenometry and radio dating methods are well calisthenics by the researchers but the indirect lichenometry and annual radial observations are very rare. In this regard an attempt was made to check the annual growth rate of a foliose lichen *Xanthoria elegans*, luxuriantly growing on a known age of substratum. The lichen *X. elegans,* was growing on the cement plastered boundary wall (age known) of the office of the chief executive officer, Gulmarg, Baramulla district Jammu & Kashmir (N34°03'17.03", E74°24'00.56" altitude 2575 mt). The wall was renovated in the month of August 2014 as per office records. Since then, lichen colonization has started. After a gap of seven years, the locality was revisited on 03 August 2021 and measured the patches and the diameter of the lichen *Xanthoria elegans.* A total of 25 quadrates were measured and it found that the thallus size ranged between 2.4 to 35.1 mm, and the average diameter was 19.2 mm (Table 3, Fig. 2). The massive variation in size was observed, which may be due to substratum was newly constructed. The results indicated that the growth of *Xanthoria elegans* on cement plaster walls was at the rate of 1.3 to 2.7 mm per year or 0.108 to 0.225 mm per month (Table 3).

Directions For Future Research

The lichenometry can be applied for dating shrinking lake levels, treeline assessment, palaeofloods, archeological structures, rock falls, debris flows, landslides, glacial deposits, earthquakes, snow avalanching as well as magnitude of permafrost or tenacious snow cover studies. Moreover, the dating involves the dimension of complete lichen populations as well as size-frequency distributions, which will use to recognize deposits of different ages.

Earlier, four potential methods were applied in estimating the age of the largest thallus: (a) standardizing lichen thallus size in contradiction of surfaces of known age (indirect lichenometry) (b) by establishing a lichen growth rate curve from direct measurement (direct lichenometry) (c) expending radiocarbon (C^{14}) dating along with lichenometry (d) by measuring lichen growth rings/annual rings (Armstrong and Bradwell, 2015; Garnett and Bradwell, 2010). It is well known that cosmogenic dating, based on beryllium-10 (10Be), is useful for longer time frames and needs minimum ages of rocks exposure exceeding 1000 years (Ivy-Ochs and Kober, 2008). Whereas radiocarbon (^{14}C) dating of suppressed soil and trees underlying moraines has wide applicability, but organics in soil samples may be adulterated and provide dates that are too old (Matthews, 2005). It must be remembered that lichen thallus measurement provides minimum dates while ^{14}C dating provides maximum dates and there is a need for standardization due to atmospheric oscillations over a period (Jomelli, *et al*., 2006).

Diverse approaches have been used to estimate the growth of lichen in the arena contingent on growth form as well as substrata. Therefore, crustose and foliose growth forms of lichens are basically used in lichenometry, which demonstrates a flat and uniform dorsiventral thallus and comparable approaches can be applied to estimate their growth also (Armstrong and Bradwell, 2015).

Precise techniques also allow to measure of the foliose and fruticose lichen growth over comparatively short time intermissions such as weeks, months as well as years (Winchester, 2023). The technique involves the dimension of folios lichen thallus perimeter, whichever is the tip of a lobe or the edge of the hypothallus in various crustose lichen species, along with fixed markings on the rock. However, the dimensions can be analyzed over innumerable time spans, such as fifteen

Table 2: Common lichen taxa endorsed for lichenometry in India, will apply in near future

S. No.	*Lichen taxa (growth form)*	*Distribution (India)*	*Geotagging*	*Earlier report (diameter in mm) (reference)*
1	*Aspicilia calcarea* (L.) Sommerf. (Crustose)	Jammu & Kaashmir (2500-4500mt) Himachal Pradesh (2500-3500mt) Uttarkhand (3000-4500mt) Sikkim (3000-4000mt) Arunachal Pradesh (3000-4000mt) Darjeeling (2500-3000mt)	N34º02′45.86′′,E75o19′20.24′′,N34o02′43.18′′,E75o22′41.68′′,N34o01′33.74′′,E75o22′12.60′′,N33o05′03.16′′E75o34′09.22′′,N34o18′10.54′′E75o17′19.90′′,N34o15′51.43′′E74o34′30.07′′,N33o47′15.54′′E74o21′18.44′′,N34º11′07.81′′E75º13′26.74′′,N34º08′33.99′′E75º12′21.99′′,N34º1419.82′′E75º17′41.78′′,N34º14′09.71′′E75º19′41.80′′,N34º13′00.78′′E75º22′13.35′′,N34o00′50.55′′E74o20′03.78′′,N34o01′28.38′′E74o18′14.18′′,N34o02′14.81′′E74o20′04.14′′,N33o39′21.47′′E76o18′15.42′′,N33o28′50.70′′E76o21′38.79′′,N30o54′03.77′′E77o06′08.40′′,N32o01′41.51′′E77o21′06.94′′,N32o30′31.91′′E76o00′25.86′′,N32o32′20.45′′E76o02′37.13′′,N30o56′23.94′′E77o06′04.87′′,N31o03′49.88′′E77o08′14.18′′,N31o03′57.19′′E77o14′58.60′′,N31o14′04.84′′E77o56′49.14′′,N32o24′27.42′′E77o13′54.31′′,N32o11′28.76′′E76o35′37.80′′,N32o35′10.33′′E77o06′59.92′′,N32o39′39.01′′E77o12′39.70′′,N31o08′33.09′′E78o25′08.44′′,N30o15′34.61′′E79o59′55.80′′,N30o12′58.30′′E79o59′53.33′′,N30o29′32.77′′E79o12′53.46′′,N30o29′17.08′′E79o12′36.48′′,N30o58′40.21′′E79o01′33.77′′,N30o15′34.05′′E79o59′55.70′′,N30o55′43.42′′E79o04′40.77′′,N30o57′06.60′′E79o02′58.09′′,N30o32′26.65′′E80o03′55.29′′,N30o28′49.73′′E80o05′52.30′′,N30o43′31.29′′E79o36′23.98′′,N30o40′36.04′′E79o02′19.18′′,N27o43′12.42′′E91o49′42.73′′,N27o38′14.12′′E91o51′2644′′,N27o01′33.06′′E88o05′01.13′′,N27o01′31.46′′E88o04′27.07′′,N27o03′38.66′′E87o59′56.18′′,N25o21′49.23′′E93o27′27.42′′,N25o21′58.29′′ E93o26′57.18′′	2.4-23.0 (Winchester, 1984)
2	*Dimelaena oreina* (Ach.) Norm. (Crustose)	Jammu & Kashmir (1500-2500mt) Himachal Prdesh (1500-4000mt) Uttarkhand (2500-3500mt)	N33o10′38.06′′E75o35′39.29′′,N33o24′01.35′′E74o39′46.48′′,N33o42′53.03′′E75o07′43.51′′,N33o39′14.09′′E75o13′43.39′′,N34o30′51.50′′E74o26′14.25′′,N34o32′57.28′′E74o09′21.91′′,N33o05′03.16′′E75o34′09.22′′,N34o18′10.54′′E75o17′19.90′′,N31o38′47.80′′E78o15′51.12′′,N31o42′48.02′′E78o33′59.70′′,N32o18′13.23′′E77o08′08.83′′,N32o18′30.83′′E77o13′01.06′′,N31o05′31.31′′E77o16′15.83′′,N31o06′22.65′′,N32o24′27.42′′E77o13′54.31′′,N32o11′28.76′′E76o35′37.80′′,N32o09′55.31′′E76o46′00.05′′,E77o09′34.78′′,N31o07′24.61′′E77o13′17.79′′,N31o58′20.03′′E77o08′57.99′′,N32o29′38.17′′E77o19′47.78′′,N32o38′31.97′′E77o12′48.79′′,N32o40′57.52′′E77o01′51.96′′,N32o29′10.47′′E77o32′53.19′′,N31o59′10.17′′E77o08′39.50′′,N31o52′14.65′′E77o03′58.73′′,N31o46′02.76′′E76o54′50.60′′,N31o27′59.68′′E76o16′31.69′′,N29o38′16.06′′E79o51′09.50′′,N29o38′10.86′′E79o50′58.21′′,N29o31′37.68′′E79o45′10.56′′,N30o40′58.45′′E79o36′42.71′′,N30o41′48.32′′E79o35′08.27′′,N30o31′16.10′′E79o07′38.27′′,N30o31′19.47′′E79o07′44.48′′,N30o31′13.77′′E79o07′41.37′′,N31o07′07.52′′E78o21′07.17′′,N30o29′20.29′′E79o13′01.24′′,N30o29′23.18′′E79o13′02.09′′,N30o29′15.72′′E79o12′30.27′′, N29o31′57.64′′ E79o45′03.40′′, N30o27′36.65′′ E79o19′10.58′′	3.0-10.0 (Awasthi et al., 2005)
3	*Diploschistes scruposus* (Schreb.) Norm (Crustose)	Jammu & Kashmir (15000-3000mt) Himachal Pradesh (1500-2000mt) UttaraKhand, Sikkim (3500-4500mt) Darjeeling (2500-3000mt) Madhya Pradesh, Maharashtra, Meghalaya, TamilNadu	N33o48′20.81′′E74o17′29.02′′,N33o55′09.49′′E74o35′16.47′′,N34o11′08.26′′E74o20′5050′′,N31o58′21.35′′E76o52′30.05′′,N30o58′14.44′′E77o03′53.90′′,N30o58′03.32′′E77o06′06.40′′,N30o58′42.72′′E77o06′26.49′′,N30o57′007.36′′E77o06′41.59′′,N30o29′20.29′′E79o13′01.24′′,N30o29′23.18′′E79o13′02.09′′,N30o29′17.08′′E79o12′36.48′′,N30o58′40.21′′E79o01′33.77′′,N30o58′44.88′′E79o01′25.79′′,N30o03′34.32′′E80o11′13.41′′,N30o03′42.22′′E80o11′56.26′′,N31o09′49.64′′E78o25′44.49′′,N31o09′46.19′′E78o25′56.84′′,N31o09′17.52′′E78o25′29.36′′,N27o25′48.77′′E88o41′28.80′′,N27o25′08.41′′E88o40′31.47′′,N27o25′05.93′′E88o41′21.21′′,N27o17′56.73′′E88o49′09.99′′,N27o20′01.35′′E88o49′41.91′′,N27o53′11.13′′E88o33′17.61′′,N26o59′25.83′′E88o17′17.13′′,N26o59′37.12′′E88o18′07.78′′,N26o59′55.19′′E88o17′42.89′′,N27o01′33.06′′E88o05′01.13′′,N27o01′31.46′′E88o04′27.07′′,N27o02′11.25′′E88o04′27.99′′,N27o02′03.82′′E88o04′46.12′′	4.4-12.6 (Hale, 1973)

4	*Lecanora campestris* (Schaer.) Hue (Crustose)	Jammu & Kashmir, Himachal Pradesh, Uttarkhand, Dajeeling 2000-3000mt), other than IHRs Assam, Rajasthan, TamilNadu	N34o29′38.81′′E74o18′18.03′′,N34o30′51.50′′E74o26′14.25′′,N34o32′57.28′′E74o09′21.91′′,N33o05′03.16′′E75o34′09.22′′,N34o18′10.54′′E75o17′19.90′′,N34o15′51.43′′E74o34′30.07′′,N33o47′15.54′′E74o21′18.44′′,N30o56′37.59′′E77o06′03.94′′,N30o56′23.94′′E77o06′04.87′′,N31o03′49.88′′E77o08′14.18′′,N31o04′58.67′′E77o05′33.02′′,N31o09′46.19′′E78o25′56.84′′,N31o09′17.52′′E78o25′29.36′′,N30o44′46.96′′E79o29′26.00′′,N30o15′34.05′′E79o59′55.70′′,N30o55′43.42′′E79o04′40.77′′,N30o57′06.60′′E79o02′58.09′′,N30o32′26.65′′E80o03′55.29′′,N30o28′49.73′′E80o05′52.30′′,N30o31′59.61′′E80o02′18.57′′,N30o46′50.83′′E79o32′07.92′′,N30o48′27.22′′E79o30′03.78′′,N30o46′52.39′′E79o26′29.52′′,N30o43′44.31′′E79o36′25.30′′,N30o43′45.81′′E79o36′17.76′′, N30o43′31.48′′E79o04′38.61′′,N30o42′14.84′′E79o03′04.82′′,N26o59′55.19′′E88o17′42.89′′,N26o59′47.10′′E88o17′23.58′′,N26o59′40.58′′E88o17′06.94′′,N26o59′40.14′′E88o17′07.99′′,N27o02′50.16′′E88o06′32.05′′,N25o19′51.44′′E92o58′41.44′′,N25o28′43.01′′ E92o34′56.59′′	1.2–23.0 (Winchester, 1984)
5	*Lecanora muralis* (Schreb.) Rabenh.= *Protoparmeliopsis muralis* (Schreb.) M. Choisy (Crustose-placoid)	Jammu & Kashmir (2000-4000mt), Himachal Pradesh (2000-3500mt), Uttarakhand (3000-4500mt), Arunachal Pradesh (4000-4500mt)	N34o30′51.50′′E74o26′14.25′′,N34o32′57.28′′E74o09′21.91′′,N33o05′03.16′′E75o34′09.22′′,N34o18′10.54′′E75o17′19.90′′,N34o15′51.43′′E74o34′30.07′′,N33o42′2032′′E74o28′52.87′′,N34o02′42.75′′E74o23′13.40′′,N34o02′39.19′′E74o23′00.15′′,N34o02′31.02′′ E74o22′18.40′′,N33o47′15.54′′E74o21′18.44′′,N33o42′25.80′′E74o25′49.23′′,N34o24′11.84′′E74o58′27.52′′,N34o25′17.90′′E74o563′45.76′′,N34o22′15.84′′E75o02′53.48′′,N33o40′10.96′′E74o31′03.13′′,N33o44′30.65′′E74o25′28.92′′,N34o01′51.57′′E74o22′04.38′′,N34o01′40.006′′E74o21′45.08′′,N34o01′38.62′′E74o21′45.80′′ N34o30′50.58′′E74o17′51.27′′,N34o28′09.28′′E74o57′53.19′′, N34o26′38.73′′E74o57′18.29′′,N34o22′02.31′′E75o05′23.44′′,N34o15′30.46′′E75o16′24.11′′,N34o00′50.55′′E74o20′03.78′′,N34o01′28.38′′E74o18′14.18′′,N34o02′14.81′′E74o20′04.14′′,N33o39′21.47′′E76o18′15.42′′,N34o1419.82′′E75o17′41.78′′,N34o14′09.71′′ E75o19′41.80′′, N34o13′00.78′′ E75o22′13.35′′, N34o14′05.37′′ E75o17′43.89′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N34o01′03.64′′ E74o19′34.92′′, N33o45′14.51′′ E77o17′44.40′′, N33o51′10.89′′E77o38′53.64′′,N30o53′14.09′′ E77o05′27.70′′, N30o54′03.77′′E77o06′08.40′′, N32o01′41.51′′ E77o21′06.94′′,N32o01′37.21′′ E77o21′09.85′′, N31o09′51.94′′ E77o45′19.78′′, N32o05′49.34′′ E76o31′35.27′′, N32o01′07.51′′ E76o50′32.88′′, N31o06′41.58′′ E77o10′18.04′′, N31o06′22.65′′ E77o09′34.78′′, N31o07′24.61′′ E77o13′17.79′′, N31o03′57.19′′ E77o14′58.60′′, N31o14′04.84′′ E77o56′49.14′′, N31o37′24.63′′ E78o27′33.64′′, N32o24′27.42′′ E77o13′54.31′′, N32o11′28.76′′ E76o35′37.80′′, N32o21′11.41′′ E77o05′43.86′′, N32o11′14.38′′ E77o18′16.08′′, N32o28′47.74′′ E77o08′27.75′′, N32o19′55.24′′ E77o21′19.91′′, N32o29′10.47′′ E77o32′53.19′′, N32o45′19.55′′ E77o09′49.09′′,N30o40′58.45′′ E79o36′42.71′′, N30o41′48.32′′ E79o35′08.27′′, N30o31′16.10′′ E79o07′38.27′′, N30o31′19.47′′ E79o07′44.48′′, N27o37′16.20′′ E91o51′49.31′′ N27o38′14.37′′ E91o51′36.61′′, N27o30′15.40′′ E92o05′57.30′′, N31o07′07.52′′ E78o21′07.17′′, N30o29′20.29′′ E79o13′01.24′′, N30o29′23.18′′ E79o13′02.09′′, N30o29′15.72′′ E79o12′30.27′′, N30o58′41.60′′ E79o01′35.16′′, N30o03′36.53′′ E80o11′50.66′′, N30o03′28.40′′ E80o11′21.92′′, N30o45′41.31′′ E79o29′53.30′′, N30o46′32.60′′ E79o28′26.12′′, N30o42′33.22′′ E79o35′39.86′′, N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′ E79o12′53.46′′, N30o29′17.08′′ E79o12′36.48′′, N30o58′40.21′′ E79o01′33.77′′, N30o58′44.88′′ E79o01′25.79′′, N30o03′34.32′′ E80o11′13.41′′, N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N31o09′46.19′′ E78o25′56.84′′, N31o09′17.52′′ E78o25′29.36′′, N30o57′06.60′′ E79o02′58.09′′, N30o32′26.65′′ E80o03′55.29′′, N30o28′49.73′′ E80o05′52.30′′	13.0-30.0 (Hakulinen, 1966) 21.4-35.4 (Winchester, 1984)
6	*Lecidea atrobrunnea* (Ram. ex Lam.	HP (2000-4500mt)	N32o01′07.51′′E76o50′32.88′′, N32o03′16.86′′ E76o45′004.11′′, N32o06′38.57′′ E77o10′58.76′′, N32o14′20.12′′ E77o13′06.80′′, N32o14′51.43′′ E77o09′39.91′′, N32o15′48.53′′ E77o09′48.69′′,	(Leonard and Rosentreter, 1994)

	andDC.) Schaer. (Crustose)		N32o02′27.96′′ E76o52′19.14′′, N31o04′51.25′′ E77o18′13.36′′, N31o05′01.76′′ E77o16′57.66′′, N31o06′07.40′′ E77o15′25.22′′, N32o21′23.60′′ E77o09′02.93′′, N32o23′34.26′′ E77o15′54.25′′, N32o26′11.04′′ E77o10′03.82′′, N32o24′27.42′′ E77o13′54.31′′, N32o35′10.33′′ E77o06′59.92′′, N32o39′39.01′′ E77o12′39.70′′, N32o36′12.35′′	8.8-18.9 (Hansen, 2008)
7	*Lobothallia alphoplaca* (Wahlenb. ex Ach.) Hafellner (Crustose-placoid)	Himachal Pradesh (3000-4500mt), Jammu and Kashmir (3500-4500mt) Darjeeling (2500-3000mt)	N34o21′57.78′′ E73o56′44.28′′, N34o28′09.28′′ E74o57′53.19′′, N34o26′38.73′′ E74o57′18.29′′, N34o22′02.31′′ E75o05′23.44′′, N33o28′50.70′′ E76o21′38.79′′, N34o10′13.09′′ E75o50′57.10′′, N34o49′11.20′′ E77o47′35.61′′, N34o57′11.72′′ E76o43′23.39′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N34o01′03.64′′ E74o19′34.92′′, N33o45′14.51′′ E77o17′44.40′′, N 31o13′47.9′′, E 77o57′30.7′′, N 31o13′17.3′′, E 77o58′28.6′′, N312o14′10.07′′ E77o57′17.51′′, N31o10′06.18′′ E77o50′24.11′′, N32o18′37.75′′ E77o21′46.83′′, N32o21′11.62′′ E77o08′56.34′′, N31o38′47.80′′ E78o15′51.12′′, N32o39′41.75′′ E77o28′21.40′′, N32o40′58.30′′ E76o44′43.30′′, N32o21′23.52′′ E77o15′08.35′′, N32o21′32.42′′ E77o13′11.19′′, N32o22′28.04′′ E77o14′02.70′′, N26o59′47.10′′ E88o17′23.58′′, N26o59′40.58′′ E88o17′06.94′′,	9.5–14.0 (Frey 1959)
8	*Physcia aipolia* (Ehrh. Ex Humb.) Fürnr. (Foliose)	Jammu & Kashmir (1500-2500mt) Himachal Pradesh (1500-2000mt),other than IHRs Karnataka and TamilNadu	N34o10′43.77′′ E74o21′42.52′′, N34o11′46.41′′ E74o18′50.25′′, N34o13′28.19′′ E74o19′46.90′′, N34o14′14.37′′ E74o19′05.33′′, N33o09′41.07′′ E75o33′28.81′′, N33o10′38.06′′ E75o35′39.29′′, N33o24′01.35′′ E74o39′46.48′′, N33o42′53.03′′ E75o07′43.51′′, N33o39′14.09′′ E75o13′43.39′′, N33o45′48.10′′ E75o14′27.42′′, N33o48′20.81′′ E74o17′29.02′′, N33o55′09.49′′ E74o35′16.47′′, N34o11′08.26′′ E74o20′5050′′, N31o57′15.30′′ E77o08′36.68′′, N31o58′20.03′′ E77o08′57.99′′, N31o59′10.17′′ E77o08′39.50′′, N31o52′14.65′′ E77o03′58.73′′, N23o30′35.24′′ E92o59′55.62′′, N23o39′31.84′′ E93o15′56.23′′	13.0-28.4 (Hakulinen, 1966) 4.5-20.6 (Porter, 1927)
9	*Physcia caesia* (Hoffm.) Fürnr. (Foliose)	Jammu & Kashmir (1500-3500mt), Himachal Pradesh (2000-2500mt), Uttarkhand (3000-4000mt), Sikkim (1500-2500mt)), other than IHRs Manipur, Nagaland, Rajasthan	N34o14′14.37′′ E74o19′05.33′′, N33o09′41.07′′ E75o33′28.81′′, N33o10′38.06′′ E75o35′39.29′′, N33o49′29.61′′ E75o21′14.51′′, N33o50′07.95′′ E75o20′50.86′′, N33o51′55.73′′ E75o18′51.75′′, N33o50′37.83′′ E75o21′19.83′′, N34o00′22.00′′ E75o19′31.47′′, N34o29′38.81′′ E74o18′18.03′′, N33o24′01.35′′ E74o39′46.48′′, N33o42′53.03′′ E75o07′43.51′′, N33o39′14.09′′ E75o13′43.39′′, N33o45′48.10′′ E75o14′27.42′′, N33o48′20.81′′ E74o17′29.02′′, N33o55′09.49′′ E74o35′16.47′′, N34o11′08.26′′ E74o20′5050′′, N31o04′51.25′′ E77o18′13.36′′, N31o05′01.76′′ E77o16′57.66′′, N31o06′07.40′′ E77o15′25.22′′, N31o03′57.19′′ E77o14′58.60′′, N31o14′04.84′′ E77o56′49.14′′, N30o31′19.47′′ E79o07′44.48′′, N30o31′13.77′′ E79o07′41.37′′, N30o38′56.26′′ E79o01′49.20′′, N30o38′29.63′′ E79o01′56.73′′, N30o29′20.29′′ E79o13′01.24′′, N30o29′23.18′′ E79o13′02.09′′, N30o29′15.72′′ E79o12′30.27′′, N3 0o58′41.60′′E79o01′35.16′′,N30o46′52.39′′E79o26′29.52′′,N30o43′ 44.31′′E79o36′25.30′′,N30o43′45.81′′E79o36′17.76′′,N30o43′31.48′ ′E79o04′38.61′′,N30o15′34.05′′E79o59′55.70′′,N30o55′43.42′′E79o 04′40.77′′,N30o57′06.60′′E79o02′58.09′′,N30o32′26.65′′E80o03′55 .29′′,N27o09′53.66′′E88o21′48.14′′,N27o21′08.39′′E88o40′07.27′′, N27o20′03.58′′ E88o30′57.80′′, N27o20′46.03′′ E88o37′53.75′′, N27o14′05.00′′ E88o34′09.27′′, N27o14′21.70′′ E88o34′05.85′′, N27o14′00.33′′ E88o33′36.45′′,	9.8–22.7 (Hakulinen, 1966)
10	*Physcia dubia* (Hoffm.) Lettau (Foliose)	Jammu & Kashmir (2500-3000mt), Himachal Pradesh (2000-2500mt), Uttarakhand (3500-4000mt)	N34o02′45.86′′ E75o19′20.24′′, N34o02′43.18′′ E75o22′41.68′′, N34o01′33.74′′ E75o22′12.60′′, N34o12′16.99′′ E74o08′39.43′′, N34o13′12.63′′ E74o09′49.72′′, N34o18′03.36′′ E74o08′07.35′′, N34o13′55.80′′ E75o04′20.90′′, N34o08′19.95′′ E75o14′48.84′′, N34o19′32.25′′ E74o58′30.28′′, N33o43′57.52′′ E74o25′52.01′′, N33o42′2032′′ E74o28′52.87′′, N34o02′42.75′′ E74o23′13.40′′, N34o02′39.19′′ E74o23′00.15′′, N34o02′31.02′′ E74o22′18.40′′, N34o01′06.39′′ E74o23′36.83′′, N30o56′37.59′′ E77o06′03.94′′, N30o56′23.94′′ E77o06′04.87′′, N31o03′49.88′′ E77o08′14.18′′, N31o04′58.67′′ E77o05′33.02′′, N31o06′41.58′′ E77o10′18.04′′, N31o08′33.09′′ E78o25′08.44′′, N30o15′34.61′′ E79o59′55.80′′, N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′ E79o12′53.46′′,	2.2-25.0 (Degelius, 1964)

			N30o29′17.08′′ E79o12′36.48′′, N30o57′06.60′′ E79o02′58.09′′, N30o32′26.65′′ E80o03′55.29′′, N30o28′49.73′′ E80o05′52.30′′, N30o31′59.61′′ E80o02′18.57′′, N30o27′15.62′′ E80o11′49.28′′, N30o28′26.65′′ E80o11′30.32′′, N30o27′22.62′′ E79o51′26.59′′, N30o25′16.88′′ E79o56′33.96′′, N31o09′51.79′′ E78o25′44.83′′, N30o58′40.21′′ E79o01′33.77′′, N30o58′44.88′′ E79o01′25.79′′, N30o03′34.32′′ E80o11′13.41′′, N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N31o09′46.19′′ E78o25′56.84′′, N31o09′17.52′′ E78o25′29.36′′, N30o44′46.96′′ E79o29′26.00′′, N30o46′50.83′′ E79o32′07.92′′,	
11	*Porpidia macrocarpa* (DC) Hertel & A.J.Schwab (Crustose)	Jammu & Kashmir, Himachal Pradesh (2000-4500mt), Uttarakhand & Sikkim (3500-4500mt)	N34o13′55.80′′ E75o04′20.90′′, N34o08′19.95′′ E75o14′48.84′′, N34o19′32.25′′ E74o58′30.28′′, N33o43′57.52′′ E74o25′52.01′′, N33o42′2032′′ E74o28′52.87′′, N34o06′03.61′′ E75o26′01.40′′, N34o07′26.47′′ E75o15′23.92′′, N34o14′20.75′′ E74o03′53.96′′, N34o14′11.10′′ E74o05′31.61′′, N34o15′07.21′′ E74o07′08.48′′, N34o08′41.68′′ E75o18′02.95′′, N34o14′01.40′′ E74o01′33.16′′, N34o15′15.41′′ E74o01′55.71′′, N34o21′57.78′′ E73o56′44.28′′, N34o28′09.28′′ E74o57′53.19′′, N34o26′38.73′′ E74o57′18.29′′, N34o22′02.31′′	8.0–16.6 (Winchester, 1984)
12	*Rhizocarpon geographicum* (L.) DC. (Crustose)	Jammu & Kashmir Himachal Pradesh, Uttarkhand (3000-4500mt), Sikkim, Arunachal Pradesh (3500-4500mt)	N34o13′55.80′′ E75o04′20.90′′, N34o08′19.95′′ E75o14′48.84′′, N34o19′32.25′′ E74o58′30.28′′, N33o43′57.52′′ E74o25′52.01′′, N33o42′2032′′E74o28′52.87′′,N34o25′17.90′′E74o563′45.76′′,N34o22′15.84′′E75o02′53.48′′,N33o40′10.96′′E74o31′03.13′′,N33o44′30.65′′E74o25′28.92′′,N34o01′51.57′′E74o22′04.38′′,N34o01′40.006′′E74o21′45.08′′,N34o01′38.62′′E74o21′45.80′′N34o02′42.75′′E74o23′13.40′′,N34o02′39.19′′E74o23′00.15′′, N34o02′31.02′′ E74o22′18.40′′, N34o01′06.39′′ E74o23′36.83′′, N34o28′09.28′′ E74o57′53.19′′, N34o26′38.73′′ E74o57′18.29′′, N34o22′02.31′′ E75o05′23.44′′, N34o15′30.46′′ E75o16′24.11′′, N34o00′50.55′′ E74o20′03.78′′, N34o01′28.38′′ E74o18′14.18′′, N34o02′14.81′′ E74o20′04.14′′, N33o39′21.47′′ E76o18′15.42′′, N34o1419.82′′ E75o17′41.78′′, N34o14′09.71′′ E75o19′41.80′′, N34o13′00.78′′ E75o22′13.35′′, N34o14′05.37′′ E75o17′43.89′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N34o01′03.64′′ E74o19′34.92′′, N33o45′14.51′′ E77o17′44.40′′, N33o51′10.89′′ E77o38′53.64′′,N31o13′43.7”,E77o57′08.3”,N31o13′47.9”,E77o57′30.7”,N31o13′17.3”,E77o58′28.6”,N32o35′10.33′′E77o06′59.92′′,N32o39′39.01′′E77o12′39.70′′,N32o36′12.35′′E77o17′43.09′′, N31o39′00.77′′ E78o12′42.96′′, N31o51′20.74′′ E77o52′02.21′′, N31o28′57.77′′E78o37′23.86′′,N31o17′03.70′′E78o35′22.00′′,N32o38′54.31′′E76o17′29.33′′,N32o41′02.43′′E76o17′45.83′′,N32o31′19.94′′E76o26′44.32′′,N32o16′23.14′′E77o08′13.95′′,N32o17′27.33′′E776o07′48.01′′,N30o29′20.29′′E79o13′01.24′′,N30o29′23.18′′E79o13′02.09′′,N30o29′15.72′′E79o12′30.27′′,N30o58′41.60′′E79o01′35.16′′,N30o03′36.53′′E80o11′50.66′′,N31o08′33.09′′E78o25′08.44′′,N30o15′34.61′′E79o59′55.80′′,N30o12′58.30′′E79o59′53.33′′,N30o29′32.77′′E79o12′53.46′′,N30o29′17.08′′E79o12′36.48′′,N30o58′40.21′′E79o01′33.77′′,N30o58′44.88′′E79o01′25.79′′,N30o03′34.32′′E80o11′13.41′′,N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N30o27′15.62′′ E80o11′49.28′′, N30o28′26.65′′ E80o11′30.32′′, N30o27′22.62′′ E79o51′26.59′′, N30o25′16.88′′ E79o56′33.96′′, N31o09′51.79′′ E78o25′44.83′′, N30o43′24.72′′ E79o36′23.02′′, N30o44′33.10′′ E79o03′06.26′′, N30o44′39.74′′ E79o03′40.39′′, N30o24′03.66′′ E79o52′01.02′′, N30o15′38.21′′ E79o47′18.33′′, N30o24′59.93′′ E79o47′50.61′′, N27o19′02.35′′ E88o50′40.82′′, N27o20′28.61′′ E88o49′52.67′′, N27o22′14.27′′ E88o46′21.59′′, N27o22′12.48′′ E88o46′38.58′′, N27o21′55.04′′ E88o47′09.67′′, N27o53′11.13′′ E88o33′17.61′′, N27o53′22.29′′ E88o31′44.41′′, N27o54′39.80′′ E88o31′44.09′′, N27o56′01.62′′ E88o34′07.51′′,N27o56′17.90′′ E88o30′20.91′′, N27o39′37.00′′ E91o51′31.61′′, N27o44′21.49′′ E91o48′28.72′′	1.0–21.5 (Leonard and Rosentreter, 1994) 2.0-15.6 (Hansen, 2008); 2.8-10.8 (Chaujar, 2006) 15.0-120.0 (Joshi & Upreti 2010)
13	*Rhizoplaca chrysoleuca* (Sm.) Zopf (Foliose)	Jammu & Kashmir (1500-4500mt), Himachal Pradesh	N34o10′43.77′′ E74o21′42.52′′, N34o11′46.41′′ E74o18′50.25′′, N34o13′28.19′′ E74o19′46.90′′, N34o14′14.37′′ E74o19′05.33′′, N33o09′41.07′′E75o33′28.81′′,N34o18′03.36′′E74o08′07.35′′,N34o13′5	3.2–8.9 (Kevin et al., 2004)

		(3000-4500mt), Uttarkhand (2500-4500mt), Sikkim and Arunachal Pradesh (3500-4500mt)	5.80′′E75o04′20.90′′,N34o08′19.95′′E75o14′48.84′′,N34o19′32.25′′ E74o58′30.28′′,N34o15′07.21′′E74o07′08.48′′,N34o24′11.84′′E74o58′27.52′′,N34o25′17.90′′E74o563′45.76′′,N34o22′15.84′′E75o02′53.48′′,N34o28′09.28′′E74o57′53.19′′, N34o26′38.73′′ E74o57′18.29′′, N34o22′02.31′′ E75o05′23.44′′, N34o15′30.46′′ E75o16′24.11′′, N34o00′50.55′′ E74o20′03.78′′, N34o01′28.38′′ E74o18′14.18′′, N34o02′14.81′′ E74o20′04.14′′, N33o39′21.47′′ E76o18′15.42′′, N33o28′50.70′′ E76o21′38.79′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N34o01′03.64′′ E74o19′34.92′′, N33o45′14.51′′ E77o17′44.40′′, N33o51′10.89′′ E77o38′53.64′′, N33o59′18.78′′ E78o03′28.32′′, N33o51′50.07′′ E77o19′33.53′′, N31o37′24.63′′ E78o27′33.64′′, N31o28′41.04′′ E78o32′02.01′′, N32o24′27.42′′ E77o13′54.31′′, N32o11′28.76′′ E76o35′37.80′′, N32o18′37.75′′ E77o21′46.83′′, N32o21′11.62′′ E77o08′56.34′′, N31o38′47.80′′ E78o15′51.12′′, N31o42′48.02′′ E78o33′59.70′′, N 31o12′51.5′′, E 77o59′21.1′′, N32o391′01.78′′ E76o31′16.19′′, N32o39′56.76′′ E76o36′44.80′′, N32o34′03.89′′ E76o36′08.81′′, N31o39′00.77′′ E78o12′42.96′′, N31o51′20.74′′ E77o52′02.21′′, N31o28′57.77′′ E78o37′23.86′′, N31o17′03.70′′ E78o35′22.00′′, N31o07′07.52′′ E78o21′07.17′′, N30o29′20.29′′ E79o13′01.24′′, N30o29′23.18′′ E79o13′02.09′′, N30o29′15.72′′ E79o12′30.27′′, N30o58′41.60′′ E79o01′35.16′′, N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′ E79o12′53.46′′, N30o29′17.08′′ E79o12′36.48′′, N30o58′40.21′′ E79o01′33.77′′, N30o58′44.88′′ E79o01′25.79′′, N30o03′34.32′′ E80o11′13.41′′, N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N31o09′46.19′′ E78o25′56.84′′, N31o09′17.52′′ E78o25′29.36′′, N30o15′34.05′′ E79o59′55.70′′, N30o55′43.42′′ E79o04′40.77′′, N30o57′06.60′′ E79o02′58.09′′, N30o32′26.65′′ E80o03′55.29′′, N30o28′49.73′′ E80o05′52.30′′, N30o31′59.61′′ E80o02′18.57′′, N30o27′15.62′′ E80o11′49.28′′, N30o28′26.65′′ E80o11′30.32′′, N30o27′22.62′′ E79o51′26.59′′, N30o25′16.88′′ E79o56′33.96′′, N31o09′51.79′′ E78o25′44.83′′, N30o43′24.72′′ E79o36′23.02′′, N30o44′33.10′′ E79o03′06.26′′, N30o44′39.74′′ E79o03′40.39′′, N30o24′03.66′′ E79o52′01.02′′, N30o03′36.53′′ E80o11′50.66′′, N30o03′28.40′′ E80o11′21.92′′, N30o45′41.31′′ E79o29′53.30′′, N30o46′32.60′′ E79o28′26.12′′, N27o18′59.03′′ E88o50′12.62′′, N27o19′58.83′′ E88o49′39.90′′, N27o19′58.55′′ E88o50′04.12′′, N27o20′01.35′′ E88o49′41.91′′, N27o19′02.35′′ E88o50′40.82′′,N27o20′28.61′′ E88o49′52.67′′,N27o22′14.27′′E88o46′21.59′′,N27o22′12.48′′E88o46′38.58′′,N27o25′08.41′′E88o40′31.47′′,N27o25′05.93′′E88o41′21.21′′,N27o25′38.36′′E88o41′28.84′′,N27o24′11.84′′E88o42′06.30′′,N27o39′37.00′′E91o51′31.61′′,N27o44′21.49′′E91o48′28.72′′,N27o37′16.20′′E91o51′49.31′′,N27o38′14.37′′E91o51′36.61′′	
14	*Umbilicaria cylindrica* (L.) Delise (Foliose)	Sikkim (3500-4000mt) Darjeeling (2500-3000mt)	N27o41′06.59′′ E88o44′00.72′′, N27o42′58.20′′ E88o45′18.66′′, N27o48′39.50′′ E88o42′37.93′′, N27o17′43.03′′ E88o49′57.90′′, N27o17′26.00′′ E88o50′02.87′′, N27o17′56.73′′ E88o49′09.99′′, N27o17′26.79′′ E88o48′57.89′′, N27o17′56.69′′ E88o50′59.42′′, N27o47′35.01′′ E88o42′40.19′′, N27o10′16.36′′ E88o01′19.75′′, N27o10′13.38′′ E88o01′08.28′′	1.0–4.0 (Frey, 1959)
15	*Umbilicaria virginis* Schaer. (Foliose)	Jammu & Kashmir, Himachal Pradesh, Uttarkhand (3500-4500mt), Sikkim (3500-4000mt)	N34o26′38.73′′ E74o57′18.29′′, N34o22′02.31′′ E75o05′23.44′′, N33o39′21.47′′ E76o18′15.42′′, N33o28′50.70′′ E76o21′38.79′′, N34o10′13.09′′ E75o50′57.10′′, N34o49′11.20′′ E77o47′35.61′′, N34o1419.82′′ E75o17′41.78′′, N34o14′09.71′′ E75o19′41.80′′, N34o13′00.78′′ E75o22′13.35′′, N34o14′05.37′′ E75o17′43.89′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N32o11′28.76′′ E76o35′37.80′′, N32o09′55.31′′ E76o46′00.05′′, N32o07′26.76′′ E76o52′58.49′′, N32o32′20.17′′E77o026′14.54′′, N32o29′38.17′′ E77o19′47.78′′, N32o38′31.97′′ E77o12′48.79′′, N32o40′57.52′′ E77o01′51.96′′, N32o29′10.47′′ E77o32′53.19′′, N 31o12′51.5′′, E 77o59′21.1′′, N32o391′01.78′′ E76o31′16.19′′, N30o43′26.67′′ E79o35′55.51′′, N30o43′35.20′′ E79o36′19.03′′, N30o41′40.97′′ E79o33′17.71′′, N30o43′31.29′′ E79o36′23.98′′, N31o08′33.09′′ E78o25′08.44′′, N30o15′34.61′′ E79o59′55.80′′,	3.0–10.5 (Hansen, 2008)

			N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′ E79o12′53.46′′, N30o29′17.08′′ E79o12′36.48′′, N30o58′40.21′′ E79o01′33.77′′, N30o58′44.88′′ E79o01′25.79′′, N30o03′34.32′′ E80o11′13.41′′, N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N31o09′46.19′′ E78o25′56.84′′, N30o15′34.05′′ E79o59′55.70′′, N30o55′43.42′′ E79o04′40.77′′, N30o57′06.60′′ E79o02′58.09′′, N30o32′26.65′′ E80o03′55.29′′,N30o28′49.73′′ E80o05′52.30′′, N27o17′56.69′′ E88o50′59.42′′, N27o17′45.62′′ E88o51′26.25′′, N27o19′02.35′′ E88o50′40.82′′, N27o20′28.61′′ E88o49′52.67′′	
16	*Xanthoparmelia conspersa* (Ach.) Hale (Foliose)	Jammu & Kashmir (3500-4000mt), Himachal Pradesh, Uttarkhand (3000-3500mt), other than IHRs Rajasthan	N34o00′50.55′′E74o20′03.78′′,N34o01′28.38′′E74o18′14.18′′,N34o02′14.81′′E74o20′04.14′′,N33o39′21.47′′E76o18′15.42′′,N31o19′40.95′′E78o00′07.16′′,N31o20′36.13′′E77o58′48.62′′,N31o22′18.80′′E78o02′30.58′′,N31o07′07.52′′E78o21′07.17′′,N30o29′20.29′′E79o13′01.24′′, N30o29′23.18′′ E79o13′02.09′′, N31o08′33.09′′ E78o25′08.44′′, N30o15′34.61′′ E79o59′55.80′′, N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′ E79o12′53.46′′, N30o29′17.08′′ E79o12′36.48′′, N30o58′40.21′′ E79o01′33.77′′, N30o29′15.72′′ E79o12′30.27′′, N30o58′41.60′′ E79o01′35.16′′, N30o03′36.53′′ E80o11′50.66′′	5.5–49.5 (Armstrong, 2005) 1.5-76.0 (Hale, 1973) 10.6-32.8 (Lawrey and Hale, 1977) 2.7-38.4 (Jones and Platt, 1969)
17	*Xanthoria elegans* (Link.) Th. Fr. (Foliose)	Jammu & Kashmir, Himachal Pradesh, Uttarakhand (3000-4500mt)	N31o03′57.19′′E77o14′58.60′′,N31o14′04.84′′E77o56′49.14′′,N31o37′24.63′′E78o27′33.64′′,N31o19′40.95′′E78o00′07.16′′,N31o20′36.13′′E77o58′48.62′′,N31o22′18.80′′E78o02′30.58′′,N32o20′19.87′′E77o12′58.59′′,N32o32′20.17′′E77o026′14.54′′,N32o29′38.17′′E77o19′47.78′′,N32o38′31.97′′E77o12′48.79′′,N32o40′57.52′′E77o01′51.96′′,N33o44′30.65′′E74o25′28.92′′,N34o01′51.57′′E74o22′04.38′′,N34o01′40.006′′E74o21′45.08′′,N34o01′38.62′′E74o21′45.80′′,N34o28′09.28′′E74o57′53.19′′,N34o26′38.73′′E74o57′18.29′′,N34o22′02.31′′E75o05′23.44′′,N34o15′30.46′′E75o16′24.11′′,N34o00′50.55′′E74o20′03.78′′,N34o01′28.38′′E74o18′14.18′′, N34o02′14.81′′ E74o20′04.14′′, N33o39′21.47′′ E76o18′15.42′′, N33o28′50.70′′ E76o21′38.79′′, N34o10′13.09′′ E75o50′57.10′′, N34o49′11.20′′ E77o47′35.61′′, N34o57′11.72′′ E76o43′23.39′′, N34o11′35.53′′ E75o21′18.23′′, N34o00′39.89′′ E74o18′51.54′′, N34o01′03.64′′ E74o19′34.92′′, N33o45′14.51′′ E77o17′44.40′′, N33o51′10.89′′ E77o38′53.64′′, N31o08′33.09′′ E78o25′08.44′′, N30o15′34.61′′ E79o59′55.80′′, N30o27′15.62′′ E80o11′49.28′′, N30o28′26.65′′ E80o11′30.32′′, N30o27′22.62′′ E79o51′26.59′′, N30o25′16.88′′ E79o56′33.96′′, N31o09′51.79′′ E78o25′44.83′′, N30o43′24.72′′ E79o36′23.02′′, N30o44′33.10′′ E79o03′06.26′′, N30o44′39.74′′ E79o03′40.39′′, N30o24′03.66′′ E79o52′01.02′′, N30o29′32.77′′ E79o12′53.46′′, N30o29′17.08′′ E79o12′36.48′′, N30o58′40.21′′ E79o01′33.77′′, N30o58′44.88′′ E79o01′25.79′′, N30o03′34.32′′ E80o11′13.41′′, N30o03′42.22′′ E80o11′56.26′′, N31o09′49.64′′ E78o25′44.49′′, N31o09′46.19′′ E78o25′56.84′′, N31o09′17.52′′ E78o25′29.36′′, N30o44′46.96′′ E79o29′26.00′′, N30o46′50.83′′ E79o32′07.92′′, N30o48′27.22′′ E79o30′03.78′′, N30o46′52.39′′ E79o26′29.52′′	5.0–9.0 (McCarthy and Smith, 1995) 1.5-13.5 (Hakulinen, 1966) 4.3– 44.3 (Vitt et al., 1988) 1.2–31.3 (Winchester, 1984) 1.0-6.0 (Honegger et al. (1996);
18	*Xanthoria parietina* (L.)Th. Fr. (Foliose)	Jammu & Kashmir, Himachal Pradesh (1500-2500mt) Uttarakhand (3000-3400mt), other than IHRs TamilNadu	N 31o13′59.9′′, E 77o56′42.9′′, N 32o32′49.19′′, E 76o06′50.42′′, N32o32′57.59′′ E76o08′33.42′′, N30o56′23.94′′ E77o06′04.87′′, N31o03′49.88′′ E77o08′14.18′′, N31o04′58.67′′ E77o05′33.02′′, N31o06′41.58′′ E77o10′18.04′′, N32o16′23.14′′ E77o08′13.95′′, N32o17′27.33′′ E776o07′48.01′′, N32o18′13.23′′ E77o08′08.83′′, N32o18′30.83′′ E77o13′01.06′′, N34o10′00.71′′ E74o19′28.63′′, N33o09′02.92′′ E75o33′05.36′′, N33o08′18.76′′ E75o32′53.91′′, N33o08′55.95′′ E75o31′34.85′′, N33o10′38.06′′ E75o35′39.29′′, N33o24′01.35′′ E74o39′46.48′′, N33o42′53.03′′ E75o07′43.51′′, N33o39′14.09′′ E75o13′43.39′′, N33o49′29.61′′ E75o21′14.51′′, N33o50′07.95′′ E75o20′50.86′′, N33o51′55.73′′ E75o18′51.75′′, N33o50′37.83′′ E75o21′19.83′′, N34o00′22.00′′ E75o19′31.47′′, N34o29′38.81′′ , N30o43′26.67′′ E79o35′55.51′′, N30o43′35.20′′ E79o36′19.03′′, 30o41′40.97′′ E79o33′17.71′′, N30o43′31.29′′ E79o36′23.98′′, N31o08′33.09′′ E78o25′08.44′′, N30o15′34.61′′ E79o59′55.80′′, N30o12′58.30′′ E79o59′53.33′′, N30o29′32.77′′	5.5-25.0 (Degelius, 1964) 5.0-21.5 (Hakulinen, 1966)

	E79o12′53.46″, N30o29′17.08″ E79o12′36.48″, N30o58′40.21″ E79o01′33.77″, N30o58′44.88″ E79o01′25.79″, N30o03′34.32″ E80o11′13.41″, N30o03′42.22″ E80o11′56.26″, N31o09′49.64″ E78o25′44.49″, N31o09′46.19″ E78o25′56.84″, N31o09′17.52″ E78o25′29.36″, N30o44′46.96″ E79o29′26.00″, N30o46′50.83″ E79o32′07.92″, N30o48′27.22″ E79o30′03.78″, N30o46′52.39″ E79o26′29.52″, N30o25′16.88″ E79o56′33.96″, N31o09′51.79″ E78o25′44.83″, N30o43′24.72″ E79o36′23.02″, N30o44′33.10″ E79o03′06.26″, N30o44′39.74″ E79o03′40.39″.

Table 3: Indirect measurement of lichen thallus of *Xanthoria elegans*, on boundary wall (35x5 m) of, office of the chief executive officer, Gulmarg, Jammu and Kashmir, Baramulla District, after a gap of seven years

15x15 cm quadrate	*No of thallus measured (n)*	*Thallus Diameter (mm)*	*Size/year*	*Size/month*
		Min-Max (mean) =(a)	*a/7= (b) mm*	*b/12 = mm*
Quadrate no 1	6	9.1-30.4 (15.1)	2.1	0.175
Quadrate no 2	6	8.3-32.2 (19.2)	2.7	0.225
Quadrate no 3	6	6.1-25.3 (16.2)	2.3	0.191
Quadrate no 4	6	5.2-22.2 (15.4)	2.2	0.183
Quadrate no 5	6	7.1-35.1 (16.1)	2.3	0.191
Quadrate no 6	6	7.2-29.6 (14.2)	2.0	0.166
Quadrate no 7	6	6.3-30.2 (17.2)	2.4	0.200
Quadrate no 8	6	8.2-29.6 (13.3)	1.9	0.158
Quadrate no 9	6	7.3-25.4 (12.4)	1.7	0.141
Quadrate no 10	6	7.1-26.3 (11.2)	1.6	0.133
Quadrate no 11	6	9.2-22.2 (11.5)	1.6	0.133
Quadrate no 12	6	7.1-28.1 (16.3)	2.3	0.191
Quadrate no 13	6	5.0-24.3 (14.1)	2.0	0.166
Quadrate no 14	6	4.1-24.2 (15.0)	2.1	0.175
Quadrate no 15	6	4.2-23.4 (13.1)	1.8	0.150
Quadrate no 16	6	5.4-20.2 (15.2)	2.1	0.175
Quadrate no 17	6	4.1-24.3 (9.1)	1.3	0.108
Quadrate no 18	6	3.4-23.4 (12.4)	1.7	0.141
Quadrate no 19	6	5.2-26.2 (11.3)	1.6	0.133
Quadrate no 20	6	3.4-32.4 (14.1)	1.5	0.125
Quadrate no 21	6	3.1-25.1 (12.1)	1.7	0.141
Quadrate no 22	6	2.4-20.1 (11.3)	1.6	0.133
Quadrate no 23	6	6.8-28.7 (15.4)	2.2	0.183
Quadrate no 24	6	8.7-30.5 (12.9)	1.8	0.150
Quadrate no 25	6	3.8-31.7 (13.4)	1.9	0.158
Mean		2.4-35.1 (19.2)	(1.3-2.7)	(0.108-0.225)

days to one month for fast-growing foliose lichen species and three to four months for slow-growing crustose lichen species (Armstrong and Bradwell, 2015). The voluminous observations employed unconditional monitoring of the growth of lichens, such as radial/diameter growth area, however the dry weight (biomass) gain will be the novel expanse of lichenometry in the coming days (Roof and Werner, 2011; Armstrong, 2015).

Earlier studies have shown that the crustose lichens in alpine environments have very slow radial growth and it was reported that *R. geographicum* has an an average radial growth of 0.1 mm yr^{-1} for six months of period (Armstrong, 2015). Whereas in the present study the radial growth of foliose lichen *Xanthoria elegans* ranges between 1.3 to 2.7 mm yr^{-1} on the boundary wall. The circular lichens most probably grow in a centrifugal manner, i.e., from the inner side to the outer zone, depending on the prevailing climatic conditions. In this regard, the radial growth can play an important role in climatic assessment in the near future (Fig. 1C). Simultaneously, the radial growth pattern observations will be useful for the assessment of annual pollutants deposition on the lichen thallus of the area as it acts as cumulative depositor sampler for the pollutants.

However, it's needless to mention that the aspect and slope normalization is important for lichenometry valuation while using it in long term climate change assessment. The local differences in microclimate, along with rock surface interactions and aspect/ slope discrepancies, will be additional imperative in determining of thicknesses of growth rings (Armstrong, 2015). However, the measurement might be distance-wise since lower elevation to the upper as well as firmness between below treeline and above the tree line. Aspect and slope-wise measurements will provide the microclimate variation impact on lichen growth as well as an indication to predict any shift in the indicator communities in the future (Fig. 3). However, in treeline areas where the majority of lichens are found growing over tree bark, we can calculate the radial growth of thallus with the help of marking on a transparency sheet and its repetition at different time intervals to check the rate of thallus expansion as well as size and number of apothecia and their correlation with microclimate as well as pollutants load in the area (Fig. 4). The repeated measurement will lead to providing some important clue for a future consequence in the area.

Numerous factors such as aspect, slope, size, texture, and surface stability can hypothetically impact the biggest size of thallus, which is achieved on a surface (Armstrong, 2015; Armstrong and Bradwell, 2015). The factors studies may be a useful investment of time in an area over many years. Conversely, the more rapid methods of direct estimating radial growth rate could be utilized in thallus growth ring observations.

Conversely, the lichenometry aspects have mainstream submissions from dating glacier exposer, landslides, and fluvial deposits, as well as rectifying the age monuments/buildings together with other archaeological assemblies (Innes, 1985). Through lichenometry, it can predict the changes in river directions, earthquake time estimation, and even their presence on a tree, which can predict the age of a tree. Further, we can analyze the qualitative and quantitative variations in secondary metabolites, which can predict the pollution (UV, metal and PAHs) exposure between different time intervals along with lichenometric data. Further the submissions of lichenometry based on diverse paleoclimatic actions/ refurbishments and prehistoric artifacts can be characterized for its age. Furthermore, other usefulness of lichenometry can be used in future studies.

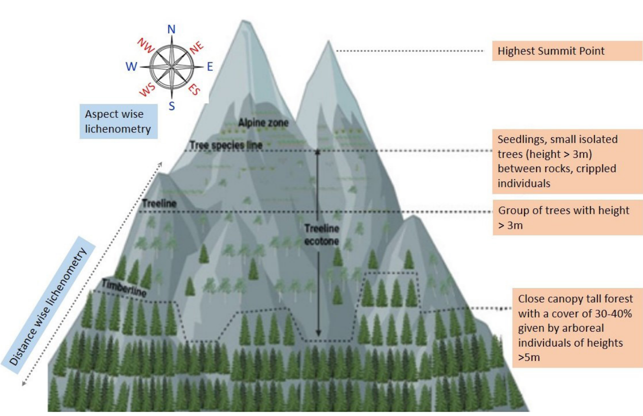

Fig. 3: A diagrammatic representation of treeline ecotone for future lichenometric studies in alpine and sub alpine ranges of Himalaya, (modified after Singh et al 2023)

Landslides

Landslides are one of the most injurious extortions in the Indian Himalayas. According to Sarkar and Kanango (2010), the major cause of the landslide is exceptionally heavy rainfall. The changed land use pattern due to the increase in anthropogenic pressure in the mountain areas poses a threat of different hazards, including landslides that lead to significant loss of property, resources, lives and biodiversity. The Himalaya is known for very high relief and intense erosion activity driven by its rivers and streams. Several issues, like deforestation, construction of dams and roads, mining, unplanned urbanization and intervention in natural drainage, may, in due course, become the triggering factor for landslides. Landslides occur frequently and without any warning, causing a calamity. Regardless of uncertainty, the greatness of these incidents, the prospective effect can be studied, investigated and calculated on the base of past incidences records and prevailing knowledge to reduce their influence (Singh, 2009).

Similarly, the database, along with satellite pictures and past geographical maps, grasp treasured information regarding to the progression of landslides in the areas. But in the absence of past historical data, complete dating of prehistoric landslides provides the distribution in time scale (Lang, *et al*. 1999). Lichenometry may find some applications in estimating the magnitude of palaeolandslides through relative dating. The lichenometric technique is applied on the lichens inhabiting stable, long-standing material. The application of lichenometry on mass movements is essential to understanding the date, frequency, and intensity of the hazards. Evaluation of the sequel of different prehistoric landslides in a particular region helps in anticipating the stability of the land and predicting future disasters in the area.

Conversely, lichenometry may be a well-implemented palaeoseismic practice for describing the extent and intensity of seismic shaking caused by prehistoric earthquakes (Bull, 2003). The geomorphic consequences of debris flows and their associated storms have been documented in many parts of the world. Nikonov and Shebalina (1979) studied the historic earthquakes in Tadjikistan by directly estimating the age of

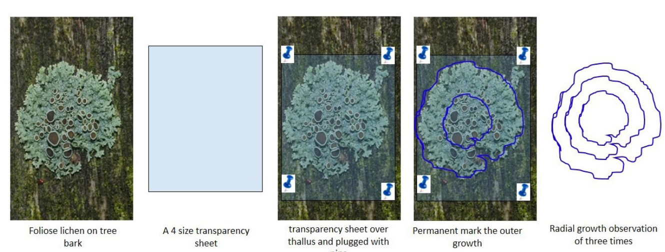

Fig. 4: Future lichenometry assessment method (lichen *Heterodrmia diademata*)

landslides with the help of lichen *Lecidea lactea*. Winchester and Chaujar (2002) carried out lichenometric dating of slope movements in North Wales. In India, Gupta (2005) studied the Pawari landslide zone in Himachal Pradesh and found that the percentage cover of lichens on slided material (boulders and pebbles) will provide a clue of climate change. The investigation implies that boulders (in debris) containing more lichen cover are more stable compared to the ones showing lesser lichen cover. Slopes covered with relatively fresh rock boulders and pebbles in the slide zone indicate an active part within the slid mass.

Archaeological evidence for dating

The idea of using lichens on archaeological remnants has been applied since back in 1939 by Renaud. However, Gerhard Follmann appears to be the first person who used lichenometry on archeological structures and studied the growth rate of *Dirinaria picta, Diploschistes anactinus* and *Lecidea paschalis* to estimate the ages of Easter Island's (Rapa Nui) monumental statues and stone platforms (Rutherford *et al.* 2008).

However, Chaujar (2006) enlightened the geological deeds at four different localities of Himachal Pradesh by calculating the dates of colonization delay and growth rate of *Rhizocarpon geographicum* growing over the rocks near Kalka-Shimla railway track and in grave yards of Sanjoli, Dharamshala, and Dalhousie. The study provokes the measurements of the largest lichen thalli that were graphically plotted against the age of the monuments and lines. The requirement of new calibrations for the growth rate of lichens and colonization delay in the regions that have experienced environmental changes irrelevant to distance has been emphasized. There is a need to develop a correlation between lichen radial growths and to determine the approximate age of manmade buildings, monuments, graveyards, memorials and parks. In India, more than 100 species of lichens are found growing over the monuments (Bajpai and Upreti, 2014). Among them, most of the species are crustose, foliose, and leprose circular in nature and they may be used to predict the age of monuments in near future.

Fluvial studies

The rivers and streams are under a continuous trend of changing their directions. In high altitudes, lichenometry may help in depicting the time period of the differential movement of rivers from its original position. Lichens usually are damaged or removed due to abrasions when boulders are transported in riverbeds. Thus, the presence of lichen thalli on particles are directly indicative of the long-standing positions of these particles and their stabilization period is equivalent to the age of lichen thallus. However, if the age of the thallus on the substratum is unwavering, then the last mobilization of the particle can easily be dated (Gob, *et al.*, 2010).

Rivers in the course of time, make different tracks, leaving small and large pebbles, stones and boulders in their previous paths. Ultimately, the smooth surface remains occupied by lichens that can be utilized to date their stabilization in the path. In this manner by measuring the largest thalli in different residual paths of the river, the minimum time of the exposure of the surface after river divergence/meandering can be evaluated. This finally can be helped in predicting the time taken by the river from its original place to its current place of flow.

The application of lichenometry in fluvial deposits was first undertaken by Gregory (1976), who used it to date flood limits and river capacity based on the presence of lichen thallus on bedrock and river banks. Similarly, the dating was performed over lichen thallus, which is contemporary on a terrace to regulate the period of their deposition and incision of the river and the existence of the largest thalli on riverbed boulders showed the longevity of their unchanging conditions (Gob, *et al.* 2003).

Volcanoes

Another inconspicuous submission of lichenometry is to date the primitive outbreak of volcanoes in a precise area and they can endure in extreme conditions of heat. Some lichen species like *Caloplaca crosbyae, Dirinaria aegialita, D. applanata, Candelariela concolor, Ramalina umbilicata, Hyperphyscia adglutinata, Syncesia* and *Xanthoparmendia* sp., are known to grow on magma rich area (Jorge-Villar and Edwards, 2009). After calibrating the growth rate and size of the lichen thalli (diameter or length) a graph can be plotted against the age of the substratum (volcanic emission). The technique will be highly useful in continents prone to volcanic explosions.

Compared to other superficial dating applications such as radiocarbon dating, dendrochronology weathering-based performances expression several complications, whereas lichenometry appears to succeed and has gained prolific attention due to simple methodology but it has some restrains as well. The complications like species documentation in the field, impact of environmental features on growth rate, nature and timing of colonization (colonization deferral), alteration of reproducibility as well as exploration of best growth rate determination methods.

Conclusion

It is concluded from the present study that the degree of retreat was quicker in Eastern Himalayan as compared to North-Western Himalaya regions. It is evidenced from this study that the lichenometric performance is extremely valuable to know as well as the data will be useful in future climate change studies together with the shift of lichen communities. Further, the measurement of radial growth of past herbarium material and their comparison at present will be useful for climate change assessment in the area. Additionally, distance and aspect-wise lichenometry will be undeniably useful in studying the impact of slope/direction on lichen growth with reference to microclimatic variations. Lichenometry was initiated in India in the preliminary years of the last decade and very limited work is done in this regard and there is more scope shortly. Moreover, qualitative and quantitative assessment of secondary metabolites in the same lichen species will be able to indicate the impact of stress in the area soon.

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Authors' Contributions

Rajesh Bajpai – original concept, collection of samples, analysis of the material, drafting the manuscript; CP Singh, review and editing manuscript.

Conflicts of Interest

The all authors declare that they have no conflict of interest.

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