

INFLUENCE OF ANTHROPOGENIC DISTURBANCES ON LICHEN COMMUNITY STRUCTURE AND BIOPROSPECTING POTENTIAL IN RECREATIONAL HOTSPOTS OF DISTRICT REASI, JAMMU & KASHMIR

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Abstract

This study documents lichen diversity across nine sites in District Reasi, Jammu and Kashmir, with an emphasis on the contrast between tourist-influenced and relatively undisturbed habitats. A total of 50 species representing 33 genera and 15 families were recorded from whole of the Reasi district. Physciaceae emerged as the dominant family, followed by Verrucariaceae and Parmeliaceae. Both crustose and foliose forms were equally represented. Among substrates, bark supported the highest number of species, followed by rock and soil. Non-tourist sites exhibited greater richness, while heavily visited sites like Katra and Reasi were characterized by a higher proportion of tolerant and cosmopolitan taxa. The findings underline how tourism pressure and environmental disturbance shape species composition, highlighting lichens as sensitive indicators for monitoring ecological health in Himalayan landscapes. The study further highlights the bioprospecting significance of several recorded lichen taxa known for their bioactive secondary metabolites and antimicrobial properties. Anthropogenic disturbances may therefore threaten not only lichen diversity but also ecologically valuable species with potential pharmaceutical and biotechnological applications.

KEYWORDS: Lichen diversity, Bioprospecting, Secondary metabolites, Bioindicators, Himalayan ecosystems

INTRODUCTION

The lichens form a mutualistic association between the fungal partner (mycobiont) and the algal partner and/or cyanobacterial partner (phycobiont) (Ahmadjian, 1993). It is believed that this symbiosis occurred as an adaptive response to extreme conditions as neither the fungal nor the algal part could survive without the other. Lichens are ubiquitous and can grow on many natural and artificial substrates, such as tree bark, rocks or human-made objects. Several environmental factors affect their distribution and abundance, most of which are microclimatic (light intensity, temperature, humidity), while the macroclimatic factors are annual precipitations and mean temperature. Furthermore, substrate properties such as pH, texture, mineral content, surface texture and moisture retention are also important factors in lichen establishment and growth (Hawksworth & Rose, 1976; James *et al.*, 1977; Hawksworth & Hill, 1984; Wolesley & Aguirre-Hudson, 1997; Mulligan, 2009). Lichens are vital sources of bioactive secondary metabolites with antimicrobial, antioxidant, antiviral and anti-inflammatory activities. The antimicrobial activity of the foliose lichens from Pir Panjal Himalayas was reported to be significantly effective against the pathogenic bacterial strains, which reflects the medicinal importance of the metabolites of lichens in this Himalayan region.

The Union Territory of Jammu and Kashmir in the northwest Himalaya (32.73°–36.66° N latitude and 73.43°–80.5° E longitude) is one of the important lichen diversity centres in India (Sheikh *et al.*, 2006). The combination of its diverse altitude gradients, heterogeneous topography, diverse types of vegetation and changing climatic conditions provide a wide range of ecological niches for lichens to colonise. The earliest records of lichen studies in the area are from the 20th century and are attributed to Smith (1931), Schubert and Klement (1966), and Awasthi and Singh (1970). More systematic and comprehensive investigations, however, began in the 21st century, with major studies by Sheikh *et al.* (2006, 2009), Khan *et al.* (2010), Solan *et al.* (2010), Kumar *et al.* (2012), Khare *et al.* (2020), Kumar and Sharma (2020), Kumar *et al.* (2021) and Gupta *et al.* (2025), substantially advancing knowledge of the lichen mycobiota of the region. Despite several surveys in districts such as Doda, Kishtwar, Rajouri, Anantnag, and Pahalgam, the lichen flora of District Reasi has remained unexplored. The present study aims to document and compare lichen composition across nine representative sites—four tourist and five non-tourist—to assess the ecological effects of tourism on lichen distribution.

The study was conducted primarily within the Reasi district including nine tehsils (**Figure 1**). Geographically, the area lies between 32°53'–33°20' N latitude and 74°35'–72°10' E longitude. Nowshera Forest Division to its west, Mahore Forest Division to its north, Udampur Forest Division to its east and Jammu Forest Division to its south. Hydrologically,

the region forms part of the Chenab River catchment, with the Reasi range mainly drained by Anji Nallah, which joins the Chenab near Reasi town. There are also a number of small streams and tributaries that flow into the Chenab drainage. It is an ecologically important region, but it has been profoundly affected by religious tourism at the shrine of Shri Mata Vaishno Devi and Shiv Khori. This has created the visitor economy of the district and made Reasi a spiritual and economic hub of the region.

It receives rainfall from two sources – monsoonal and winter time – with the maximum rainfall in July-August. Climatic conditions are quite different as per elevation, as lower elevations, Pouni, Reasi and Katra have hot summers, and the higher elevations are cooler with frequent snowfall in the months of November to February. The complex climatic and altitudinal zonation leads to a mosaic of habitats which are favourable for rich vegetation and lichen colonization. District Reasi hosts a diverse vegetation assemblage dominated by *Acacia catechu*, *Cassia fistula*, *Terminalia bellerica*, *Anogeissus latifolia*, *Mallotus philippensis*, and related species, with pure stands of *Dalbergia sissoo* in some areas. Additional taxa such as *Quercus leucotrichophora*, *Pyrus pashia*, *Indigofera tinctoria*, *Phyllanthus emblica*, and *Pinus* spp. contribute to its floristic richness. Administratively, Reasi District consists of 259 villages and 147 panchayat halqas, organized into nine tehsils and twelve rural development blocks. The complex interplay of physiography, vegetation, and climate provides a dynamic ecological framework that favors the establishment and diversification of lichens across the district. Tourism activities in District Reasi have increased recently resulting in more anthropogenic pressure which may threaten ecologically sensitive lichen communities and at the same time reduce availability of species possessing valuable secondary metabolites. Habitat degradation, vehicular pollution, tourist pressure and microclimatic alterations can influence both species diversity and metabolite production in lichens thereby affecting their ecological as well as biotechnological significance.

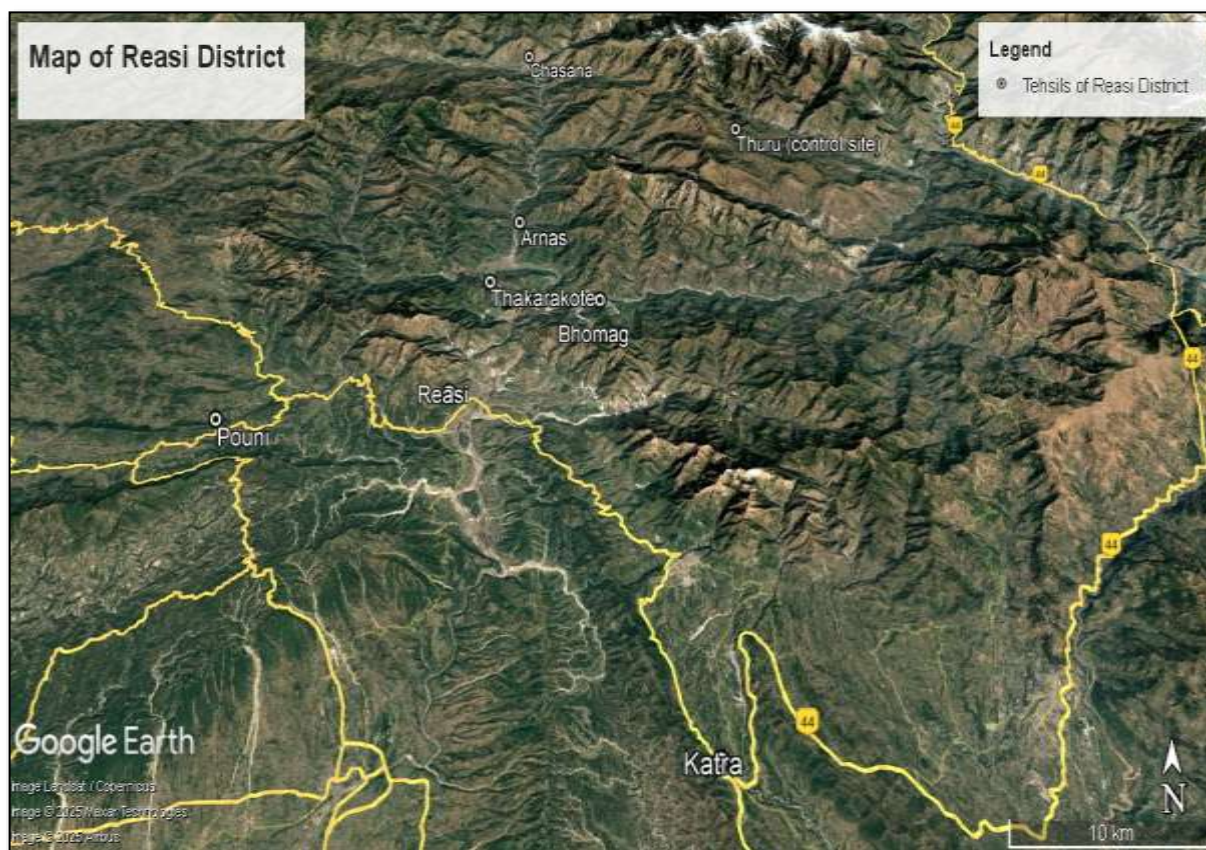


Figure 1: Digital map of the study area

METHODOLOGY

Lichen specimens were collected systematically on a site basis through extensive field surveys conducted between 2021 and 2023. Samples were obtained from major substrate types, including bark, rock, and soil. The collected specimens were examined and identified at the Centre for Biodiversity Studies, Baba Ghulam Shah Badshah University, Rajouri. Morphological and anatomical features were studied using stereomicroscopic and compound light microscopy, while chemical characterization was carried out using thin-layer chromatography (TLC), and standard spot tests following Elix *et al.* (1993). Species were identified using regional and national monographs and identification keys authored by Awasthi (1988, 1991, 2000), Upreti (1998), Singh and Sinha (2010), Nayaka and Upreti (2011), Kumar *et al.* (2012), Bhat *et al.* (2014), and Goni *et al.* (2015). Selected Study Sites were classified into two major land use activities categories, tourist area and non-tourist area, according to land use pattern. Of the nine selected sites four were designated as tourist sites that were significantly affected by human activities and five were designated as non-tourist sites that represent relatively less disturbed natural environments. The details of these sites, their coordinates and altitudes, have been recorded in Table 1 and the lichen diversity and abundance have been used as a basis for subsequent comparative analysis between the two categories.

Table 1: Categorization of study area into tourist and non- tourist sites

S.No	Site	Categorization	Coordinates	Altitude(m)
1	Mahore (site1)	Non-tourist	33.5110N° 75.0794E°	1667-2586m
2	Thuru (Site 2)	Non-tourist	33.2629 N° 74.9834 E°	2000-2567m
3	Katra (Site3)	Tourist (Shrine of Shri Mata Vaishno Devi, Aghar Jitto, Nau Deviyaan, Baba Dhansar)	32.9915N° 74.9318E°	572-847m
4	Reasi (Site4)	Tourist (Shiv Khori, Baba Banda Bahadur)	33.0828 N° 74.8331 E°	420-637m
5	Chasana (Site5)	Non-tourist	33.3506 N ° 74.8240 E°	801-1282m
6	Bhomag (Site6)	Tourist (Asia's highest Railway bridge)	33.0966 N° 74.9135 E°	873-1172m
7	Thakarakote (Site7)	Tourist (Salal Project, Sihad Baba)	33.1688 N° 74.7956 E°	511-934m
8	Arnas (Site8)	Non-tourist	33.2070 N° 74.8166 E°	524-578m
9	Pouni (Site9)	Non-tourist	33.0527 N° 74.6304 E°	573-677m

RESULTS AND DISCUSSION

The current study has identified 50 lichen species spread across 33 genera and 15 families. A detailed list of these species, along with their growth forms and the substrates where they were found, is given in Table 2. Analysis of this table shows that Physciaceae is the most common family, consisting of 7 genera, followed by Verrucariaceae with 5 genera and Parmeliaceae with 4 genera. Other families, including Acarosporaceae, Candellariaceae, Chrysotrichaceae, Pertusariaceae, and Psoraceae, each have one represented species. A comparative review of the dominant lichen families found in this study area was performed against those recorded in nearby regions. The present findings align with those of Bhat (2018), who also identified Physciaceae as the predominant family in District Rajouri. Similarly, Mishra and Upreti (2016) reported that Physciaceae was the leading family in the Kumaon Himalayas. Kumar *et al.* (2012) corroborated these results, demonstrated Physciaceae as the most dominant family in their research on the Ladakh region. Conversely, Sharma *et al.* (2019) recognized Parmeliaceae as the dominant family in Padder Valley, Jammu and Kashmir, with Physciaceae following closely. Additionally, Goni *et al.* (2015) reported Parmeliaceae as the leading family in certain areas of Jammu and Kashmir.

Additional examination of the growth forms reveals that there are 22 species in both crustose and foliose categories, whereas leprose and squamulose forms each have three species represented. According to Sharma *et al.* (2019), the foliose form was the most prevalent in Padder Valley, followed by crustose and fruticose forms. In a similar way, Bhat (2018) noted that the crustose lichens in District Rajouri were dominant. Additionally, Mishra and Upreti (2016) found that the foliose type was the most prevalent lichen form in the Kumaon Himalayas. In contrast, Sheikh *et al.* (2013) found that crustose forms were the most abundant in Jammu and Kashmir, with foliose and fruticose forms following in lesser numbers. Table 1 shows that corticolous (27 species), saxicolous (20 species), and terricolous (three species) are the most common substrates for lichen growth in the research area. Interestingly, some species that live in soil were also found to grow on surfaces made of bark and rock. These findings are consistent with earlier studies, including Sharma *et al.* (2019) in the Padder Valley, Sheikh *et al.* (2013) in Jammu and Kashmir, and Mishra and Upreti (2016) in the Kumaon Himalayas, who reported a predominance of corticolous lichens across different Himalayan regions. However, Bhat (2018) indicated that saxicolous substrates were the most favoured by lichens in District Rajouri.

Table 2: Species of lichens reported from study area along with their family, growth form and substratum:

Family	Genus	Species	Growth form	Substratum
Acarosporaceae	<i>Pleopsidium</i>	<i>flavum</i>	Crustose	Rock
Candellariaceae	<i>Candellaria</i>	<i>concolor</i>	Foliose	Bark

Chrysotrichaceae	<i>Chrysothrix</i>	<i>chlorine</i>	Leprose	Bark
Collemataceae	<i>Collema</i>	<i>limosum</i>	Foliose	Rock
	<i>Collema</i>	<i>subflaccidum</i>	Foliose	Bark
	<i>Collema</i>	<i>pulcellum</i>	Foliose	Bark
	<i>Leptogium</i>	<i>denticulatum</i>	Foliose	Rock
Graphidaceae	<i>Diploschistes</i>	<i>eugeneus</i>	Crustose	Rock
	<i>Diploschistes</i>	<i>scruposus</i>	Crustose	Rock
	<i>Graphis</i>	spp	Crustose	Bark
Lecanoraceae	<i>Lecanora</i>	<i>achroa</i>	Crustose	Rock
	<i>Lecanora</i>	<i>albescens</i>	Crustose	Rock
	<i>Lecanora</i>	<i>muralis</i>	Crustose	Rock
	<i>Lecanora</i>	<i>perplexa</i>	Crustose	Rock
	<i>Rhizoplaca</i>	<i>chrysoleuca</i>	squamulose	Rock
Lichinaceae	<i>Phylliscum</i>	<i>indicum</i>	Crustose	Rock
	<i>Phylliscum</i>	spp	Crustose	Rock
Parmeliaceae	<i>Parmelia</i>	spp	Foliose	Rock
	<i>Parmotrema</i>	<i>paesoredium</i>	Foliose	Bark
	<i>Punctelia</i>	<i>subrudecta</i>	Foliose	Rock
	<i>Xanthoparmelia</i>	<i>congenesis</i>	Foliose	Bark
Pertusariaceae	<i>Pertusaria</i>	<i>melastornella</i>	Crustose	Rock
Physciaceae	<i>Buellia</i>	<i>disjecta</i>	Crustose	Rock
	<i>Dirinaria</i>	<i>aegiatita</i>	Crustose	Rock
	<i>Hyperphyscia</i>	<i>adglutinata</i>	Foliose	Bark
	<i>Hyperphyscia</i>	<i>granulata</i>	Foliose	Bark
	<i>Hyperphyscia</i>	<i>syncola</i>	Foliose	Bark
	<i>Phaeophyscia</i>	<i>hispidula</i>	Foliose	Bark
	<i>Phaeophyscia</i>	<i>orbicularis</i>	Foliose	Bark
	<i>Phaeophyscia</i>	<i>pyrrophora</i>	Foliose	Bark
	<i>Physcia</i>	<i>dilitata</i>	Foliose	Bark
	<i>Physconia</i>	<i>distorta</i>	Foliose	Bark
	<i>Pyxine</i>	<i>cocoes</i>	Foliose	Bark
Psoraceae	<i>Psora</i>	<i>decipiens</i>	Crustose	Soil/Rock
Ramalinaceae	<i>Biatora</i>	spp	Crustose	Rock
	<i>Bacidia</i>	<i>arnoldiana</i>	Crustose	Bark/Rock
	<i>Bacidia</i>	<i>incongruens</i>	Crustose	Bark
	<i>Bacidia</i>	spp	Crustose	Bark
Stereocaulaceae	<i>Lepraria</i>	<i>lobificiens</i>	Leprose	Soil/rock/bark
	<i>Lepraria</i>	spp	Leprose	Soil/rock/bark
Teloschistaceae	<i>Caloplaca</i>	<i>ahmediana</i>	Crustose	Rock
	<i>Caloplaca</i>	<i>subsoluta</i>	Crustose	Rock
	<i>Xanthoria</i>	<i>parietina</i>	Foliose	Bark
Verrucariaceae	<i>Dermatocarpella</i>	<i>squamulosum</i>	Foliose	Rock
	<i>Dermatocarpon</i>	<i>miniatum</i>	Foliose	Rock
	<i>Dermatocarpon</i>	<i>vellereum</i>	Foliose	Rock
	<i>Endocarpon</i>	<i>rosettum</i>	Squamulose	Rock
	<i>Endocarpon</i>	spp	Squamulose	Rock

	<i>Sturothele</i>	<i>fissa</i>	Crustose	Rock
	<i>Verrucaria</i>	<i>caerulea</i>	Crustose	Rock

Table 3 presents a comparative account of lichen species recorded from tourist as well as non-tourist sites within District Reasi.

Table 3 List of lichens found at tourist and non-tourist sites in the study area

S.No	Lichen species at Non-tourist site	Lichen species at tourist site
1	<i>Bacidia incongruens</i>	<i>Bacidia arnoldiana</i>
2	<i>Bacidia</i> spp	<i>Biatora</i> spp
3	<i>Biatora</i> spp	<i>Cadellaria concolor</i>
4	<i>Buellia disjecta</i>	<i>Caloplaca subsoluta</i>
5	<i>Caloplaca ahmediana</i>	<i>Dermatocarpella squamulosum</i>
6	<i>Caloplaca subsoluta</i>	<i>Dermatocarpon vellereum</i>
7	<i>Candellaria concolor</i>	<i>Diploschistes euganeus</i>
8	<i>Chrysothrix chlorina</i>	<i>Diploshistes scruposus</i>
9	<i>Collema limosum</i>	<i>Dirinaria aegialita</i>
10	<i>Collema pulcellum</i>	<i>Graphis</i> spp.
11	<i>Dermatocarpon miniatum</i>	<i>Hyperphyscia adglutinata</i>
12	<i>Dermatocarpon vellereum</i>	<i>Hyperphyscia syncola</i>
13	<i>Diploschistes euganeus</i>	<i>Lepraria lobificiens</i>
14	<i>Diploschistes scruposus</i>	<i>Lepraria</i> spp
15	<i>Graphis</i> spp	<i>Parmelia</i> spp
16	<i>Hyperphyscia adglutinata</i>	<i>Phaeophyscia hispidula</i>
17	<i>Hyperphyscia syncola</i>	<i>Phaeophyscia pyrrophora</i>
18	<i>Lecanora achroa</i>	<i>Phylliscum indicum</i>
19	<i>Lecanora albescens</i>	<i>Phylliscum</i> spp.
20	<i>Lecanora muralis</i>	<i>Physcia dilitata</i>
21	<i>Lecanora perplexa</i>	<i>Physconia distorta</i>
22	<i>Lepraria lobificiens</i>	<i>Verrucaria caerulea</i>
23	<i>Leptogium denticulatum</i>	
24	<i>Parmotrema praesoredium</i>	
25	<i>Phaeophyscia hispidula</i>	
26	<i>Phaeophyscia orbicularis</i>	
27	<i>Phaeophyscia pyrrophora</i>	
28	<i>Phylliscum indicum</i>	
29	<i>Physcia dilitata</i>	
30	<i>Physconia distorta</i>	
31	<i>Pleopsidium flavum</i>	
32	<i>Psora decipiens</i>	
33	<i>Punctelia subrudecta</i>	
34	<i>Pyxine cocoes</i>	
35	<i>Rhizoplaca chrysoleuca</i>	
36	<i>Sturothele fissa</i>	
37	<i>Xanthoparmelia congenesis</i>	
38	<i>Xanthoria parietina</i>	

The table 2 highlights the distributional differences between the two habitat types, reflecting how varying degrees of anthropogenic disturbance influence lichen composition (**Figure 2**). Tourist centres such as Katra, Reasi, Bhomag and Thakarakote, which experience high visitor influx and infrastructural activity, supported a relatively smaller lichen assemblage dominated by tolerant and cosmopolitan taxa. According to the official records of the Shri Mata Vaishno Devi Shrine Board, every year millions of people visit and constantly more and more urban development is taking place to meet

the needs of the pilgrim tourism infrastructure, which matches the findings of Sharma and Raina (2014) in Katra. The impact of high anthropogenic activity on local lichen and cryptogam diversity is known to favour only tolerant and widespread species (Boggess *et al.*, 2024; Sevgi *et al.*, 2019). Increased pollution levels due to urbanization and the disturbances during the pilgrimage in the Himalayan region are known to cause dominance of pollution-tolerant taxa like Pyxine, Physcia and Lecanora (Upreti & Nayaka, 2008; Shukla *et al.*, 2014; Dar & Ahmad, 2015). All of them confirmed that Katra–Reasi and neighboring areas, with a high number of tourists and infrastructure, host a relatively small community consisting of tolerant and cosmopolitan species. Non-tourist sites, however, such as Thuru, Mahore, Chasana, Arnas and Pouni had more species and a number of sensitive taxa were limited to these less disturbed sites. (Dar and Parthasarthy., 2022; Kumar, 2024; Shukla and Upreti, 2011). The side by side listing allows direct comparison of taxa found in different ecological conditions highlighting the importance of the tourism intensity in the creation of diversity patterns for the lichen flora in the study area. Further, a detailed analysis of the data has been done by categorizing the species into three groups, reported in Table 4:

1. Lichen species exclusive to non-tourist sites
2. Lichen species exclusive to tourist sites
3. Common lichen species found at both sites

Table 4. Comparative representation of lichen species in non-tourist, tourist, and common sites of Reasi District

S.no.	Non-Tourist sites Exclusive Species	Tourist sites Exclusive Species	Common Species (Found in Both)
1	<i>Bacidia incongruens</i>	<i>Bacidia arnoldiana</i>	<i>Biatora spp.</i>
2	<i>Bacidia spp.</i>	<i>Dermato carpella squamulosum</i>	<i>Caloplaca subsoluta</i>
3	<i>Buellia disjecta</i>	<i>Dirinaria aegialita</i>	<i>Candellaria concolor</i>
4	<i>Caloplaca ahmediana</i>	<i>Lepraria spp.</i>	<i>Dermato carpon vellereum</i>
5	<i>Chrysothrix chlorina</i>	<i>Parmelia spp.</i>	<i>Diploschistes euganeus</i>
6	<i>Collema limosum</i>	<i>Phylliscum spp.</i>	<i>Diploschistes scruposus</i>
7	<i>Collema pulcellum</i>	<i>Verrucaria caerulea</i>	<i>Graphis spp.</i>
8	<i>Dermato carpon miniatum</i>		<i>Hyperphyscia adglutinata</i>
9	<i>Leptogium denticulatum</i>		<i>Hyperphyscia syncola</i>
10	<i>Lecanora achroa</i>		<i>Lepraria lobificiens</i>
11	<i>Lecanora albescens</i>		<i>Phaeophyscia hispidula</i>
12	<i>Lecanora muralis</i>		<i>Phaeophyscia pyrrophora</i>
13	<i>Lecanora perplexa</i>		<i>Phylliscum indicum</i>
14	<i>Parmotrema praesoredium</i>		<i>Physcia dilitata</i>
15	<i>Phaeophyscia orbicularis</i>		<i>Physconia distorta</i>
16	<i>Pleopsidium flavum</i>		
17	<i>Psora decipiens</i>		
18	<i>Punctelia subrudecta</i>		
19	<i>Pyxine cocoes</i>		
20	<i>Rhizoplaca chrysoleuca</i>		
21	<i>Staurothele fissca</i>		
22	<i>Xanthoparmelia congenesis</i>		
23	<i>Xanthoria parietina</i>		



Figure 2: Anthropogenic disturbances in study area

It is evident from the table 4 that the Reasi District has three different ecological categories of lichens. Less disturbed habitats like Thuru and Mahore have more of non-tourist exclusive species. These taxa (*Leptogium denticulatum*, *Xanthoparmelia congenesis*, *Parmotrema praesoredium*, etc.) can be used as good indicators of pristine environmental conditions, as they grow on clean air and stable microhabitats. A number of the taxa recorded, such as *Leptogium denticulatum*, *Xanthoparmelia congenesis* and *Parmotrema praesorediosum*, are well-recognized indicators of unpolluted air and microclimatic stability. Cyanobacterial lichens like *Leptogium* species are extremely sensitive to the atmospheric pollutants and they demand constant humidity and continuity of the habitat; hence they grow mostly in pristine habitats (Jayalal *et al.*, 2014; Upreti & Nayaka, 2008). *Xanthoparmelia* is found in stable, well-lit substrates in undisturbed habitats, and suffers severely at the hands of anthropogenic stress (Hale, 2002). Similarly, foliose *Parmotrema* spp. are physiologically sensitive to heavy metal and air pollution (Conti & Cecchetti, 2001; Huynh *et al.*, 2016; Raimundo-Costa *et al.*, 2021), and are good bioindicator species of air quality. Species-level sensitivity ratings available in the NACSE/NPS Lichen Air Sensitivity Database (n.d.) also classify these genera among the most pollution-sensitive groups. Recent Indian studies further corroborate that terricolous and foliose lichens with narrow microclimatic requirements thrive only under stable and undisturbed conditions (Rai *et al.*, 2021). Collectively, these findings substantiate that the presence of these taxa reflects sites with clean air and ecologically stable microhabitats. Tourist exclusive species, including *Dirinaria aegialita* and *Parmelia* spp., are typically tolerant of pollution, dust, and substrate disturbance associated with high visitor pressure in areas like Katra and Reasi. Several macrolichen taxa recorded from heavily visited pilgrimage and tourism zones—most notably *Dirinaria aegialita* and a number of *Parmelia* spp.—are well documented as pollution- and disturbance-tolerant. Studies of Indian and Himalayan lichen assemblages identify *Dirinaria* and related physcioid genera as common in urbanized or disturbed lowland and foothill sites and associate their dominance with increased dust, heavy-metal deposition, and substrate disruption (Nayaka, 2003; Shukla *et al.*, 2011). Reviews and biomonitoring studies further

show that many *Parmelia/Parmotrema* group members either tolerate or bioaccumulate pollutants and are therefore frequently found in anthropogenically altered environments (Yang, 2023; Arya, 2024). Recent regional surveys from the Reasi (Jammu & Kashmir) area and adjacent Himalayan localities likewise report a preponderance of pollution-tolerant functional groups (physcioid/crustose–foliose taxa) at high-visitor sites, consistent with tourist-driven disturbance and dust deposition (Darshni *et al.*, 2025). The totality of these sources corroborates the idea that high visitor numbers at pilgrimage/tourist sites (such as Katra-Reasi) favour the growth of tolerant *Dirinaria* and *Parmelia* taxa and decrease the occurrence of sensitive taxa. *Phaeophyscia hispidula*, *Physconia distorta* and *Caloplaca subsoluta* are common and occur throughout the vegetation, under both disturbed and natural conditions. *Phaeophyscia hispidula*, *Physconia distorta* and *Caloplaca subsoluta* are common species with very broad ecological tolerances, found both under natural and disturbed conditions. *P. hispidula* is known to be tolerant of heavy metal deposition and urban pollutants in the Garhwal Himalaya (Shukla & Upreti, 2007; Shukla, 2012) indicating the wide tolerance to anthropogenic stress. The studies on *Physconia* and related genera show that species of this group are eurytolerant both in terms of their land-use and in terms of the type of their substrate disturbance, even though they are found in a wide range of environments (Agnana *et al.*, 2017; Vicol, 2011). The generalist ecology of Genus *Caloplaca* is suggested by its frequent occurrence on both bark and rock substrates in disturbed forest landscapes (Tiwari & Prajapati, 2016). These results corroborate the hypothesis that these are generalist components of lichens in both stable and disturbed environments. This distribution pattern indicates that tourism intensity directly influences lichen assemblages, with sensitive species receding from high-disturbance zones while tolerant and cosmopolitan species persist or proliferate in impacted environments. The reduction in lichen diversity observed in highly disturbed recreational hotspots may have implications extending beyond ecological imbalance. Investigation on foliose lichens from Pir Panjal Himalaya demonstrated antimicrobial activity against clinically important bacterial strains highlighting medicinal potential of Himalayan lichen flora. Similar taxa observed within the present study area further emphasize the pharmaceutical relevance of conserving lichen rich habitats in district Reasi (Bhat *et al.*, 2024). Environmental stress induced by anthropogenic activities may also influence metabolite biosynthesis and physiological adaptation in lichens. Integrating ecological monitoring with molecular and biochemical investigations could therefore provide deeper insights into stress-associated variations in lichen communities (Rondilla & Edrada-Ebel, 2026).

CONCLUSION

The present study, conducted across nine sites in the Reasi District (Jammu & Kashmir), documents 50 lichen species belonging to 33 genera and 15 families, and reveals a marked contrast in species composition between tourist-influenced and non-tourist habitats. The dominance of the family Physciaceae in our assemblage aligns with earlier Himalayan studies (e.g., Bhat 2018; Mishra & Upreti 2016) and underscores its adaptability across varying micro-climates and disturbance regimes. Growth-form analysis demonstrated equal representation of crustose and foliose types (22 each) and minimal occurrence of leprose and squamulose forms; substrate-wise, corticolous lichens predominated (27 species), followed by saxicolous (20) and terricolous (3). The patterns are similar to others from the Himalayan context (e.g., Sheikh *et al.* 2013; Sharma *et al.* 2019) and confirm that bark-based substrata continue to be the most suitable niche in this region.

Indeed, our comparison of the lichen assemblages of tourist and non-tourist sites shows a distinct anthropogenic impact on lichens. A number of sensitive taxa associated with undisturbed microhabitats are found in the non-tourist sites whereas more tolerant and cosmopolitan taxa are found in tourist intensive areas. We, therefore, believe that our work confirms the lichen communities as early warning systems of habitat disturbance and atmospheric changes. This is similar to the results of international assessment of lichen bio-monitoring (e.g., Thakur 2024; Frati *et al.* 2023).

Our results indicate that conservation and management of undisturbed lichen habitats is important, particularly in the context of touristic landscapes. Proper planning of tourism in Reasi region should include ecosystem-health monitoring with lichens, control development of infrastructure around pilgrimage and adventure sites and continue to maintain substrate integrity (bark, rock) to ensure the full spectrum of lichens in the area.

Overall, the study adds to the expanding collection of Himalayan lichenological data and identifies local examples of the effects of tourism and disturbance on lichen diversity. These insights can complement regional biomonitoring approaches and to contribute to biodiversity assessment protocols in mountain ecosystems. Beyond this, it also highlights the need to consider anthropogenic disturbances not only in terms of community structure of lichens, but also in terms of the threat that these disturbances pose to species with high bioprospecting potential. Conservation strategies must be tailored to those taxa of lichens that are ecologically sensitive and potentially pharmacologically useful. The results suggest that there is a significant pharmaceutical potential of the lichen diversity of the area which requires further investigations by molecular characterization, metabolomic profiling and bioactivity screening.

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