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Lichenological studies in Nepal: A critical review

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ABSTRACT

Lichens are some of the ubiquitously distributed symbionts with a circumpolar distribution. The Himalayan habitats are lichenologically among the most researched region in Asia. European and Japanese researchers initiated the lichenological research in the Nepal Himalayas, which was later carried out predominantly by Indian lichenologists. The cumulative diversity of lichens in Nepal constitutes 882 species belonging to 186 genera and 61 families. Though the lichenological studies in Nepal largely constitute taxonomic and diversity enumeration studies, works in other applied fields have started in the last decade. The present review refers to the various taxonomical studies on lichens of Nepal by various researchers. The review also investigates the works done in the field of biomonitoring and bioprospection. The review conclusively discusses the prospects of lichen research in the country regarding the rich lichen biodiversity recorded so far and the various developments in the field of modern lichenology.

INTRODUCTION

Lichen, a symbiotic association of a dominant fungus (mycobiont) and a green (photobiont) and/or blue-green algae (cyanobiont) are often regarded as self-sustainable miniature ecosystems and are among the most successful symbionts in nature with circumpolar distribution (Farrar 1976; Longton 1988; Seaward 1988; Galloway 1992; Nayaka and Rai 2022). Although the total global diversity of lichen species is still speculative but has been estimated between 13,500 to 28,000 by different researchers (Hawksworth et al. 1996; Sipman and Aptroot 2001; Lücking et al. 2009). Lichens cover about 8% of the earth's terrestrial domains and their diversity increases at higher elevations in montane habitats (Nash III 2008; Rai et al. 2015). The Himalayan habitats are among some of the lichen-rich regions of the world (Upreti 1998). In the Indian subcontinent, lichenological research is well developed in India and now, taxonomic and diversity studies have diversified in various applied aspects of lichenology (Nayaka and Upreti 2021). Apart from India, the second most lichenologically studied nation in the subcontinent is Nepal. The lichenological studies in Nepal were initiated in the nineteenth century and mainly cover taxonomic, diversity, and ecological studies along with a few studies related to biomonitoring and bioprospection.

Nepal is a small landlocked Himalayan country with a total area of 147,516 km^2. The country harbors a large diversity of different plant groups ranging from higher plants to cryptogams such as bryophytes, fungi, and lichens (Paudel et al. 2012). Nepal largely falls in the central Himalayas and like the western and eastern Himalayas, shows a stratified vegetational pattern along the steep inclines of elevation and climate (Singh and Singh 1987). Western and Japanese researchers initiated the lichenological research in Nepal and further pioneered by Indian lichenologists. The lichenological research has been mainly done in the north and central Nepal, the area near Mt. Everest, and in some instances in eastern Nepal. Far west Nepal was largely untouched until CSIR-NBRI's Lichenology laboratory started exploring the region in the past decade. The current review has been done to enumerate the lichenological research in different fields of lichenology and critically explore the various future aspects of lichen studies in Nepal.

MATERIALS AND METHODS

A total of 223 abstracts/citations were identified for preliminary review using, Endnote X 7.0.1 (Bld 7272), searching the database of PubMed, Web of Science (TS), and LILACS, and manually through Google Scholar and Science Direct. The dissertations and thesis of the

central Department of Botany, Tribhuvan University, were accessed at https://elibrary.tucl.edu.np/. After the removal of duplicates and screening for relevant titles and abstracts, a total of 82 articles were chosen for a full-text study. Further, the articles of the offline journals such as Kavaka, Geophytology and others were searched physically in the literature bank of the Lichenology Laboratory, CSIR-National Botanical Research Institute. Finally, 124 articles were studied and used for preparing the present review.

RESULTS AND DISCUSSION

The lichenological research in Nepal can be categorized in the following headings.

Floristic Enumerations and Taxonomic Studies

The lichen diversity studies in Nepal though started in the early nineteenth century, the most of it was elucidated in the twentieth century. Among the various lichenologist who worked on the lichen flora of Nepal, the works of J. Poelt, Y. Asahina, S. Kurokawa, and D.D. Awasthi contributed largely to generating the country's current knowledge of lichen diversity. J. Poelt started his lichenological exploration of Nepal in 1962, where he explored the southern flank of the Mount Everest region, Solu Khumbu. In his successive expeditions, Poelt explored central Nepal. Most of his collections are housed at Munich State Botanical Collection (M) and Graz University Herbarium (GZU). Poelt published many enumerations and new species records of lichen species in about twenty publications. D.D. Awasthi, in the year 1957-58 explored many lichenologically rich regions of Nepal, such as Mewa Khola valley, and nearby regions, and reported a substantial diversity of lichens in the area. Currently, most of his collection is preserved in CSIR-National Botanical Research Institute herbarium (LWG), Lucknow, Uttar Pradesh, India. Dr. Awasthi published the taxonomic information of the Nepalese lichens in many enumerations, catalogs, keys, and compendiums. The Japanese lichenologists, I. Yoshimura, Y. Asahina, and S. Kurokawa, explored the eastern regions of Nepal extensively and published several new lichen species from the region.

Following is the chronological description of all the lichen diversity studies done in the last three centuries in different regions of Nepal.

Initiation of lichen diversity studies in Nepal: The nineteenth century

The first record of lichen from Nepal dates back to the year 1820 by the collection of Nathaniel Wallich done during 1820-26, from the eastern and northern regions of the country (Wallich 1826). Later lichen collections were done by J.D. Hooker and Thompson in 1846, published by Nylander (Nylander 1860).

Lichen Diversity Studies in Nepal in the Twentieth Century (19001-2000)

The twentieth century can be deemed as the most prolific century for lichen diversity studies in Nepal. Various expeditions led by researchers from Europe, Japan, and India lead to elucidating a considerable lichen diversity In Nepal. The twentieth century recorded the first indigenous Nepalese research on lichen diversity in the country. The following is a decadal account of various lichen diversity studies done in Nepal during the twentieth century.

Paulson (1925), published an account of about thirty-one lichen taxa collected by an amateur lichenologist Sommervella in 1924, from the Mt. Everest region of northern Nepal. Based on the collections of a Japanese explorer Nakao (1952-53), Asahina (1955) reported sixty-two lichens from different parts of eastern Nepal. Abbayes (1958), described many lichen species from their expeditions to Nepal between 1952 and 1954.

Awasthi (1960a), enumerated the genus *Physcia* from Nepal. Awasthi (1960b), enumerated lichens of Cho-Oyu from eastern Nepal. Awasthi (1963), published additions to the lichen flora of Nepal. Awasthi (1965), cataloged the lichen diversity of Nepal. Asahina and Kurokawa (1966) published sixty-two species of lichens new to science from their collections in eastern Nepal. Lamb (1966), reported ten species of lichen genera *Stereocaulon* from eastern Nepal. Poelt enumerated lichen genera *Ochrolechia*, and *Lecanora* from central Nepal (Poelt 1966a, b). Kurokawa (1967), recorded fifty-three species of lichens from the Rolwaling region (central-north Nepal), of which twenty-six species were new to Nepal. Bystrek (1969), enumerated twelve species of *Alectoria* from eastern Nepal of which three species- *A. perspinosa* Bystrek, *A. poeltii* Bystrek and *A. variabilis* Bystrek were new to science. Poelt and Reddi (1969), enumerated lichen genera *Candelaria* and *Candelariella* from Nepal.

Yoshimura (1971), reported *Lobaria subretigera* Inumaru, a synonym of *L. pseudopulmonaria* Gyeln., from the Rolwaling region of Nepal, and *Lobaria pseudopulmonaria* (= *L. isidiosa* (Müll. Arg.) Vain.), from Panchthar, east Nepal. Abbayes (1974), elucidated the distribution of *Cladonia* species from Nepal Himalayas. Kurokawa (l974), enumerated *Anaptychia* from eastern Nepal. Mitchell (1974), reported on the lichen genus *Leptogium* sect. *Mallotium* in Nepal. Jahns and Seelen

(1974) enumerated lichen genera *Baeomyces* from eastern Nepal. Poelt (1974) revised the lichen genera *Physica*, *Physciopsis*, and *Physconia* from Nepal Himalayas. The study reported 19 species of *Physica*, of which four were new to science, and fifteen species were new records for Nepal. The study further recorded two species each of *Physconia*, and *Physciopsis* from Nepal. Schmidt (1974), described lichens genera *Chaenotheca* and *Coniocybe* from Nepal. Vezda & Poelt (1974), reported two new species to science- *Dimerella lutea* (Dicks.) Trevis., and *Pachyphiale himalayensis* Vězda & Poelt. Poelt (1977a) enumerated many lichens from the Mt. Everest and Langtang region of central Nepal. Poelt (1977b, c) enumerated the lichen genera *Ioplaca*, *Dermatocarpon,* and *Solorina* from the Langtang region of central Nepal. Poelt (1977d), reported 12 species of *Umbilicaria* from Nepal. Hertel (1977), described 24 saxicolous species of *Lecidea* from Nepal of which seven species were new to science. Awasthi and Sharma (1978), reported several additions to the lichen flora of Nepal.

Awasthi (1982), enumerated the lichen genus *Cetraria* from eastern Nepal. Awasthi and Joshi (1982), enumerated the cyanolichen genus *Peltigera* from Nepal. Awasthi (1984), enumerated the genera *Hypogymnia* and *Menegazzia* from Nepal. Awasthi and Awasthi (1985), enumerated lichen genera *Alectoria*, *Bryoria,* and *Sulcaria* from various regions of Nepal. Vitikainen (1986), reported *Peltigera dolichospora* (D.A. Lu) Vitik., a new lichen species from eastern Nepal. Awasthi (1986), enumerated the genus *Usnea* from Nepal. Awasthi and Mathur (1987) enumerated many species of lichen genera *Bacidia*, *Badimia*, *Fallhaenra,* and *Mycobilimbia* from Nepal. Upreti (1987), prepared keys of sixty-two species of lichen genus *Cladonia* recorded from Nepal and India. Awasthi (1988), published a key of the macrolichens of Nepal along with India. Kurokawa (1988), recorded twenty-four species of genera *Parmelia*, and fourteen species of *Anaptychia* from Kathmandu valley, central Nepal. Poelt and Mayrhofer (1988), reported new lichen species-*Bryonora selenospora* Poelt & H. Mayrhofer, *B. reducta* Poelt & H. Mayrhofer, and *B. rhypariza* var. *cyanotropha* Poelt & H. Mayrhofer, from the Langtang region of central Nepal. Pant and Awasthi (1989), enumerated the lichen family Caliciales from Nepal.

Sharma and Kurokawa (1990a, b), enumerated lichen genera *Anaptychia*, *Parmelia,* and *Xanthoparmelia* from Nepal. Awasthi (1991), keyed out the microlichens of Nepal along with the lichens of India and Srilanka. Esslinger and Poelt (1991), while studying terricolous samples of *Parmelia* reported *Parmelia masonii* Essl. & Poelt from the Langtang and Khumbu region of central Nepal. Poelt and Obermayer (1991), revised the lichen genus *Bryonora* from Nepal Himalayas. Pant and Upreti (1993), recorded five species of *Diploschistes* from Nepal- *D. bisporus* (Bagl.) J. Steiner*, D. muscorum* (Scop.) R. Sant.*, D nepalensis* G. Pant & Upreti*, D. rampoddensis* (Nyl.) Zahlbr., and *D. scruposus* (Schreb.) Norman. Poelt and Grube (1993a, b), reported *Lecanora* subgen. *Placodium*, and *Tephromela* from central Nepal. Poelt and Petutschnig (1993) described the lichen genus *Xanthoria* and *Teloschistes* from mt. Everest and Langtang regions of central Nepal. Goffinet and Hastings (1995), reported sorediate taxa of *Peltigera-P. didactyla* var. *extenuata* (Nyl. ex Vain.) Goffinet & Hastings from mesic habitats of Nepal. Sharma (1995), compiled a checklist of lichens in Nepal which recorded 465 lichen species and 79 genera. Baniya (1996), reported 99 lichen species from Shivapuri and Sikles, out of which 33 species were new records in Nepal. Shakya et al. (1997), enlisted 471 lichen species from Nepal. Pathak (1998), described 52 species of lichens from Hetauda and Dang, central Nepal. Devkota (1999), enumerated 55 species of lichens from Namobuddha, Kavrepalanchok, Bagmati province, central Nepal. Pant and Upreti (1999), enumerated the lichen genus *Stereocaulon* from Nepal.

Lichen Diversity Studies in Nepal in the 21st Century (2001 onwards)

Upreti and Dixit (2002), reported eleven lichen species belonging to seven genera and five families, found growing on the plastic net, used as the fence in the nursery plots of Royal Botanical Garden, Kathmandu. The lichen species recorded were- *Heterodermia diademata* (Taylor) D.D. Awasthi, *H. firmula* (Linds.) Trevis, *H. incana* (Stirt.) D.D. Awasthi, *Lecanora flavidofusca* Müll. Arg., *Micarea* sp., *Parmotrema nilgherrense* (Nyl.) Hale, *Parmotrema tinctorum* (Despr. Ex Nyl.) Hale, *Pertusaria* sp., *Phaeophyscia endococcina* (Körb.) Moberg, *P. hispidula* (Ach.) Essl., and *Xanthoria candelaria* (L.) Arn. Pant and Awasthi (2003), enumerated the lichen genus *Ramalina* from Nepal. Upreti and Chatterjee (2004), mentioned the occurrence of *Tephromela khatiensis* (Räsänen) Lumbsch based on a specimen collected by Dr. D.D. Awasthi from east Nepal and annotated as *Lecanora* sp. Devkota (2006), studied the Phulchuki area of Kathmandu district, central Nepal. The study recorded 32 species of lichens belonging to nine families and ten genera among which the Parmeliaceae family dominated (Devkota 2006). Awasthi (2007), in a compendium of macrolichens of India, Nepal, and Sri Lanka enumerated the macrolichen diversity of Nepal.

Jørgensen and Olley (2010) reported *Leptogium sphaerosporum* P.M. Jørg. & Olley, a new species to science from the Langtang area of Nepal. Baniya et al. (2010), compiled a record of 525 species constituting the lichen flora of Nepal which represented by 40 families and 121 genera. Upreti and Divakar (2010), described the occurrence of *Sticta indica* D.D. Awasthi & Upreti in eastern Nepal, Mewa Khola valley between the elevation of 2600-2700 m. McCune et al. (2012), described seventeen species of *Hypogymnia* from the Himalayas of India and Nepal, of which four species were reported from Nepal. The *Hypogymnia* species reported from Nepal were- *Hypogymnia flavida* McCune & Obermayer (from Mewa Khola valley, east Nepal), *H. pseudobitteriana* (D.D. Awasthi) D.D. Awasthi (from Langtang Himal, the valley of Langtang Khola, North Nepal), *H. thomsoniana* (Müll. Arg.) D.D. Awasthi (from Mewa Khola valley, Topkegola near Sooduporthari in east Nepal), and *H. vittate* (Ach.) Parrique (from Mewa Khola valley, east Nepal). Olley and Sharma (2013), published a provisional checklist of the lichens of Nepal. The study recorded 792 lichen species belonging to 187 genera. Baral (2015), enumerated lichens from the Manaslu conservation area and Sagarmatha national park of central Nepal. The study recorded 81 species belonging to 15 families, of which Parmeliaceae dominated followed by Physceaceae and Cladoniaceae, respectively. Devkota et al. (2017c), studied the lichen family Lobariaceae in Nepal and assessed the conservation status of the family. The study recorded *Lobaria adscripturiens* (Nyl.) Hue, *L. fuscotomentosa* Yoshim., *L. aff. Quercizans* Michx., and *Sticta limbata* (Sm.) Ach. as new records for Nepal and discussed the conservation status according to IUCN parameters.

Rai et al. (2017), for the first time, explored the far west region of Nepal and recorded 28 new lichen species from the community forest of Dadeldhura, Mahakali zone, belonging to 13 families and 21 genera. The new lichen records were, *Acarospora fusca* B. de Lesd., *Arthonia recedens* Stirt., *Bacidia subannexa* (Nyl.) Zahlbr., *Buellia aethalea* (Ach.) Th. Fr., *B. disciformis* (Fr.) Mudd, *B. disjecta* Zahlbr., *Canoparmelia pustulescens* (Kurok.) Elix, *Chrysothrix candelaris* (L.) J.R. Laundon, *Cladonia coniocraea* (Flörke) Spreng., *Collema cristatum* (L.) Weber ex F.H. Wigg., *Endocarpon subrosettum* Ajay Singh & Upreti, *Graphis chlorotica* A. Massal., *G. proserpens* Vain., *Hafellia tetrapla* (Nyl.) Pusswald, *Herpothallon isidiatum* Jagad. Ram & G.P. Sinha, *Heterodermia albidiflava* (Kurok.) D.D. Awasthi, *H. hypochraea* (Vain.) Swinscow & Krog, *Hyperphyscia adglutinata* (Flörke) H. Mayrhofer & Poelt, *Lecanora luteomarginata* Nayaka, Upreti & Lumbsch, *Leptogium platinum* (Tuck.) Herre, *Myelochroa indica* (Hale) Elix & Hale , *Pyrenula complanata* (Mont.) Trevis., *Pyxine berteriana* (Fée) Imshaug, *P. farinosa* Kashiw., *Rinodina sophodes* (Ach.) A. Massal., *Verrucaria acrotella* Ach., *V. margacea* (Wahlenb.) Wahlenb., and *Xanthoparmelia australasica* D.J. Galloway. Karmacharya et al. (2018), recorded eighteen new species records from the family *Graphidaceae* from Nepal. The study is a substantial addition to the microlichens from Nepal. The new species records were, *Diorygma hieroglyphicum* (Pers.) Staiger & Kalb, *D. junghuhnii* (Mont. & Bosch) Kalb, Staiger & Elix, *Graphis antillarum* Vain., *G. breussii* G. Neuwirth & Lücking, *G. cincta* (Pers.) Aptroot, *G. cleistoblephara* Nyl., *G. galactoderma* (Zahlbr.) Lücking, *G. leprographa* Nyl., *G. lineola* Ach., *G. paradisserpens* Sipman & Lücking, *G. pertricosa* (Kremp.) A.W. Archer, *G. pinicola* Zahlbr., *G. stenotera* Vain., *G. subvelata* Stirt., *Pallidogramme chrysenteron* (Mont.) Staiger, Kalb & Lücking, *P. divaricoides* (Räsänen) Pushpi Singh & Kr.P. Singh and *Phaeographis leiogrammodes* (Kremp.) Müll. Arg.

Baniya (2020), concluded that the lichen flora of Nepal consists of 550 species of lichens that belong to 130 genera. The study found that the family Parmeliaceae with 110 species and 32 genera exhibits dominance followed by Physciaceae with 64 species and 11 genera and Lecanoraceae with 49 species and eight genera. Shrestha (2021), recorded 47 lichen species from Khaptad National Park, belonging to 29 genera and 14 families. The study further concluded that the lichen family Parmeliaceae was dominant with 17 species in the Khaptad National Park. Orange and Chhetri (2022), described one new genus and nine new species to science from Gandaki Pradesh, Kaski district, central Nepal. The newly described genus was *Nesothele*, and new species are- *Nesothele glebulosa* Orange, *Thelidium uvidulum* Orange, *Verrucaria antepotens* Orange, *V. lacteal* Orange, *V. parvipeltata* Orange, *V. senta* Orange, *Willeya eminens* Orange, *W. irrigate* Orange, and *W. nepalensis* Orange.

There are many lichen species named after their type locality from Nepal e.g., *Chaenotheca nepalensis* A.F.W. Schmidt, *Dimerella nepalensis* G. Thor & Vězda, *Gyalideopsis nepalensis* Vězda & Poelt, *Ramonia nepalensis* G. Thor & Vězda, *Cetrariastrum nepalense* (Taylor) W.L. Culb. & C.F. Culb., *Everniastrum nepalense* (Taylor) Hale ex Sipman, *Phaeophyscia nepalensis* (Poelt) D.D. Awasthi, and *Usnea nepalensis* G. Awasthi (Thor and Vězda 1984, Awasthi 1986).

Cumulative Lichen Diversity of Nepal

Considering all the published literature over the years, the current diversity of lichen in Nepal consists of 882 species belonging to 186 genera, and 61 families (Sharma 1995, Olley and Sharma, 2013, Rai et al., 2017, Devkota et al. 2017c, Karmacharya et al. 2018, Orange and Chhetri 2022). Among the total recorded lichen species, foliose is the most dominant (45%) growth form followed by crustose (39%) and fruticose lichen (17%). The dominance of foliose lichens primarily belonging to the family Parmeliaceae followed by Physciaceae, which may be due larger presence of temperate broad-leaved and coniferous forests at mid-elevations, conducive-less to non-polluted ambient air nutrient deposition, slow and lower level of urbanization, and still not so intense level of land use in the majority of the country.

As evident from the above account, there is a progressive increase in the number of lichen species recorded as lichenological research in Nepal is gaining momentum with time.

Ecological Studies of Lichens in Nepal

The lichen community dynamics in Nepal, like other parts of the Himalayas, is highly influenced by the heterogeneity of the montane habitats. In the last few decades, there has been a drastic change in the land use pattern in the Himalayas which has also affected the lichen diversity in Nepal. Following is the account of the few ecological studies done in various regions of Nepal Himalayas.

Shakya (2001), studied the ecology of lichens and their use as bioindicators in Phulchoki, Kathmandu district in central Nepal. Shrestha (2001), analyzed the nutrient content in the lichen growing on the *Quercus semecarpifolia* in Phulchowki Hill, Lalitpur, Nepal. Baniya et al. (2010), studied the elevational distribution pattern of lichens in Nepal employing generalized additive modeling and found that the maximum lichen diversity was at mid-elevations (i.e., 3100–3400 m). Nag et al. (2012), studied the diversity pattern of epiphytic lichen growing in the community forest. The study found a correlation between wood harvesting and lichen community dynamics in the community forest of Dadeldhura, Mahankali zone, far west Nepal. Chongbang (2013), analyzed the lichen species richness and community composition patterns along the altitudinal and land use gradients in the Kanchenjunga Conservation Area, Nepal. Shanki (2014), studied the lichen diversity and community composition along the gradients of altitudinal and land use types in the Manaslu Conservation Area, Central Nepal. Chongbang et al. (2018), studied the effects of elevation, land use, and canopy openness on species richness and composition of lichens in Ghunsa valley of Kanchenjunga Conservation Area, Eastern Nepal. The study found a gradual increase in lichen diversity from cultivated land to forests concluding that land use depended on substrate types and canopy openness influenced the distribution of lichen communities in the Himalayas.

The ecological studies on lichens of Nepal done so far though are few but they appropriately elucidate both the natural community dynamics of lichens and the changes in land use intensity introduced in the last few decades.

Lichen-based Pollution Bio-indicator Studies in Nepal

Lichens are considered excellent organisms for monitoring organic, inorganic, metalloids, polycyclic hydrocarbons, trace elements, and even radioactive substances present in the environment. The lichen-based pollution studies have been proved useful for the assessment of various pollutant deposition in the Himalayas (Shukla et al. 2014, Rai and Gupta 2022). The following are the few studies done where lichen has been used as a bio-indicators of pollution.

Chettri (1997), studied the responses of *Cladonia convoluta* (Lam.) and *C. rangiformis* (L.) Hoffm. against heavy metals. Bergamaschi et al. (2002), analyzed the biomonitoring potential of some lichen species-*Parmotrema*, *Hypotrachyna*, *Usnea*, *Etherodermia*, and *Hypogymnia* for about 20 trace elements in the Sagarmatha National Park, central Nepal. The study finds that elements such as Pb, Cu, Zn, Cd, As, Sb, and Br were not only deposited in lichens from the local soils but also, by long transport, from other anthropogenic sources. Pandey et al. (2002), analyzed the concentration of heavy metals in lichens collected in and around the Hetauda Industrial area, Narayani zone, Makwanpur district, central Nepal. The study reported that the lichens collected from the sites inside the industrial area had higher metal levels than the outside areas. Among the analyzed lichens *Pyxine meissnerina* Nyl. accumulated higher concentrations of the metals than other lichen species analyzed.

Ethnolichenological and Other Ecosystem-services Studies in Nepal

Lichens have been traditionally used in Asian countries as condiments and for perfume making. The use of lichens by montane tribes is well known, which in the past few decades has resulted in unsustainable commercial harvesting in the Himalayas (Upreti et al. 2005).

Moxham (1986) reported that about 800 tons of lichens are commercially harvested from Nepal for processing in the perfumery industry in India. The study found that oakmoss -*Evernia prunastri* (L.) Ach. and tree moss-*Pseudevernia furfuracea* (L.) Zopf are the primary species of lichens harvested from Nepal along with montane regions of France, Yugoslavia, Bulgaria, Morocco, and North India. Bhattarai et al. (1999), studied the nutritional contents of three lichen species i.e., *Parmelia nepalensis* Taylor, *Ramalina farinacea* (L.) Ach., and *R. conduplicans* Vain., and found them to be rich in carbohydrate, fat, crude fiber, and minerals. Panthi et al. (2012, 2015), in their studies on the diet of red panda (*Ailurus fulgens*) in Dhorpatan Hunting Reserve, Nepal, central Nepal. The study recorded that the diet of the red panda consists of 1-3% of foliose lichens. Pyakurel et al. (2018), studied the changes in 17 years of trade in medicinal plants from Darchula, far west Nepal. The study found that there has been a substantial increase in 2014–15 of 2.3-fold in volume and 17.2-fold in value as compared to 1997–98. The study further found that lichens were among the two most important medicinal commodities, and concluded that its increased trade was the result of increased demand in India and China. Pyakurel et al. (2019), analyzed the trade and conservation status of lichens along with other fungi, and medicinal plants. The study found that though the collection and trade of lichens is banned in Nepal, it constitutes about 7% of the total volume of illegal trade, which is threatening the survival of certain lichen species. Devkota et al. (2017a), enumerated the indigenous knowledge of lichen used by the tribal communities of Nepal. Devkota et al. (2017b), analyzed the anti-legislative illegal trade of lichens in Nepal and its effect on the conservation of lichen species in the country. Baniya (2020), mentioned traditional uses of lichens in Nepal as food, and traditional medicines.

Lichen Bioprospection Studies in Nepal

The lichens produce an array of unique secondary metabolites with potent antimicrobial activities (Elix and Stocker-Wörgötter 2008; Ranković 2015). Though there have been substantial studies worldwide where lichen bioactivities of lichen extracts have been studied, such studies are very limited in Nepal. Following are the few studies done on Nepalese lichens to assess their various bioactivities.

Devkota (1999), studied the antibiotic properties of *Heterodermia diademata* (Taylor) D.D. Awasthi, *Parmelia nepalensis* Taylor, and *Parmelia reticulata* Taylor. Baral and Maharjan (2011), assessed the antimicrobial and phytochemical potentials of high altitudinal lichens- *Usnea longissima* Ach. (mentioned as *Usnea longifolia*), *Cetraria* spp, *Parmotrema reticulatum* (Taylor) M. Choisy, and *Evernistrium nepalense* (Taylor) Hale ex Sipman. The study concluded that the lichen extracts were substantially effective against bacterial pathogens and phytopathogenic fungi tested. Jha et al. (2017), studied the antioxidant, antimicrobial, and toxicity activities of 84 lichen species collected from the Annapurna conservation area, central Nepal. The lichen extracts of studied lichen showed effective antibacterial (against gram-negative bacterium *Klebsiella pneumoniae*), antifungal activity (against the yeast, *Candida albicans*), and intense toxicity against brine shrimp.

Paudel et al. (2018), analyzed the antioxidant and antimicrobial activities of endolichenic fungi *Preussia* sp. isolated from *Canoparmelia* sp., collected from the Annapurna conservation area of central Nepal. The study isolated two compounds from endolichenic fungi *Preussia* sp. and three biological activities – DPPH reducing activities, brine shrimp toxicity, and antimicrobial activity against *Staphylococcus aureus* were studied. One of the compounds (compound 2), showed strong antioxidant activity.

Lichenometry Studies in Nepal

Bunds et al. (2010), studied the glacial lake outburst floods (GLOF)near Kyanjin Gompa in Langtang Valley, Nepal. The study used *Rhizocarpon geographicum* (L.) DC. maximum diameter data to correlate the rock surface exposure age for producing an apparent growth curve, which will give an estimate of the event of GLOF. Emmerman (2015), studied the growth rate of *Rhizocarpon geographicum* on Buddhist sacred walls, the mani walls, situated between Langtang Village and Kyanjin Gompa in Langtang Valley, eastern Nepal. A lichen growth curve was developed using different sources of indirect data and determined the wall's age. Emerman (2017) and Emerman et al. (2016) studied the area of Mani walls, Buddhist sacred walls in Langtang Valley, eastern Nepal Himalaya. The study used the map lichen *Rhizocarpon geographicum* to determine the age of the walls by comparing the lichen growth data with survey data from local inhabitants and detected the destruction of the wall during an earthquake event.

Future Prospects of Lichenological Studies in Nepal

Since the taxonomical account of different lichen taxa together with their diversity in some regions of the country are available, which will enable the researchers

to further explore the other multidimensional applications of lichenology such as environmental and pollution biomonitoring, biodeterioration studies, lichen dyes and climate change studies.

The lichens may be a good source of unique pharmaceutics but their low biomass and slow growth rate in nature restrict their feasibility for large-scale pharmaceutical use. As the process of lichenization is not very well understood yet, the *in-vitro* culture of lichen species (largely the mycobiont culture) is not very successful to get exact similar secondary metabolites as that of intact lichen thallus. The process of lichen culture is very tedious and time-consuming, making the whole practice of high-volume culture is non-feasible. The development of antimicrobial nanoparticles from lichens is some of the recent advances in applied lichenology (Pandian et al. 2017; Goga et al. 2021). The secondary metabolites of the Himalayan lichens exhibit antimicrobial properties (Tiwari et al. 2011; Rai et al. 2022), and the nanoparticles produced by Himalayan lichens also exhibit enhanced bioactivities (Rai and Gupta 2019). The lichens from Nepal should be studied for their various bioactivities and the advancement in nanoparticle synthesis from lichen extracts must be utilized for further development of lichen bioprospection in Nepal.

The lichens also harbor a large diversity of endolichenic fungi residing inside the thalli and have been the source of many novel metabolites with bioactivities such as antimicrobial, anti-inflammatory, etc. Endolichenic fungi provide an opportunity to discover novel natural compounds useful for humankind (Gao et al. 2016). Though there has been a study on the bioactivity of endolichenic fungi from Nepal, the lichens of Nepal given their rich lichen biodiversity must be further studied both for the endolichenic fungi and the isolation of novel compounds exhibiting various bioactivities.

The biodeterioration activities of lichens on monuments and historical buildings not only provide information on the extent of damage to the buildings but also indicate the environmental changes in the surrounding areas. Nepal is a culturally rich country that has several monuments and historical buildings where biodeterioration studies by lichens can be undertaken. The available information on monument and historical buildings can be useful for the conservation of monuments for preservation.

Lichens due to their slow growth rate and specific annual growth of the thalli have been very helpful in carrying out climate change studies. Specific lichen species e.g., *Rhizocarpon geographicum* are used in assessing the exposure time of the rock-forming glacier moraines during the events of the retreat of the glaciers. The lichen diameter change from the glacier mouth downwards can help assess the approximate time of glacier retreat. There have been some studies where lichenometry has been used to date certain sacred structures in Nepal, but the glacier retreat studies are lacking. The montane and glacier-rich area in Nepal can be studied for glacier retreat studies utilizing lichens. A variety of remote sensing data can be employed to map lichen distribution patterns at various scales where the spatiotemporal changes in the distribution of lichen communities can be used to develop predictive climate change models. The Lichen distribution pattern in higher alpine regions of Nepal Himalayas can play a vital role in long-term climate change monitoring programs.

The taxonomic knowledge available of lichens of Nepal must be extensively utilized for the assessment of the diversity and distribution patterns against various natural and anthropogenic factors. The diversity pattern studies of Nepalese lichens can be used for the development of a database for future research work on lichens of Nepal.

Besides diversity studies, lichenological research in Nepal now can be prioritized for studies such as bioprospection of lichen secondary metabolites, biodeterioration studies, biomonitoring, and climate change studies.

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