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Cover: Himalayan Gray Langur *Semnopithecus ajax* (adult female) © Rupali Thakur.

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COMMUNICATION

Contribution to the moss flora of northern Sikkim, India

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Abstract: Study of species composition and community structure is an essential requirement for maintaining the ecosystem functions, conservation, and sustainable use. Bryophytes are integral components of biodiversity and resilient during perturbation. The present investigation was, therefore, a survey in North Sikkim district (India) to study the diversity and distribution of mosses resulting in a total of 113 species in 74 genera and 28 families as new records to the study area. Of these, 14 species are considered rare based on their frequency of occurrence. The family Meteoriaceae which consists of mainly epiphytic taxa is found to be dominant and widely spread in the study area followed by Pottiaceae, Leucobryaceae, and Dicranaceae families. Sixteen species are found to be remarkable in contributing major biomass to the forest floors and as epiphytes. Five species are recorded to be endemic to this area. Most of the epiphytic species are found to be abundant in the area, indicating the good health of ecosystem. The data would be useful in the planning of conservation and management of biodiversity.

Keywords: Biodiversity, Bryophyta, ecosystem, endemicity, *Hylocomium himalayanum*, Meteoriaceae, northeastern India.

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Author contributions: HY and AD studied the detailed morphological characters for the identification and also prepared the herbarium of the samples. PLU surveyed the area and made the collection the of plant material and established the identity of the specimens.

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INTRODUCTION

Ecosystem functioning and stability is dependent on the richness of biodiversity (Noble & Dirzo 1997). Forest composition, species richness, diversity pattern, and spatial or temporal distribution are important ecological attributes significantly correlated with prevailing environmental as well as anthropogenic variables (Gairola et al. 2014). Bryophytes are abundant in some ecosystems and play an important role in providing resilience to environmental changes (Muscolo et al. 2014). Understanding species diversity and distribution patterns is crucial for evaluating the roles of plant groups in the ecosystem at a micro-level. Regular surveys for species occurrence are required for developing models for biodiversity management and ecological restoration. Variations in species composition cover at spatial and temporal scales reflect the heterogeneity of the environmental conditions (Whitmore 1984), which is the basis for the complexity and diversity of any ecosystem. Climatic conditions and developmental activities have led to an unusual loss of biodiversity and ecosystem services (Dierick & Hölscher 2009).

Bryophytes also play an important role in nutrient cycling, water retention, succession, and providing microhabitat for many plants and animals. Despite their small size, they comprise major components of biomass and photosynthetic production. The gap dynamics in the forest is influenced by the bryophyte diversity and micro- communities (Levin 1992; Kimmerer & Young 1996). Bryophyte diversity also adds to the aesthetic value and integrity of the environment. They are considered as bioindicators of air and water quality and can be used in developing an "Index of Atmospheric Purity" (IAP) (Larsen 2007). In recent years, bryophytes have been widely used for bioremediation and pollution monitoring as well as in molecular biology studies. The factors controlling the distribution of species and population dynamic of bryophytes is unfortunately poorly understood. Such studies can provide a model for the management of biodiversity.

Sikkim is situated within the Himalaya Biodiversity Hotspot and is rich in affluent flora and fauna diversity (Rahman 2012). It harbours tremendous biodiversity, though it just covers 0.2% of the geographical area of India. Currently, many species are subjected to various threats, including the biological, natural, and anthropogenic activities, which limit the regeneration of species. These concerns should be addressed with strategic methods.

Pradhan & Badola (2008) reported the use of *Sphagnum squarrosum* (peat moss) in dressing and bandaging cuts and wounds and as an important resource for fuel in the Dzongu Valley of Sikkim. Singh & Singh (2013) studied the liverworts of a part of Sikkim. Gangulee (1969–80) described the mosses of a few areas in Sikkim. The area of northern Sikkim is unexplored in terms of bryodiversity assessment and is home to many endemic and monotypic taxa. We wanted to check the influence of moss diversity on the community composition of the area. The present study is, therefore, planned to document the mosses of the North Sikkim district.

Area of Study

Sikkim State (27°31'58.699"N & 88°30'43.985"E) is located on the northeastern side of India bordered by Bhutan, Tibet, and Nepal. It has an altitudinal range varying from 300–4,000 m, representing tropical, temperate, sub-tropical, and alpine regions, and a small portion of cold desert. Approximately 80% of its geographical area is under forest cover (Sikkim Biodiversity Action Plan 2012). Present surveys were made in the North Sikkim District, especially in Lachung-Yumthang Valley and Lachen-Thangu Valley (Figure 1).

Lachung and Yumthang (27°49'33.3336''N & 88°41'44.9916''E) is a mountain valley situated at an altitude of 2,900 m. The valley is filled with temperate vegetation, especially Rhododendrons and conifers, and is rich in myriad waterfalls and streams which maintain the moisture in the valley. The Lachen and Thangu (27°43'59.99"N & 88°32'59.99"E and 27°53'31.94"N & 88°32'11.33"E) valley is situated at an altitude of 2,750 m, consisting of Rhododendrons, conifers, and alpine vegetation.

MATERIALS AND METHODS

During March 2013, mosses were collected from various areas of the North Sikkim District, particularly the Lachung-Yumthang and Lachen-Thangu Vallies. The moss patches were peeled off with a knife and collected in small polythene bags. To keep the sample pure, each population was kept separate. The moss samples were air-dried and some related data such as date of collection, locality, and habitat along with the substratum type were marked on the packets. Voucher specimens are deposited in the herbarium of Department of Botany, University of Delhi (DUH), Delhi (India). For identification of the samples, the dried materials were soaked in water for a few minutes. Morphologically, different speciemens

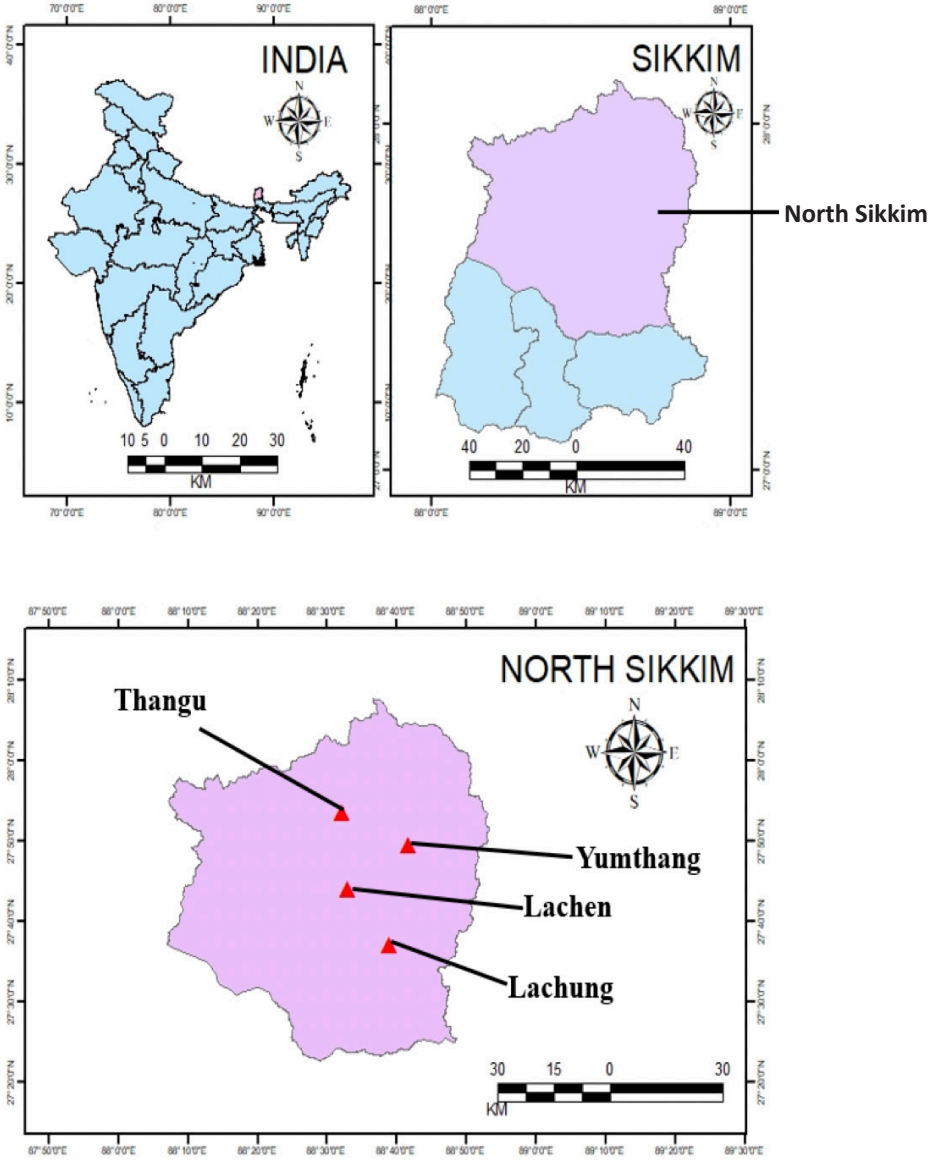

Figure 1. Map showing the study area.

were separated on the basis of microscopic observations. Different parts of each sample were observed under the microscope and identified with the help of various Floras (Gangulee 1969 – 1980; Chopra 1975; Flora of North America Editorial Committee 2007; Flora of China 2008; Koponen & Sun 2017).

RESULTS AND DISCUSSION

The study is based on the species diversity of mosses recorded during the survey undertaken in various sites of North Sikkim District. The present study reveals 113 species of mosses belonging to 74 genera and 28 families (Table 1).

Most frequently encountered species in the study area were *Brachythecium kamounense*, *Rhynchostegiella humillima*, *Ptychostomum capillare*, *Bryum cellulare*, *Campylopus richardii*, *Dicranum scoparium*, *Entodon nepalensis*, *Hylocomium himalayanum*, *Hypnum sikkimense*, *Barbella pendula*, *Floribundaria sparsa*, *Trachypodopsis serrulata*, *Pogonatum microstomum*, *Barbula angustifolia*, *Hyophila rosea*, and *Thuidium sparsifolium*. Few investigated sites act as refugia for native bryophyte species. These sites provide specific microhabitat and should be protected from any disturbance. Some of the photographs of mosses are presented in Image 1 and Image 2. Present study

Table 1. List of recorded species of mosses, with their habitat and growth form. Families are arranged according to Shaw et al. (2009).

	Taxa	Growth form and habitat
Polytrichaceae		
1	*Atrichum obtusulum* (Müll. Hal.) A. Jaeger ++	Turf, shaded soil
2	*Atrichum subserratum* (Harv. & Hook. f.) Mitt.	Turf, exposed soil
3	*Pogonatum fuscatum* Mitt.	Turf, exposed soil
4	*Pogonatum microstomum* (R. Br. ex Schwägr.) Brid.	Turf, exposed soil
5	*Pogonatum neesii* (Müll. Hal.) Dozy	Turf, shaded Soil
6	*Pogonatum urnigerum* (Hedw.) P. Beauv.	Turf, shaded soil
7	*Polytrichastrum formosum* (Hedw.) G.L. Sm. +	Turf, shaded soil
Fissidentaceae		
8	*Fissidens geppii* M. Fleisch.	Turf, termite mound
9	*Fissidens grandifrons* Brid.	Turf, rocks in streams
Bruchiaceae		
10	*Trematodon conformis* Mitt.	Tall turf, shaded soil
Rhabdoweisiaceae		
11	*Oncophorus virens* (Hedw.) Brid. +	Turf, wet rocks
12	*Oncophorus wahlenbergii* Brid. +	Turf, wet rocks
13	*Oreoweisia laxifolia* (Hook. f.) Kindb.	Turf, shaded rocks
14	*Symblepharis reinwardtii* (Dozy & Molk.) Mitt.	Turf, shaded rocks
15	*Symblepharis vaginata* (Hook. ex Harv.) Wijk & Margad.	Turf, shaded rocks
Dicranaceae		
16	*Ceratodon stenocarpus* Bruch & Schimp.	Turf, exposed rocks
17	*Cynodontium polycarpum* (Hedw.) Schimp. +	Turf, wet rocks
18	*Dicranoloma subreflexifolium* (Müll. Hal.) Paris	Tall Turf, shaded rocks
19	*Dicranum assamicum* Dixon	Tall Turf, shaded rocks
20	*Dicranum crispifolium* Müll. Hal.	Tall Turf, shaded rocks
21	*Dicranum himalayanum* Mitt.	Tall Turf, tree base
22	*Dicranum scoparium* Hedw. ++	Tall Turf, exposed rocks
23	*Ditrichum flexicaule* (Schwägr.) Hampe	Turf, exposed rocks
24	*Ditrichum tortipes* (Mitt.) Kuntze	Turf, exposed rocks
Leucobryaceae		
25	*Campylopus ericoides* (Griff.) A. Jaeger	Tall Turf, rocks
26	*Campylopus fragilis* (Brid.) Bruch & Schimp. ++	Tall Turf, exposed rocks
27	*Campylopus milleri* Renauld & Cardot	Tall Turf, exposed rocks
28	*Campylopus richardii* Brid. ++	Tall Turf, exposed rocks
29	*Campylopus savannarum* (Müll. Hal.) Mitt.	Tall Turf, exposed rocks
30	*Campylopus zollingerianus* (Müll. Hal.) Bosch & Sande Lac.	Tall Turf, exposed rocks
31	*Dicranodontium asperulum* (Mitt.) Broth.	Tall Turf, shaded rocks
32	*Dicranodontium didictyon* (Mitt.) A. Jaeger	Tall Turf, shaded rocks
33	*Ochrobryum kurzianum* Hampe +	Turf, wet rocks

	Taxa	Growth form and habitat
Pottiaceae		
34	*Anoectangium stracheyanum* Mitt.	Turf, wet rocks
35	*Barbula angustifolia* Brid. ++	Short Turf, exposed rocks
36	*Didymodon vinealis* (Brid.) R.H. Zander	Short Turf, exposed rocks
37	*Gymnostomum calcareum* Nees & Hornsch. ++	Cushion, wet rocks
38	*Hydrogonium arcuatum* (Griff.) Wijk & Margad.	Short Turf, wet rocks
39	*Hydrogonium pseudoehrenbergii* (M. Fleisch.) P.C. Chen	Turf, wet rocks
40	*Hymenostomum edentulum* (Mitt.) Besch. ++	Cushion, wet rocks
41	*Hymenostylium recurvirostrum* (Hedw.) Dixon ++	Cushion, exposed rocks
42	*Hyophila rosea* R.S. Williams ++	Turf, exposed rocks
43	*Syntrichia princeps* (De Not.) Mitt.	Turf, exposed rocks
Bryaceae		
44	*Brachymenium longicolle* Thér.	Turf, shaded rocks
45	*Bryum bessonii* Renauld & Cardot	Turf, tree branches
46	*Bryum cellulare* Hook. ++	Turf, shaded rocks
47	*Bryum recurvulum* Mitt.	Turf, shaded rocks
48	*Bryum badhwarii* Ochi	Turf, soil
49	*Ptychostomum capillare* (Hedw.) D.T. Holyoak & N. Pedersen ++	Turf, tree branches
Mniaceae		
50	*Epipterygium tozeri* (Grev.) Lindb.	Turf, tree branches
51	*Mielichhoferia assamica* Dixon	Turf, rocks
52	*Plagiomnium confertidens* (Lindb. & Arnell) T.J. Kop.	Mat, wet rocks
53	*Plagiomnium cuspidatum* (Hedw.) T.J. Kop.	Mat, wet soil
54	*Plagiomnium drummondii* (Bruch & Schimp.) T.J. Kop.	Mat, wet soil
55	*Plagiomnium japonicum* (Lindb.) T.J. Kop.	Mat, wet rocks
56	*Plagiomnium medium* (Bruch & Schimp.) T.J. Kop.	Mat, tree branches
57	*Pseudobryum cinclidioides* (Huebener) T.J. Kop.	Mat, tree bases
Climaciaceae		
58	*Climacium americanum* Brid. +	Dendroid, tree base
Amblystegiaceae		
59	*Amblystegium serpens* (Hedw.) Schimp.	Mat, aquatic
60	*Hygrohypnum choprae* Vohra	Mat, aquatic
Helodiaceae		
61	*Actinothuidium hookeri* (Mitt.) Broth.	Mat, wet rocks
Thuidiaceae		
62	*Pelekium velatum* Mitt.	Mat, moist rocks
63	*Thuidium glaucinum* (Mitt.) Bosch & Sande Lac.	Weft, forest floor
64	*Thuidium pristocalyx* (Müll. Hal.) A. Jaeger	Weft, forest floor
65	*Thuidium recognitum* (Hedw.) Lindb.	Weft, shaded rocks

	Taxa	Growth form and habitat
66	*Thuidium sparsifolium* (Mitt.) A. Jaeger	Weft, shaded rocks
Brachytheciaceae		
67	*Brachythecium kamounense* (Harv.) A. Jaeger +	Mat, exposed rocks
68	*Brachythecium longicuspidatum* (Mitt.) A. Jaeger	Mat, exposed rocks
69	*Bryhnia decurvans* (Mitt.) Dixon +	Mat, shaded rocks
70	*Homalothecium nilgheriense* (Mont.) H. Rob.	Mat, tree bark
71	*Oxyrrhynchium vagans* (A. Jaeger) Ignatov & Huttunen +	Mat, wet rocks
72	*Rhynchostegiella divaricatifolia* (Renauld & Cardot) Broth.	Mat, wet rocks
73	*Rhynchostegiella humillima* (Mitt.) Broth. ++	Mat, wet rocks
74	*Rhynchostegiella menadensis* (Sande Lac.) E.B. Bartram	Mat, wet rocks
Meteoriaceae		
75	*Aerobryidium filamentosum* (Hook.) M. Fleisch.	Pendent, tree branches
76	*Barbella convolvens* (Mitt.) Broth.	Pendent, tree branches
77	*Barbella pendula* (Sull.) M. Fleisch. ++	Pendent, tree branches
78	*Barbella spiculata* (Mitt.) Broth.	Pendent, tree branches
79	*Chrysocladium flammeum* (Mitt.) M. Fleisch.	Mat, tree branches
80	*Diaphanodon blandus* (Harv.) Renauld & Cardot	Mat, tree bark
81	*Floribundaria sparsa* (Mitt.) Broth.	Pendent, tree branches
82	*Meteorium polytrichum* Dozy & Molk. ++	Pendent, tree branches
83	*Pseudospiridentopsis horrida* (Mitt. ex Cardot) M. Fleisch.	Mat, tree bark
84	*Trachypodopsis auriculata* (Mitt.) M. Fleisch.	Pendent, tree bark
85	*Trachypodopsis serrulata* (P. Beauv.) M. Fleisch. ++	Pendent, tree branches
86	*Trachypodopsis himantophylla* (Müll. Hal. ex Renauld & Cardot) M. Fleisch.	Creeping and Pendent, tree trunk and branches
87	*Trachypus bicolor* Reinw. & Hornsch.	Creeping, tree trunk and branches
Fabroniaceae		
88	*Levierella neckeroides* (Griff.) O'Shea & Matcham	Mat, fallen logs
Hypnaceae		
89	*Ectropothecium dealbatum* (Reinw. & Hornsch.) A. Jaeger	Mat, shaded forest floor
90	*Hypnum macrogynum* Besch. ++	Mat, shaded soil and rocks
91	*Hypnum sikkimense* Ando	Mat, shaded soil
Hylocomiaceae		
92	*Hylocomium himalayanum* (Mitt.) A. Jaeger ++	Feather, forest floor
93	*Macrothamnium leptohymenioides* Nog.	Weft, forest floor
94	*Meteoriella soluta* (Mitt.) S. Okamura	Pendent, tree branches
Rhytidiaceae		
95	*Rhytidium rugosum* (Ehrh. ex Hedw.) Kindb.	Mat, forest floor
Symphyodontaceae		
96	*Chaetomitriopsis glaucocarpa* (Reinw. ex Schwägr.) M. Fleisch.	Mat, tree
Plagiotheciaceae		
97	*Plagiothecium neckeroideum* Schimp.	Mat, tree base
98	*Plagiothecium nemorale* (Mitt.) A. Jaeger	Mat, tree base
Entodontaceae		
99	*Entodon luteonitens* Renauld & Cardot	Turf, exposed rocks
100	*Entodon nepalensis* Mizush. ++	Mat, fallen logs
Pylaisiadelphaceae		
101	*Brotherella pallida* (Renauld & Cardot) M. Fleisch.	Mat, wet rocks
102	*Pylaisiadelpha capillacea* (Griff.) B.C. Tan & Y. Jia	Mat, forest floor
103	*Taxithelium nepalense* (Schwägr.) Broth.	Mat, rocks
Sematophyllaceae		
104	*Meiothecium jagorii* (Müll. Hal.) Broth.	Mat, fallen wood
105	*Sematophyllum humile* (Mitt.) Broth.	Mat, tree branches
106	*Sematophyllum phoeniceum* (Müll. Hal.) M. Fleisch.	Mat, tree bark
Pterobryaceae		
107	*Symphysodontella subulata* Broth.	Mat, wet rocks
Neckeraceae		
108	*Dixonia orientalis* (Mitt.) H. Akiy. & Tsubota +	Mat, wet rocks
109	*Macrocoma tenuis* (Müll. Hal.) Vitt	Turf, tree branches
110	*Thamnobryum macrocarpum* (Brid.) Gangulee	Feather, wet rocks
111	*Zygodon brevisetus* Wilson ex Mitt. +	Turf, tree branches
Myuriaceae		
112	*Myurium rufescens* (Reinw. & Hornsch.) M. Fleisch. +	Mat, wood pieces
Anomodontaceae		
113	*Anomodon acutifolius* Mitt.	Tail, tree trunk

+—Rare | ++—Widely distributed.

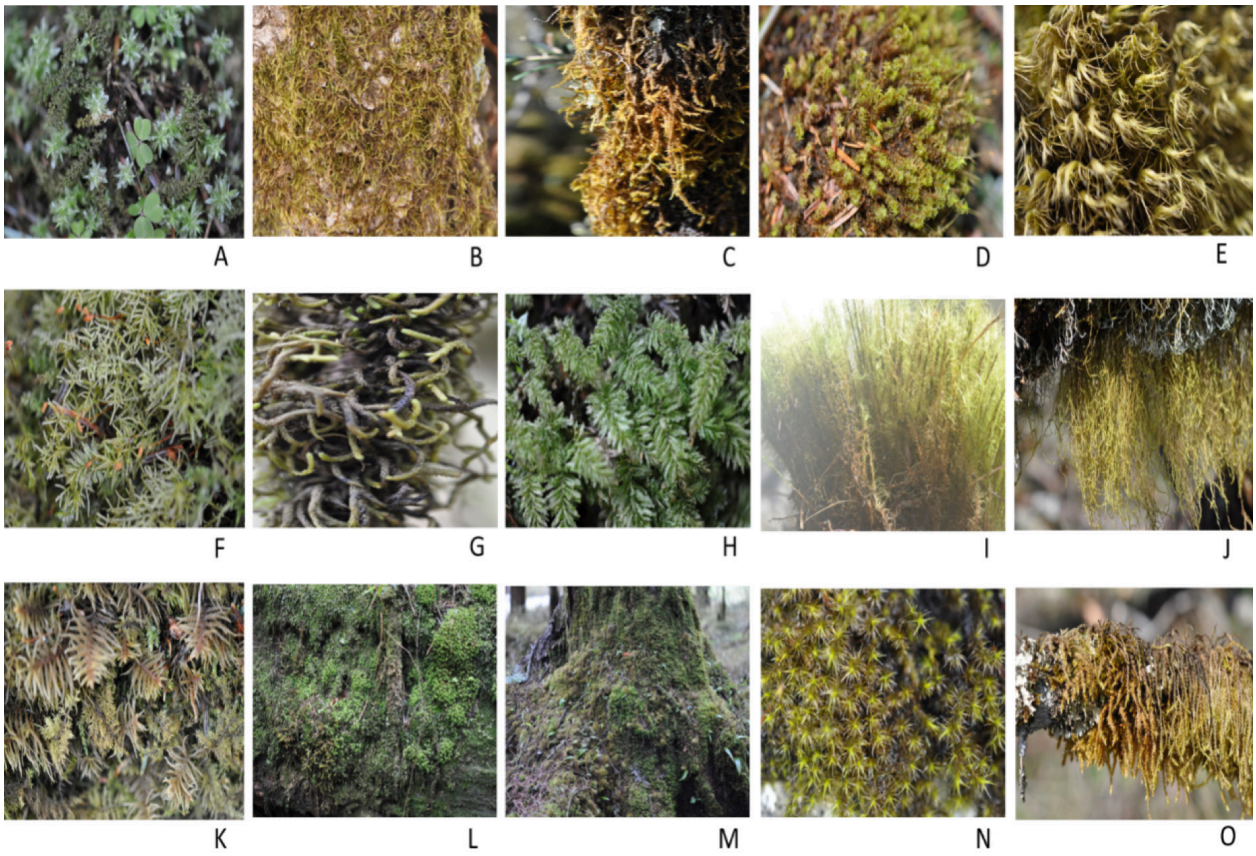

Image 1. The habitat of different bryophytes: A—*Atrichum subserratum* | B—*Diaphanodon blandus* | C—*Pseudospiridentopsis horrida* | D—*Syntrichia princeps* | E—*Dicranum crispifolium* | F—*Rhytidium rugosum* | G—*Meteorium Polytrichum* | H—*Pseudobryum cinclioides* | I—*Dicranoloma subreflexifolium* | J—*Barbella pendula* | K—*Hylocomium himalayanum* | L—*Hymenostomum edentulum* | M—*Barbula angustifolia* | N—*Oreoweisia laxifolia* | O—*Aerobryidium filamentosum*. © Prem Lal Uniyal.

highlights the relationship between variability of habitat and the species diversity, which can be used as a model. These species are recorded from more than five distant locations of the study area found on variety of substrata. Seventeen species are of frequent occurrence which appear to be highly tolerant and possess adaptability and high regeneration potential. Epiphytic species were found in abundance and their occurrence in large number indicate congenial environment provided by associated vegetation. Species richness in the communities was found to be considerably higher. The family Meteoriaceae was found to be the most prevalent with the highest diversity and species richness in the study area, with 13 species, followed by Pottiaceae with 10 species, and Leucobryaceae and Dicranaceae with nine species each. Meteoriaceae was found on tree bark and hanging from tree branches. Members of these families are ecologically important as they retain large amounts of water. The wide occurrence of these families is due to their habitat adaptation and favourable environmental conditions. Diverse tree and shrub species play a major role in the wide occurrence of epiphytic mosses.

A few species such as *Hygrohypnum choprae*, *Oxyrrhynchium vagans*, *Climacium americanum*, *Ochrobryum kurzianum, Chaetomitriopsis glaucocarpa*, *Myurium rufescens*, *Dixonia orientalis*, *Polytrichastrum formosum*, *Oncophorus virens*, and *Oncophorus wahlenbergii* are found only in very few locations (only one or two samples) and considered to be rare and highly specific to the habitats in the study area. Acrocarpous mosses are generally considered as more drought tolerant than pleurocarpous taxa. Most of the taxa are found growing on exposed sites with hard substrata like stones and rocks. *Bryum cellulare* and *Hyophila rosea* are observed to be common invader of every type of substrate such as rocks, cement floor, bricks, mortar, small rocks, and boulders. They are presumed to be highly tolerant to drought, disturbance, pollution etc. They have a high reproductive potential and found with capsules as well as gemmae. However, many of the taxa are found in sterile conditions which indicate their reproduction by vegetative means only.

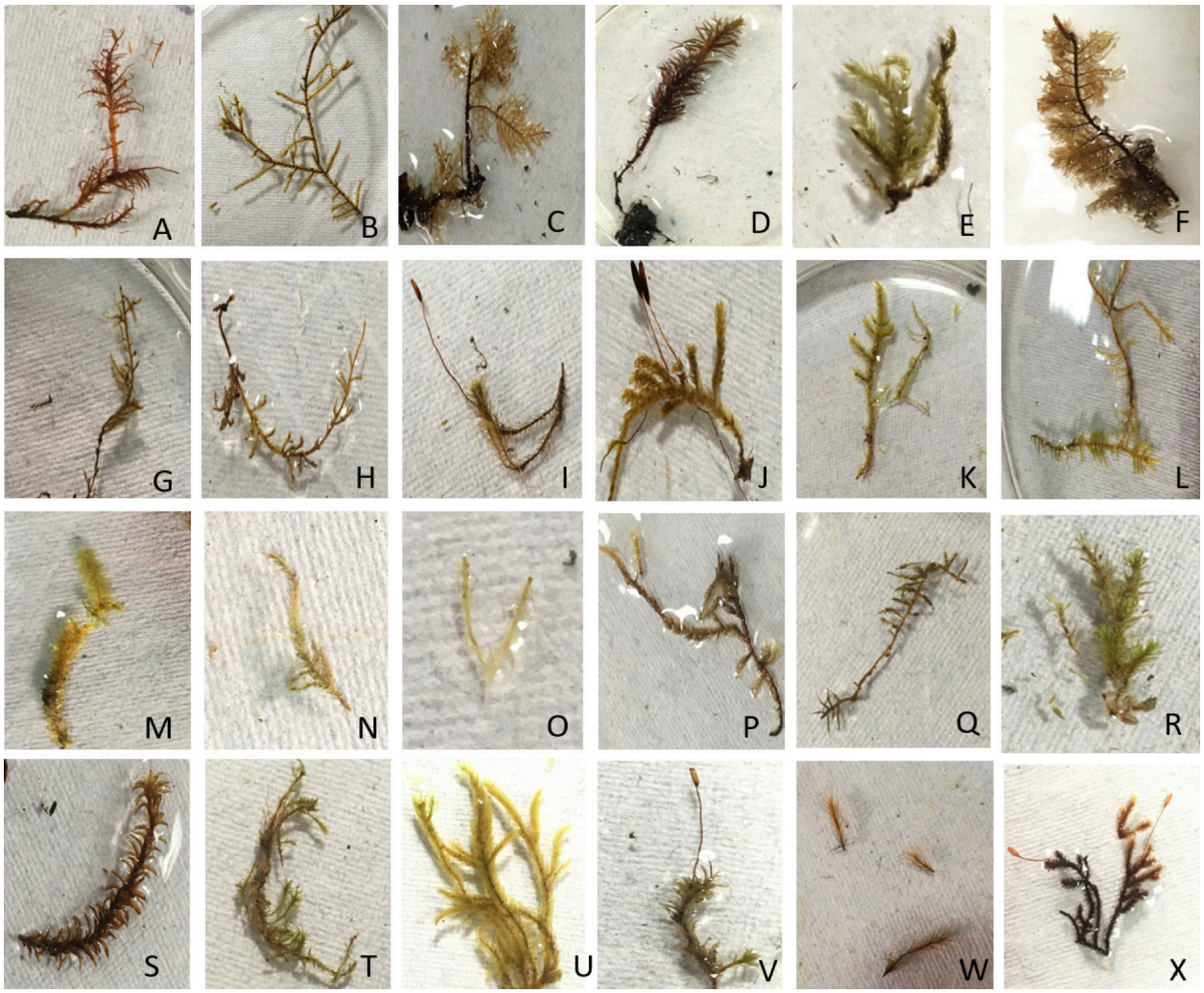

Image 1. Some identified bryophyte taxa: A—*Anomodon acutifolius* | B—*Taxithelium nepalense* | C—*Thuidium recognitum* | D—*Polytrichum formusum*,E—*Barbella spiculata* | F—*Pelekium velatum* | G—*Levierella fabroniacea* | H—*Macrothamnium leptohymenoides* | I—*Hymenostomum edentulum* | J—*Entodon luteonitens* | K—*Rhynchostegiella divariatifolia* | L—*Rhynchostegium pellucidum* | M—*Leucomium decolyi* | N—*Epiterygium tozeri* | O—*Amblystegium serpens* | P—*Homalothecium nilgheriense* | Q—*Thamnobryum macrocarpum* | R—*Hydrogonium pseudoehrenbergii* | S—*Syntrichia princeps* | T—*Anoectangium stacheyanum* | U—*Brachythecium kamounense* | V—*Hydrogonium arcuatum* | W—*Ditrichum flexicaule* | X—*Macromitrium perrottetii*. © Himani Yadav.

Growing on calcium and magnesium rich substrata, *Brachymenium longicolle*, *Fissidens geppi*, *F. grandifrons*, *Gymnostomum calcareum*, *Hydrogonium arcuatum*, and *H. pseudoehrenbergii* can occupy exposed surfaces of rocks and boulders with no trace of vegetation. Members of Thuidiaceae are widely found and observed under shady conditions, specifically on the thick litter. Turf growth form is considered as dominant in the study area and their distribution can be correlated with local climate. Some green algae are also found to be associated with moss colonies of the collected taxa.

The taxa reported as new from the Sikkim region are: *Barbella spiculata*, *Campylopus milleri*, *Fissidens geppii*, and *Mielichhoferia assamica.* Earlier, they were recorded to be restricted to nearby regions such as Meghalaya and Darjeeling only. Extended distribution of *Barbella spiculata* (Mitt.) Broth., *Campylopus milleri*, *Fissidens geppii*, *Mielichhoferia assamica*, and *Zygodon brevisetus* were also recorded in the area. These species were earlier reported to be endemic to nearby areas of Darjeeling and Meghalaya also.

Most preferred colonization substrates were found to be exposed rocks where the representation was nearly 51% of the recorded taxa. This can be explained by the fact that in the favorable environment the rocky habitat was free of competition and thus available for mosses. Living tree trunks were the second most used substrate occupied by 32% of the recorded taxa. However, the

biomass of the mosses on the living trees was found more usually. The tree trunk species followed by decaying trunks are reported as the suitable substrates for bryophytes in tropical forests (Richards 1984).

The study area seems to harbour many new and unique taxa of mosses. Epiphytic species play an important role in protecting the host species by providing continuous moisture and retaining nutrients. Mosses are highly sensitive to the alteration of habitat by recreational activities, which may alter the distribution pattern of the sensitive species of their own kind and cause a decrease in their population size, which consequently may alter the species composition of the associated invertebrate fauna. Also, there is a need to explore and identify the moss species of the concerned contrasting sites to prepare a database. A comprehensive report of the species composition and their role in the functions of the ecosystem and, subsequently, for the conservation of these species together with their habitats is also required. Sikkim is typified by its richness, high diversity, and endemic species of plants (Singh et al. 2008; Singh & Pusalkar 2020). The high richness of species marks the area as a gene bank for many plant species.

Plant species composition is considered as a marker of ecosystem health and the existence of various ecological factors influences species diversity (Sefidkon et al. 2005). The present study area shows diverse topographic features and microhabitats, which has a great potential for prospering with a rich biodiversity. The use of such natural diversity can be related to the interaction among the species. Most of the habitats of the sites were covered during the present study, and species composition was variable in different aspects.

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