Patterns of lichen richness across elevation in the Manaslu Conservation Area, central Nepal

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Abstract

This study investigates the distribution of lichen richness along elevation gradients in the Manaslu Conservation Area, Central Nepal. A total of 95 lichen species, belonging to 40 genera and 18 families were recorded. The dominant growth forms were foliose, fruticose, crustose, and squamulose. Corticolous lichens were the most prevalent, followed by saxicolous, terricolous, and muscicolous species. Among the families, Parmeliaceae exhibited the highest species diversity, followed by Cladoniaceae. A hump-shaped relationship between elevation and lichen species richness was observed, with the peak occurring at approximately 3000 meters in the Manaslu Conservation Area. This pattern aligns with similar findings in other mountainous regions worldwide, indicating optimal growth conditions in the mid-elevation range. Contrasting lichen richness patterns with other regions in Nepal underscored the influence of broader environmental factors. The dominance of the Parmeliaceae and Cladoniaceae families highlights their ecological importance in shaping the lichen community structure. These findings have implications for lichen conservation and management strategies. Preserving the unique environmental conditions and microhabitats within the peak elevation range is crucial for maintaining lichen diversity. Further research is necessary to comprehend the underlying ecological processes and guide targeted conservation efforts.

Keywords: Climate, Forest, Hump-shaped, Species richness, Unimodal

1. Introduction

Lichens, fascinating symbiotic organisms consisting of a fungal partner and a photosynthetic partner (an alga or a cyanobacterium), exhibit remarkable adaptability and can be found in diverse habitats across the globe [1, 2]. These unique organisms play a crucial role in ecological processes and serve as valuable indicators of environmental conditions [3] and habitat suitability [4].

Nepal, with its vast range of elevations, from the lowland Tarai to the soaring peaks of the Himalayas, provides an excellent opportunity to investigate lichen richness patterns across elevation gradients [5–7]. The unique elevational gradient present in the Manaslu Conservation Area (MCA) offers an excellent opportunity to study the patterns of lichen richness [8]. As one ascends from the subtropical forests at lower elevations to the alpine meadows and rocky slopes at higher elevations, the environmental conditions change dramatically [5]. These changes in temperature, precipitation, and substrate availability are likely to affect the distribution and diversity of lichen species [9].

Several studies conducted in different mountainous regions worldwide have demonstrated that lichen diversity typically follows a distinct pattern along elevational gradient [5, 9]. Generally, species richness tends to be highest at mid-elevations, with a decline observed towards both lower and higher elevations. This pattern, often referred to as the mid-elevation peak, is thought to arise due to a combination of various factors, including climatic conditions, habitat complexity, and the presence of specific microhabitats. However, it is essential to note that the elevational lichen richness patterns can be influenced by regional and local factors, such as forest types and anthropogenic disturbances [10, 11].

Species richness patterns of lichens along elevational gradient in the Himalaya have been widely investigated and unimodal patterns have been observed in various areas [5, 6, 12–14]. However, some researchers reported a significant monotonic increase of total lichen species richness with elevation [15].

Understanding the lichen richness pattern along elevation gradients is of particular interest [16, 17], as elevation is a significant environmental factor that influences temperature, precipitation, and many other critical variables. Relatively few studies on elevational richness patterns of lichens in Nepalese Himalaya have been undertaken (5, 8, 15). Hence, the present study aimed to determine the lichen species richness pattern along elevation in MCA and to compare it with the general pattern found in Nepal.

2. Materials and Methods

2.1 Study area

The study was conducted in the MCA, located in Central Nepal (Fig. 1). MCA shares its borders with Tibet, China to the north and east of Gorkha district, while Manang and Lamjung are situated to the west and south, within the latitude range of 28°21′ – 28°45′ N and longitude range of 84°30′ – 85°12′ E. The conservation area spans an area of 1,663 square kilometers, and encompasses a wider range of elevation spanning from 2,000 meters above sea level (m asl) to 8,163 m asl, the peak of Mt. Manaslu. This diverse topography and climatic conditions make MCA an ideal location for studying the patterns of species distribution, including lichens. The primary focus of this study was Namrung village and the areas along the Budhi Gandaki River up to Samagaun village, encompassing elevations from 2,200 m asl to 4,400 m asl. Namrung village is characterized by *Quercus semecarpifolia* and *Pinus wallichiana* forest.

2.2 Lichen collection and identification

Field work was conducted in October 2012 to collect lichen specimens from various habitats. The specimens were gathered using a knife, chisel-hammer, and placed in separate paper envelopes. Details such as localities, elevations, life forms, and substrate types of each lichen sample collected were recorded. The collection was made within an elevation range of 2,225 m asl to 4,000 m asl. Subsequently, the collected lichen specimens were identified at the Laboratory of the Central Department of Botany, Tribhuvan University in Kathmandu. To identify the lichens, relevant keys and checklists were used, specifically those by Awasthi [18, 19], and Baniya et al. [20]. The identification process involved studying the morphology, anatomy, and chemistry of the specimens.

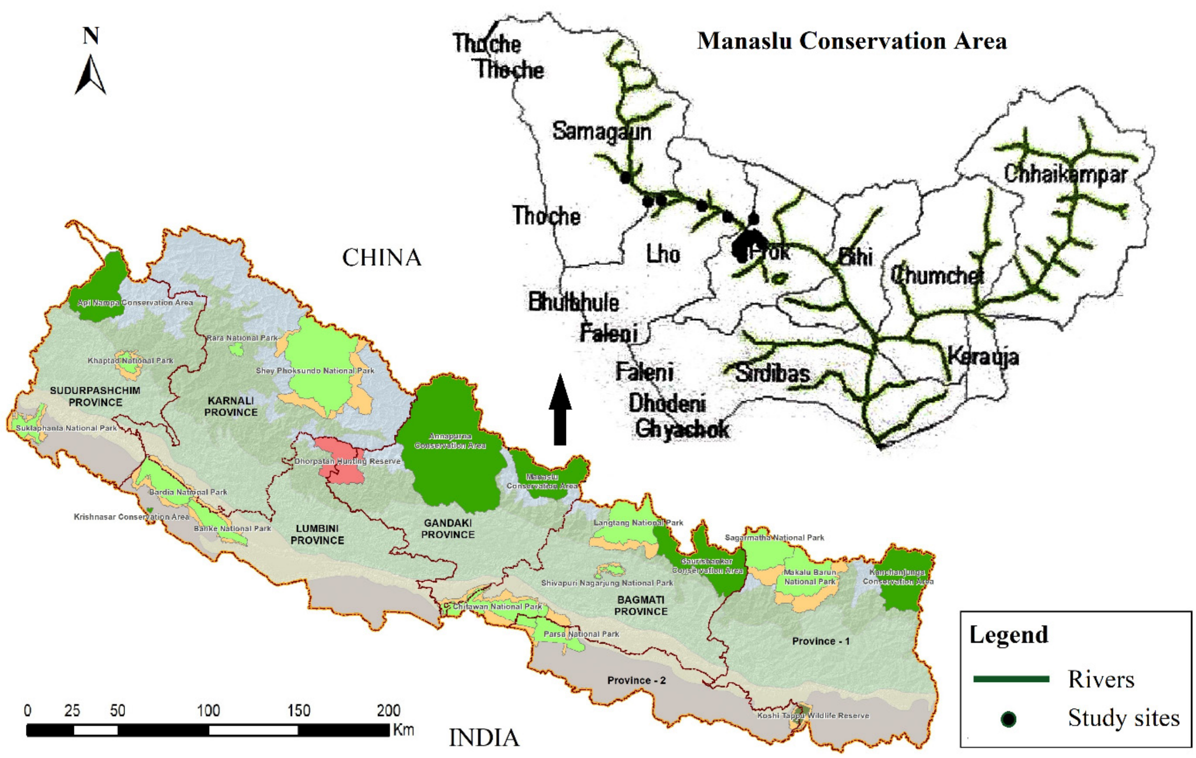

Fig. 1: Map of the study area: Manaslu Conservation Area (MCA) showing the location of study sites

Lichens are identified mainly based on chemical compounds located inside their thallus. Three chemical reagents viz. Potassium hydroxide solution (K), Calcium hypochlorite solution (C) and *para*-Phenylenediamine (Pd) combinedly called as color spot tests were applied on its thalli [1]. In addition to these color spot tests, lichen chemicals were extracted in acetone and loaded in precoated silica gel (Silica gel 60 F254) then after run into different solvent media. The lichen chemicals would be identified after washing it in dilute Sulphuric Acid and drying in a hot air oven [21]. Insights on chemical constituents in each lichen thallus were taken after color test and confirmed lists of chemicals. Voucher specimens were deposited at the Lichen Herbarium of Tribhuvan University Central Herbarium (TUCH).

2.3 Statistical analysis

The list of lichens occurring within the MCA was compared to the lichen checklist provided by Baniya et al. [20] in order to determine their respective elevation ranges. The obtained elevation range was then interpolated using the same method as described by Baniya et al. [5]. For instance, a lichen species called '*Baeomyces pachypus*' found in the MCA at an elevation of 3,000 m asl. After comparing it with the Nepali lichens checklist by Baniya et al. [5], it was determined that this species occurs within an elevation range of 2,768-4,200 m asl. In our interpolation method, we utilized this latter elevation range. The count of lichen species occurring at each elevation was determined using this method, and a regression analysis was performed to examine the relationship between lichen species richness and elevation. To conduct the regression analysis, we used the '*glm*' function, which is specifically designed for fitting generalized linear models, as described by McCullagh and Nelder [22]. This function extends linear regression to accommodate response variables with distributions beyond the assumptions of normality. In our case, lichen species richness is a count variable, so we specified the *Poisson* family and loglink functions. To address potential over-dispersion in our data, we utilized the quasi-poisson family of link functions to minimize the impact of errors. It is worth noting that in our *'glm'* regression analysis, we considered the 'deviance' more important than the p-value as a measure of model fit and goodness-of-fit assessment [22].

All statistical analyses were performed under the free statistical software environment R version 4.2.3 [23].

3. Results

3.1 Species diversity

A total of 95 lichen species belonging to 40 genera and 18 families were recorded in the MCA, Central Nepal (Table 1).

Table 1: Lichen species diversity in MCA

Family	Latin name	Life form	Habitat	Distribution range (m asl)
Baeomycetaceae	*Baeomyces pachypus* Nyl.	Squamulose	Terricolous	2768-4200
Candelariaceae	*Candelaria sphaerobola* Poelt & Reddi	Crustose	Muscicolous	3000-3900
	Candelariella xanthostigma (Pers. ex Ach.) Lettau	Crustose	Saxicolous	2700-3600
Chrysothricaceae	*Chrysothrix candelaris* (L.) J.R. Laundon	Crustose	Saxicolous	2200-3600
Cladoniaceae	*Cladonia amaurocraea* (Flörke) Schaer.	Fruticose	Terricolous	3100-5000
	Cladonia arbuscula (Wallr.) Flot.	Fruticose	Terricolous	2438
	Cladonia carneola (Fr.) Fr.	Fruticose	Terricolous	2400-4100
	Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	Fruticose	Muscicolous	2400-4000
	Cladonia corymbescens (Nyl.) Nyl.	Fruticose	Muscicolous	3900-5100
	Cladonia delavayi Abbayes	Fruticose	Terricolous	2900-5100

Family	Scientific name	Life form	Habitat	Distribution range (m asl)
	Cladonia fruticulosa Kremp.	Fruticose	Terricolous	3600
	Cladonia furcata (Huds.) Schrad.	Fruticose	Terricolous	2160-3800
	Cladonia mongolica Ahti	Fruticose	Terricolous	3100-4500
	Cladonia pyxidata (L.) Hoffm.	Fruticose	Saxicolous	2200-4267
	Cladonia ramulosa (With.) J.R. Laundon	Fruticose	Saxicolous	2000-3366
	Cladonia rangiferina (L.) Weber	Fruticose	Terricolous	2900-4000
	Cladonia rei Schaer.	Fruticose	Saxicolous	3800
	Cladonia submultiformis Asahina	Fruticose		3100-3800
	Cladonia yunnana (Vain.) Abbayes	Fruticose	Terricolous	3900-4000
Coccocarpiaceae	*Coccocarpia erythroxyli* (Spreng.) Swinscow & Krog	Foliose	Saxicolous	3150
	Coccocarpia pellita (Ach.) Müll. Arg.	Foliose	Corticolous	2400-2900
Graphidaceae	*Graphis guimarana* Vain.	Crustose	Corticolous	2200
	Graphis scripta (L.) Ach.	Crustose	Corticolous	1600-4000
	Graphis subglauconigra Nagarkar & Patw.	Crustose	Corticolous	2000-3600
Icmadophilaceae	*Thamnolia vermicularis* (Sw.) Schaer.	Fruticose	Terricolous	4000-5455
Lecanoraceae	*Protoparmeliopsis peltata* (Ramond) Arup, Zhao Xin & Lumbsch	Foliose	Saxicolous	2700
Lobariaceae	*Lobaria meridionalis* Vain.	Foliose	Corticolous	2200-3400
	Lobaria pindarensis Räsänen	Foliose	Corticolous	2700-4000
	Lobaria pseudopulmonaria Gyeln.	Foliose	Corticolous	2550-4050
	Lobaria retigera (Bory) Trevis.	Foliose	Corticolous	1600-3650
	Ricasolia japonica (Zahlbr.) Cornejo	Foliose	Corticolous	2200-4200
	Sticta limbata (Sm.) Ach.	Foliose	Corticolous	2200
	Sticta weigelii var. *weigelii* Isert ex Ach.	Foliose	Corticolous	3100
Pannariaceae	*Leptogium askotense* D.D. Awasthi	Foliose	Corticolous	1500-3800
	Leptogium austroamericanum (Malme) C.W. Dodge	Foliose	Corticolous	3600
	Leptogium brebissonii Mont.	Foliose	Corticolous	1800-3700
	Leptogium burnetiae C.W. Dodge	Foliose	Corticolous	1500-3400
	Leptogium delavayi Hue	Foliose	Corticolous	3000-4100
	Leptogium pedicellatum P.M. Jørg.	Foliose	Corticolous	1500-3800
	Leptogium saturninum(Dicks.) Nyl.	Foliose	Saxicolous	1500-4000
	Leptogium trichophorum Müll. Arg.	Foliose	Corticolous	1450-2200
Parmeliaceae	*Bryoria asiatica* (Du Rietz) Brodo & D. Hawksw.	Fruticose	Terricolous	2400-4000
	Bryoria confusa (D.D. Awasthi) Brodo & D. Hawksw.	Fruticose	Corticolous	3450-3740
	Bryoria nitidula (Th. Fr.) Brodo & D. Hawksw.	Fruticose	Corticolous	2768-3900
	Cetrelia braunsiana (Müll. Arg.) W.L. Culb. & C.F. Culb.	Foliose	Corticolous	3150-3594
	Cetrelia cetrarioides (Delise) W.L. Culb. & C.F. Culb.	Foliose	Corticolous	2200-3800
	Cetreliopsis rhytidocarpa subsp. *langtangii* Randlane and Saag	Foliose	Corticolous	2880-3500
	Dolichousnea longissima (Ach.) Articus	Fruticose	Corticolous	2400-3750
	Emodomelanelia masonii (Essl. & Poelt) Divakar & A. Crespo	Foliose	Corticolous	3000-6100
	Flavoparmelia caperata (L.) Hale	Foliose	Corticolous	2250-3800
	Flavoparmelia flaventior (Stirt.) Hale	Foliose	Corticolous	2250-3500
	Hypogymnia vittata (Ach.) Parrique	Foliose	Corticolous	2800-4200
	Hypogymnia wattiana(Müll. Arg.) D.D. Awasthi	Foliose	Corticolous	4000
	Hypotrachyna cirrhata (Fr.) Divakar, A. Crespo, Sipman, Elix & Lumbsch	Foliose	Corticolous	1900-4000

Family	Scientific name	Life form	Habitat	Distribution range (m asl)
	Hypotrachyna nepalensis (Taylor) Divakar, A. Crespo, Sipman, Elix & Lumbsch	Foliose	Corticolous	1400-3600
	Melanelia stygia (L.) Essl.	Foliose	Saxicolous	2500-2700
	Menegazzia terebrata (Hoffm.) A. Massal.	Foliose	Corticolous	1300-4000
	Montanelia panniformis (Nyl.) Divakar, A. Crespo, Wedin & Essl.	Foliose	Saxicolous	2400
	Montanelia sorediata (Ach.) Divakar, A. Crespo, Wedin & Essl.	Foliose	Saxicolous	4000
	Nephromopsis nephromoides (Nyl.) Ahti & Randlane	Foliose	Corticolous	2400-3800
	Parmotrema grayanum (Hue) Hale	Foliose	Corticolous	2200
	Parmotrema reticulatum (Taylor) M. Choisy	Foliose	Corticolous	1500-4000
	Punctelia neutralis (Hale) Krog	Foliose	Corticolous	3100
	Usnea aciculifera Vain.	Fruticose	Corticolous	1200-2225
	Usnea dendritica Stirt.	Fruticose	Corticolous	1200-4000
	Usnea norkettii G. Awasthi	Fruticose	Corticolous	3000-3700
	Usnea pictoides G. Awasthi	Fruticose	Corticolous	2800
	Usnea spinosula Stirt.	Fruticose	Corticolous	3600
	Usnea thomsonii Stirt.	Fruticose	Corticolous	1800-3400
	Xanthoparmelia mexicana (Gyeln.) Hale	Foliose	Corticolous	2700-3700
Peltigeraceae	*Dendriscosticta platyphylla* (Trevis.) Moncada & Lücking	Foliose	Corticolous	2200-3100
	Dendriscosticta praetextata (Räsänen) Moncada & Lücking	Foliose	Corticolous	2100-3800
	Nephroma helveticum var. *helveticum* Ach.	Foliose	Corticolous	2160-3100
	Peltigera polydactylon var. *polydactylon* (Neck.) Hoffm.	Foliose	Terricolous	1950-2920
	Peltigera praetextata (Flörke ex Sommerf.) Zopf	Foliose	Terricolous	3400
	Solorina bispora Nyl.	Foliose	Terricolous	2200-3200
	Solorina saccata (L.) Ach.	Foliose	Terricolous	3400
Pertusariaceae	*Pertusaria quassiae* (Fée) Nyl.	Crustose	Corticolous	2200-3200
Physciaceae	*Heterodermia comosa* (Eschw.) Follmann & Redón	Foliose	Corticolous	1500-3400
	Heterodermia diademata (Taylor) D.D. Awasthi	Foliose	Corticolous	1200-3800
	Heterodermia firmula (Linds.) Trevis.	Foliose	Saxicolous	1200-2200
	Heterodermia incana (Stirt.) D.D. Awasthi	Foliose	Corticolous	1800-2200
	Heterodermia obscurata (Nyl.) Trevis.	Foliose	Saxicolous	1400-4000
	Heterodermia punctifera (Kurok.) D.D. Awasthi	Foliose	Corticolous	2250-3200
	Leucodermia boryi (Fée) Kalb	Foliose	Muscicolous	2000-3700
	Phaeophyscia hispidula var. *hispidula* (Ach.) Essl.	Foliose	Corticolous	1400-3600
	Polyblastidium dendriticum (Pers.) Kalb	Foliose	Corticolous	2200
Ramalinaceae	*Ramalina intermedia* (Delise ex Nyl.) Nyl.	Fruticose	Corticolous	3800
	Ramalina roesleri (Schaer.) Nyl.	Fruticose	Corticolous	2200-3600
	Ramalina sinensis Jatta	Fruticose	Corticolous	2200-3700
	Ramalina usnea (L.) R. Howe	Fruticose	Corticolous	3500
Stereocaulaceae	*Stereocaulon glareosum* (Savicz) H. Magn.	Fruticose	Saxicolous	2700-4400
	Stereocaulon piluliferum Th. Fr.	Fruticose	Saxicolous	2160-5150
Umbilicariaceae	*Umbilicaria indica* var. *indica* Frey	Foliose	Saxicolous	1800-3150
Verrucariaceae	*Dermatocarpon miniatum* (L.) W. Mann	Foliose	Saxicolous	3200-3700

3.2 Life-form diversity

Among the recorded lichens, 57.9% were foliose, 33.7% fruticose, 7.4% crustose, and 1.05% squamulose (Fig. 2).

3.3 Habitat diversity

About 60% of the total lichen species were found on trees (corticolous), 18% on rocks (saxicolous), 16.8% on soil (terricolous), and 4.2% on mosses (muscicolous) (Fig. 2).

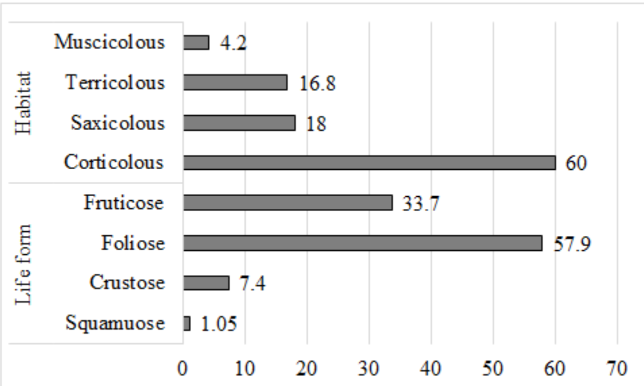

Fig. 2: Different life forms and habitats of lichen species

3.4 Family wise diversity

The most dominant family was Parmeliaceae (n=29), followed by Cladoniaceae (n=15) while single lichen species recorded from each family viz. Baeomycetaceae, Chrysothricaceae, Icmadophilaceae, Lecanoraceae, Pertusariaceae, Umbilicariaceae, and Verrucariaceae (Fig. 3).

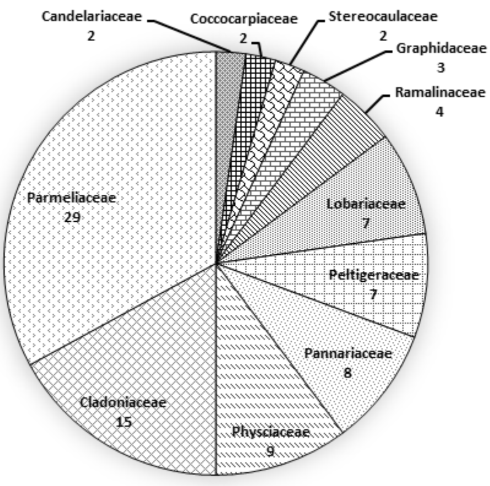

Fig. 3: Distribution of lichen families in MCA

3.5 Lichen species richness along elevation

A hump-shaped relationship between elevation and lichen species richness was observed (Fig. 4A). The maximum modeled lichen species richness, total 56 species, occurred at an elevation of 3,000 m asl in the MCA (Fig. 4B).

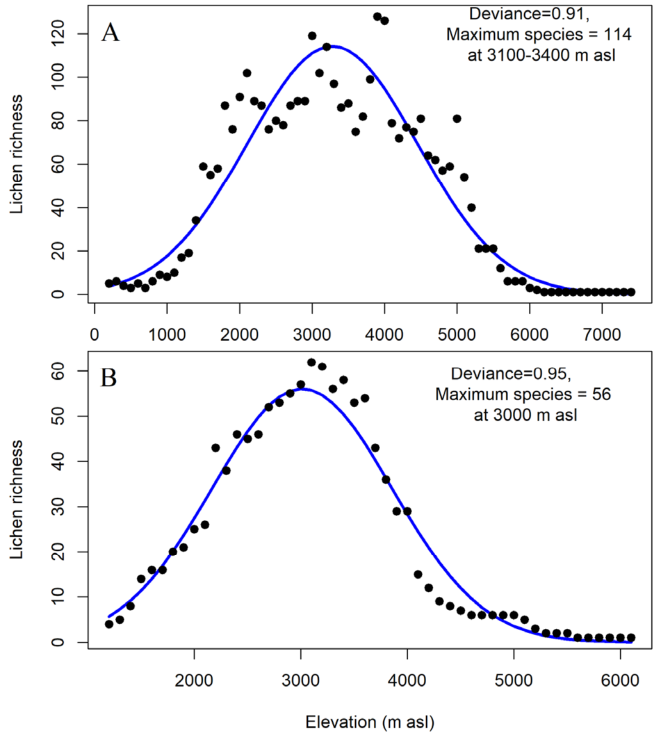

Fig. 4: Relationship between lichen richness and elevation. A. Total lichen species richness in Nepal; B. Lichen species richness in MCA

4. Discussion

The findings of this study provided valuable insights into the lichen richness patterns along elevation gradients in the MCA, Central Nepal. The recorded presence of 95 lichen species, belonging to 40 genera and 18 families, highlights the remarkable diversity of lichens in this region (Table 1). Previous researches have recorded 250 lichen species from MCA [8] while Baral [24] enumerated lichens from MCA and Sagarmatha National Park and recorded 13 lichen species from MCA. The lichen species exhibited a variety of growth forms, with foliose species being the most dominant, followed by fruticose, crustose, and squamulose species in line with several previous studies [25, 20, 15, 26]. Furthermore, lichens showed preferences for specific habitats, with corticolous (tree bark-dwelling) species being the most abundant, followed by saxicolous (rock-dwelling), terricolous (soil-dwelling), and muscicolous (moss-dwelling) species. Among the families, Parmeliaceae was the most diverse, followed by Cladoniaceae which corresponds with the findings of Baral [24] from the same area.

The observed hump-shaped relationship between elevation and lichen species richness is an intriguing finding that has been documented in various mountainous regions across the globe [5, 6, 12–14]. This pattern suggests that lichen richness reaches its maximum at a specific elevation before declining at both lower and higher elevations. In the case of the MCA, the peak of lichen species richness was found to occur at approximately 3000 m which was 100 m ahead then the pattern found by Baniya et al. [5].

Climatic conditions, such as temperature, precipitation, and humidity, play a crucial role in shaping lichen distributions [9, 12, 13, 27]. The mid-elevation zone often provides optimal conditions for lichen growth and reproduction, leading to higher species richness. In the MCA, the 3,000 m elevation range may offer favorable temperatures and moisture levels for a diverse array of lichen species. The availability of suitable substrates, such as tree bark and rocks, also contributes to the observed pattern, as different microhabitats and ecological niches are more abundant at intermediate elevations.

The dominance of the Parmeliaceae family in terms of lichen species richness aligns with global trends in lichen diversity. Parmeliaceae is known for its adaptability and wide ecological tolerance, enabling its members to thrive in diverse habitats across different elevations [28]. The prevalence of this family in the MCA suggests its ecological significance in shaping the lichen community structure. The Cladoniaceae family, another prominent group, is often associated with pioneer species that colonize exposed substrates such as rocks and soil. Their presence in the study area reflects the ecological importance of these lichens in early successional stages and their ability to establish in challenging environments [29].

The recorded hump-shaped pattern of lichen richness in the MCA aligns with similar elevational patterns observed in other mountainous regions of Nepal [5, 15]. Several studies conducted in different parts of the country have reported similar trends, with lichen richness peaking at intermediate elevations.

5. Conclusion

In conclusion, the study conducted in the MCA, Central Nepal, reveals important patterns of lichen richness along elevation gradients. The presence of 95 lichen species, representing 40 genera and 18 families, highlights the remarkable diversity of lichens in this region. The dominance of foliose lichens and corticolous species further underscores their ecological significance in the area.

The hump-shaped relationship between elevation and lichen species richness indicates that the peak of lichen diversity occurs at around 3000 meters in the MCA. This pattern aligns with similar findings in other mountainous regions worldwide, where mid-elevation zones provide optimal climatic conditions and a range of microhabitats conducive to higher species richness. The prevalence of Parmeliaceae and Cladoniaceae families further emphasizes their adaptability and ecological importance within the lichen community.

These findings have implications for lichen conservation and management strategies in the MCA and similar regions. Conservation efforts should focus on safeguarding diverse substrates and maintaining suitable ecological niches to ensure the survival of lichen communities.

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