Bryophyte diversity and associated invertebrate communities along altitudinal habitats in Sindhupalchok District of central Nepal.

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Abstract: Pradhan, N. and Khanal, B. (2023): Bryophyte diversity and associated invertebrate communities along altitudinal habitats in Sindhupalchok District of central Nepal. *Frahmia* 35:1-9.[1]

This study brought a list of 100 bryophyte species divided into 13 orders, 36 families, and 60 genera. Bryofloral environments displayed invertebrates, predominantly arthropods, which included 21 orders and 86 species from 64 families. The observed invertebrates were residents, passersby, or transitory over bryophyte-covered areas. This study, conducted from August to October, covered an elevation range of 800 to 2000 meters. The correlation (r) between bryophytes and insects along altitudinal habitats was non-significant and negative (r = -0.1328). The Shannon-Weiner Index of 3.34 and 3.78 for bryophytes and invertebrates, indicated good diversity, and Simpson's Index of 0.0332 and 0.0233 showed high diversity and were evenly distributed with Equitability Index of 0.93 and 0.9357 for bryophytes and invertebrates, respectively.

1. Introduction

Since bryophyte and invertebrate communities may be found everywhere, from the tropics to the poles and from sea level to above the tree line, they are extremely important for latitudinal and altitudinal research (Andrew et al. 2003). The faunal association of bryophytes is a crucial aspect to study, as many of the potential habitats of this plant have been heavily impacted by anthropogenic causes. This small flora grows on the ground, on tree trunks, on walls, or on any other object where it finds its optimal conditions of biophysical gradients. This ground flora provides shelter and wandering ground for different invertebrate groups. The diversity of bryophytes decreases with the rise in elevation above 3000 m (Begon et al. 1990), followed by a decrease with associated invertebrate species.

According to Merry Field and Royce (2002), several aquatic invertebrates that are related to mosses have evolved to tolerate the periodic drying of their habitats. The soil nematodes are good examples of invertebrates that find their shelter in bryophyte habitats. Many invertebrates have a significant food source in bryophytes bodies (Suren, 1993). The mid-altitudinal range displays high diversity, according to a prior study conducted in the tropics (Andrew et al. 2003).

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Ramazzotti (1958) and Gadea (1964) separated ombrophilous and erogenous moss animals, putting those that dwell entirely in bryophytes in the first category and those that just spend a portion of their life cycle there in the latter. They focused mostly on the tiny water fauna (Protozoa, Porifera, and Nematodes), which cannot carry water from the soil to higher tissue because they lack vascular structure. Bryophytes need constantly shaded environments, grow damp, and receive plenty of rain frequently.

The invertebrate fauna is likely to play an important role in the bryophyte community by facilitating the return of detritus matter to ecosystem-level nutrient cycling (Glime, 2013). Merrifield and Ingham (1998) suggested that the diversity of feeding strategies found in moss invertebrate communities provides evidence of within-bryophyte community nutrient cycling.

Gerson (1982) mentioned that the bryophytes can also serve as food for some invertebrates like beetles, orthopterans, collembolan, caterpillars, or aphids. Mosses represent a food component of the ground hopper *Tetrix ceperoi*, whose main diet component is *Bryum argenteum* (Koárek et al. 2008). Several detritophagous species (such as millipedes, woodlice, and earthworms) find food sources in bryophyte growths too.

2. Material and methods

Study area

This study was conducted in Sindhupalchok district (Map 1), which stands at the geographical position of 27° 36’ N to 28° 13’ N and 85° 27’ E to 85° 85' E with an area of 2542 km². This district is connected to Kathmandu through Sankhu of Bhaktapur district and borders Rasuwa to the west and Kavrepalanchok to the south (Department of Information 1971). The area lies in subtropical to alpine regions experiencing hot and cold climates.

Map.1. Map of Nepal showing study area indicated by white bordered black spot

Forceps were used to collect invertebrates from the bryophyte substrate and then stored in tiny vials with 70% Ethyl alcohol. The collected bryophyte substrate was shaken again to drop the remaining specimens of invertebrates onto a white tray or piece of cloth. The collection of bryophytes was made using grids of 11-inch squares from 10 grids spaced 10 metres apart. Lal (2017), Venkataraman (2010), and Jonathan and Kulkarni (1986) were consulted for invertebrate identification. The recorded bryophytes were identified by consulting books by Gangulee (1969–1988), Kashyap (1972), Pradhan (2015), Pradhan and Shrestha (2021–2022), Smith (1980), and Zhu and So (1996).

The Shannon-Wiener diversity index is a quantifiable measure used to determine species richness (the number of species within the community). This Index (H) was calculated using the equation $H = - p_i(\log p_i)$, where p_i is the proportion of each species in the sample. The proportion of species *i* relative to the total number of species (p_i) is calculated and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed across species and multiplied by 1. The values of the Shannon diversity index typically lie between 1.5 and 3.5.

The species richness of bryophytes and invertebrate species at various altitudinal settings was also measured using Simpson's richness Index (D) with the formula, $D = \Sigma n_i (n_i-1) / N(N-1)$ where n is the total number of organisms of certain species and N is the total number of organisms across all species. The lower the value of Shannon's index indicates low diversity and lower the value of Simpson's index (range: 0-1) indicates high diversity. The inverse of Simpson's index is positively correlated with Shannon's index.

Equitability Index assumes a value between 0 and 1 with 1 being complete evenness. The Shannon's equitability was calculated: $J=H/H_{max}$, where, H is the Shannon-Wiener's diversity index and H_{max} is the $\log_2$ of S, where, S is the total number of species in the sample.

The correlation coefficient (r) was used to determine the relationship between the two variables.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

r = Correlation Coefficient, X and Y = Variables, N = Number of Variable

3. Resulats

Invertebrates, mostly arthropods, were observed on bryofloral grounds, as were some insects and invertebrates. Except for one mollusk and two annelids, the 64 families of invertebrates in this study were largely made up of arthropods (Fig. 1). These invertebrates are directly or indirectly associated with bryophyte habitats. They appeared to be temporarily wandering on bryofloral patches; some were observed between the thalli, and others were clinging to their rhizoids.

A rich diversity of bryophytes was recorded in this region, which represented all three divisions: Anthocerotophyta, Marchantiophyta, and Bryophyta. Anthocerotophyta represented 2 families, 2 genera, and 4 species. The diversity of Marchantiophyta noted in this study was 19 families, 23 genera, and 39 species, while the next division, Bryophyta, was a little higher in diversity with 16 families, 35 genera, and 57 species and included both acrocarpous and pleurocarpous mosses (Appendix I). Overall, 100 species of this plant recorded in this study were associated differently with invertebrates at varying altitudinal ranges (Fig. 1).

Bryophytes			Invertebrates		
EI	S- WI	SI	EI	S-WI	SI
0.93	3.34	0.0332	0.9357	3.78	0.0233

Table 1. Evenness and diversity indices of Bryopytes and Invertebrates in study areas (EI= Equitable Index; S-W I= Shannon Weiner Index; SI= Simpson Index)

The Shannon-Weiner Index (S-WI) 3.34 and 3.78 for bryophytes and invertebrates respectively indicated a good diversity within the range of 1.5 to 3.5. The Equitable index (EI) for both groups indicated that they are almost even in distribution (Table 1). Simpson's Index (SI) lower values of 0.0332 and 0.0233 for bryphytes and invertebrates respectively showed a high diversity, this index is inversely propotional to Shannon and Weiner Index (Table 1).

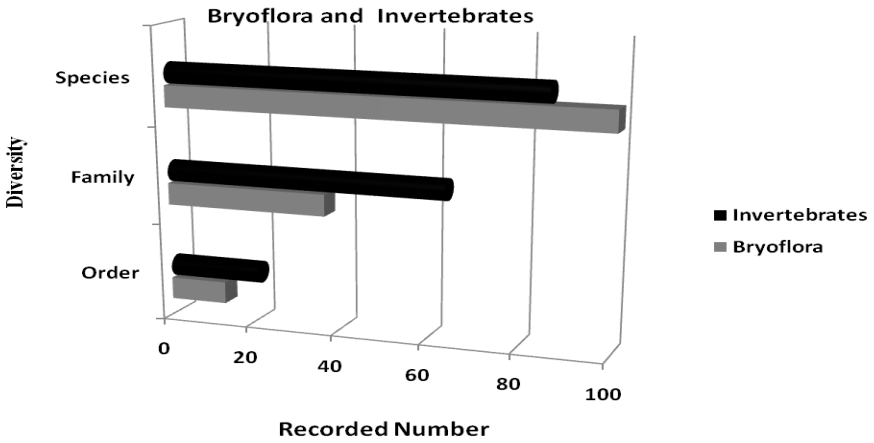

Fig.1. Bar graph shows associated species of bryophytes and Invertebrates recorded in studied areas of Sindhupalchok District of central Nepal.

This study showed a negative relationship between bryophytes and invertebrates as indicated by the correlation coefficient, r = -0.1328.

A list of bryophyte species and associated invertebrates is provided in Appendix I.

4. Discussion

Nematodes were typically seen on the moist substrates of many bryophytes. The mesic forest, which offers a home to numerous invertebrates, is the most significant environment for the flourishing of many bryophyte species. Numerous spider and beetle species also preferred the moist environment. A few invertebrates like millipedes, slugs, and snails were found on patches of this green plant.

Mosses alter soil conditions and affect the distribution of several arthropod species (Gerson, 1969). Arthropod survival and abundance frequently depend on the existence of mosses in harsh conditions. Some of their capsules attract flies, which then disperse their spores over greater distances. Insects that are frequently discovered in moss-covered areas are mostly flies (Diptera). Bozanic et al. (2013) made an effort to clarify the parameters that affect invertebrates which live in moss clumps in the Czech Republic. They looked at 61 faunal samples of 15 different moss species, which revealed a list of 45 different invertebrate species of 13 different taxonomic groups. They discovered that the size of the moss clumps and the height above ground were two main variables affecting the invertebrate population.

Many insects, especially beetles, were seen sheltering under bryophyte colonies, and earthworms were noted under the soil surface, remaining close to the rhizoids of some bryophyte species. Andrew et al. (2003) recorded that six of the invertebrate families in bryophyte habitats at Mt. Rufus locations were unique, and five of them were noted at one location only. He also stated that 97% of

invertebrates noted in bryophyte habitats in New Zealand were from the orders Collembola (60%), Acari (28%), and Diptera (9%). In their study, they also reported on 45 families of invertebrates.

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Appendix I

Bryophytes and Associated Invertebrates (800-2000 m)

Bryophytes		Invertebrates		
Family	Scientific name	Elevation	Family	Scientific name
Anthocerotaceae	*Anthoceros chambensis*	1480	Thripidae	*Scirtothrips dorsalis*
Anthocerotaceae	*Anthoceros punctatus*	1450	Carabidae Acrididae	*Carabus* sp. *Hieroglyphus banian*
Anthocerotaceae	*Anthoceros longii*	1300	Carabidae Mutillidae	*Trechus himalayanus* Velvet Ants
Notothyladaceae	*Phaeoceros laevis*	1700	Lucanidae	*Dorcus antaeus*
Aytoniaceae	*Asterella multiflora*	1480-2000	Scarabaeidae Forficulidae Gryllidae	*Eupatorus* sp. *Forficula beelzebub* *Gryllotalpa africana*
Aytoniaceae	*Asterella wallichiana*	1450	Tenebrionidae	*Acropteryx* sp.
Aytoniaceae	*Plagiochasma appendiculatum*	1300	Halticidae Plectidae	*Haltica* sp. *Plectus* sp.
Aytoniaceae	*Plagiochasma pterospermum*	1700	Chrysomelidae	*Laccopters quadrimaculata*
Aytoniaceae	*Reboulia hemispherica*	1450-2000	Cerambicidae	*Hoplocerambyx spinicornis*
Cephaloziaceae	*Cephalozia bicuspidata*	800	Coccinellidae	*Coccinela septopunctata*
Cephaloziellaceae	*Cephaloziella calyculata*	800	Sepsidae	*Dicranosepsis bicolor*
Conocephalaceae	*Conocephalum conicum*	1250-2000	Acrididae Formicidae	*Hieroglyphus banian* *Aphaenogaster* sp.
Conocephalaceae	*Conocephalum japonicum*	960-1800	Mantidae	*Mantis religiosa*
Cyathodiaceae	*Cyathodium tuberosum*	800-1700	Blattidae	*Periplaneta americana*
Dumortieraceae	*Dumortiera hirsuta*	800-1300	Apidae	*Apis dorsata*
Frullaniaceae	*Frullania ericoides*	1740	Vespidae	*Polistes* sp.
Frullaniaceae	*Frullania delatata*	980-1200	Apidae	*Orientalibombus* sp.

Frullaniaceae	*Frullania muscicola*	1280-1840	Forficulidae	*Forficula* sp.
Frullaniaceae	*Frullania tamarisci*	1310-1800	Forficulidae	*Forficula acris*
Jungermanniaceae	*Jungermannia atrovirens*	980	Forficulidae	*Forficula beelzebub*
Jungermanniaceae	*Jungermannia exertifolia*	870-1250	Forficulidae	*Eparchus insignis*
Jungermanniaceae	*Jungermannia hyaline*	800-1440	Labiduridae	*Labidura riparia*
Jungermanniaceae	*Jungermannia subelliptica*	830-1530	Aphididae	*Aphis* sp.
Jungermanniaceae	*Jungermannia truncate*	820-980	Cicadidae	*Platylomia radah*
Lejeuneaceae	*Lejeunea cavifolia*	960-1800	Ameroseiidae	*Epicriopsis* sp.
Lepidoziaceae	*Bazzania tridens*	800-1700	Lampyridae	*Luciola cruciata*
Lophocoleaceae	*Heteroscyphus argutus*	800-1300	Chironomidae	Midges
Lophocoleaceae	*Heteroscyphus planus*	1740	Simuliidae	*Simulium* sp.
Lophocoleaceae	*Lophocolea minor*	980-1200	Calliphoridae	*Calliphora* sp.
Marchsntiaceae	*Marchantia emarginata*	1280-1840	Calliphoridae	*Lucilia* sp.
Marchsntiaceae	*Marchantia paleaces*	1310-1800	Tachinidae Scarabiidae	*Tachinid* sp. *Onthophagus* sp.
Marchsntiaceae	*Marchantia polymorpha*	980	Culicidae	*Anophilus* sp.
Metzgeriaceae	*Metzgeria conjugata*	870-1250	Tabanidae	*Tabanus rubidius*
Metzgeriaceae	*Metzgeria hamata*	1500-2000	Culicidae	*Anopheles culicifacies*
Myliaceae	*Mylia taylorii*	820-980	Tipulidae	*Tipula* sp.
Plagiochileaceae	*Plagiochila chinensis*	830-1530	Sarcophagidae	*Sarcophaga crassipalpis*
Porellaceae	*Porella nitens*	820-980	Muscidae	*Musca domestica*
Riccaceae	*Riccia crystallina*	900-1000	Anthomyiidae	*Delia platura*
Riccaceae	*Riccia discolor*	800-1350	Aphididae	*Capitophorus* sp.
Riccaceae	*Riccia pathankotensis*	800	Cicadidae	*Platylomia radah*
Scapaniaceae	*Scapania undulata*	800	Lygaeidae	*Lygaeus* sp.
Targioniaceae	*Targionia hypophylla*	1200-1840	Gryllotalpidae	*Gryllotalpa orientalis*
Bartramiaceae	*Philonotis mollis*	900-1000	Lycaenidae	*Zizeeia maha*
Bartramiaceae	*Philonotis thwaitsii*	800-1350	Lycaenidae	*Freyeria putli*
Bartramiaceae	*Philonotis turneriana*	800	Lycaenidae	*Celastrina pusp*
Brachytheciaceae	*Brachythecium buchanii*	800	Lycaenidae Nymphalidae	*Arophala* sp. *Argyreus hyperbius*
Brachytheciaceae	*Eurhynchium proelongum*	1200-1840	Nymphalidae	*Precis iphita*

Brachytheciaceae	*Eurhynchium reparoides*	1750-1825	Pieridae	*Pieris brassicae*
Bryaceae	*Anomobryum julaceum*	850-1530	Nymphalidae Ichneumonidae	*Eurema brigitta* *Megarhyssa* sp.
Bryaceae	*Bryum apiculatum*	1490	Pieridae	*Eurema hecabe*
Bryaceae	*Bryum argenteum*	950-1600	Nymphalidae	*Callerebia scanda*
Bryaceae	*Bryum capillare*	1090-1650	Nymphalidae	*Mycalesis* sp.
Bryaceae	*Bryum coronatum*	800-900	Erebidae	*Cyana* sp.
Bryaceae	*Pohlia flexuosa*	850-1250	Erebidae	*Spilosoma punctaria*
Bryaceae	*Pohlia leucostoma*	1050	Erebidae	*Lemyra stigmata*
Bryaceae	*Rhodobryum giganteum*	1400-1540	Erebidae	*Spilaractia casignata*
Calymperaceae	*Octoblepharum albidum*	1200-1300	Erebidae	*Creatonotus gangis*
Dicraniaceae	*Campylopus ericoides*	850-1450	Erebidae	*Mangina argus*
Dicraniaceae	*Campylopus nilghriensis*	930-1330	Erebidae	*Areas galactina*
Dicraniaceae	*Garckea phascoides*	850-1450	Erebidae	*Euproctis* sp.
Dicraniaceae	*Trematodon longicolle*	950-1600	Erebidae Scarabaeidae	*Asota caricae* *Onthiophagus* sp.
Entodontaceae	*Erythrodontium julaceum*	1760	Erebidae	*Amata bicincta*
Entodontaceae	*Entodon prorepens*	1400-1500	Geometridae	*Arichanna* sp.
Fissidentaceae	*Fissidens bryoides*	870-1300	Zygaenidae	*Campylotes histrionicus*
Fissidentaceae	*Fissidens ceylonensis*	870-1900	Notodontidae	*Gazalina chrysolopha*
Fissidentaceae	*Fissidens crenulatus*	820-1450	Libellulidae	*Orthefrum sabina*
Fissidentaceae	*Fissidens javanicus*	820-1380	Gomphidae	*Lamelligomphus biforceps*
Fissidentaceae	*Fissidens nobilis*	1300-1650	Araneidae	*Araneus* sp.
Fissidentaceae	*Fissidens robinsonii*	900-980	Salticidae	*Saltis.* sp.
Fissidentaceae	*Fissidens sylvaticus*	820-1750	Salticidae Erebidae	*Bocus* sp. *Spilosoma casignatum*
Fissidentaceae	*Fissidens taxifolius*	900-2000	Gnaphosidae	*Gnaphosa* sp.
Funariaceae	*Funaria hygrometrica*	840-1550	Araneidae Forficulidae	*Cyclosa* sp. *Forficula* sp.
Funariaceae	*Physcomitrium eurystomum*	840-900	Sparassidae	*Heteropoda* sp.
Hypnaceae	*Taxiphyllium taxirameum*	780-1590	Lumbricidae Forficulidae	*Lumbricus terrestris* *Eparchus insignis*
Mniaceae	*Mnium rostratum*	1890	Hirudinidae	*Hirudo medicinalis*
Plagiotheciaceae	*Plagiothecium neckeroideum*	1500	Dorylaimidae	*Eudorylaimus* sp.
Polytrichaceae	*Pogonatum aloides*	1700	Plectidae	*Plectus* sp.
Polytrichaceae	*Pogonatum microphyllum*	1950	Dorylaimidae	*Eudorylaimus* sp.
Pottiaceae	*Anoectangium thomsonii*	1150	Blattidae	*Periplaneta americana*
Pottiaceae	*Barbula constricta*	830-1270	Culicidae	*Anopheles culicifacies*
Pottiaceae	*Barbula indica*	1500	Labiidae	*Labia* sp.

Pottiaceae	*Bryoerythrophyllum recurvirostrum*	860	Psychodidae	*Phleobotomus* sp.
Pottiaceae	*Hydrogonium arcuatum*	850-1600	Cicindellidae Hirudinidae	*Cicindela virgule* *Hirudo medicinalis*
Pottiaceae	*Hyophila involuta*	820-1490	Lucanidae Chrysomelidae	*Dorcus antaeus* *Laccoptera quadrimaculata*
Pottiaceae	*Merceya gediana*	800-1360	Gryllotalpidae	*Gryllotalpa major*
Pottiaceae	*Semibarbula orientalis*	850	Dorylaimidae	*Eudorylaimus* sp.
Rhytidiaceae	*Rhytidium rugosum*	850-1300	Arctiidae	*Spilosoma casignatum*
Stereophyllaceae	*Entodontopsis anceps*	800-1300	Nymphalidae Dorylaimidae Chrysomelidae	*Acraea issoria* *Eudorylaimus* sp. *Colasposoma semicostatum*
Stereophyllaceae	*Entodontopsis leucostega*	800-1530	Lygaedae	*Lygaeus* sp.
Stereophyllaceae	*Entodontopsis wightii*	800	Megascolecidae	*Pheritima posthuma*
Thuidaceae	*Haplocladium angustifolium*	1300-1500	Tipulidae	*Tipula* sp.
Thuidaceae	*Herpetineuron toccoace*	800-1400	Chrysomelidae	*Corynodes pyrophorus*
Thuidaceae	*Thuidium cambifolium*	980-1600	Acridiidae	*Hieroglyphus banian*
Thuidaceae	*Thuidium glaucinoides*	1470	Forficullidae	*Forficula acris*
Thuidaceae	*Thuidium tamariscellum*	980-1500	Coccinellidae	*Cocinella spetopunctata*