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Species composition, morphological variation, and host preferences of epiphytic bryophytes in dominant forest types in central Himalaya

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Abstract

Bryophytes are the second largest group of land plants constituting an essential part of the forest ecosystem. Only limited studies have been carried out on the epiphytic bryophytes of the Himalayan region. The present study was done to assess the species composition, morphological variation, and host preferences of epiphytic bryophytes on the stem bark of four dominant phorophytes namely; *Quercus leucotrichophora* A.Camus, *Quercus floribunda* Lindl. ex A.Camus, *Quercus semecarpifolia* Sm. and *Pinus excelsa* Wall. in their respective forest sites i.e. Kailakhan (1845-1950 m), Lands' End (2000- 2230 m), Naina Peak (2400-2600 m) and Sigri (2100-2450 m), respectively. The effect of tree canopy and substrate on the epiphytic bryophytes was also analyzed. Fifty-nine bryophyte species were recorded in all phorophytes belonging to 44 genera, 25 families, and nine orders. The maximum number of species belonged to the family Brachytheciaceae (seven) followed by Thuidiaceae (six). Three morphological forms (acrocarpous mosses, pleurocarpous mosses, and leafy liverworts) and five growth forms (tuft, mat, turf, pendant, and weft) were found in collected bryophyte species. Species richness varied

from 23 on *Q. leucotrichophora* to 40 on *P. excelsa*. A maximum (of 32) species were reported from girth class D (*P. excelsa*) and a minimum (of nine) from girth class A (*Q. floribunda*). Tree bark pH and moisture content were found significant factors for the distribution of epiphytic bryophytes in forests. On the basis of regression analysis, Bark pH contributed to 8.64% of species richness, while moisture contributed 21.67% to species of the epiphytic bryophytes. The present study will be highly useful in assessing conservation status and predicting the effect of changing abiotic factors on bryophyte distribution and productivity.

Keywords: Bark pH and Moisture; *Brachytheciaceae*; Growth and Morphological forms, *Quercus leucotrichophora*, Species richness

1. Introduction

Bryophytes grows in almost all terrestrial and freshwater environment. The growth success of bryophytes depends upon their unique physiological water relation system. Epiphytic bryophytes are plants that grow on other plants, such as trees. The diversity of these bryophytes can be influenced by a variety of factors, including topography and forest types (Toro Manríquez et al. 2020; Rola et al. 2021; Zhang et al. 2023). Topography, or the physical features of the land, can affect the moisture and nutrient availability of epiphytic bryophytes. For example, in mountainous areas, there may be a greater diversity of bryophytes due to the variety of microclimates that exist at different elevations (Ah-Peng et al. 2007; Hernández-Hernández et al. 2019). Bryophyte diversity may also be influenced by the slope of the land, with steeper slopes potentially supporting a greater number of species due to variations in moisture and light levels (Hernández-Hernández et al. 2019; Bourgouin et al. 2022). Forest types can also influence epiphytic bryophyte diversity. Different tree species can provide different microhabitats and nutrients for bryophytes. For example, some tree species may have rough bark that provides more

surface area for bryophytes to attach to and grow on, while other tree species may have smoother bark that is less hospitable for bryophytes (Mitchell et al. 2022). Overall, the influence of topography and forest types on epiphytic bryophyte diversity is complex and multifaceted. Factors such as microclimate, tree species composition, and habitat complexity can all play a role in shaping the diversity of epiphytic bryophytes in a given area (Rola et al. 2021; Shen et al. 2022; Tie et al. 2023). Host preferences of epiphytic bryophytes can be influenced by a variety of factors, including the texture and pH of the tree bark, as well as the microclimate and nutrient availability in different forest types (Chantanaorrapint 2010; Adubasim et al. 2018). Understanding these preferences can be important for conservation efforts and for predicting the distribution and diversity of epiphytic bryophytes in different forest ecosystems.

The central Himalaya region is known for its diverse forest types, ranging from subtropical to alpine (Joshi and Garkoti 2023). Epiphytic bryophytes are an important component of these forests, and their distribution and host preferences in this region can vary depending on the forest type (Pande and Joshi 2004; Awasthi et al. 2013; Joshi and Upreti 2014; Bhatt and Bhatt 2021). Epiphytic bryophytes are an important component of both oak and pine forests in the central Himalaya. While the composition and abundance of these bryophytes may vary between these two forest types, there are several species that are common to both. In oak forests, which occur at elevations between 1,500 and 2,500 meters, epiphytic bryophytes are relatively diverse and abundant. Oak forests in the central Himalaya are dominated by two main species, *Quercus leucotrichophora* A. Camus and *Quercus floribunda* Lindl. ex A. Camus, and epiphytic bryophytes can be found growing on the bark of these and other tree species. In pine forests, which occur at elevations between 1,000 and 2,500 meters, epiphytic bryophytes are less diverse and abundant than in oak forests. Pine forests in the central Himalaya are dominated by two main

species, *Pinus roxburghii* Sarg. and *Pinus wallichiana* Jacks, and epiphytic bryophytes can be found growing on the bark of these and other tree species. In both oak and pine forests, the distribution and abundance of epiphytic bryophytes are influenced by factors such as tree species composition, microclimate, and disturbance regime (Singh, and Singh 1988; Awasthi et al. 2013; Bahuguna et al. 2014; Sharma et al. 2021; Dhyani et al. 2021). For example, areas with higher tree species diversity and greater microhabitat complexity may support higher diversity and abundance of epiphytic bryophytes. Additionally, disturbances such as logging or fire can affect the distribution and abundance of epiphytic bryophytes by altering the availability of suitable substrates for colonization.

There have been several studies on bryophytes in the central Himalaya region, which have contributed to our understanding of the diversity, distribution, and ecology of these plants in this area. Awasthi et al. (2013) investigated the distribution and diversity of bryophytes in the subtropical forests of the central Himalaya. The study found that moisture and exposure to sunlight were important factors influencing the distribution of bryophytes in this region. Another study conducted by Grau et al. (2007) investigated the diversity and ecology of bryophytes in the temperate forests of the central Himalaya. The study found that bryophytes were less diverse in these forests compared to subtropical forests, and that their distribution was influenced by elevation, moisture, and tree species composition. The study also found that some species of bryophytes were more common on certain tree species, suggesting that host preferences may play a role in their distribution. A more recent study conducted by Dhyani et al. (2021) investigated the diversity and distribution of bryophytes in the alpine forests of the central Himalaya. The study found that bryophytes were relatively rare in these forests, but that they were present on a variety of tree

species including Himalayan birch, juniper, and rhododendron. The study also found that the distribution of epiphytic bryophytes in this region was influenced by elevation and moisture.

Despite all these studies, only very few have focused on the epiphytic bryophytes of Kumaun Himalayas, especially across the altitude and habitat type. A broad study on the composition and quantitative characteristics along an altitudinal gradient and contrasting aspects, observations on the seasonal variation in biomass and net primary production, and the effect of tree canopy characteristics and substrate on the epiphytic bryophyte vegetation are completely lacking in central Himalaya. These forests exhibit the luxuriance of epiphytic vegetation on their trunks due to their diverse microclimatic conditions and the variations in the substrate quality. The present study was conducted on the ecological study of the epiphytic bryophyte vegetation along altitudinal gradients in four dominant forests in central Himalaya. The purpose of this study was to determine species richness, structure, species composition, biomass, and productivity of epiphytic bryophytes and to correlate them with ecological parameters such as altitude, temperature, and bark type. The present study will be helpful in understanding the ecological value of different components of epiphytic bryophytes. The main objectives of the study were: a) To study the species composition of epiphytic bryophyte vegetation on tree trunks along an altitudinal gradient and contrasting aspects. b) To study quantitative characteristics of epiphytic bryophyte vegetation. To study the effect of substrate quality on the vegetation.

2. Material and methods

2.1 Study area

Nainital, the study area is situated in Kumaun Himalaya. It covers an area of 208.5 sq. km and lies between 29°19"- 29°28" N latitude and 79°22"-79°38" E longitude (Table 1). Nainital

derives its name from the lake lying in a saucer-shaped depression within the Gagar range of Kumaun Himalaya. The lake is surrounded on all sides by seven hills, except on the southwest. On the west, the Ayarpatta (2235 m), is named due to the former abundance of Ayar trees (*Lyonia ovalifolia* Wall. Drude) followed by the Deopatta (2273 m). Adjacent to Deopata is Handi Bandi (2139 m) near Barapatthar and next to Handi Bandi is Naina Peak (formerly named Cheena Peak) at an altitude of 2611 m followed by the Alma (2270 m), Laria Kanta (2481 m) and Sher-ka-Danda (2267 m) peaks on the eastern extremities. The four forest sites located in and around Nainital town and their characteristic features are given in Table 1. The study area has a temperate climate with a monsoon pattern of rainfall. The year may be divided into three seasons: (i) Summer (from March up to mid-June) May and June are the hottest months; (ii) Rainy (mid-June to September). The monsoon usually strikes in the second week or third week of June and lasts up to the end of September. The heaviest precipitation occurs in the month of July and August. The rainy season accounts for about three-fourths of the annual rainfall and; (iii) Winter (from mid-October up to February). January is the coldest month when the temperature goes down frequently to freezing point or even below. Occasional rains and snowfalls are also experienced during this season. During the study period (2012-2017) mean minimum temperature ranged from 5 °C (January) to 22 °C (July) and the mean maximum temperature varied from 18 °C (January) to 32 °C (May). Annual mean monthly rainfall ranged between 3 mm (in November) and 879 mm in August. Meteorological data of the study area (2012-2017) are given in Figure 1. The area around Nainital Lake is surrounded by rocks of the Krol series, which are basically carbonate rocks around 570 million years old. Rock type also includes black, grey, and green slate or phyllite with subsidiary calcareous interbeds (Valdia 1988). The soil of the Nainital town is principally sandy loam originating from Krol limestone. Medium-grade metamorphic rock i.e Schist contributes light

sandy soil up to a considerable depth and provides a good base for tree growth. Brown soil including humus was the principal component of the Oak forest inhabiting the growth of understory vegetation. On the other hand, the podzolic type of soil was the characteristic feature of pine forests having an organic mat over a grey-leached layer.

2.2 Phytosociological analysis of vegetation

In the present study, four dominant phorophytes namely; *Q. leucotrichophora*, *Q. floribunda*, *Q. semecarpifolia*, and *P. excelsa* in their respective forest sites i.e. Kailakhan (1845-1950 m), Lands' End (2000- 2230 m), Naina Peak (2400-2600 m) and Sigri (2100-2450 m), respectively. In each selected forest site, three stands i.e. Hill Base (HB), Hill Slope (HS), and Hill Top (HT) were marked attitudinally (Table 1). Within these stands by the point center quadrat method, 10 quadrats of 5.65 m radius (equivalent to the area covered by 10 × 10 m quadrat) were placed for the selection of dominant tree species only. In each quadrat, trees were categorized into five Girth Classes (GC). The diameter of the tree was measured at 1.37 m (cbh). The girth classes were: (i) Girth Class (GC) A = up to 50 cm, (ii) Girth Class (GC) B = 51-100 cm, (iii) Girth Class (GC) C = 101-150 cm (iv) Girth Class (GC) D = 151-200 cm, (v) Girth Class (GC) E = 201 cm and above. In each girth class, on the basis of bryophyte cover, at least five trees were selected for the phytosociological analysis of epiphytic bryophyte vegetation. A sampling of bryophytes was done seasonally. On each selected tree, twelve quadrats of size 5 × 5 cm (three on each aspect i.e. N=North; S=South; E=East and W=West) were placed randomly representing small microhabitats. The plant samples were collected along with the underlying substratum (bark) and brought to the laboratory for identification, the phytosociological study of bryo-vegetation, and the analysis of substratum. The plants were separated according to their morphological forms, growth forms, habits and other distinguishing field characteristics. Slides of leaves and other plant parts

were prepared in gum-chloral mounting media (Watson 1955). Plants were identified confirmed with the specimens stored in the herbarium of Bryology laboratory at the Department of Botany, Kumaun University, Nainital, and also at Bryology Laboratory, N.B.R.I. Lucknow. The collected sample of each quadrat was separated carefully from species and then primary data on frequency, density, and biomass were computed. These data were used to develop the values of abundance, A/F ratio, IVI, diversity, and concentration of dominance following Curtis and McIntosh (1950). Species diversity was calculated following Shannon-Wiener Index and Similarity Index. Diversity is usually considered a function of the relative distribution of individuals among the species. Diversity in different forest sites was quantified by following diversity indices. Diversity is measured as the number of species occurring within an area of a given size. It, therefore, measures the richness of a potentially interactive assemblage of species. The diversity index was calculated by using the Shannon-Wiener information index (Shannon and Wiener 1949).

$$H' = 3.3219 [\log_{10} N - (\sum N_i \log_{10} N_i/N)]$$

Where N_i is the total density of species i and N is the total density of all the species.

Simpson (1949) proposed for the first time a widely used index, which varies inversely with species heterogeneity and in fact measures the concentration of dominance (C_d). It varies between 0-1. Whittaker (1972) suggested that this index is appropriate for communities exhibiting strong dominance and was calculated as:

$$C_d = (N_i / N)^2$$

Where, N_i = the total number of individuals of a species. N = the total number of individuals of all species.

Species richness is expressed by the total number of species in a given community (Whittaker, 1972).

Similarity Index (SI) was calculated by using the formula given by Sørensen (1948):

$$SI = \frac{2C}{(A + B)} \times 100$$

Where A is the number of species in stand A, B is the number of species in stand B, and C is the common species in both stands.

A spherical densitometer is used to measure the canopy cover of the selected forest types. It consists of “1/4” twenty-four squares engraved on the convex surface of the densitometer. Each square is then subdivided mentally into four smaller squares (1/8”×1/8”) and represented by an imaginary dot in the centre of each of the smaller squares that makes a total of 96 dots. The number of dots for the measurement can be counted. After selecting the site, the instrument level was held far enough from the body so that it did not come under the grid of dots in the densitometer. After this, the number of dots that were covered by the canopy shadow was counted and then multiplied with the factor 1.04 to obtain the overhead area occupied by the canopy in percent. A total of four readings were taken about a reference tree and then averaged. The operator should be positioned with his/her back toward the tree and readings was taken after moving toward the North, East, South, and West side of the reference tree. “The reference tree in each site represents a typical dominant or co-dominant species in the stand. The points selected around each reference tree should be far enough (from the reference tree) so that the crown of the reference tree is just outside the overstory area being estimated” (Lemon, 1956). The physical characteristics of bark like, texture, nature, and colour were noted in field diary and the girth class wise collected samples were brought to the laboratory to study the pH, water holding capacity (WHC), and moisture content

percent. The dried bark samples were ground into fine powder by a miller grinder (Macro Scientific, New Delhi, India) and after making a slurry (1:10) in distilled water kept for half an hour (Brodo, 1973). The pH of the samples was determined with the help of a digital pH meter (CyberScan 510, Thermo Fisher Scientific, USA). About 5 g of bark sample was oven-dried at 80 °C for 48 hours, then cooled and reweighed. Thereafter, the dried pieces of bark were immersed in 100 mL of distilled water until saturation. The sample volume was measured by the water displacement method. The water holding capacity of the sample was expressed as water absorbed by the sample per unit volume (Brodo, 1973). The formula used is as follows:

$$\text{WHC (\%)} = \frac{\text{Volume of water absorbed by dry bark}}{\text{Volume of bark sample}} \times 100$$

The fresh samples of bark were weighed and oven dried at 80°C till constant weight (Misra, 1968).

The moisture content was calculated on a dry-weight basis (Jackson, 1958).

$$\text{MC (\%)} = \frac{\text{Fresh weight of bark} - \text{Dry weight of bark}}{\text{Dry weight of bark}} \times 100$$

2.3 Statistical analysis

Data organization and processing were performed with Microsoft Excel 2016. The analysis of phytosociological data for bryophytes was conducted using R version 4.2.2 and PAST software. Relationships between bryophyte species and environmental variables were examined through Redundancy Analysis (RDA) using the Vegan package in R. Shannon-Wiener, Equitability, and Dominance diversity indices were calculated with PAST version 4.10. Comparisons of diversity indices across different forest types were made using the non-parametric Kruskal-Wallis test, followed by Tukey HSD. Additionally, the contribution of individual tree species to various bryophyte categories was illustrated with a chord diagram using R.

3.1 Results

3.1 Bark properties

The barks were smooth to rough in texture (as the girth class increases the roughness also increases) and hard in nature and in higher girth classes often the bark is sloughed off as large and small flakes, especially in *Q. semecarpifolia* and *P. excelsa*. Among the tree species, the water-holding capacity of bark was found minimum (43.8%) for *P. excelsa* and a maximum (74%) for *Q. floribunda* trees. In general, barks of all the studied phorophytes were acidic in nature ranging from 5.3 to 6.3. The colour of *Q. leucotrichophora* bark is generally grey but becomes blackish brown in rainy season. Water holding capacity was minimum in Girth Class A (46.2%) and maximum in Girth Class C (73.7%). The pH of bark ranged from 5.3 to 6.3 in Girth Class A and Girth Class C, respectively. Percent moisture content varied between 43.2 (Girth Class A) and 73.4 (Girth Class C). The colour of *Q. floribunda* bark was light grey and become dark brown in rainy season. Water holding capacity was minimum in Girth Class A (51.2%) and maximum in Girth Class E (74%). The pH of bark ranged from 5.3 to 6.2 in Girth Class A and Girth Class D, respectively. Percent moisture content ranged between 40.1 (Girth Class A) and 84.5 (Girth Class C) (Table 2). The colour of *Q. semecarpifolia* bark was light grey and become blackish brown when it becomes wet (Table 3.4). Water holding capacity was minimum in Girth Class A (53.7%) and maximum in Girth Class D (73.6%). The pH of bark ranged from 5.4 to 6.2 in Girth Class A and Girth Class D, respectively. Percent moisture content varied between 46.3 (Girth Class A) and 84.4 (Girth Class D). The colour of *P. excelsa* bark varied between greenish-grey and greyish-brown. Water holding capacity was recorded minimum for Girth Class A (43.8%) and maximum for Girth Class D (67.2%), while the pH of bark ranged from 5.3 to 6.3 in Girth Class A and Girth

Class C, respectively. Percent moisture content varied between 39.7 (Girth Class A) and 83.4 (Girth Class D) (Table 2).

3.2 Epiphytic bryophytes order, family, morphological forms, and growth forms

The recorded fifty-nine species of mosses and liverworts belonged to forty-four genera, 25 families, and 9 orders (Table 3). A maximum number of bryophytes were found on the barks of *P. excelsa* (40) followed by *Q. semecarpifolia* (35), *Q. floribunda* (33) and *Q. leucotrichophora* (29). Out of the four morphological forms, only 3 forms were observed. These were pleurocarpous mosses (34); acrocarpous mosses (19) and leafy liverworts (6). In the present study, five types of growth forms viz. mats (13), pendant (5), tuft (32), turf (6), and wefts (3) were identified. The order-wise distribution pattern across the sites is represented in Fig.1. In all the forest types, the maximum number of species was reported in order Hypnobryales while the minimum number (one) of species was in Hypnales and Polytrichales. Across the study sites, the distribution pattern of bryophyte species in 25 families is given in Fig.2. The maximum number of species was found in Brachytheciaceae (7) followed by Thuidiaceae (6). Twelve families were represented by a single species.

In the current study, pleurocarpous mosses (34) dominated over acrocarpous mosses (19) and leafy liverworts (6) (Table 3). The morphological distribution of bryophytes across the sites is given in Fig.3. Accordingly, the maximum number of pleurocarpous mosses (25) were reported from *P. excelsa*, while a minimum (19) were reported from *Q. leucotrichophora* and *Q. floribunda*. Across the sites, number of acrocarpous mosses ranged from 9 (*Q. leucotrichophora*) to 11 (*Q. semecarpifolia*). Interestingly, a greater number (5) of leafy liverworts were present on the barks of *P. excelsa* compared to two oaks (*Q. semecarpifolia* = 2 and *Q. leucotrichophora* = 1).

3.3. Girth class-wise distribution of epiphytic bryophytes

The heterogeneous assemblages of bryophytes exhibited different degrees of species composition of bryophytes across the sites as indicated by the similarity index between the phorophytes (Table 4). In this study, across the oaks, on the basis of bryophyte species composition maximum of 76.47% similarity was found between *Q. floribunda* and *Q. semecarpifolia* followed by 70.97% in between *Q. leucotrichophora* and *Q. floribunda*, while minimum similarity (52%) was found between *Q. floribunda* and *P. excelsa*. These results suggested that *P. excelsa* contained a species subset that was different from the oak trees, while the three oak species displayed overlap in bryophyte diversity.

In *Q. leucotrichophora* maximum similarity was reported between GC-D and GC-E (SI=80%), while in *Q. floribunda*, *Q. semecarpifolia*, and *P. excelsa*, the maximum similarity was between girth classes C and D with similarity index 92%, 83% and 89%, respectively. In general, across the sites, the community pattern depicted that *Trachypodopsis* was the major contributor to the community formed across all girth classes of the *Q. leucotrichophora* tree showing its wide amplitude. The pattern also showed co-dominance of species like *Fabronia pusilla* (GC-A) and *Brachythecium buchananii* (GC-B) in their girth classes as these species prefer xeric conditions like low moisture content (GC-A=49.9%, and GC-B=56.5%) of the substrate in which they reside. In *Q. floribunda* phorophytes, the community pattern clearly indicated the restriction of *Frullania* and *Lindbergia* to lower girth classes (A and B) and may be called pioneer species. The lower values of moisture content in GC-A (51.78%) and GC-B (57.94%) tree barks helped *Frullania* and *Lindbergia* to grow to favor their xeric nature. Likewise, a higher percentage of moisture in barks of GC-C (67.44%), GC-D (68.95%), and GC-E (63.30%) showed that moist conditions were preferred by *Cryptolepton*, *Trachypodopsis*, and *Plagiothecium*, respectively (Table 4).

The community pattern was totally different in the case of *Q. semecarpifolia*. *Entodon* and *Herpetineuron* were the pioneer species that showed their presence in only GC-A showing their xeric nature i.e. low moisture content (55.33%) of bark. The presence of *Cryptoleptodon*, *Hyophila*, *Hymenostylium*, and *Anomodon* in higher girth classes (C, D, and E) showed their preferences on barks containing high moisture content i.e., 72.16%, 66.82%, and 63.87%, respectively. In *P. excelsa* phorophytes, *Frullania* (GC-A) and *Bryoerythrophyllum* (GC-B) were restricted to the lower girth classes showing their xeric nature and preferences to barks having low moisture content (GC-A=44.05%; GC-B=55.56%). *Leucodon* and *Anomodon* showed their preferences on barks of girth classes containing high moisture content (GC-D=63.96%; GC-E=59.02%).

3.4 Distribution pattern of epiphytic bryophytes

The distribution pattern of bryophytes was also examined across twelve stands of four forest types (4 forests × 3 stands). On the basis of distribution pattern, the species were grouped under five categories (ubiquitous, > 60%; moderate, 40–60%; intermediate, 20-40%; rare, 10-20% and accidental, <10%) according to their presence (% frequency) across the stands. Out of 59 bryophyte species, ten species showed ubiquitous distribution as these showed their presence in more than 60% stands, while nine species had moderate distribution by their occurrence in 40-60% of stands. The intermediate distribution pattern was marked by 23 species with 20-40% presence across stands. Ten species were rare occupying 10-20% frequency class. Seven species namely; *Bryum capillare* Hedw., *Atrichum obtusulum* (Müll. Hal.) A. Jaeger, *Campylopus ericoides* (Griff.) A. Jaeger, *Entodon pulchellus* (Griff.) A. Jaeger, *Fissidens bryoides* Hedw., *Frullania retusa* Hattori & Thaitong, and *Platygyrium russulum* (Mitt.) A. Jaeger showed their accidental presence as these species were present in less than 10% stands (Table 5).

The detailed distribution of 25 families, 5 growth form, 9 orders and 3 morphological forms of 59 bryophyte species across four forest types is depicted in Fig.5. The diagram illustrates the bryophyte species associated with different morphological and growth forms, with the width of each bar indicating the diversity of bryophyte species within that morphological and growth forms. In the present study, in general, 17 species of mosses and liverworts showed host-specific relationships. For example, eleven species namely, *Amblystegium serpens* Schimp., *Atrichum obtusulum* (Müll. Hal.) A. Jaeger, *Campylopus ericoides* (Griff.) A. Jaeger, *Clastobryum capillaceum* (Griff.) Broth., *Entodon pulchellus* (Griff.) A.Jaeger, *Fissidens bryoides* Hedw., *Frullania dilatata* (L.) Dumort., *Platygyrium russulum* (Mitt.) A. Jaeger, *Rhynchostegiella menadensis* (Sande Lac) E.B. Bartram, and *Thuidium assimile* Jaeger were restricted to the stems of *P. excelsa* trees, whereas three species viz., *Bryum argenteum* Hedw., *Fissidens sylvaticus* Griff., and *Thuidium sparsifolium* (Mitt.) A. Jaeger were present only on *Q. leucotrichophora* stems and two species, *Entodon plicatus* Müll.Hal., and *Bryum capillare* Hedw. were restricted to *Q. semecarpifolia* tree. The leafy liverwort, *Porella densifolia* (Steph.) S.Hatt. was present only on the stems of *Q. floribunda* trees. In general, thirteen species were common to all the phorophytes (Fig.6).

3.5 Environmental factors influencing bryophyte species distribution

According to RDA analysis, bark pH, WHC, altitude, canopy cover and moisture, are the main factors correlated with bryophyte composition (Fig.7). The first axis explained 45.78% of trait variation and the second axis explained 35.22 % of the variance. As shown in Fig.6, moisture, and altitude correlated to axis I, WHC and canopy cover correlated with axis II. *B. capitulatum*, *B. argenteum*, *F. sylvaticus*, *T. sparsifolium*, *M.ancistrodes*, and *E. cyperoides* species are located with higher Ph. *P.densifolia*, *D.gemmascens*, *M. squarrosa*, *F. pusilla*, and *T. tamariscellum*

growing in sites with higher WHC and canopy cover. *P. spinulosa*, *P. cuspidatum*, *C. prionophyllum*, *L. tuberculosa* and *M. submacrocarpum* species growing in sites with altitude and moisture (Fig.7).

4. Discussion

The bark properties of a tree can have a significant influence on the diversity of epiphytic bryophytes that grow on it. Some of the bark properties that can affect epiphytic bryophyte diversity include bark texture, thickness, pH, water-holding capacity, and nutrient content. Bark texture and thickness can influence the ability of bryophytes to attach to the bark surface and to grow on it. For example, some bryophytes may prefer smooth bark surfaces, while others may require rougher textures for attachment. Similarly, the thickness of the bark can affect the amount of moisture and nutrients that are available to the bryophytes. The barks were smooth to rough in texture (as the girth class increases the roughness also increases) and hard in nature and in higher girth classes often the bark is sloughed off as large and small flakes, especially in *Q. semecarpifolia* and *P. excelsa*. The pH of the bark can also influence the diversity of bryophytes that grow on it. Some bryophytes prefer acidic environments, while others prefer alkaline or neutral environments. The pH of the bark can be influenced by factors such as the type of tree species, the soil in which it grows, and the amount of atmospheric pollution in the area. In general, barks of all the studied phorophytes were acidic in nature ranging from 5.3 to 6.3. Similar acidic nature of bark was also reported by Joshi (1993) in high-altitude Kharsu oak (pH=5.8-5.9) and Silver fir (pH=5.3-5.5) tree species. Contrary to this, the studies of Pande et al. (2005) and Bargali et al. (2014) reported that the pH of Horse Chestnut (pH=6.8-7.3) and *Platanus orientalis* (pH= 5.5-6.7) bark was towards the alkaline side. The water-holding capacity of the bark can also be important for epiphytic bryophyte diversity. Bryophytes require moisture to grow, and the ability of the bark to hold water

can affect the availability of moisture to the bryophytes. The nutrient content of the bark is also important, as bryophytes require nutrients such as nitrogen and phosphorus to grow. The nutrient content of the bark can be influenced by factors such as the type of tree species, the soil in which it grows, and the amount of atmospheric pollution in the area. Márialigeti et al. (2009) reported that the occurrence of epiphytic bryophytes was affected by major abiotic factors such as bark type, light, humidity, etc. As bark characteristics vary among tree species, bryophytic species richness also varies accordingly. Among the common species, *Herpetineuron toccoe* (Sull. & Lesq. in Sull.) Card. has the broadest range of host trees followed by *Brachythecium buchananii* (Hook.) A. Jaeger, *Fabronia*, *Plagiothecium*, *Cryptoleptodon*, *Desmatodon*, *Lejeunea*, *Leucodon* and *Trachypodopsis*. Host specificity may refer to the absolute restriction of an epiphytic species to a host species or it may refer to the ecological success of a species, measured as cover, fertility, vitality, or frequency. It may also refer to restriction to host species or forest types (Barkman 1958; Iwatsuki 1960). These results suggested that bryophytes possess adaptations specific to their preferred host tree type. These differences may be attributed to the bark structure, pH, and moisture retention ability of tree bark. Competitive exclusion may be another factor in preventing conifer-type bryophytes from colonizing oaks (Kenkel and Bradfield 1986). In contrast competition exclusion is likely less significant than abiotic factors in preventing oak-type bryophytes from colonizing pine.

The continuity and naturalness of forests can be easily recognized by epiphytic bryophytes and lichens as these are considered indicator species (Ek et al., 2002). For ensuring moisture and stability of an ecosystem, these forest-dwelling plants (bryophytes) form an integral part of forest biodiversity and support other existing plant species like pteridophytes and orchids (Glime, 2007). Community patterns of bryophytes were identified across the phorophytes indicating a change in

community pattern from lower to higher girth class. In general, 20 bryophyte communities were identified in each of the four studied phorophytes. Pleurocarpous mosses (61.9%) showed their dominance over acrocarpous mosses (28.6%) and leafy liverworts (9.5%) in communities formed across girth classes, which clearly indicated that there was a certain successional pattern among bryophytes. Pande (1984) and Joshi (1993) also observed the dominance of pleurocarpous mosses in community formation on different phorophytes of Nainital.

Epiphytic habitat was considered xeric in nature and represents harsh environments for the growth of bryophytes (Nishida 1978; Gradstein 1992; Medina et al., 2010). The present study revealed that barks of Oaks phorophytes of central Himalaya harbor a rich bryoflora on account of sufficient moisture content, rough texture, and a large number of cracks and crevices for the settlements of bryophytic propagules. On the other side, some of the species occurring on *P. excelsa* tree barks reveal a few morphological characters that exhibit xerophytic characters (Table 4). For example, dentate and serrated leaf margins in *Fabronia*, *Hyophila*, and *Plagiomnium* provide greater surface area for receiving moisture (Glime, 2007). The aggregation of mosses (tuft forms) facilitates capillary uptake and retention of externally held water in mosses like *Campylopus* and *Desmatodon*.

Research has shown that the girth, or circumference, of a tree, is positively correlated with the number of species of epiphytic bryophytes that inhabit it. Across the girth classes, bryophytic species richness did not show any regular pattern. For *Q. leucotrichophora*, the pattern of species richness was in the order: C > E > D > B > A. For, pattern was D > C > E > B > A, and for *Q. semecarpifolia* the pattern was C > D > E > B > A, and for *P. excelsa* the pattern was D > C > E > B > A. In general, species richness was maximum in higher girth classes compared to the lower girth classes of each phorophyte. This is because larger trees provide a greater surface area and

microhabitat diversity for bryophytes to grow on, as well as more resources such as moisture and nutrients. In addition, different species of bryophytes have different habitat preferences, and larger trees can provide a range of microhabitats, such as crevices, branch forks, and bark roughness, that can support a greater diversity of bryophyte species. Across the girth classes, maximum (32) species were reported from girth class D (*P. excelsa*) and minimum (9) from girth class A (*Q. floribunda*). In the present study, some species showed host specific relationships. Three species, *B. argenteum*, *F. sylvaticus* and *Thuidium sparsifolium* (Mitt.) A. Jaeger showed their preference to *Q. leucotrichophora* tree stems, while *B. capillare* and *E. plicatus* were restricted to *Q. semecarpifolia* tree stems. On contrary to this, maximum (11) species i.e., *Amblystegium serpens*, *Atrichum obtusulum*, *Campylopus ericoides*, *Clastobryum capillaceum*, *Entodon pulchellus*, *Fissidens bryoides*, *Frullania dilatata*, *Platygyrium russulum*, *Rhynchostegiella menadensis* and *Thuidium assimile* were confined to the *P. excelsa* tree and minimum (1) species i.e. *P. densifolia* was restricted to *Q. floribunda* tree. Among oaks, maximum (76.47%) similarity was found between *Q. floribunda* and *Q. semecarpifolia* followed by 70.97% in between *Q. leucotrichophora* and *Q. floribunda*, while minimum similarity (52%) was found in between *Q. floribunda* and *P. excelsa*. Comparing the bryodiversity of present study with other studies revealed that maximum similarity (SI=73.85%) was recorded between phorophytes *Q. semecarpifolia* (present study) and *Q. leucotrichophora* (previous study), while minimum similarity (8.69%) was found in between *P. excelsa* (present study) and *Erythrina arborescens* (previous study). In *Q. leucotrichophora*, *Trachypodopsis* was the significant component of the bryophyte community in each girth class, but in other phorophytes the species changed with the change in girth class. It appears that with the ageing of trees, the percent moisture content, roughness, hardness, and nature of barks had increased which resulted in the variation in community pattern.

5. Conclusions

In conclusion, the morphological variation and host preferences of epiphytic bryophytes play an important role in their distribution and diversity in forest ecosystems. Bryophyte species exhibit a range of morphological characteristics, such as size, and shape, which are important for their ability to colonize and persist on different types of tree hosts. Host preferences also influence bryophyte diversity, with certain species being more commonly found on specific tree species or on trees with certain characteristics, such as bark texture or moisture levels. Understanding the morphological variation and host preferences of epiphytic bryophytes is important for conservation efforts aimed at preserving forest biodiversity. Conserving a range of tree species and maintaining a variety of microhabitats for bryophytes to grow on can help to maintain the diversity of epiphytic bryophytes and other associated plant and animal species. Further research is needed to better understand the mechanisms underlying morphological variation and host preferences of epiphytic bryophytes and to develop effective conservation strategies to protect these important components of forest ecosystems.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

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AUTHOR CONTRIBUTIONS

RB conceived the idea. RB, and RKJ, designed and conducted the field experiment, RB and RKJ analyzed the data. RKJ, and RB wrote the manuscript and approved the final manuscript

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Figure

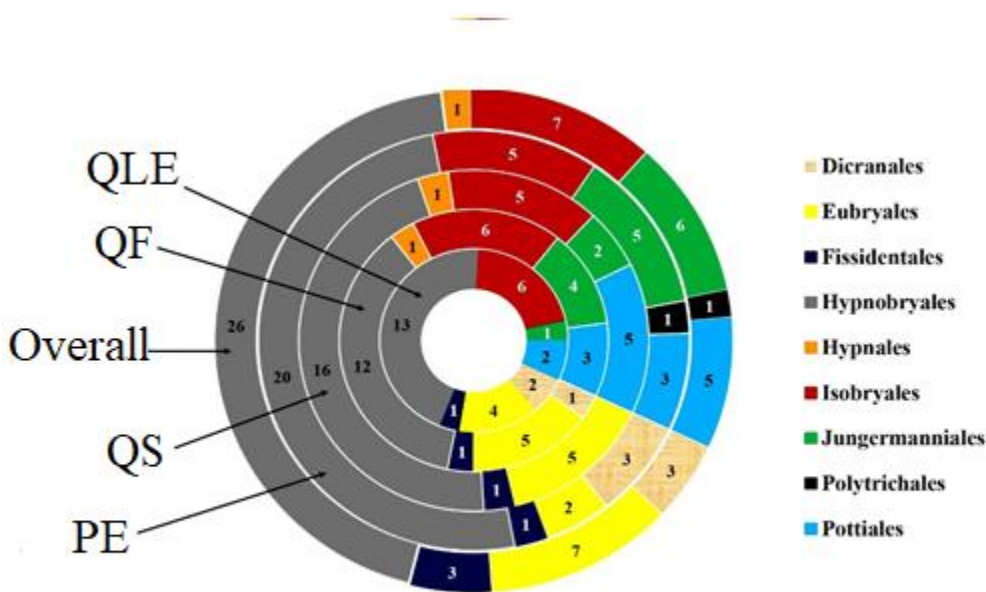


Fig. 1. Order wise distribution pattern of epiphytic bryophytes across the sites

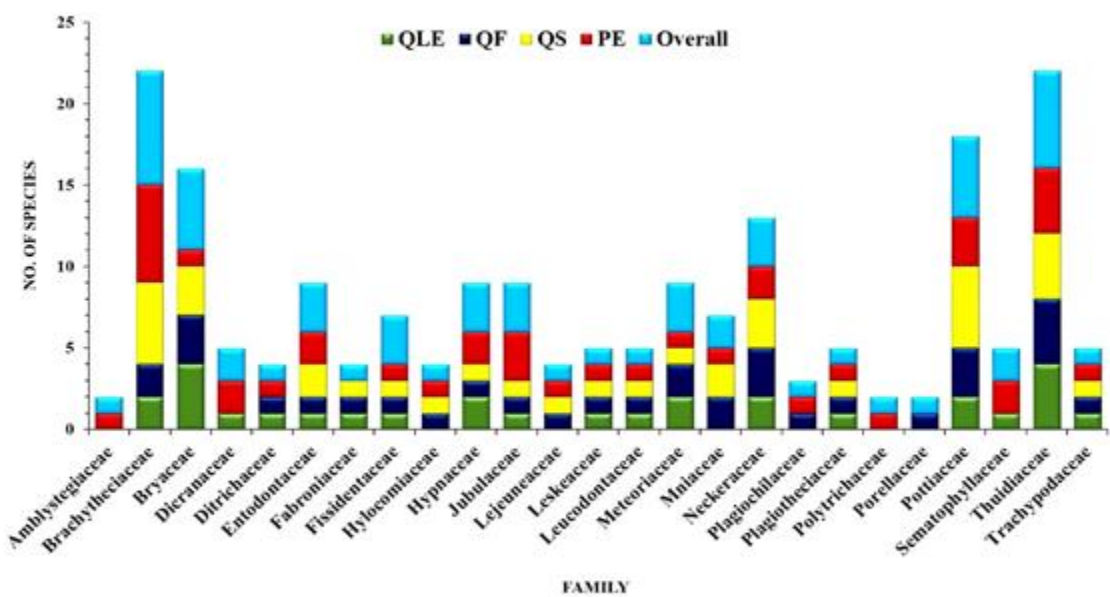


Fig. 2. Family wise distribution pattern of epiphytic bryophytes across the sites

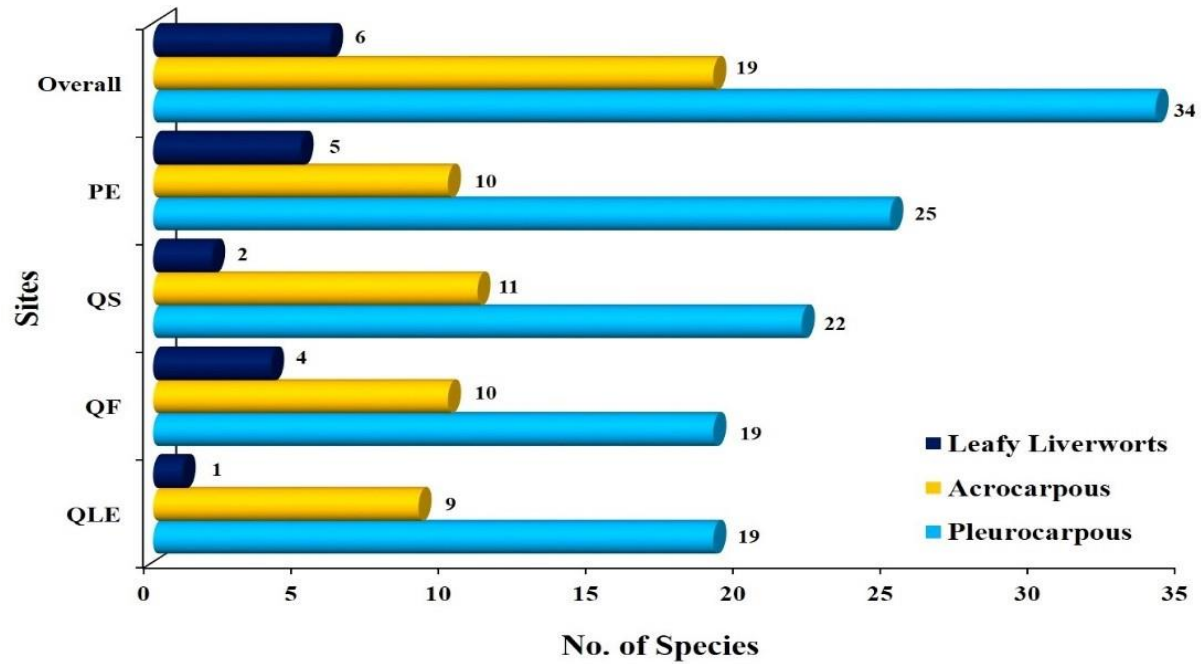


Fig. 3. Morphological distribution pattern of bryophyte across the sites

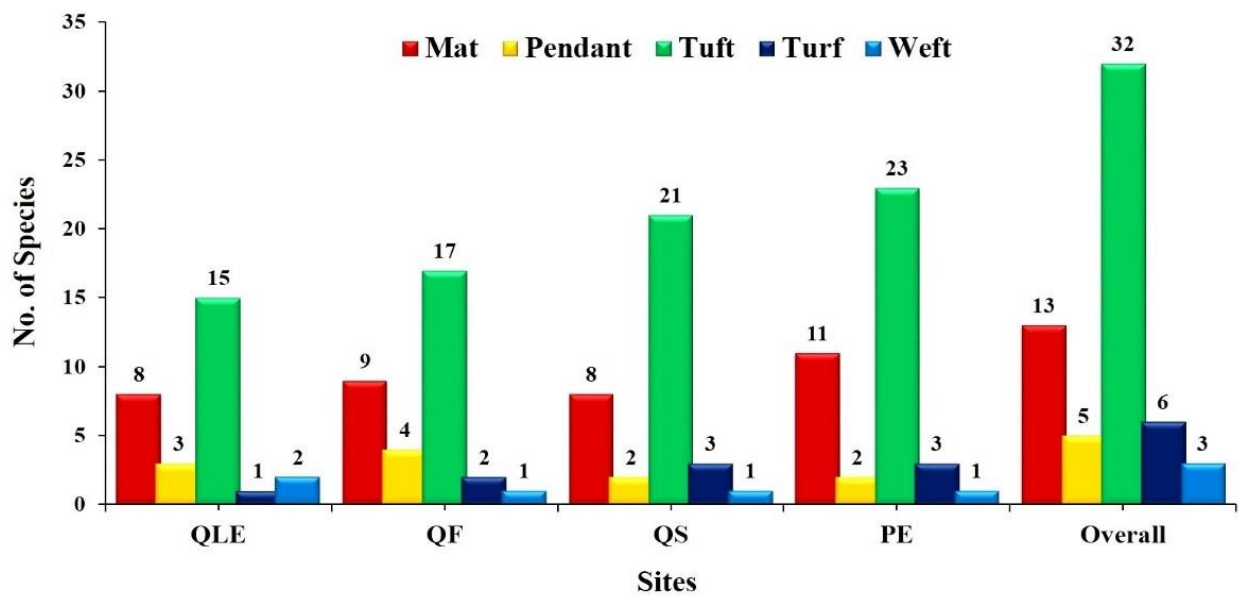


Fig. 4. Distribution pattern of bryophyte growth forms across the sites

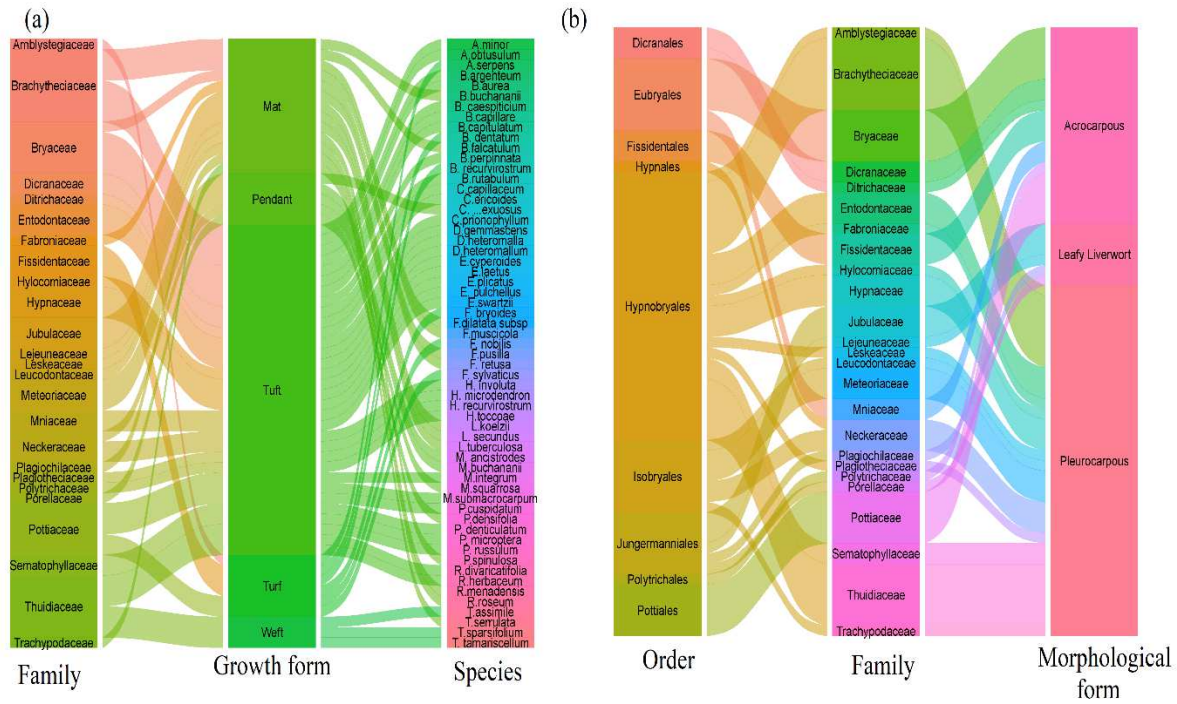


Fig.5. Alluvial plot indicating the species, family order diversity, their affiliation with either growth and morphological form

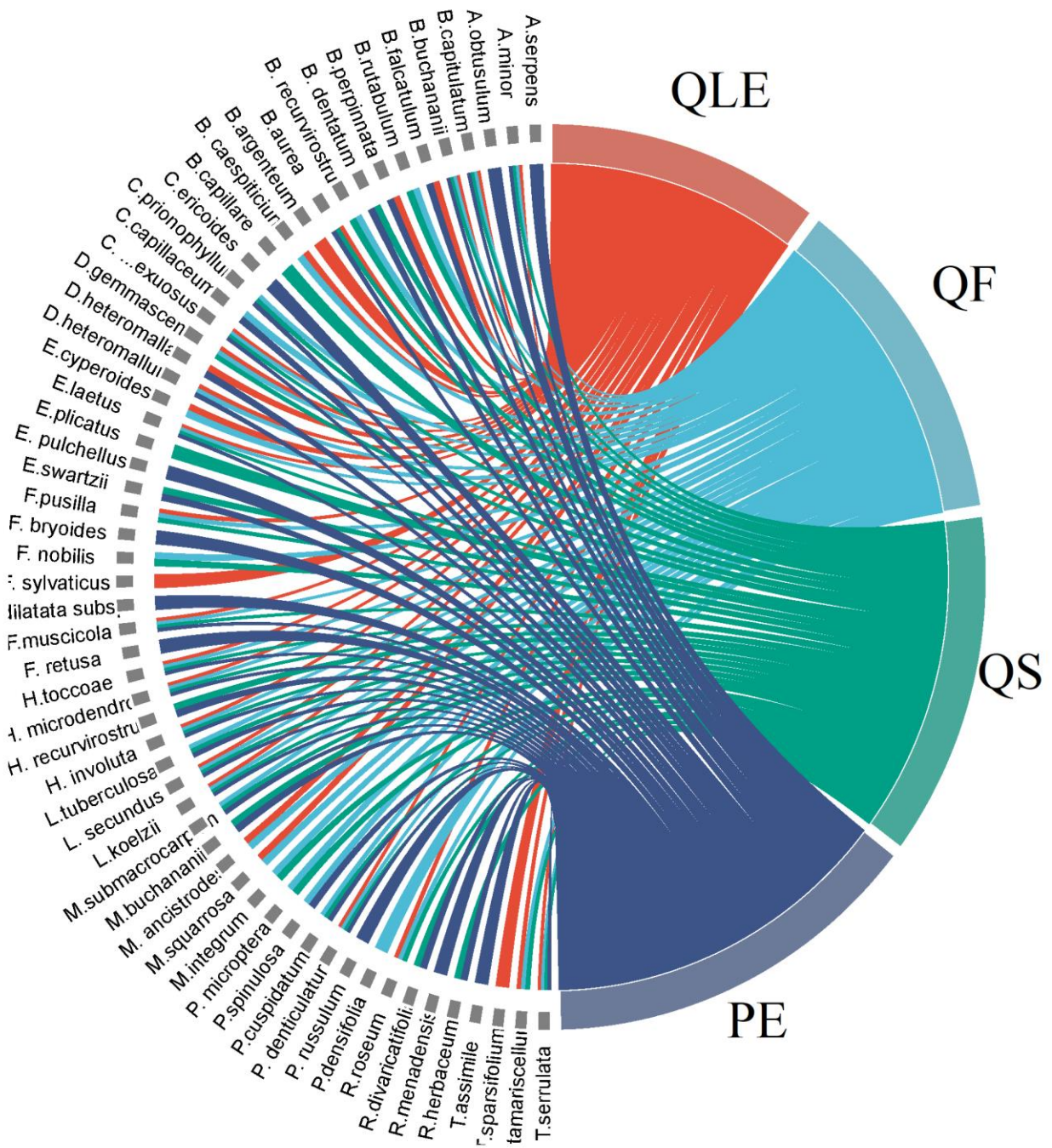


Fig.6. Chord diagram showing the bryophyte species distribution in different habitat types of forest types in central Himalaya

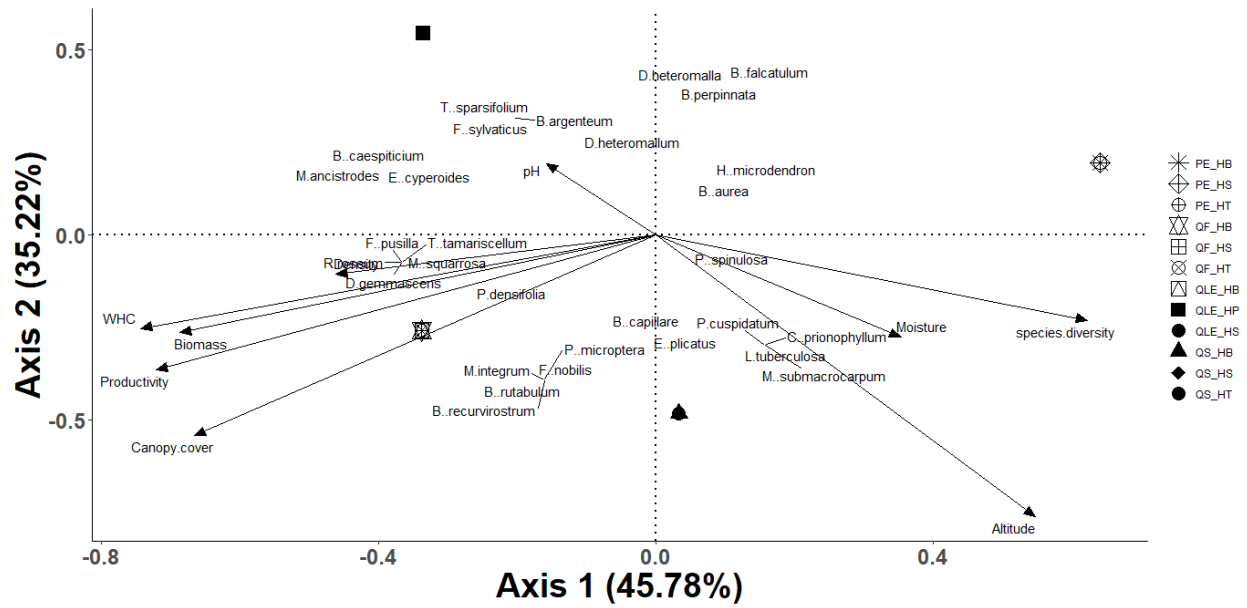


Fig.7. Redundancy analysis of bryophyte species and environmental factor

Table 1. Forest types and its physical attributes.

Forest Type	Altitude	Latitude/Longitude	Aspect
<i>Quercus leucotrichophora</i> A. Camus (Kailakhan)	1845 m-1950 m	29°22'29.72"N/79°28'54.57"E 29°22'26.49"N/79°28'43.96"E	North-East
<i>Quercus floribunda</i> Lindl. ex. A. Camus (Lands End)	2000 m- 2230 m	29°23'02.70"N/79°26'19.34"E 29°22'47.77"N/79°26'35.87"E	North-West
<i>Quercus semecarpifolia</i> Sm. (Naina Peak)	2400 m-2600 m	29°24'19.02"N/79°26'00.73"E 29°24'29.12"N/79°26'11.81"E	South-East
<i>Pinus wallichiana</i> L. (Sigri)	2100 m-2450 m	29°27'118.90"N/79°24'44.60"E 29°27'23.64"N/79°25'11.11"E	North-West

Table 2:

Sites	Altitude(m)	Biomass(g m-2)	Productivity (g m-2 yr-1)	species diversity	Density (ind. m-2)	Canopy cover (%)	WHC (%)	pH	moisture
QLE_HB	1880	44.04	49.53	1.933	4619	84.24	73.7	5.9	73.4
QLE_HS	1915	30.84	40.19	1.876	4093	73.84	71.4	5.8	71.8
QLE_HT	1950	29.02	34.18	1.932	4082	69.96	68.4	6	69.3
QF_HB	2075	27.47	29.93	2.124	3610	74.88	68.7	5.9	78.3
QF_HS	2150	38.52	45.73	2.357	4653	81.12	73.2	5.7	69.2
QF_HT	2230	41.99	51.38	2.42	4891	85.28	74	5.8	57.6
QS_HB	2460	34.54	44.66	1.928	3618	81.12	67.6	6.1	79.2
QS_HS	2530	35.33	49.16	2.127	4581	87.36	73.6	5.6	84.4
QS_HT	2600	34.47	45.23	2.238	4393	83.2	72.5	5.8	82.3
PE_HB	2200	25.68	24.72	2.634	4189	64.83	63.5	5.9	73.6
PE_HS	2300	23.91	23.56	2.527	3941	62.4	67.2	5.8	79.8
PE_HT	2450	25.66	26.78	2.294	3251	67.6	65.3	5.7	72.3

Table 3. Distribution of epiphytic bryophytes of the study sites across the order, family, morphological forms and growth forms.

S. No.	Bryophyte Species	Order	Family	Morphological Form	Growth Form
1.	<i>Amblystegium serpens</i> var. <i>juratzkanum</i>	Hypnobryales	Amblystegiaceae	Pleurocarpous	Turf
2.	<i>Anomodon minor</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Tuft
3.	<i>Atrichum obtusulum</i>	Polytrichales	Polytrichaceae	Acrocarpous	Tuft
4.	<i>Brachymerium capitulatum</i>	Eubryales	Bryaceae	Acrocarpous	Tuft
5.	<i>Brachythecium buchananii</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Mat
6.	<i>Brachythecium falciculatum</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Mat
7.	<i>Brachythecium rutabulum</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Tuft
8.	<i>Brotherella perpinnata</i>	Hypnobryales	Sematophyllaceae	Pleurocarpous	Tuft
9.	<i>Bryoerythrophyllum dentatum</i>	Pottiales	Pottiaceae	Acrocarpous	Turf
10.	<i>Bryoerythrophyllum recurvirostrum</i>	Pottiales	Pottiaceae	Acrocarpous	Turf
11.	<i>Bryosedgwickia aurea</i>	Hypnobryales	Hypnaceae	Pleurocarpous	Tuft
12.	<i>Bryum argenteum</i>	Eubryales	Bryaceae	Acrocarpous	Tuft
13.	<i>Bryum caespiticium</i>	Eubryales	Bryaceae	Acrocarpous	Tuft
14.	<i>Bryum capillare</i>	Eubryales	Bryaceae	Acrocarpous	Tuft
15.	<i>Campylopus ericoides</i>	Dicranales	Dicranaceae	Acrocarpous	Tuft
16.	<i>Claopodium prionophyllum</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Tuft
17.	<i>Clastobryum capillaceum</i>	Hypnobryales	Sematophyllaceae	Pleurocarpous	Tuft
18.	<i>Cryptoleptodon flexuosus</i>	Isobryales	Neckeraceae	Pleurocarpous	Pendant
19.	<i>Desmatodon gemmascens</i>	Pottiales	Pottiaceae	Acrocarpous	Tuft
20.	<i>Dicranella heteromalla</i>	Dicranales	Dicranaceae	Acrocarpous	Tuft
21.	<i>Ditrichum heteromallum</i>	Dicranales	Ditrichaceae	Acrocarpous	Tuft
22.	<i>Ectropothecium cyperoides</i>	Hypnobryales	Hypnaceae	Pleurocarpous	Tuft
23.	<i>Entodon laetus</i>	Hypnobryales	Entodontaceae	Pleurocarpous	Tuft
24.	<i>Entodon plicatus</i>	Hypnobryales	Entodontaceae	Pleurocarpous	Tuft
25.	<i>Entodon pulchellus</i>	Hypnobryales	Entodontaceae	Pleurocarpous	Tuft
26.	<i>Eurhynchium swartzii</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Tuft
27.	<i>Fabronia pusilla</i>	Hypnobryales	Fabroniaceae	Pleurocarpous	Mat
28.	<i>Fissidens bryoides</i> var. <i>schmidii</i>	Fissidentales	Fissidentaceae	Acrocarpous	Turf
29.	<i>Fissidens nobilis</i>	Fissidentales	Fissidentaceae	Acrocarpous	Turf
30.	<i>Fissidens sylvaticus</i>	Fissidentales	Fissidentaceae	Acrocarpous	Turf
31.	<i>Frullania dilatata</i> subsp. <i>subdilatata</i>	Jungermanniales	Jubulaceae	Leafy Liverwort	Mat
32.	<i>Frullania muscicola</i>	Jungermanniales	Jubulaceae	Leafy Liverwort	Mat
33.	<i>Frullania retusa</i>	Jungermanniales	Jubulaceae	Leafy Liverwort	Mat
34.	<i>Herpetineuron toccoae</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Tuft
35.	<i>Homaliodendron microdendron</i>	Isobryales	Neckeraceae	Pleurocarpous	Tuft
36.	<i>Hymenostylium recurvirostrum</i>	Pottiales	Pottiaceae	Acrocarpous	Tuft
37.	<i>Hyophila involuta</i>	Pottiales	Pottiaceae	Acrocarpous	Tuft
38.	<i>Lejeunea tuberculosa</i>	Jungermanniales	Lejeuneaceae	Leafy Liverwort	Mat
39.	<i>Leucodon secundus</i>	Isobryales	Leucodontaceae	Pleurocarpous	Mat
40.	<i>Lindbergia koelzii</i>	Hypnobryales	Leskeaceae	Pleurocarpous	Mat
41.	<i>Macrothamnium submacrocarpum</i>	Hypnobryales	Hylocomiaceae	Pleurocarpous	Tuft
42.	<i>Meteorium buchananii</i>	Isobryales	Meteoriaceae	Pleurocarpous	Pendant
43.	<i>Meteoriopsis ancistrodes</i>	Isobryales	Meteoriaceae	Pleurocarpous	Pendant
44.	<i>Meteoriopsis squarrosa</i>	Isobryales	Meteoriaceae	Pleurocarpous	Pendant
45.	<i>Mnium integrum</i>	Eubryales	Mniaceae	Acrocarpous	Tuft

46.	<i>Pinnatella microptera</i>	Hypnales	Neckeraceae	Pleurocarpous	Tuft
47.	<i>Plagiochila spinulosa</i>	Jungermanniales	Plagiochilaceae	Leafy Liverwort	Mat
48.	<i>Plagiomnium cuspidatum</i>	Eubryales	Mniaceae	Acrocarpous	Tuft
49.	<i>Plagiothecium denticulatum</i>	Hypnobryales	Plagiotheciaceae	Pleurocarpous	Tuft
50.	<i>Platygyrium russulum</i>	Hypnobryales	Hypnaceae	Pleurocarpous	Tuft
51.	<i>Porella densifolia</i>	Jungermanniales	Porellaceae	Leafy Liverwort	Pendant
52.	<i>Rhodobryum roseum</i>	Eubryales	Bryaceae	Acrocarpous	Mat
53.	<i>Rhynchostegiella divaricatifolia</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Tuft
54.	<i>Rhynchostegiella menadensis</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Mat
55.	<i>Rhynchostegium herbaceum</i>	Hypnobryales	Brachytheciaceae	Pleurocarpous	Tuft
56.	<i>Thuidium assimile</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Weft
57.	<i>Thuidium sparsifolium</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Weft
58.	<i>Thuidium tamariscellum</i>	Hypnobryales	Thuidiaceae	Pleurocarpous	Weft
59.	<i>Trachypodopsis serrulata</i>	Isobryales	Trachypodaceae	Pleurocarpous	Mat

Table 5. Distribution pattern of epiphytic bryophytes

S. No.	Bryophyte Species	Frequency Class (%)	No. of Species	Group
1.	<i>Anomodon minor</i> , <i>Brachymenium capitulatum</i> , <i>Brachythecium buchananii</i> , <i>Cryptoleptodon flexuosus</i> , <i>Ditrichum heteromallum</i> , <i>Frullania muscicola</i> , <i>Herpetineuron toccoeae</i> , <i>Hyophila involuta</i> , <i>Lindbergia koelzii</i> and <i>Trachypodopsis serrulata</i>	> 60	10	Ubiquitous
2.	<i>Bryosedgwickia aurea</i> , <i>Entodon laetus</i> , <i>Fabronia pusilla</i> , <i>Homaliodendron microdendron</i> , <i>Lejeunea tuberculosa</i> , <i>Leucodon secundus</i> , <i>Macrothamnium submacrocarpum</i> , <i>Plagiothecium denticulatum</i> and <i>Thuidium tamariscellum</i>	40 – 60	9	Moderate
3.	<i>Brachythecium falciculatum</i> , <i>B. rutabulum</i> , <i>Bryoerythrophyllum dentatum</i> , <i>B. recurvirostrum</i> , <i>Bryum caespitium</i> , <i>Claopodium prionophyllum</i> , <i>Desmatodon gemmascens</i> , <i>Dicranella heteromalla</i> , <i>Ectropothecium cyperoides</i> , <i>Eurhynchium swartzii</i> , <i>Fissidens nobilis</i> , <i>F. sylvaticus</i> , <i>Frullania dilatata</i> , <i>Hymenostylium recurvirostrum</i> , <i>Meteorium buchananii</i> , <i>Meteoriopsis ancistrodes</i> , <i>M. squarrosa</i> , <i>Mnium integrum</i> , <i>Pinnatella microptera</i> , <i>Plagiochila spinulosa</i> , <i>Plagiomnium cuspidatum</i> , <i>Rhodobryum roseum</i> and <i>Rhynchostegiella divaricatifolia</i>	20 – 40	23	Intermediate
4.	<i>Amblystegium serpens</i> , <i>Brotherella perpinnata</i> , <i>Bryum argenteum</i> , <i>Clastobryum capillaceum</i> , <i>Entodon plicatus</i> , <i>Porella densifolia</i> , <i>Rhynchostegiella menadensis</i> , <i>Rhynchostegium herbaceum</i> , <i>Thuidium assimile</i> and <i>T. sparsifolium</i> ,	10 – 20	10	Rare
5.	<i>Atrichum obtusulum</i> , <i>Bryum capillare</i> , <i>Campylopus ericoides</i> , <i>Entodon pulchellus</i> , <i>Fissidens bryoides</i> , <i>Frullania retusa</i> and <i>Platygyrium russulum</i>	< 10	7	Accidental