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LICHEN AS BIOINDICATOR FOR MONITORING ENVIRONMENTAL STATUS IN WESTERN HIMALAYA, INDIA

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Abstract

The use of bioindicator communities (lichen) to assess the environmental status of an area is a well-proved strategy to monitor any habitat without any logistic and instrumental facilities. In the present study, 13 bioindicator communities of lichen have been used to assess the environmental status of holy pilgrimage (Badrinath), western Himalaya, India. Three sites (*i.e*. Badrinath, Mana & pilgrimage route from Bhimpul to Vasudhara) have been comparatively assessed. The results of the study reveals that Badrinath site is less polluted and experiences low degree of anthropogenic disturbances compared to Mana, and pilgrimage route (Bhimpul to Vasudhara). Human settlements, construction of civil works, vehicular emission, and trampling and trekking by tourists are the major threats on these habitats, which ultimately decrease the quality of vegetation and adjacent environment. Controlled vehicular use, promotion of modern way of cooking and managed trekking in these pilgrimage routes could be helpful to combat the decreasing vegetation and environmental quality therein.

Keywords: Bioindicator, Lichen, Vehicular pollution, Anthropogenic disturbances, Badrinath

Introduction

Lichens are slow growing organism and most successful symbiotic association between autotrophic alga and heterotrophic fungus (Farrar, 1976; Galloway, 1992). They are adopted to grow on several kinds of substrates and are reported from all the possible climatic conditions (Ahti, 1959; Sheard, 1968; Pirintsos *et al*., 1995; Rai *et al*., 2012). These unique organisms are very sensitive and able to accumulate a range of atmospheric pollutants (Shukla and Upreti, 2008; Shukla and Upreti, 2012; Bajpai *et al*., 2014). These qualities of the organism attract the environment monitoring workers to use it as a bioindicator to determine the degree and intensity of atmospheric pollution (Sloof *et al*., 1988; Nimis *et al*., 1993; Bajpai *et al*., 2010; Khare *et al*., 2010; Rai *et al*., 2012; Van der Wat and Forbes, 2015). Lichen species are highly habitat and climate specific and form the specific communities in different macroclimates (Eldridge and Rosentreter, 1999; Will-wolf *et al*., 2002; Zedda *et al*., 2011; Rai *et al*., 2012). A wide distribution range, adoptability to grow on different substrates and ability to survival in extreme environmental conditions makes them ideal monitors for the assessment of environmental status of a particular area. The poikilohydric nature and unique physiology makes lichens susceptible to climatic variations, pollution, and other environmental factors (Blum, 1973; Lange *et al*., 1986; Rai *et al*., 2013). The responses against these variables are reliable at genetic, species, population and community levels (Rosentreter *et al*., 2014). Natural and/or anthropogenic induced changes in a small area can be easily identified through the occurrence of lichen communities growing in that area (Scutari *et al*., 2004; Lalley *et al*., 2006). The monitoring of environmental status of different regions has also been conducted with the help of predictive ability of lichen communities (Srivastava, 2005; Satya and Upreti, 2011; Logesh *et al*., 2014).

Since the last ten decades, a considerable changes/decline in the lichens diversity all around the world has been observed (Hauck, 2009). In context of Indian scenario, Himalayan region is the reserve bank of the lichen diversity (Negi and Gadgil, 1996; Upreti, 1998). At present, the Himalayan region is facing extensive deterioration of air quality owing to increase of anthropogenic disturbances (Rai *et al*., 2010; Shukla and Upreti, 2011; Rai *et al*., 2012); which resulted in the rapid decline of lichen diversity (Upreti, 1998; Upreti and Nayaka, 2008). The western Himalaya of Uttarakhand state of India is encountering higher anthropogenic disturbances, bears the higher human as well as animal population and higher magnitude of local tourists due to the presence of holy pilgrimages and sacred shrines in this state, in comparison with the other west Himalayan states of the country. Badrinath is one of the important pilgrimages of the state as well as the country. Although, the floristic diversity of lichen from Badrinath area was studied earlier (Shukla and Upreti, 2007); no biomonitoring study using lichen communities has been executed in the area so far. Thus, the present study was carried out in and around Badrinath holy pilgrimage area. The present study was aimed to compare the level of pollution and anthropogenic disturbances using distribution pattern of bioindicator lichen communities.

Material and Methods

Study Area:

Badrinath is a holy pilgrimage, situated in extreme north-west of Chamoli district in the Uttarakhand state of India. It is situated between N 30°44'1.43 to N 30°46'33.74 and E 79°29'32.8 to E 79°29'37.4 with an elevation ranged from 2950 to 3670m on the bank of Alaknanda River (Gupta *et al*., 2014). The area comprises of typical alpine habitat characterized by alpine grasslands, devoid of big tress with small shrubs of *Junipers*, *Berberis* and other herbs scattered onto the open grasslands. Three sites (*i.e*. Badrinath, Mana & pilgrimage route from Bhimpul to Vasudhara) were selected to conduct the present study (Figure 1).

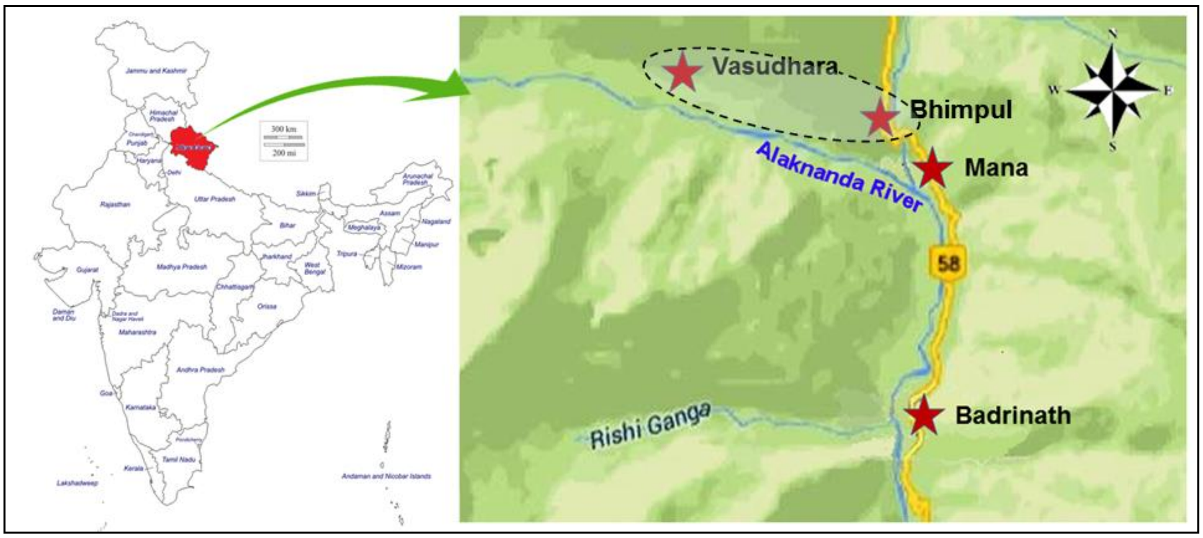

Figure 1. Map showing distribution of lichen communities

Lichen Sampling and Identification:

During the field trips (2013), more than 500 lichen samples were randomly collected by employing opportunistic survey representing their population size from Badrinath, Mana and pilgrimage route from Bhimpul to Vasudhara (Table 1).

The random samplings were carried out according to the availability of the lichens. The geographical co-ordinates of sampling sites were also recorded. The lichens samples were examined morphologically, taxonomically, anatomically and chemically for their identification with the help of previous works (Awasthi, 1988, 1991, 2000, 2007; Gupta *et al*., 2014; Gupta *et al*., 2016). The morphological features were studied with Leica EZ4 bionocular (40X) and anatomical structures were studied by Nikon Eclipse E400 compound Microscope. The chemistry of all the specimens were performed by colour spot tests (K,C,P) followed by thin layer chromatography (TLC) methods for detection of lichen substances in solvent A (180 toluene: 60 dioxane: 8 acidic acid) (Culberson, 1972). The identification of lichen substances was made on the basis of the position and colour of the spots by charts and data published in reverent references of Elix and Ernst-Russel (1993) and Orange *et al.* (2001). Voucher specimens of identified species have been deposited in the herbarium of National Botanical Research Institute (LWG), Lucknow.

Table 1: Topographical features of Study sites

S.No.	**Sites**	**Elevation**	**Vegetation**
1.	Badrinath (B)	2950 – 3000 m	Devoid of trees, scare growth of shrubs, open rocks, boulders
2.	Mana (M)	3000 – 3100 m	Devoid of tree, shrubs (except cultivated trees and shrubs)
3.	Enroute from Bhimpul to Vasudhara (B-V)	3100 – 3500 m	Open grasslands with big boulders and rocks and scattered branches of *Berberis*, *Junipers* shrubs.

Assessment of pollution and anthropogenic disturbance level:

To assess the level of pollution and anthropogenic disturbances, the passive way of biomonitoring (El-Shenaway *et al.*, 2010) was done using well-defined bioindicator lichen communities following Upreti (2014). The randomly collected lichen samples were grouped (three groups) *viz.* Badrinath (B), Mana (M) and pilgrimage route from Bhimpul to Vasudhara (B-V) according to their localities. Samples were further grouped according to their indicator communities in each locality. Finally, based on the number of lichen samples of an indicator community, the percentage of population was calculated for all three study sites. On the basis of distribution and population percentage of lichen communities, the level of pollution and anthropogenic disturbances have been assessed for these three study sites.

Result and Discussion

In total, 85 lichen species from three localities (Badrinath, Mana and enroute from Bhimpul to Vasudhara) have been identified and congregated into 13 bioindicator communities (Table 2). The indications of these communities have already been described by several workers in past (Will-Wolf *et al.*, 2002; Pinho *et al.*, 2004; Srivastava, 2005; Khare *et al.*, 2010; Satya and Upreti, 2011; Zedda *et al.*, 2011; Shukla *et al.*, 2014; Upreti, 2014).

Table 2: List of bioindicator lichen communities with representing species, indication and population percentage in three sites of Badrinath pilgrimage

S.No.	Community	Name of Species	Indication	Study Sites		
				B	**M**	**B-V**
1.	Aspicilioid	*Acarospora smaragdula* (Wahlenb.) A. Massal *Acarospora fusca* B. de Lesd. *Aspicilia maculate* (H. Magn.) *Aspicilia calcarea* (L.) Korb. *Candelariella aurella* (Hoffm.) Zahlbar *Dimelaena oreina* (Ach.) Norm *Diploschistes scruposus* (Schreb.) Norman *Diploschistes muscorum* (Scop.) R. Sant. *Lobothallina praeradiosa* (Nyl.) Hafellner *Lobothallina alphoplaca* (Wahlenb.) Hafellner. *Rhizocarpon geographicum* (L.) DC *Rhizocarpon disporum* (Naeg. ex. Hepp) Mull Arg.	Exposed illuminated less or moderately polluted areas	44.0%	35.0%	21.0%
2.	Dimorphic	*Cladonia fimbriata* (L.) Fr. *Cladonia pyxidata* (L.) Hoffm. *Cladonia subsquamosa* Kremp. *Cladonia coniocraea* (Florke) Spreng. *Cladonia ochrochlora* Florke. *Stereocaulon foliolosum* Nyl. *Stereocaulon alpinum* Laurer in Funck. *Stereocaulon myriocarpum* Th. Fr.	High tourist pressure, trampling	52.0%	18.0%	30.0%
3.	Lecanoriod	*Lecanora muralis* (Schreb.) Rabenh *Lecanora frustulosa* (Dicks.) Ach. *Lecanora muralis* var. *dubyi* (MÜll. Arg) Poelt *Lecanora garovaglio*i (Körb.) Zahlbr	Open and disturbed vegetation	30.0%	27.0%	43.0%
4.	Lecideoid	*Mycobilimbia hunana* (Zahlbr.) D.D Awasthi *Sarcogyne privigna* (Ach.) A Massal.	Open and disturbed vegetation	25.0%	30.0%	45.0%
5.	Leprarioid	*Lepraria lobificans* Nyl.	Construction disturbances	0.0%	100.0%	0.0%
6.	Lobarian	*Lobaria kurokawae*Yoshim *Peltigera horizontalis* (Huds.) Baumg. *Peltigera collina* (Ach.) Schrad *Petigera rufescen*s (Weiss) Humb *Peltigera praetextata* (FlÖrke ex Sommerf.) Zopf.	Air pollution	60.0%	0.0%	40.0%
7.	Parmelioid	*Cetraria nigricans* Nyl. *Cetrelia cetrarioides* (Delise) W.L. Club & C.F. Club. *Everniastrum cirrhatum* (Fr.) Hale ex Sipman *Melanohalea infumata* (Nyl.) O. Blanco A. Crespo Divakar, Essl., D. Hawksw & Lambush *Melanohalea exasperatul*a (Nyl.) O. Blanco, A. Crespo,	Anthropogenic disturbances	18.0%	24.0%	58.0%

		Divakar, Essl., D. Hawksw & Lambush *Melanelia disjuncta* (Erichsen) Essl. *Flavoparmelia caperata* (L.) Hale *Hypotrachyna awasthii* Hale & Patw. *Hypotrachyna incognita* (Kurok.) Hale *Hypotrachyna flexilis* (Kurok) Hale. *Parmotrema praesorediosum* (Nyl.) Hale *Parmelia saxalitis* (L.) Ach. *Parmelia sulcata* Taylor in Mackay *Parmelia squarrosa* Hale *Puntelia subrudecta* (Nyl.) Krog.				
8.	Peltuloid	*Peltula patellata* (Bagl.) Swincow & Krog.	Stable rocks	100.0%	0.0%	0.0%
9.	Physcioid	*Heterodermia microphylla* (Kurok.) Skorepa *Heterodermia japonica* (M. SatÖ) Swins & krog *Heterodermia boryi* (Fee) Kr. P. Singh & S.R Singh *Heterodermia pseudospeciosa* (Kurok.) W.L. Culb. *Heterodermia hypocaesia* (Yasuda ex Rasänen) D.D. Awasthi. *Physcia albinea* (Ach.) Nyl. *Physcia gomukhensis* D.D. awasthi & S.R. Singh *Phaeophyscia constipate* Nyl. Moberg. *Phaeophyscia hispidula* (Ach.) Essl. *Phaeophyscia primaria* (Peolt) Trass. *Pheaophyscia pyrrhophora* (Poelt) D. D awasthi & M Josh *Physconia detersa* (Nyl.) Poelt. Shorepa *Physconia muscigena* (Ach.) Peolt.	Vehicular pollution	31.0%	57.0%	12.0%
10.	Teloschistacean	*Candelaria concolor* (Dicks.) Arnold *Caloplaca lithophila* H. Magn. *Xanthoria elegans* (Link) Th. Fr. *Xanthoria candelaria* (L.) Th. Fr. *Xanthoria ulophyllodes* Räsänen.	Higher ultraviolet radiation	13.0%	40.0%	47.0%
11.	Umbilicarioid	*Normandina pulchella* (Borrer) Nyl. *Dermatocarpon vellereum* Zschacke *Dermatocarpon miniatum* (L.) W. Mann. *Endocarpon rosettum* Ajay Singh &Upreti. *Endocarpon subrosettum* Ajay Singh &Upreti *Lasallia pustulata* (L.) Merat. *Lasallia pertusa* (Rassad) Llano. *Rhizoplaca chrysoleuca* (Sm.) Zopf. *Umbilicaria indica* Frey.	Higher ultraviolet radiation	15.0%	46.0%	39.0%

12.	Usnioid	*Ramalina sinensis* Jatta *Usnea subfloridana* Stirton. *Usnea orientalis* Motyka *Usnea pseudosinensis* Asahina *Usnea subflorida* (Zahlbr.) Mof. *Usnea perplexans* Stirt.	Healthy vegetation and air quality	64.0%	0.0%	36.0%
13.	Xanthoparmelioid	*Xanthoparmelia bellatula* (Kurok. & Filson) Elix & J. Johnst. *Xanthoparmelia congensis* (B. Stein) Hale. *Xanthoparmelia mexicane* (Gyeln.) Hale. *Xanthoparmelia terricola* Hale. T.H. Nash & Elix.	High tourist pressure, trekking	57.0%	31.0%	12.0%

Note: B, Badrinath; M, Mana; B-V, Enroute from Bhimpul to Vasudhara.

Aspicilioid community represented by the species of *Acarospora*, *Aspicilia*, *Candelariella*, *Dimelaena*, *Diploschistes*, *Lobothallina* and *Rhizocarpon* genera indicates the exposed illuminated area with moderate pollution level. Out of the total samples, Badrinath (B) was represented by 44.0%, Mana (M) by 35.0% and Bhimpul to Vasudhara (B-V) with only 21.0% population (Figure 2A). Dimorphic community representing the species of *Cladonia* and *Stereocaulon* genera indicates the trampling and other tourist pressures. Out of the total samples, B represented 52.0%, B-V 30.0% and M only 18.0% population (Figure 2B). Lecanoriod community represented by the species of genus *Lecanora* indicates the open and disturbed vegetation. Among them, B-V represented 43.0%, B 30.0% and M 27.0% population (Figure 3A). Lecideoid community represented by the species of *Mycobilimbia* and *Sarcogyne* genera also indicates the open and disturbed vegetation. B-V represented 45.0%, M 30.0% and B 25.0% population (Figure 3B). Leprarioid community represented by a single species (*Lepraria lobificans* Nyl.) of *Lepraria* genus indicates the presence of anthropogenic disturbances caused by the civil construction woks. The species was encountered and sighted only from the Mana (M) village. Lobarian community represented by the species of *Lobaria* and *Peltigera* genera indicates the level of air pollution. B represented 60.0% and B-V 40.0% population; while the community was found absent in Mana (M) village (Figure 4A). Parmelioid community represented by the species of *Cetraria*, *Everniastrum*, *Melanohalea*, *Melanelia*, *Flavoparmelia*, *Hypotrachyna*, *Parmotrema* and *Parmelia* genera indicates the status of anthropogenic disturbances. B-V represented 58.0%, B 22.0% and M 20.0% population (Figure 4B). Peltuloid community was represented by a single species (*Peltula patellata* (Bagl.) Swincow & Krog.) of *Peltula* genus indicates the presence of stable rocks *i.e.* lower risk of landslides. The species was encountered from the Badrinath (B) area only. Physcioid community represented by the species of *Heterodermia*, *Physcia*, *Phaeophyscia* and *Physconia* genera indicates the level of vehicular pollution. M represented 57.0%, B 31.0% and B-Vonly 12.0% population (Figure 5A). Teloschistacean community represented by the species of *Candelaria*, *Caloplaca* and

Xanthoria genera indicates the higher level of ultraviolet radiation. B-V represented 47.0%, M 40.0% and B only 13.0% population (Figure 5B). Umbilicarioid community represented by the species of *Normandina*, *Dermatocarpon*, *Endocarpon*, *Lasallia*, *Rhizoplaca* and *Umbilicaria* genera also indicates the higher level of ultraviolet radiation. M represented 46.0%, B-V 39.0% and B only 15.0% population (Figure 6A). Usnioid community represented by the species of *Ramalina* and *Usnea* genera also indicates the healthy vegetation and good air quality. B represented 64.0%, and B-V 36.0% population; while no Usnioid community was encountered from Mana (M) village (Figure 6B). Xanthoparmelioid community represented by the species of *Xanthoparmelia* genus indicates the trekking and tourist pressure. B represented 57.0%, M 31.0% and B-V only 12.0% population (Figure 6C).

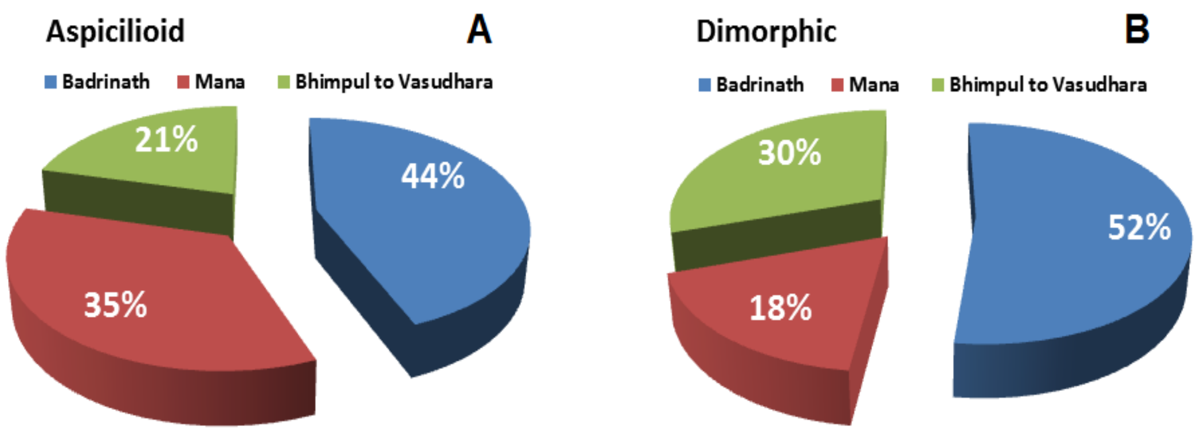

Figure 2. Contribution by different sites in lichen community of: A- Aspicilioid; B- Dimorphic

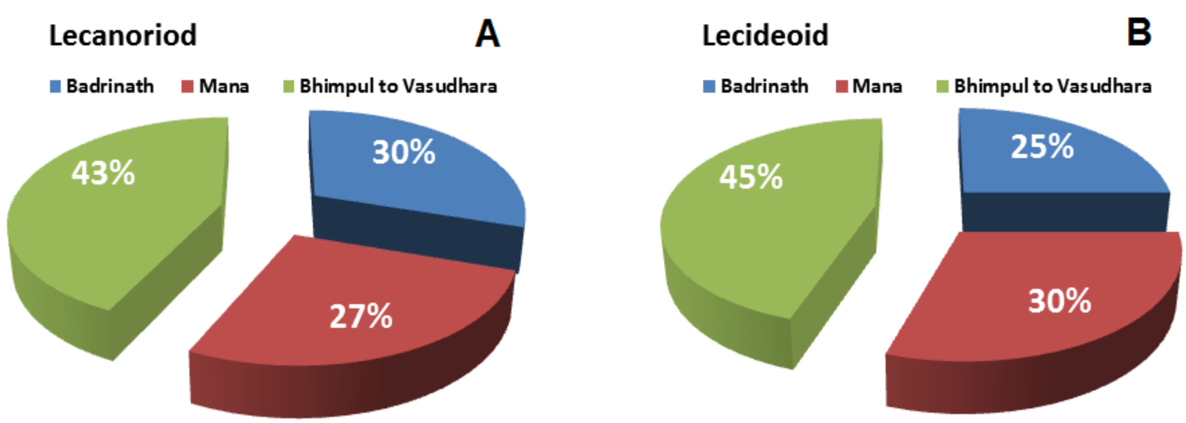

Figure 3. Contribution by different sites in lichen community of: A- Lecanoriod; B- Lecideoid

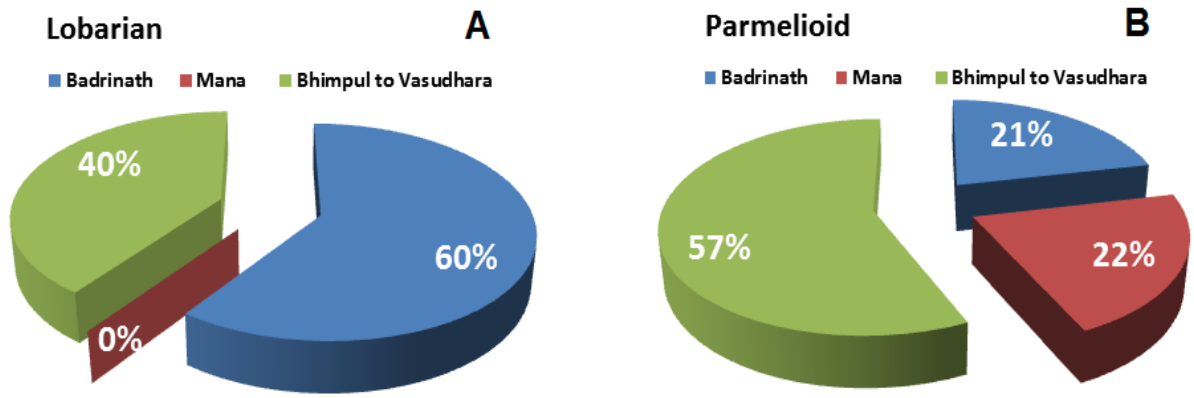

Figure 4. Contribution by different sites in lichen community of: A- Lobarian; B- Parmelioid

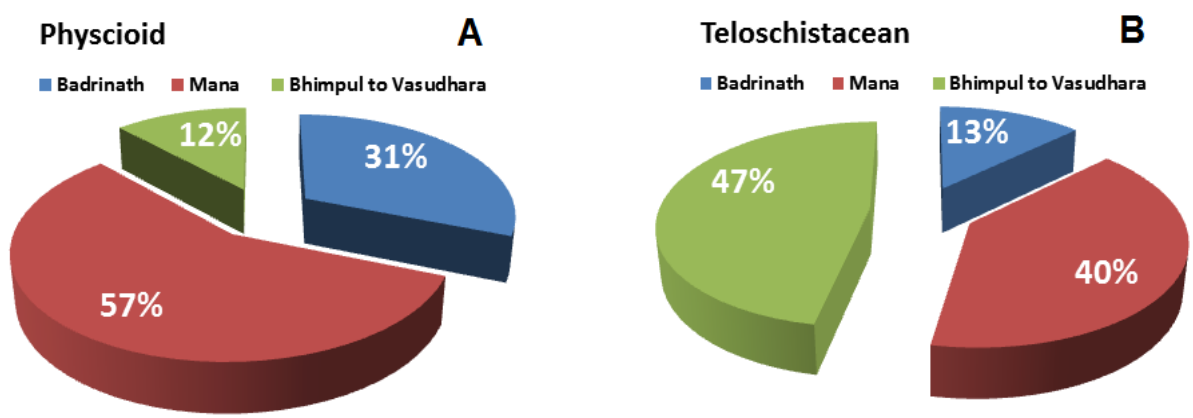

Figure 5. Contribution by different sites in lichen community of: A- Physcioid; B- Teloschistacean

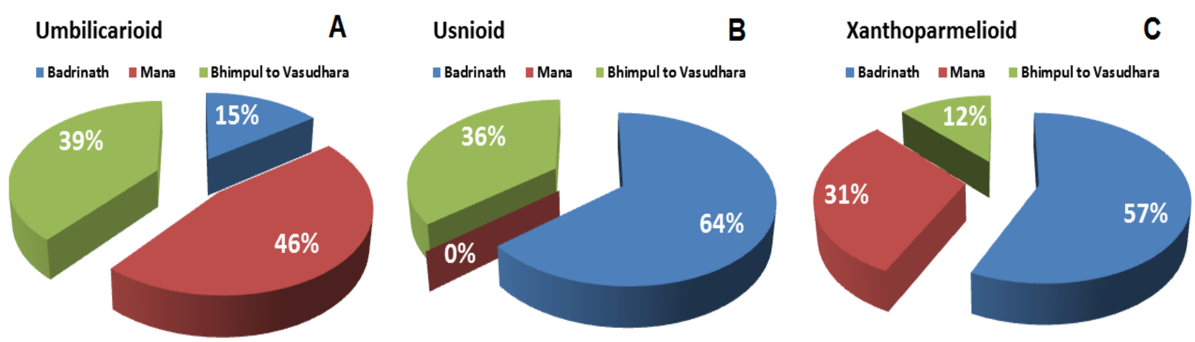

Figure 6. Contribution by different sites in lichen community of: A- Umbilicarioid; B- Usnioid; C- Xenthoparmelioid

The presence of Aspicilioid community members in Badrinath (B) and Mana (M) area with higher population percentage clearly indicates that both the areas are facing less to moderate anthropogenic disturbances. As the Lobarian, Physcioid and Usnioid communities indicates the air quality, it is very clear that the Badrinath (B) area has the good air quality, less pollution and less vehicular pollution in comparison with the Mana (M) area. The absence of Lobarian and Usnioid communities in Mana indicated the worst condition of air quality in this area. Such kind of indications is also observed by other workers in different areas (Sloof *et al*., 1988; Pinho *et al*., 2004; Shukla *et al*., 2014). The presence of Physcioid community in very few localities of enroute from Bhimpul to Vasudhara (B-V) indicates very less vehicular pollution in this area. Teloschistacean and Umbilicarioid communities comprise the ultraviolet tolerant lichen species. The presence of lichen species of Teloschistacean & Umbilicarioid communities from Mana (40.0% & 46.0%) and B-V (47.0% & 39.0%) respectively indicates the presence of higher ultraviolet radiation in these two sites in comparison to Badrinath area with 13% & 15% population respectively. Upreti *et al*. (2014) also utilizes these species as indicator of ultraviolet radiation. Lecanoriod & Lecideoid communities comprise the lichen species which can tolerate higher anthropogenic disturbances. B-V site represent the maximum (43.0% & 45.0%) population of Lecanoriod & Lecideoid communities respectively and clearly indicates the presence of higher anthropogenic pressure, which is reflected by the disturbed vegetation present in the pilgrimage route. The status of anthropogenic disturbances has also been accessed by the distribution of these indicator lichen communities by Shukla and Upreti (2011) and Rai *et al*. (2012). The species of Dimorphic & Xanthoparmelioid communities are very sensitive to any kind of disturbances caused by trampling & trekking of tourists and demolished from the area suffering from such type of pressure. Presence of good population of these indicator species from Badrinath area (52.0% & 57.0% respectively) reveals the low pressure trampling & trekking pressures; while the lower population of these communities from Mana and B-V area designates these areas with higher tourist pressure. The similar observation has also been observed in other area of Garhwal Himalaya (Khare *et al*., 2010). The Leprarioid community is the pioneer ones, which appears very first after any civil construction in an area. The presence of this community only from the Mana site reveals that several kinds of civil constructions (roads, houses etc.) are going on in this area, which ultimately caused the adverse effects on the lichen as well as entire vegetation (Satya and Upreti, 2011; Upreti, 2014). The members of Peltuloid community always found to grow on the older rocks and boulders and thus they are the good indicators of the landslides area. The presence of this community only from Badrinath site reveals that the landslides occurred very rarely in this area; while it occurred frequently in Mana and B-V sites as no indicator species has been collected from these two areas. The Parmelioid members have the higher tolerance capacity against different anthropogenic activities and environmental pollution (Shukla and Upreti, 2012; Bajpai *et al*., 2014). The presence of luxurious population of the species (58.0%) belonging to this community at B-V site reveals the higher anthropogenic activities in this site in comparison with the other two sites, Mana (24.0%) and Badrinath (18.0%) population.

Over all the Parmelioid, Peltuloid, Leprarioid, Dimorphic, Xanthoparmelioid, Lecanoriod, Lecideoid, Teloschistacean and Umbilicarioid bioindicator communities cumulatively indicates that the Badrinath site is comparatively bears healthy vegetation, less polluted, ultraviolet radiation and also facing the lower level of anthropogenic disturbances; on the other hand Mana & enroute from Bhimpul to Vasudhara (B-V) sites bears disturbed vegetation, more polluted, ultraviolet radiationand facing higher level of anthropogenic disturbances. When we talk about the air quality, it has been exposed by good population of Lobarian, Physcioid and Usnioid communities that Badrinath site is again represents the good air quality; while in Mana site the air quality is in bad condition as it very less and/or no population of these communities. This is may be due to the heavy vehicular and household pollution as the site has a good human settlement.

Conclusion

The study reveals that the Badrinath site of Badrinath holy pilgrimage of Western Himalaya is still comparatively less polluted and disturbed. The Mana site has been found as highly polluted and disturbed due to human settlement, different construction of civil works and vehicular emittion. The pilgrimage route from Bhimpul to Vasudhara (B-V) has also been found highly disturbed but here trampling and trekking caused by tourists was the major source of disturbances. Some suggestions to overcome the increasing level of pollution & anthropogenic disturbances and to conserve not only the lichen as well as other vegetation are, governmental control on the use of vehicles in higher elevation areas, promotion of lesser pollution emitting way of cooking (LPG, biogas, modern stove etc.) and managed trekking in the pilgrimage routes.

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