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Research Article

SPECIES COMPOSITION AND DIVERSITY OF BRYOPHYTES ALONG THE ELEVATION GRADIENT IN PALPA DISTRICT, WEST NEPAL

Tulsi Neupane[1], Deepak Raj Pant[1], Giri Prasad Joshi[1]*

[1]*Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal*
**Correspondence: giri.joshi@cdb.tu.edu.np*

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ABSTRACT

Bryophytes are a distinct group of land plants that hold significant ecological and economic value. They form the second most diverse plant group, after angiosperms, yet remain the least explored and recorded. Previous studies have suggested exploring additional areas in Nepal to complete the documentation of the bryoflora. This study aims to document the species composition and diversity of bryophytes, along with environmental variables and soil macronutrients, in the tropical and subtropical bioclimatic zone of western Nepal. The bryophytes were studied quantitatively in 125 1 x 1 m quadrats across five elevation bands (300 to 1500 m asl.) at intervals of ca. 300 m, with five replicates in each band. Within each plot, a range of environmental factors (elevation, bareground, rock and canopy cover, coverage of herbs and bryophytes) were measured along with soil macronutrients (organic carbon, nitrogen, phosphorus, and potassium). Altogether, 39 bryophyte species were recorded, with mosses being the most prevalent group. Regression results indicated that bryophyte species richness increases with elevation but decreases as canopy cover and bareground expand. Despite appropriate climatic conditions, the instability of the topography due to frequent landslides minimize the occurrence of bryophytes in the present area.

Keywords: Bryophyte, Elevation gradient, Environmental variable, Species richness, Soil

INTRODUCTION

Bryophytes are the second most diverse group in the plant kingdom after angiosperms (Buck & Goffinet, 2000). Bryophytes, the basal clade of land plants, are believed to have evolved between 470 and 551 million years ago (Nickrent et al., 2000; Morris et al., 2018). They are recognized as a separate group comprising three distinct lineages: liverworts, hornworts, and mosses (Smith, 1991). They exhibit diverse life forms and can grow in diverse habitats, including damp soil, rock, moist or damp places, and shady areas (Joshi et al., 2024). Additionally, they can tolerate high temperatures, extreme desiccation, and cold conditions. In Nepal, their distribution is reported from the lowland tarai (62 m asl) to the highest elevation of 6500 m in the Himalayas (Pradhan, 2016).

The exploration of Nepalese bryophytes has a long history, beginning with the collections of Francis Buchanan-Hamilton during 1802-1803 and Nathaniael Wallich during 1820-1821 from the Kathmandu Valley and surrounding areas (Long, 2022; Pradhan & Shrestha, 2022). Subsequent bryological explorations continued until 2005 through expeditions conducted primarily by Indian, Japanese, and British researchers, with a major focus on central and eastern Nepal (Pradhan & Shrestha, 2022). Since 1982, Pradhan, a pioneering Nepalese bryologist, has made substantial contributions to the study of Nepalese bryophytes and added numerous species to the country's bryophyte flora (Pradhan, 2002, 2013, 2014, 2018; Pradhan and Joshi, 2006; 2007a, 2007b). To date, 1318 species have been documented in Nepal, representing approximately 6.5% of the world's total bryophyte diversity (ca. 20,000 species), and about 53% of the bryophytes reported from India (2489 taxa) (Patiño & Vanderpoorten, 2018; Borkataky et al., 2022; Pradhan, 2023). Comparatively, bryophyte diversity in other South Asian countries has been documented as 568 species in Sri Lanka (O'Shea, 2002), 367 species in Bhutan (Gyeltshen et al., 2019), and 339 species in Pakistan (Higuchi and Nishimura, 2003). The lowest number of bryophyte species in the region has been recorded from Bangladesh with 249 species (Tabassum et al., 2020). Although bryophyte diversity in Nepal is lower than that of India, it is higher than that reported from other South Asian countries.

The distribution of bryophytes is associated with the availability of moisture content in the habitat, disturbances in the habitat, mountain slopes, and aspects (Sharma et al., 2021; Khati et al., 2022; Joshi et al., 2024). Their distribution is also influenced by various factors like rainfall, temperature, elevation, and latitude (Sveinbjornsson & Oechel, 1992).

Several studies have reported varying patterns of bryophyte diversity along elevation gradients. An increasing trend in species richness with elevation has been documented by Gradstein et al. (1989) in the Colombian Andes (500-4500 m), Bruun et al. (2006) in northern Fennoscandia (250-1525 m), and Ah-Peng et al. (2007) in La Reunion (250-850 m). In contrast, a hump-shaped pattern, with peak diversity at mid-elevations, was observed by da Costa et al. (2015) in Itatiaia National Park (600-2787 m), and González et al. (2017) in Ecuador (2700-4000 m). Similar mid-elevation peaks have been consistently reported from Nepal, including studies by Grau et al. (2007) in the central Himalayas (100-5500 m), Pradhan (2013) in Panch Pokhari region (850-4300 m), Pradhan (2014) in Chandragiri (1350-2300 m), and Pradhan (2023) in Langtang National Park (1500-4380 m). Conversely, a decreasing trend in species richness with increasing elevation was reported by Vittoz et al. (2010) in Switzerland, from the treeline to the nival zones. An insignificant relationship between bryophyte richness and elevation was documented by Grytnes et al. (2006) in western Norway (310-1135 m), where moisture conditions were considered a more influential factor than elevation.

Despite more than two centuries of botanical exploration, the bryophyte flora remains incompletely documented, particularly in the underexplored regions of far-eastern and far-western Nepal. Furthermore, ecological studies that examine the influence of environmental variables (elevation, bare ground, rock cover, canopy cover, and herb and bryophyte cover) on bryophyte species richness remain limited. To date, such investigations have been conducted only in a few regions, notably central Nepal (Sharma, 2018) and far-western Nepal (Paudel, 2019). In this context, the present study aims to investigate bryophyte species composition and richness along a short elevation gradient in the Palpa district of western Nepal.

MATERIALS AND METHODS

Study area

The Palpa district of western Nepal extends from 27˚34' - 27˚57' N latitude and 83˚15' - 84˚22' E longitude (Fig. 1). It covers an area of about 1366 square Kilometers, with 52.11% under forest cover (Mahato, 2014). Out of the total land area of Palpa, 18% lie in the Siwalik (Chure) region, and 82% lie in the Mahabharat range (DFO, 2007). The study site spans tropical and sub-tropical bioclimatic zones along the Dovan-Chahara trail. Lower elevations are characterized by *Shorea robusta* and mixed hardwood forests, while higher elevations are dominated by *Pinus roxburghii* and *Schima-Castanopsis* forest types. The meteorological data of the last ten years revealed maximum rainfall in July (516 mm) while no rainfall in November. The hottest days were experienced in June (30°C), and the coolest in January (6.22°C) (Fig. 2).

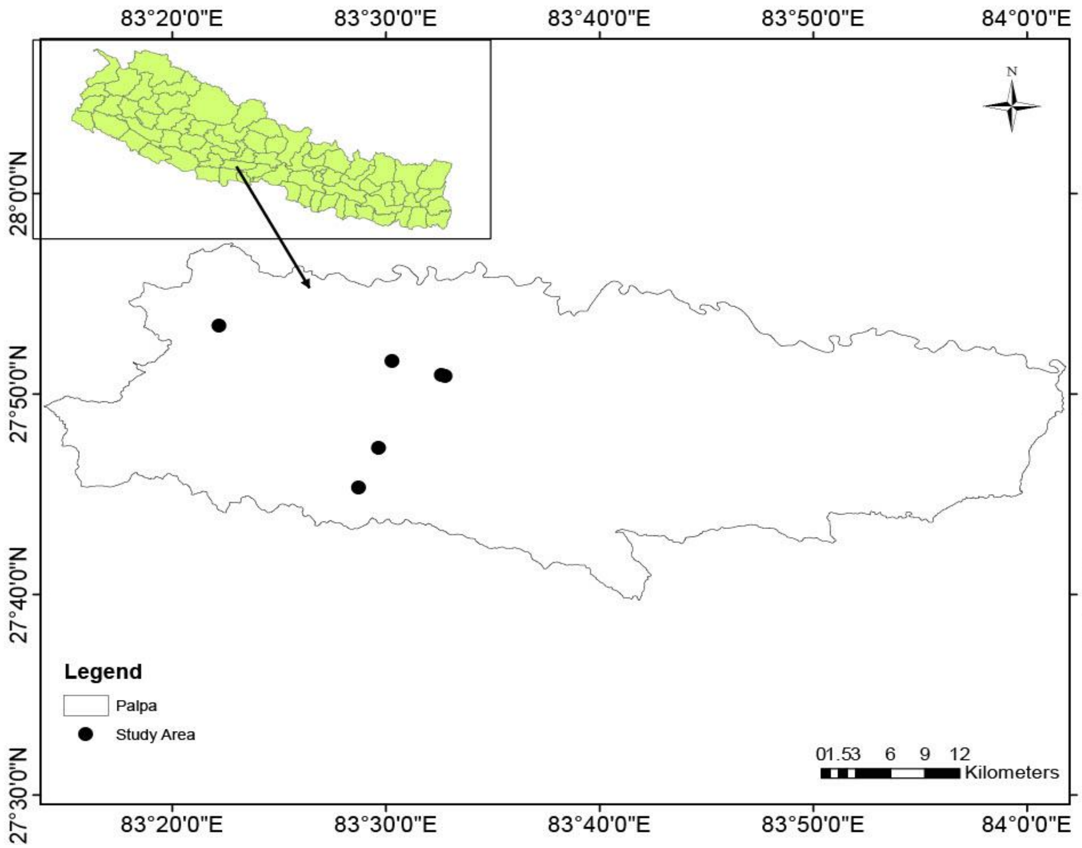

Figure 1. Map of Palpa district showing the study area

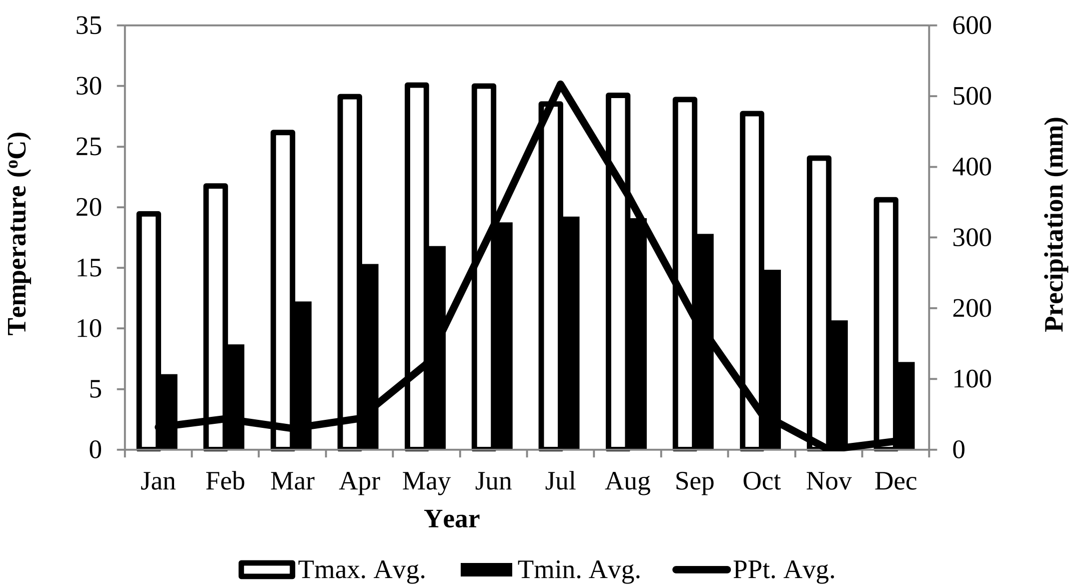

Figure 2. Ombrothermic graph of climatic data of Palpa from 2011-2021

(Source: Department of Hydrology and Meteorology (DHM, 2022)

Sampling design

Systematic random sampling was done following Sharma (2018), with minor modifications described below. The study area was categorized into five elevation bands, spanning 300 to 1500 m, with an interval of approximately 300±85 m, adjusted according to the local topography. At each elevation band, a circular sample plot of 10 m radius, and within it, 5 subplots of 1 m x 1 m, were laid down. The subplots were laid in a way that one plot lies at the center, and the remaining ones lie in four different directions. The sampling sites were selected to cover all the possible habitats (terrestrial, lithophytic and epiphytic). The circular plots were repeated five times at each band and were laid at least 50 m away from one another. The sample plots were geolocated with a GPS (eTrex, GARMIN). The soil samples were also collected from the sampling sites for nutrient analysis. For every subplot, the bryophytes were noted together with environmental factors (elevation, bare ground, rock and canopy coverage, coverage of herbs and bryophytes). The environmental factors were quantitatively calculated on a scale between 0% to 100%.

Identification of the specimens

The collected specimens were identified following Gangulee (1969-1980), Kashyap (1929), Kashyap and Chopra (1932), Cases et al. (2009), Pradhan and Shrestha (2021, 2022). The identified specimens were properly cited following TROPICOS. The species were categorised according to Goffinet et al. (2009) for mosses, Crandall-Stotler et al. (2009) for liverworts, and Stotler and Crandall-Stotler (2005) for the hornworts. The voucher specimens (T 001 - T 074) were deposited at the TUCH (Tribhuvan University Central Herbarium).

Species richness and macronutrient analysis

The species' richness was calculated by the formula following Ingerpuu and Sarv (2015).

Where species richness = no. of species per plot

The soil samples collected from different plots were analysed following different protocols: soil organic matter (OC) by Walkey and Black method (Gupta, 2002; Broadbent, 2015), potassium (K) content by flame photometer (Thomos, 1982), phosphorous (P) content by modified Olsen's bicarbonate method (Gupta, 2002), nitrogen (N) by Kjeldahl method (Bremner, 1960), and soil texture for each elevational band by hydrometer method (Bouyoucos, 1962).

Statistical analysis

The data on the relationship between species richness pattern and different environmental variables were analysed by Generalized Linear Model (GLM). Using multivariate analysis or ordination, the link between bryophyte species richness and other environmental factors was investigated. For this, Detrended Correspondence Analysis (DCA) was done by using R packages version 3.6.2 (R Core Team, 2019). As the DCA showed the axis length and eigenvalue greater than 2.5 and 0.5, respectively, Canonical Correspondence Analysis (CCA) was performed.

RESULTS

Species composition

A total of 39 bryophyte species were recorded, encompassing 5 classes, 10 orders, 21 families, and 27 genera (Table 1). Mosses were the most prevalent lineage (51%), followed by liverworts (41%), and hornworts (8%). Similarly, Bryopsida was recorded as the dominant class (16 species), and Marchantiales as the dominant order (10 species) (Table 1).

Table 1. Bryophyte species, their habitats, and elevational distribution

S.N.	Ranks	Species	**Habitat	Elevation m asl
	[a]**Marchantiopsida**			
	[b]**Marchantiales**			
1	*Marchantiaceae	*Marchantia emarginata* Ren. Blume & Nees	Lit. + Ter.	300-900
2		*Marchantia polymorpha* L.	Ter.	600
3	*Aytoniaceae	*Asterella khasyana* (Griff.) Grolle	Lit. + Ter.	1235-1586
4		*Asterella multiflora* (Steph.) Pandé *et al.*	Lit. + Ter.	575-900
5		*Asterella wallichiana* (Lehm. & Lindenb.) Grolle	Ter.	286-1260
6		*Plagiochasma appendiculatum* Lehm & Lindenb.	Lit. + Ter.	300-900

7		*Reboulia hemisphaerica* (L.) Raddi	Lit. + Ter.	600-1500
8	*Conocephalaceae	*Conocephalum conicum* (L.) Dumort.	Ter.	572-1586
9	*Dumortieraceae	*Dumortiera hirsuta* (Sw.) Nees	Ter.	273-1580
10	*Monosoleniaceae	*Monosolenium tenerum* Griff.	Lit. + Ter.	325-600
	[a]Jungermaniopsida			
	[b]Porellales			
11	*Lejeuneaceae	*Lejeunea* sp.	Epi.	900-1500
	[b]Jungermanniales			
12	*Lophocoleaceae	*Heteroscyphus planus* (Mitt.) Schiffn.	Ter.	600-1500
13		*Heteroscyphus argutus* (Reinw. Blume & Nees) Schiffn.	Ter.	900
14	*Jungermanniaceae	*Jungermannia* sp.	Ter.	600-1500
15	*Gymnomitriaceae	*Nardia* sp.	Ter.	1200-1500
16	*Scapaniaceae	*Scapania* sp.	Lit.	300-1500
	[a]Polytrichopsida			
	[b]Polytrichales			
17	*Polytrichaceae	*Atrichum undulatum* var. *subserratum* (Harv. & Hook. f.) Paris	Ter.	1200-1500
18		*Pogonatum microstomum* (R. Br. exSchwägr.) Brid.	Lit. + Ter.	900-1500
19		*Pogonatum submacrophyllum* Herzog	Lit. + Ter.	900-1500
20		*Polytrichum commune* Hedw.	Lit.	300-900
	[a]Bryopsida			
	[b]Funariales			
21	*Funariaceae	*Funaria hygrometrica* Hedw.	Lit. + Ter.	300-1500
	[b]Dicranales			
22	*Dicranaceae	*Dicranum setchwanium* Broth.	Ter.	600-1200
23		*Dicranum himalayanum* Mitt.	Ter.	1586
24	*Fissidentaceae	*Fissidens bryoides* Hedw.	Ter.	600-900
25		*Fissidens sylvaticus* Griff.	Ter.	300-900
26		*Fissidens taxifolius* Hedw.	Ter.	300-900
27		*Fissidens* sp.	Ter.	1200
28	*Bruchiaceae	*Trematodon longicollis* Michx.	Lit. + Ter.	300-900
	[b]Bryales			
29	*Bryaceae	*Bryum* sp.	Ter.	1200-1500
30		*Bryum caespiticum* Hedw.	Ter.	1200-1500
	[b]Bartramiales			
31	*Bartramiaceae	*Philonotis falcata* (Hook.) Mitt.	Lit. + Ter.	600-1500
32		*Philonotis thwaitesii* Mitt.	Lit. + Ter.	1470-1586
	[b]Pottiales			
33	*Pottiaceae	*Hyophila involuta* (Hook.) A. Jaeger	Ter.	635-1140
34		*Bryoerythrophyllum dentatum* (Mitt.) P.C. Chen	Ter.	300-1500
35	**[b]Hypnales**			
	*Meteroriaceae	*Meteriopsis reclinata* (Müll. Hal.) M. Fleisch.	Epi.	1480-1586
36	*Brachytheciaceae	*Eurhynchium praelongum* (Hedw.) Schimp.	Epi.	1480-1586
	[a]Anthocerotopsida			
	[b]Anthocerotales			
37	*Anthocerotaceae	*Anthoceros punctatus* L.	Ter.	900-1500
38		*Anthoceros* sp.	Ter.	1500
39		*Folioceros assamicus* D.C. Bhardwaj	Ter.	600-1500

[a] = Class, [b] = Order, * = Family, ** Lit. = Lithophytes, Ter. = Terrestrial, Epi. = Epiphyte

Among the 21 families of bryophytes, equal representation was observed for liverworts and mosses, i.e., 10 families each (16 species of liverworts and 20 species of mosses). Among the bryophyte families, Aytoniaceae was the most abundant, comprising five species, followed by Polytrichaceae and Fissidentaceae with four species each, Anthocerotaceae with three species. In a similar vein, six families (Pottiaceae, Bartramiaceae, Bryaceae, Dicranaceae, Lophocoleaceae, and Marchantiaceae) included two species each, while the remaining families were represented by a single species (Fig. 3, Table 1).

Altogether, 27 genera of bryophytes were recorded. Among them, *Fissiden* was the most dominant genus with four species, followed by *Asterella* with three species (Table 1).

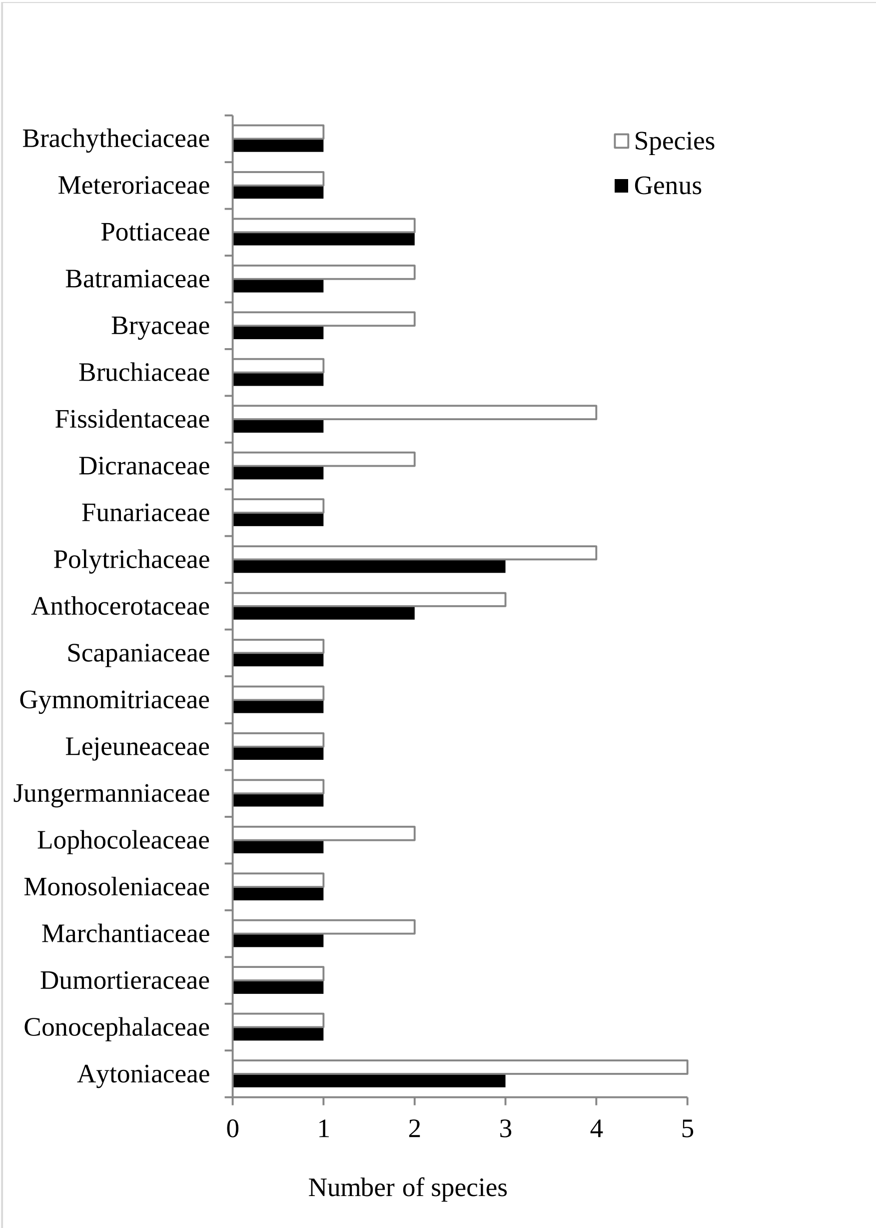

Figure 3. Family-wise distribution of genera and species

The bryophytes were grown on four different habitat types (epiphytic, lithophytic, terrestrial, lithophytic + tettestrial) with more than half of the species (56%) on terrestrial habitats and very small number on lithophytic habitats (5%) (Fig. 4).

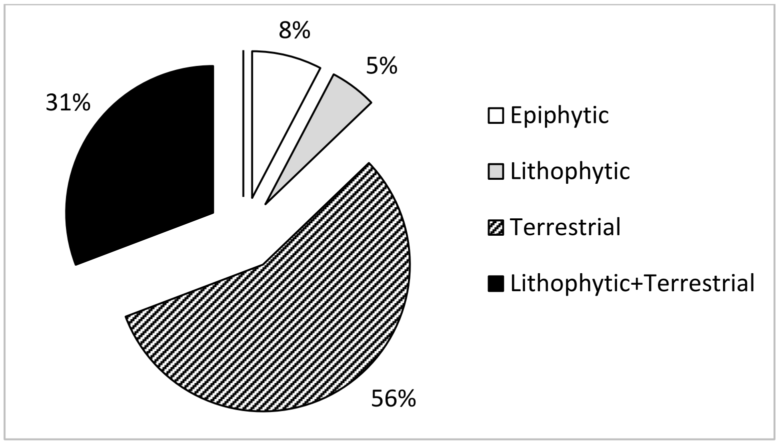

Figure 4. Habitat-wise distribution of bryophytes

Species richness pattern with different environmental variables

Regression analysis

The regression analysis revealed an insignificant relationship with tested soil parameters (OC: $p = 0.4423$, N: $p = 0.4308$, P: $p = 0.8648$, K: $p = 0.2663$), and other environmental factors (rock coverage: $p = 0.1814$, herb coverage: $p = 0.8769$, other plants: $p = 0.0988$). However, significant inclining linear relationship was obtained between species richness and elevation range (Fig. 5), declining relation with canopy cover (Fig. 6) and bareground (Fig. 7).

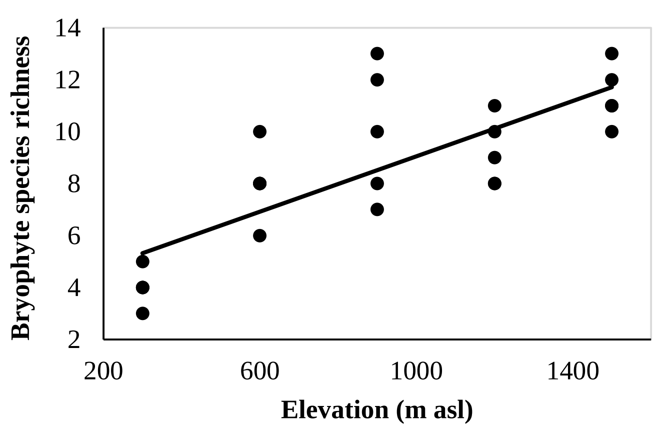

Figure 5. Correlation between the elevation range and bryophyte species richness. The fitted line represents a first-order Generalized Linear model (GLM) ($y = 0.0053x + 3.72$, $R^2 = 0.6206$, $p < 0.001$)

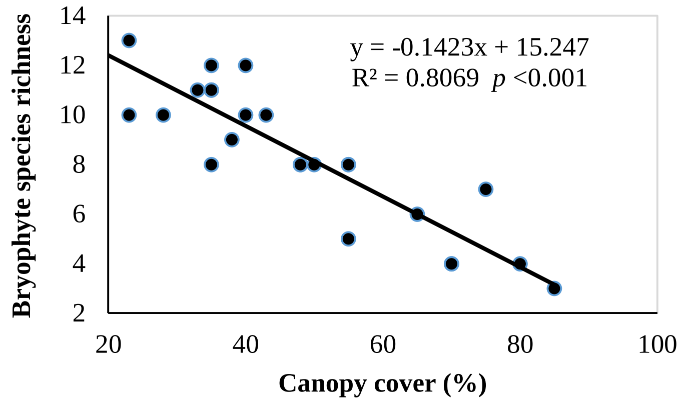

Figure 6. Correlation between bryophyte species richness and canopy cover. The fitted line represents a first-order Generalized Linear model (GLM)

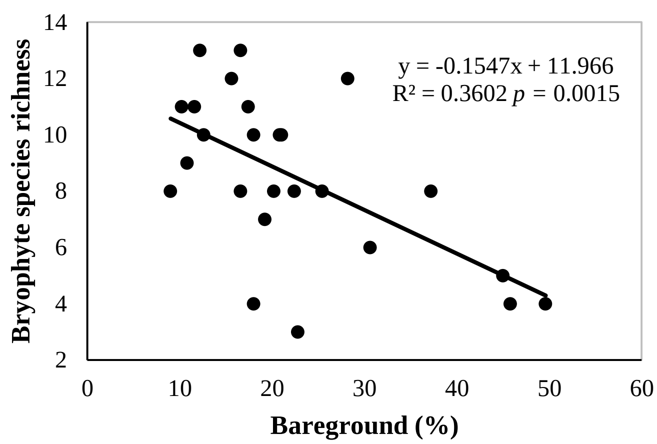

Figure 7. Correlation between bryophyte species richness and bare ground. The fitted line represents a first-order Generalized Linear model (GLM)

Ordination

The CCA analysis revealed elevation as the most significant gradient, represented by the first CCA axis (Fig. 8). All measured environmental factors (bare ground, canopy cover, rock cover, other associated plants, bryophyte cover) and soil parameters varied significantly with the bryophytes species richness. Soil parameters (carbon, nitrogen and potassium) and bryophyte cover were strongly and positively correlatted, but they were negatively correlated with elevation. There was a considerable negative association between the soil phosphorus content and other plants. Conversely, soil phosphorus content and other plant cover were negatively correlated with rock cover, canopy cover, bare ground and herb cover.

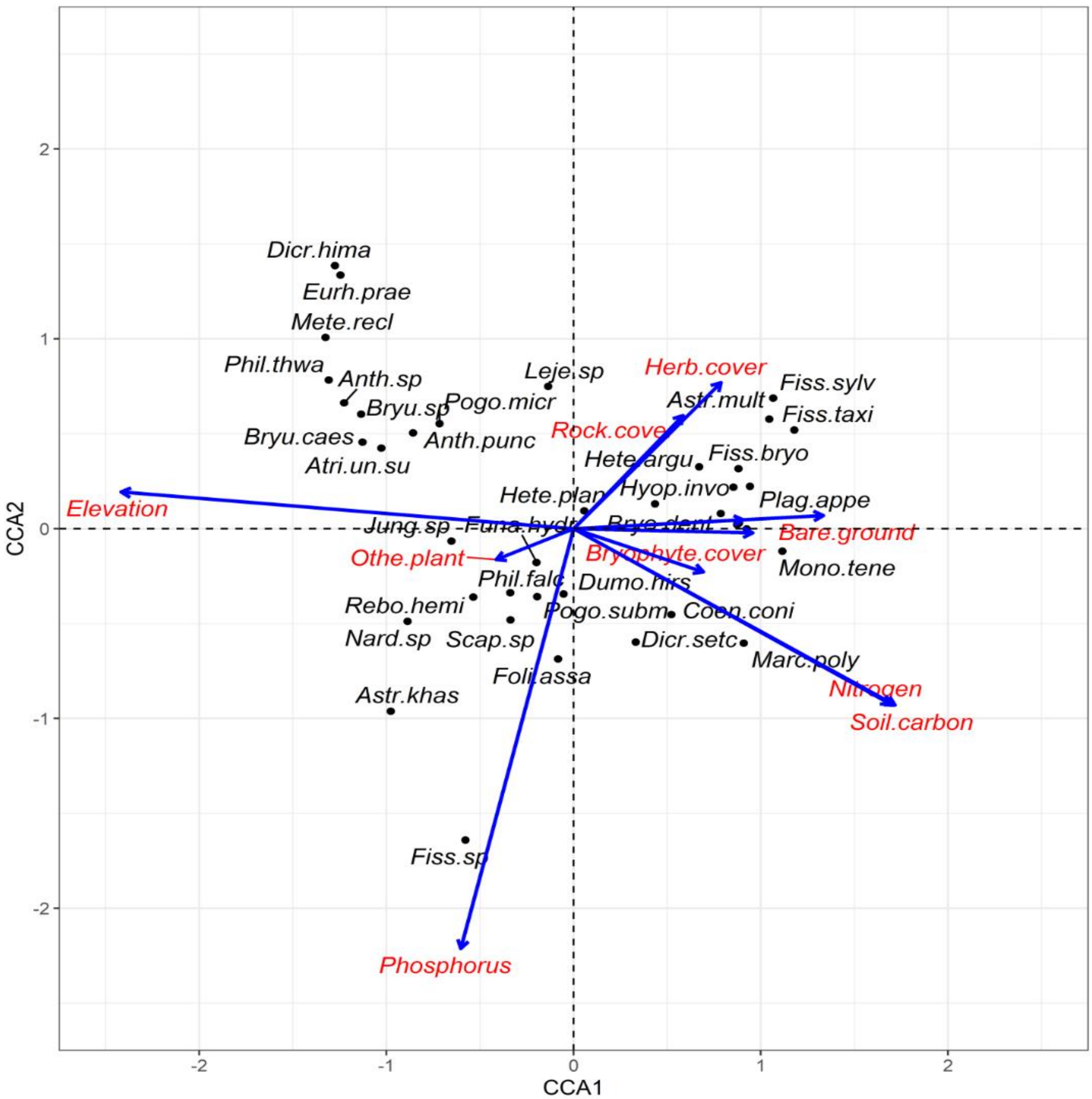

Figure 8. CCA triplot showing environmental factors represented by arrows, with species name in abbreviated form

Bryophyte species with high abundance at high elevations and low abundance at lower elevations included *Anthoceros punctatus*, *Anthoceros* sp., *Atrichum undulatum* var. *subserratum*, *Bryum caespiticum*, *Bryum* sp., *Dicranum himalayanum*, *Eurhynchium praelongum*, *Lejeunea* sp., *Meteriopsis reclinata*, *Philonotis thwaitesii*, *Pogonatum microstomum. Bryoerythrophyllum dentatum* and *Monosolenium tenurum* were observed on bare ground at low elevations and in canopy-rich habitats, often growing alongside other bryophyte species. Similarly, *Coenocephalum conicum* and *Marchantia polymorpha* favored soils with high nitrogen and carbon content. Additionally, *Dicranum setchwanium*, *Dumortiera hirsuta*, and *Pogonatum submacrophylum* were also recorded at lower elevations, occurring in association with other bryophytes like *Jungermannia*, *Lejunia*, and *Fissidens* sp. *Fissidens* sp., *Folioceros assamicus*, and *Funaria hygrometrica* were associated with phosphorus-rich soils. Likewise, *Marchantia emarginata* and *Polytrichum commune* were recorded in the areas with high potassium levels. Furthermore, herb cover supported the presence of *Asterella multiflora*, *Fissidens sylvaticus*, and *F. taxifolius*, whereas rock-dominated sites favored *Fissidens bryoides*, *Heteroscyphus argutus*, *H. planus*, and *Hyophila involuta* (Fig. 8).

DISCUSSION

Species composition provides insight into plant communities and the abiotic conditions of a specific geographical area. Although Nepal is relatively small, its varied topography supports a high level of floral and faunal diversity. In terms of bryophytes, the country harbors about 6.5% of the global bryoflora, totaling 1,318 species (Pradhan, 2023). In this study, a total of 39 bryophyte species were identified and documented.

Worldwide distribution pattern of three lineages of bryophyte shows dominance of mosses followed by liverworts and hornworts (Asakawa et al., 2013). The similar distribution pattern has been noticed in adjoining countries like China (Song et al., 2021), Bangladesh (Tabassum et al., 2020), different regions of India like Odisha (Mishra et al., 2016), Uttarakhand (Asthana & Sahu, 2013; Sahu & Asthana, 2015), Western Ghats of Karnataka (Aruna & Krishnappa, 2014). The dominance of mosses in the present study is consistent with the overall pattern of bryophyte distribution in Nepal (Pradhan, 2013, 2014, 2015, 2020; Sharma et al., 2021; Khati et al., 2022). The proportional distribution of three lineages of bryophytes may be due their desiccation tolerance capacity which is higher for mosses follwed by liverworts and hornworts (Vitt et al., 2014). The dominancy of the members of the class Bryopsida, this study is consistent with the work of Paudel (2019) in the same elevation range (109 to 1600 m asl) of far west Nepal. Besides, some similar studies carried out in various regions of the country in higher elevation (ca. 1500- 2700 m asl) by Sharma (2018), and Sharma et al. (2021) also showed high dominance of members of Bryopsida. The studies in India by Alam et al. (2012) also showed the similar results.

Monosolenium tenerum, a rare bryophyte, was recorded from moist habitat at the elevation range of 325 – 600 m of present study area but not observed at similar elevations in far west Nepal (Paudel, 2019). Similarly, *Funaria hygrometrica* occurred in both tropical and subtropical zones. *Philonotis thwaitesii* was restricted to the sub-tropical band in this study, despite earlier reports of its occurrence in the tropical zone (Paudel, 2019). Likewise, *Eurhynchium praelongum*, recorded only at the highest elevation (1480-1586 m asl) in the present study, was not reported by Paudel (2019) from the same elevation range in far western Nepal.

There are multiple environmental factors, such as climate, elevation, slope, depth of litter, vegetation type, soil pH and soil Eh (redox potential), that affect the availability of the species, richness, composition, diversity, and govern their ability for the luxuriant growth (Sun et al., 2013). Previous studies in Nepal have reported a hump shaped pattern of bryophyte species distribution curve along elevational gradients with peak richness occurring in the temperate zone (Grau et al., 2007; Pradhan, 2013, 2014, 2023). Because the present study was limited to tropical and sub-tropical bioclimatic zones, a linear species-richness pattern was obtained, consistent with the Rapoport's elevational rule. Both mosses and hornworts showed a significant positive linear relationship with elevation, with the trend being more pronounced for mosses. The increasing richness of hornworts with elevation may reflect their preference for moist soil conditions, as moisture availability tends to be slightly higher at upper elevations within the study area.

The Regression analysis indicated a significant yet decreasing relationship with bareground, suggesting that bryophyte richness increases as the area of bareground declines. This could be due to the limited moisture and lack of suitable microhabitats in the exposed areas, which restrict bryophyte establishment. Only species capable of tolerating dry and harsh conditions are likely to survive, which may explain the reduced diversity observed. In contrast, no meaningful relationship was detected between bryophyte richness and rock cover, grass cover, or other plant species. This differs from the findings of Pharo et al. (2005), who reported a clear decline in richness with increasing grass cover. Such a difference may stem from variations in habitat types and environmental conditions that weaken the statistical associations between these variables and species richness. Another possible factor is the dense forest canopy, which can limit sunlight and other essential resources required for the growth of bryophytes and other plant groups in that land. This observation is consistent with the results of Fenton and Frego (2005).

The bryophyte species richness showed a linear decline with canopy cover, indicating that areas with denser canopies tend to have lower richness. Canopy cover is reported as the best predictor for the distribution of bryophytes (Pharo & Vitt, 2000; Vanderpoorten & Engels, 2002). This finding was also like Fenton and Frego (2005), who suggested that remnant canopies favor higher bryophyte diversity than open and cleared canopies. A similar trend was observed for both liverworts and mosses, although the relationship was not significant for hornworts, likely due to their limited suitable habitat.

The CCA-based multivariate analysis of the species composition and environmental variables indicated that species distribution is shaped by multiple biotic and abiotic factors rather than a single environmental variable. The ordination plot showed that the species such as *Anthoceros punctatus*, *Anthoceros* sp., *Atrichum undulatum* var. *subserratum*, *Bryum caespiticum*, *Bryum* sp., *Dicranum himalayanum*, *Eurhynchium praelongum*, *Lejeunea* sp., *Meteriopsis reclinata*, *Philonotis thwaitesii*, and *Pogonatum microstomum* were more strongly associated with elevation. Furthermore, the ordination plot showed that most species of moss were concentrated at higher elevations, likely due to their strong ability to tolerate and adapt to harsh environmental conditions. This agrees with the findings of Vitt et al. (2014), who noted that the capacity of mosses to occupy a wide range of habitats contributes to their overall species richness. The greater diversity recorded at higher elevations in the present study may also be linked to the loamy-sand texture of the soil, which is favorable for bryophyte growth. A similar observation was made by Vanderpoorten and Engels (2002).

Funaria hygrometrica, which commonly occurs in both rocky and terrestrial habitats, was present across nearly the entire elevation range, particularly in disturbed habitats such as roadsides and in areas with both open and closed canopy covers. Nevertheless, the CCA plot indicated that this species is closely associated with soil phosphorus levels. Earlier studies also suggested that greater abundances of *F. hygrometrica* inside the forest floor with litter and canopy cover, at higher elevations may be due to high concentrations of soil macronutrients, including calcium, potassium, nitrogen, and phosphorus (Hoffman, 1966; Southorn, 1977).

CONCLUSION

Altogether 39 species of bryophytes belong to 27 Genera, and 21 families are documented from this study. Most bryophyte species in the area tend to favor terrestrial habitats. Among the environmental factors examined, higher elevations were associated with increased species richness, whereas greater bare ground cover and denser canopy cover negatively affected richness. The environmental variables, together with soil parameters, show species specific impact on distribution. Overall, the species count in this study is lower than what has been documented from comparable elevation ranges in far western Nepal. It is because of the topography of the area with frequent landslides, which makes the substratum unfit for bryophytes. Bryophytes usually prefer to grow in degraded landmasses, but excessive rainfall erodes the substratum. Additionally, landslides, even in seasons other than monsoon, avoid the binding of soil particles. Consequently, these characteristics hinder the establishment of bryophytes on the ground, on rocky substrates, and even on other higher plants.

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AUTHORS CONTRIBUTION

Conceptualization: TN; Methodology: TN, DRP, GPJ; Validation: GPJ; Investigation: TN; Data analysis: TN, GPJ; Writing-original draft: TN; Writing-review & editing: TN, DRP, GPJ; Supervision: GPJ; Funding acquisition: TN

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ORCIDs

Tulsi Neupane:
https://orcid.org/0009-0000-5970-6786
Deepak Raj Pant:
https://orcid.org/0000-0002-5247-8052
Giri Prasad Joshi:
https://orcid.org/0000-0001-9166-3974

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

ETHICAL STATEMENT

We declare that it is our original work and has not been previously published or submitted for publication elsewhere.

DATA AVAILABILITY STATEMENT

The data supporting this study are available from the corresponding author upon reasonable request.

SUPPLEMENTARY INFORMATION

None

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