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.
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 (Gairrola 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 & Holscher 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 Vallyes. 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 specimens...
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 ++ | Tall Turf, shaded soil |
| 2 | Atrichum subserratum (Harv. & Hook. f.) Mitt. | Tall Turf, shaded soil |
| 3 | Pokonatum fusatum Mitt. | Tall Turf, shaded soil |
| 4 | Pokonatum microstomum (R. Br. ex Schwäg.) Brid. | Tall Turf, shaded soil |
| 5 | Pokonatum neesi (Müll. Hal.) Dozy | Tall Turf, shaded soil |
| 6 | Pokonatum urinigerum (Hedw.) P. Beauv. | Tall Turf, shaded soil |
| 7 | Polytrichastrum formosum (Hedw.) G.L. Sm. + | Tall Turf, shaded soil |
| Fissidentaceae | |
| 8 | Fissidens geppii M. Fleisch. | Tall Turf, shaded soil |
| 9 | Fissidens grandifrons Brid. | Tall Turf, shaded soil |
| Bruchiaceae | |
| 10 | Trematodon conformis Mitt. | Tall Turf, shaded soil |
| Rhabdoweisiaceae | |
| 11 | Oncophorus verrucosus (Hedw.) Brid. + | Tall Turf, shaded soil |
| 12 | Oncophorus wahlenbergii Brid. + | Tall Turf, shaded soil |
| 13 | Oreoepisaxia laxifolia (Hook. f.) Kindb. | Tall Turf, shaded soil |
| 14 | Symbathecis reinwardtii (Dozy & Molk.) Mitt. | Tall Turf, shaded soil |
| 15 | Symbathecis vaginata (Hook. ex Harv.) Wijk & Margad. | Tall Turf, shaded soil |
| Dicranaceae | |
| 16 | Ctenostoma stenocephalum Bruch & Schimp. | Tall Turf, shaded soil |
| 17 | Cynodontium polycastrum (Hedw.) Schimp. + | Tall Turf, shaded soil |
| 18 | Dicranoloma subflexifolium (Müll. Hal.) Paris | Tall Turf, shaded soil |
| 19 | Dicranum assimilicium Dixon | Tall Turf, shaded soil |
| 20 | Dicranum crispifolium Müll. Hall. | Tall Turf, shaded soil |
| 21 | Dicranum himalayananum Mitt. | Tall Turf, shaded soil |
| 22 | Dicranum scoparium Hedw. ++ | Tall Turf, shaded soil |
| 23 | Ditrichium flexicaule (Schwäg.) Hampe | Tall Turf, shaded soil |
| 24 | Ditrichium tortipes (Mitt.) Kuntze | Tall Turf, shaded soil |
| Leucobryaceae | |
| 25 | Campylium ericoides (Griff.) A. Jaeger | Tall Turf, shaded soil |
| 26 | Campylium fragilis (Brid.) Bruch & Schimp. ++ | Tall Turf, shaded soil |
| 27 | Campylium milleri Renaud & Cardot | Tall Turf, shaded soil |
| 28 | Campylium richardi Brid. ++ | Tall Turf, shaded soil |
| 29 | Campylium savannarum (Müll. Hal.) Mitt. | Tall Turf, shaded soil |
| 30 | Campylium zollingerianus (Müll. Hal.) Bosch & Sande Lac. | Tall Turf, shaded soil |
| 31 | Dicranodontium asperum (Mitt.) Broth. | Tall Turf, shaded soil |
| 32 | Dicranodontium didiclyeum (Mitt.) A. Jaeger | Tall Turf, shaded soil |
| 33 | Ochrybryum kurzianum Hampe + | Tall Turf, shaded soil |

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| Taxa | Growth form and habitat |
|------|-------------------------|
| 66   | Thuidium sparsifolium (Mitt.) A. Jaeger | Weft, shaded rocks |
| 67   | Brachythecium kamoumense (Harv.) A. Jaeger | Mat, exposed rocks |
| 68   | Brachythecium longicuspisatum (Mitt.) A. Jaeger | Mat, exposed rocks |
| 69   | Brynza decurans (Mitt.) Dixon ++ | Mat, shaded rocks |
| 70   | Homalotheicum nilgherense (Mont.) H. Rob. | Mat, tree bark |
| 71   | Oxypyrhynchium vagans (A. Jaeger) Ignatov & Huttunen ++ | Mat, wet rocks |
| 72   | Rhynchostegiella diversicatfolia (Renaud & Cardot) Broth. | Mat, wet rocks |
| 73   | Rhynchostegiella humilima (Mitt.) Broth. ++ | Mat, wet rocks |
| 74   | Rhynchostegiella menadensis (Sande Lac.) E.B. Bartram | Mat, wet rocks |
| 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 flabellum (Mitt.) M. Fleisch. | Mat, tree branches |
| 80   | Diaphanodon blandus (Harv.) Renaud & 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 serratula (P. Beauv.) M. Fleisch. ++ | Pendent, tree branches |
| 86   | Trachypodopsis himantephylla (Müll. Hal. ex Renaud & Cardot) M. Fleisch. | Creeping and Pendent, tree trunk and branches |
| 87   | Trachypus bicolor Reinw. & Hornsch. | Creeping, tree trunk and branches |
| 88   | Levierella neckeroides (Griff.) O'Shea & Matcham | Mat, fallen logs |
| 89   | Ectropothecium drosbatum (Reinw. & Hornsch.) A. Jaeger | Mat, shaded forest floor |
| 90   | Hypnum macrogyrum Besch. ++ | Mat, shaded soil and rocks |
| 91   | Hypnum sikkimense Ando | Mat, shaded soil |
| 92   | Hylocomium himalayum (Mitt.) A. Jaeger ++ | Feather, forest floor |
| 93   | Macrothamnium leptohymenioides Neg. | Weft, forest floor |
| 94   | Meteoriella soluta (Mitt.) S. Okamura | Pendent, tree branches |
| 95   | Rhytidiadelphus rugosus (Ehrh. ex Hedw.) Kindb. | Mat, forest floor |
| 96   | Chaetomitiopsis glaucaecarpa (Reinw. ex Schwägr.) M. Fleisch. | Mat, tree |
| 97   | Plagiothecium neckeroides Schimp. | Mat, tree base |
| 98   | Plagiothecium nemorale (Mitt.) A. Jaeger | Mat, tree base |
| 99   | Entodon luteontenis Renaud & Cardot | Turf, exposed rocks |
| 100  | Entodon nepalensis Mizush. ++ | Mat, fallen logs |
| 101  | Brotherella pallida (Renaud & 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 |
| 104  | Meiotheium jagorii (Müll. Hal.) Broth. | Mat, fallen wood |
| 105  | Sematophyllum humile (Mitt.) Broth. | Mat, tree branches |
| 106  | Sematophyllum phoenicium (Müll. Hal.) M. Fleisch. | Mat, tree bark |
| 107  | Symphysodontella subulata Broth. | Mat, wet rocks |
| 108  | Dicranum orientale (Mitt.) H. Akly & Tsubota + | Mat, wet rocks |
| 109  | Macrocoma tenuis (Müll. Hal.) Vitt | Turf, tree branches |
| 110  | Thamnolyllum macrocarpus (Brid.) Gangulee | Feather, wet rocks |
| 111  | Zygodon brevisetus Wilson ex Mitt. + | Turf, tree branches |
| 112  | Myriopteris acutifolia (Griff.) O'Shea & Matcham | Mat, wood pieces |
| 113  | Myriopteris acutifolia Mitt. | Tail, tree trunk |

++—Rare | ++—Widely distributed.
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, Ochrohypnum 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.
Growing on calcium and magnesium rich substrata, Brachymenium longicolle, Fissidens geppii, 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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