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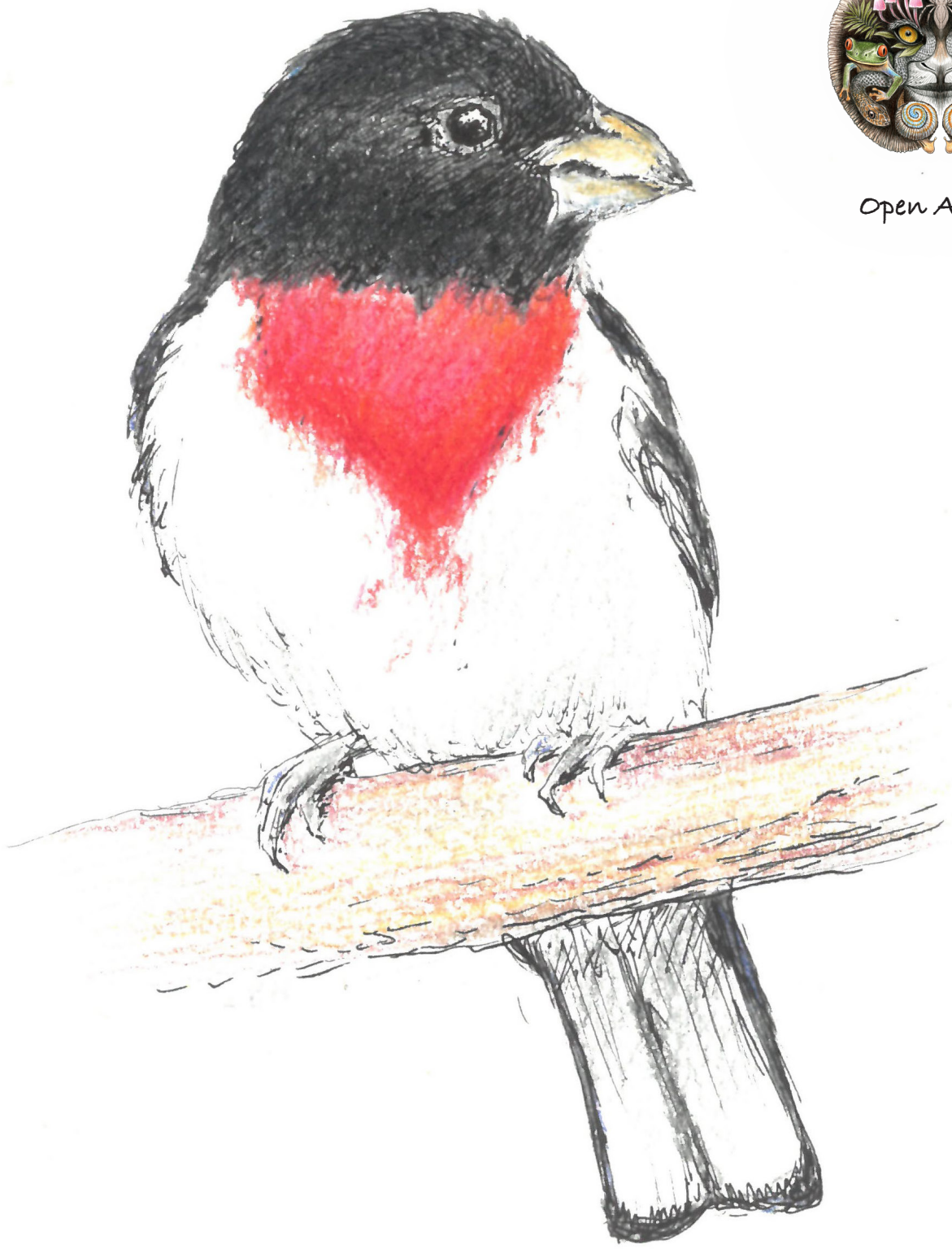

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Cover: Rose-breasted Grosbeak *Pheucticus ludovicianus*, pen & ink with colour pencil. © Lucille Betti-Nash.

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COMMUNICATION

Diversity of mosses (Bryophyta) in Pangi valley (Himachal Pradesh, India): an unexplored domain of northwestern Himalaya

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Abstract: Diversity of mosses of a unique and unexplored geographical location in Himalaya, the Pangi valley in Himachal Pradesh, India is investigated. A total of 49 moss species belonging to 21 families have been recorded, including *Hedwigia emodica*, the detail on the type specimen of which is uncertain and *Encalypta vulgaris*, a rare moss in the Himalaya. In addition, 13 moss species are new records for Himachal Pradesh. The dominant mosses of the surveyed area are *Philonotis* and *Grimmia*, where the latter is frequently found on basic, barren boulders in sunny positions. Among the recorded moss species, 35 are terrestrial, six aquatic, and eight epiphytes. The findings will be useful for forest policies and management of bryophytes conservation in areas which have extreme climatic conditions.

Keywords: Bryophytes, ecosystem, growth forms, hotspots, indicator, macroclimate, patch size, population, richness, taxa.

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Competing interests: The authors declare no competing interests.

Author detail and **Author contribution:** AD is a PhD research scholar. He is currently working on biosystematics aspects of bryophytes. KS and RKS are associate professors and have expertise in bryophyte taxonomy and ecology, respectively. PLU is a senior professor. He has an expertise in biosystematics of bryophytes, pteridophytes, and gymnosperms. All the authors were involved in field trips and moss species collections. AD and PLU confirmed the identity of the specimens. AD photographed the slides sections, wrote the initial draft of the manuscript. KS and RKS were involved in data compilation. PLU edited the entire manuscript and finalized the draft.

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INTRODUCTION

The Himalayan region constitutes one of the biodiversity hotspots of India, which comprises different kinds of forests and ecosystems in the northwestern Himalaya such as tropical, sub-tropical, temperate, sub-alpine, and alpine forests (Hajra & Rao 1990). The environmental factors such as topography, soil, climate, and geographical location influence the diversity of vegetation in forest ecosystem in the Himalaya (Arora 1995). The biodiversity and productivity in a forest are the two most important attributes, which are associated with the proper functioning of a forest ecosystem in the Himalaya (Haq et al. 2021). Any kind of ecological disturbances in the Himalaya can also affect the global climate by bringing changes in the precipitation and temperature (Khan et al. 2012) and hence affect the vegetation. Therefore, the Himalaya are an excellent zone to study about the biogeographical and ecological patterns of vegetation (Körner 2000) and of course to evaluate the diversity and community composition.

The bryophytes constitute a major part of Himalayan flora. The northwestern (NW) Himalaya comprises an enormous bryophyte diversity and composition. Various authors (Chopra & Kumar 1981; Tewari & Pant 1994; Nath et al. 2008; Alam 2013; Sahu & Asthana 2014) have done preliminary studies on the bryoflora of the NW Himalaya. However, there are still many unexplored domains in the Himalayan region which need to be investigated thoroughly so that the bryophyte species diversity and their role can be assessed. The Pangi valley in Chamba district of Himachal Pradesh (India) is one such unexplored part of the NW Himalaya. The area majorly consists of bare granite rocks and experiences harsh winters and cold summers.

The objective of the present study was to assess the moss species diversity in Pangi valley. The study will be helpful in modelling the species-habitat relationship, comparing the species diversity in the disturbed and non-disturbed sites to make better planning for conservation strategies.

MATERIALS AND METHODS

The mosses were collected from the Pangi valley, Himachal Pradesh (India), located at an average elevation of 2,287 m (32.8883^{0}N, 76.4211^{0}E and 32.9266^{0}N, 76.4619^{0}E; Image 1), in the month of June 2022. The area is dominated by conifers which remains dry during most of the year due to little precipitation and a higher snowfall period. The samples were placed in separate bags and the GPS data, their substrate, along with growth forms were noted down. The samples were carefully observed under the microscope (Olympus CX21*i*) and separated from each other to have the pure samples of the species. The mosses were identified based on their growth forms and micromorphological characters along with the help of relevant literatures (Gangulee 1969–1980; Chopra 1975; Anderson 2007). The mosses are classified following Goffinet et al. (2008). Voucher specimens are deposited at the Herbarium DUH, University of Delhi (India).

RESULTS

In the present study, a total of 49 taxa of mosses under 21 families were recorded. Most of the mosses belong to families Pottiaceae, Bartramiaceae, Grimmiaceae, Amblystegiaceae, and Bryaceae. The genera such as *Grimmia* Hedw. and *Philonotis* Brid. were found to be the most dominant in the surveyed area with the maximum number of species. Species of *Grimmia* were found growing on basic and barren substrates in sunny positions in isolated patches. Some populations were encountered on basic sandstone near the river Chenab. The plants survived the winter well under snow and produced high numbers of sporophytes in spring. *Encalypta* Hedw. and *Hedwigia* P.Beauv., represented by few populations, are rare in the area. The record of *Hedwigia emodica* Hampe ex Müll.Hal. is the interesting one. Species of *Philonotis* were found to occur on soil or rock along the banks of streams, rivers in spring and waterfall areas, often in the open. Here, the authors also recorded extended distribution of 13 taxa for Himachal Pradesh (Table 1).

DISCUSSION

The bryodiversity of Himachal Pradesh has been studied or reviewed by various authors (Lal 2005; Singh & Singh 2008; Singh & Singh 2010; Dandotiya et al. 2011; Alam 2013; Pande et al. 2017; Kumar et al. 2022). These investigations provided several new records and interesting findings. However, in terms of moss richness and diversity, there are still many under-explored regions in Himachal Pradesh which require frequent and comprehensive field visits.

The climatic condition of the valley allows the development of mosses that are adapted to these

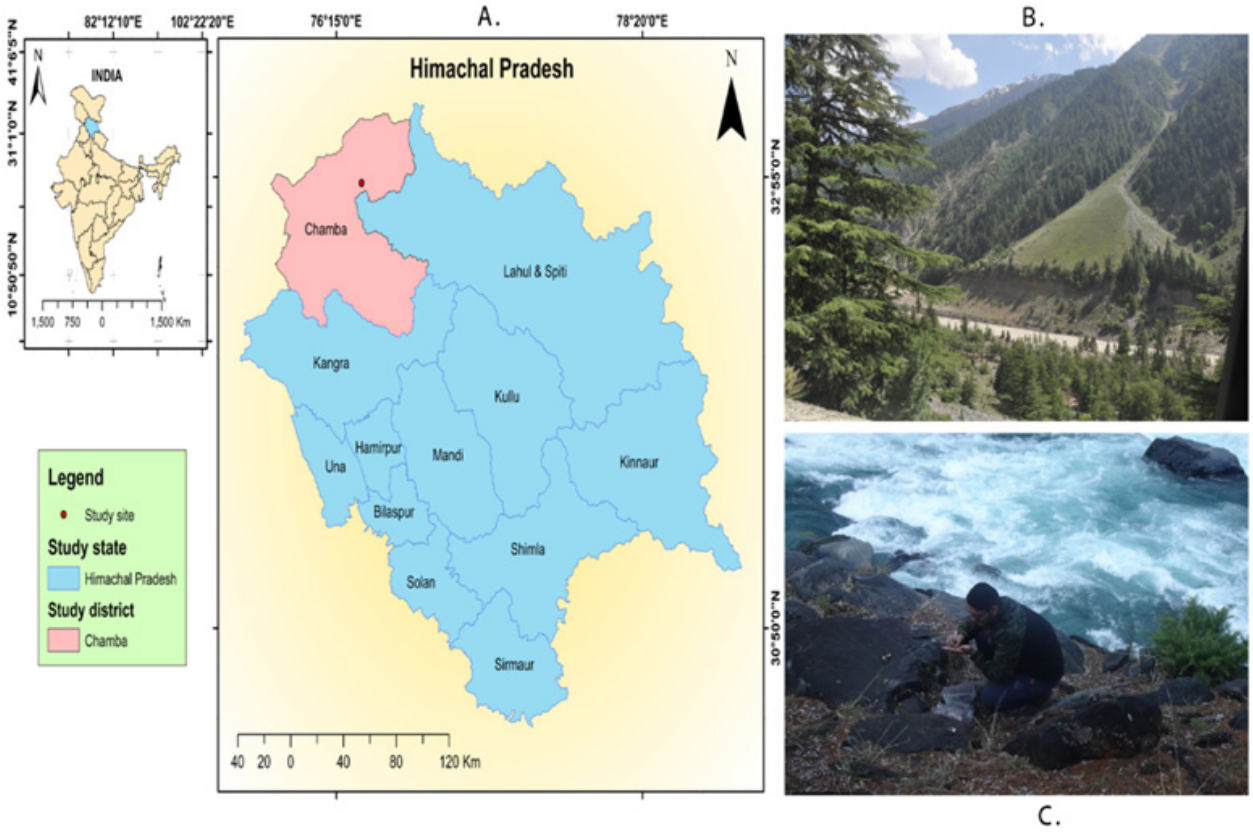

Image 1. A—Map showing the study area | B—Landscape view of the study site | C—Moss collection during study | © Anshul Dhyani & Kumar Shantanu.

climatic extremities. Several adaptive features such as the presence of long hyaline tip and compact growth in Grimmiaceae, presence of chlorophyllose cells in between the hyalocyst cells in Leucobryaceae, and the thick-coarsely papillated, small quadrate surface cells in Pottiaceae (Scott 1982) help these mosses to store water and prevent its loss, enabling these mosses to thrive in harsh and extreme climatic conditions (Image 2 & 3). Other features such as the lanceolate leaves to minimize water loss and optimize light absorption in Grimmiaceae also help in surviving the extreme conditions. In addition, the wax coating on the leaves of Polytrichaceae members prevent them from water loss as well as extreme sunlight and is considered an adaptation. In the family Pottiaceae, several species show leaf curling in response to change in humidity, which is also recognised as an adaptation factor to extreme conditions as well (Geissler 1982). The mat, cushion, turf, weft, and many such forms are also known as adaptation states to the climate. It is interesting to mention that, in *Ptychostomum pseudotriquetrum* (Hedw.) J.R.Spence & H.P.Ramsay ex Holyoak & N.Pedersen, there is production of UV-B absorbing anthocyanin pigments that check the physiological activities of the moss under extreme cold or desiccation (Dunn & Robinson 2006; Glime 2017).

A total of six species of *Encalypta* are known to occur in the northwestern Himalayan region of India, with *E. vulgaris* the only species reported from Spiti valley and Kangra in Himachal Pradesh previously (Chopra 1975). We found only few small patches of *E. vulgaris* in the studied area and one patch with a length of ca. 15 cm. which showed relatively less abundance as compared to the other reported moss taxa. The genus *Encalypta* seems to require a specific habitat condition, i.e., restricted to limestones particularly found growing in the microsites such as on exposed dry rock crevices and on ledges wedged among stones. The genus is easily distinguished by its large plate-like red perigonia which was established in the large patches along with the other herbaceous plants. Moreover, it harbours many small aquatic animals.

Only three species of *Hedwigia* have been reported from the Himalaya, viz., *H. ciliata* (Hedw.) Boucher, *H. stellata* Hedenäs, and *H. emodica* (Dalton et al. 2013). The major distinguishing characters of *H. emodica* from other species of its relatives are the presence

Table 1. Table showing the list of reported bryophyte taxa along with new records, growth form, patch size and families (Classification follows Goffinet et al. 2008).

Taxon	Substratum	Moss patch size	Growth form	Family	Voucher number
1. *Anacolia menziesii* (Turner) Paris†	Rock	Small	Open tuft	Bartramiaceae	DUH15324
2. *Anoectangium stracheyanum* Mitt.	Rock	Small	Dense tuft	Pottiaceae	DUH15325
3. *Brachythecium kamounense* (Harv.) A.Jaeger	Soil, Rock	Small	Mat	Brachytheciaceae	DUH15415
4. *Bryoerythrophyllum recurvirostrum* (Hedw.) P.C.Chen	Rock	Medium	Tuft	Pottiaceae	DUH15326
5. *Bryum argenteum* Hedw.	Open soil	Small	Mat	Bryaceae	DUH15291
6. *B. kashmirense* Broth.	Rock	Small	Thin mat, Julaceous	Bryaceae	DUH15327
7. *Chionoloma tenuirostre* (Hook. & Taylor) M.Alonso, M.J.Cano & J.A.Jiménez	Wet rocks	Small	Tuft	Pottiaceae	DUH15328
8. *Cratoneuron filicinum* (Hedw.) Spruce	Near waterfall	Small	Tuft	Amblystegiaceae	DUH15239
9. *Cynodontium polycarpon* (Hedw.) Schimp. †	Open rock	Small	Tuft	Dicranaceae	DUH15330
10. *Didymodon hastatus* (Mitt.) R.H.Zander	Calcium rock	Small	Tuft	Pottiaceae	DUH15331
11. *Encalypta vulgaris* Hedw.	Rock	Large	Cushion	Encalyptaceae	DUH15332
12. *Entodon luteonitens* Renauld & Cardot†	Forest floor	Small	Tuft	Entodontaceae	DUH15333
13. *Fissidens grandifrons* Brid.	Waterfall	Small	Mat/ Tuft	Fissidentaceae	DUH15335
14. *F. taxifolius* Hedw.	Dry Soil	Small	Tuft	Fissidentaceae	DUH15336
15. *Grimmia donniana* Sm.	Rock	Small	Cushion	Grimmiaceae	DUH15337
16. *G. elongata* Kaulf. †	Rock	Small	Cushion	Grimmiaceae	DUH15338
17. *G. funalis* (Schwägr.) Bruch & Schimp.	Calcium wet rock	Medium	Cushion	Grimmiaceae	DUH15306
18. *G. fuscolutea* Hook.	Rock	Medium	Cushion, mat	Grimmiaceae	DUH15339
19. *Haplocladium schimperi* Thér.	Tree base, Rock	Small	Mat	Leskeaceae	DUH15292
20. *Hedwigia emodica* Hampe ex Müll. Hal. †	Tree bark	Small	Tuft	Burseraceae	DUH15340
21. *Hygroamblystegium tenax* (Hedw.) Jenn.	Rock and Walls	Small	Tuft	Pottiaceae	DUH15341
22. *Hymentostylium recurvirostrum* (Hedw.) Dixon	Rock	Medium	Tuft/ Cushion	Pottiaceae	DUH15342
23. *Hypnum cupressiforme* (Hedw.)	Forest floor	Small	Mat	Hypnaceae	DUH15343
24. *Lescuraea incurvata* (Hedw.) E.Lawton	Dry Rocks	Small	Mat	Leskeaceae	DUH15344
25. *Leucodon secundus* (Harv.) Mitt.	Tree bark	Medium	Tuft	Leucodontaceae	DUH15424
26. *L. sinensis* Thér.†	Tree bark	Medium	Tuft/ Mat	Leucodontaceae	DUH15345
27. *Lewinskya speciosa* (Nees) F. Lara, Garilleti & Goffinet†	Tree branches	Small	Tuft	Orthotrichaceae	DUH15346
28. *Orthotrichum erubescens* Müll. Hal. †	Tree branches	Medium	Cushion	Orthotrichaceae	DUH15347
29. *Oxyrrhynchium hians* (Hedw.) Loeske	Waterfall	Medium	Tuft	Brachytheciaceae	DUH15348
30. *Palustriella decipiens* (De Not.) Ochyra†	Waterfall	Small	Tuft	Amblystegiaceae	DUH15349
31. *Philonotis bartramioides* (Griff.) D.G.Griffin & W.R.Buck	Calcium wet rock	Large	Tuft/ Cushion	Bartramiaceae	DUH15350
32. *P. leptocarpa* (Mitt.) †	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15352
33. *P. mollis* (Dozy & Molk.) Mitt. †	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15353
34. *P. roylei* (Hook.f.) Mitt.	Calcium wet rock	Medium	Tuft/ Cushion	Bartramiaceae	DUH15354
35. *P. turneriana* (Schwägr.) Mitt.	Wet Soil Calcium rich	Medium	Tuft	Bartramiaceae	DUH15355
36. *Plagiothecium cavifolium* (Brid.) Z.Iwats.	Tree base	Small	Mat	Plagiotheciaceae	DUH15314
37. *Pseudoleskeopsis zippelii* (Dozy & Molk.) Broth. †	Rock	Small	Mat	Leskeaceae	DUH15356
38. *Ptychomitrium tortula* (Harv.) A.Jaeger	Tree bark	Small	Tuft	Ptychomitriaceae	DUH15316

Taxon	Substratum	Moss patch size	Growth form	Family	Voucher number
39. *Ptychostomum pseudotriquetrum* (Hedw.) J.R.Spence & H.P.Ramsay ex Holyoak & N.Pedersen	Open Rock	Medium	Tuft	Bryaceae	DUH15357
40. *Reimersia inconspicua* (Griff.) P.C.Chen	Rock, Soil	Small	Tuft	Pottiaceae	DUH15358
41. *Rhynchostegium planiusculum* (Mitt.) A.Jaeger	Forest floor	Small	Tuft	Brachytheciaceae	DUH15359
42. *R. riparioides* (Hedw.) Cardot	Waterfall	Small	Tuft	Brachytheciaceae	DUH15360
43. *Rosulabryum capillare* (Hedw.) J.R.Spence	Open soil	Small	Tuft	Bryaceae	DUH15361
44. *Sarmentypnum exannulatum* (Schimp.) Hedenäs	Near waterfall	Small	Mat/ Cushion	Calliergonaceae	DUH15362
45. *Syntrichia ruralis* (Hedw.) F.Weber & D.Mohr.	Open dry soil	Small	Tuft	Pottiaceae	DUH15365
46. *Symphysodontella tortifolia* Dixon†	Rock	Small	Tuft	Pterobryaceae	DUH15363
47. *Syrrhopodon armatus* (Schwägr.)	Soil	Medium	Tuft	Calymperaceae	DUH15317
48. *Thuidium assimile* (Mitt.) A.Jaeger	Forest floor	Medium	Tuft	Thuidiaceae	DUH15364
49. *Tortella tortuosa* (Schrad. ex Hedw.) Limpr.	Dry rocks	Small	Tuft	Pottiaceae	DUH15366

†—New records to Himachal Pradesh | Moss Patch Size: Small = 0–3 cm, Medium = 3–8 cm, Large = < 8 cm

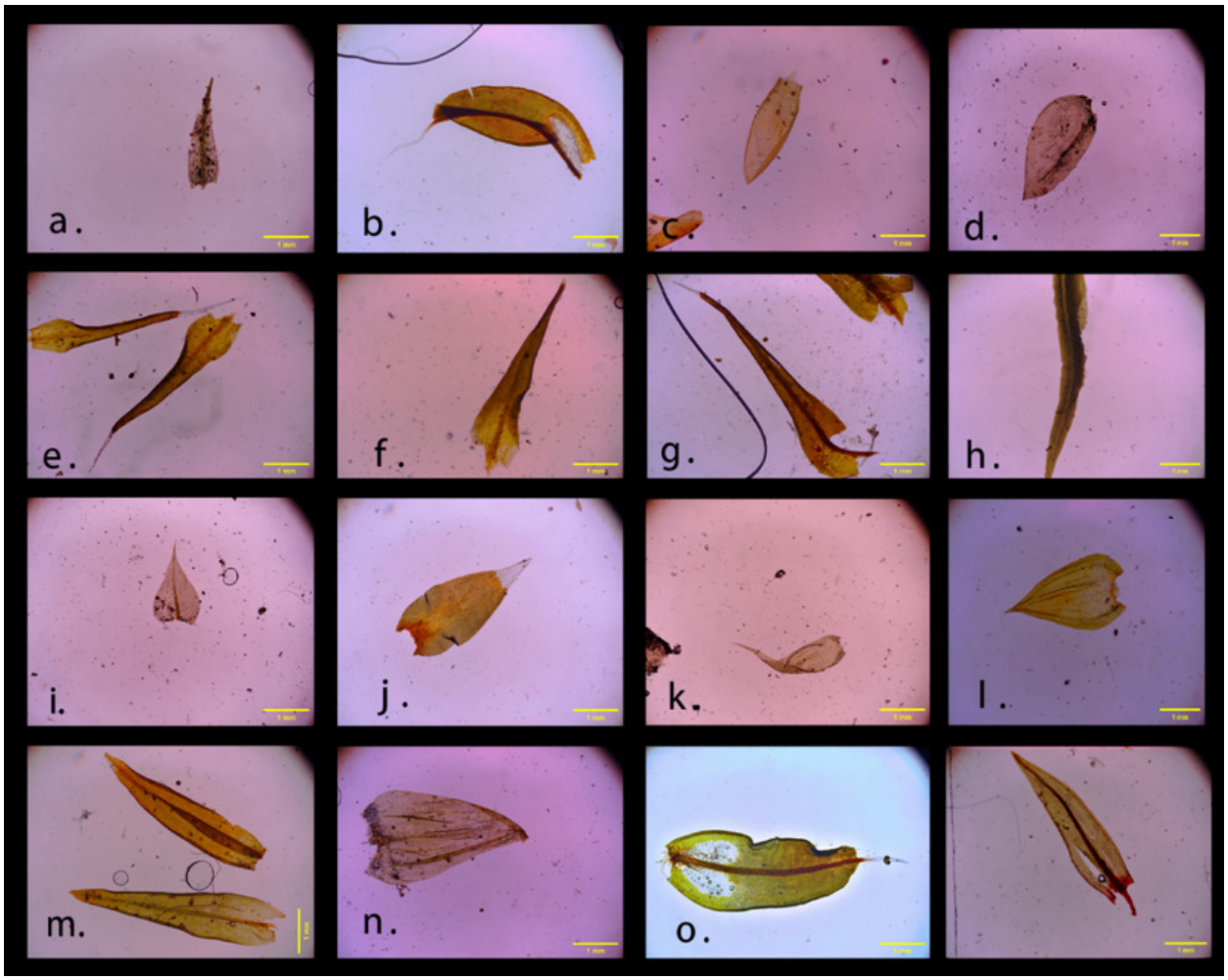

Image 2. Section photographs of some recorded mosses: a—*Sarmentypnum exannulatum* | b—*Encalypta vulgaris* | c—*Entodon luteonitens* | d—*Oxyrrhynchium hians* | e—*Grimmia fuscolutea* | f—*G. funalis* | g—*G. donniana*, h. *Fissidens taxifolius* | i—*Haplocladium schimperi* | j—*Hedwigia emodica* | k—*Hypnum cupressiforme* | l—*Leucodon sinensis* | m—*Orthotrichum griffithii* | n—*Rhynchostegium planiusculum* | o—*Syntrichia ruralis* | p—*Ptychostomum pseudotriquetrum*. © Anshul Dhyani.

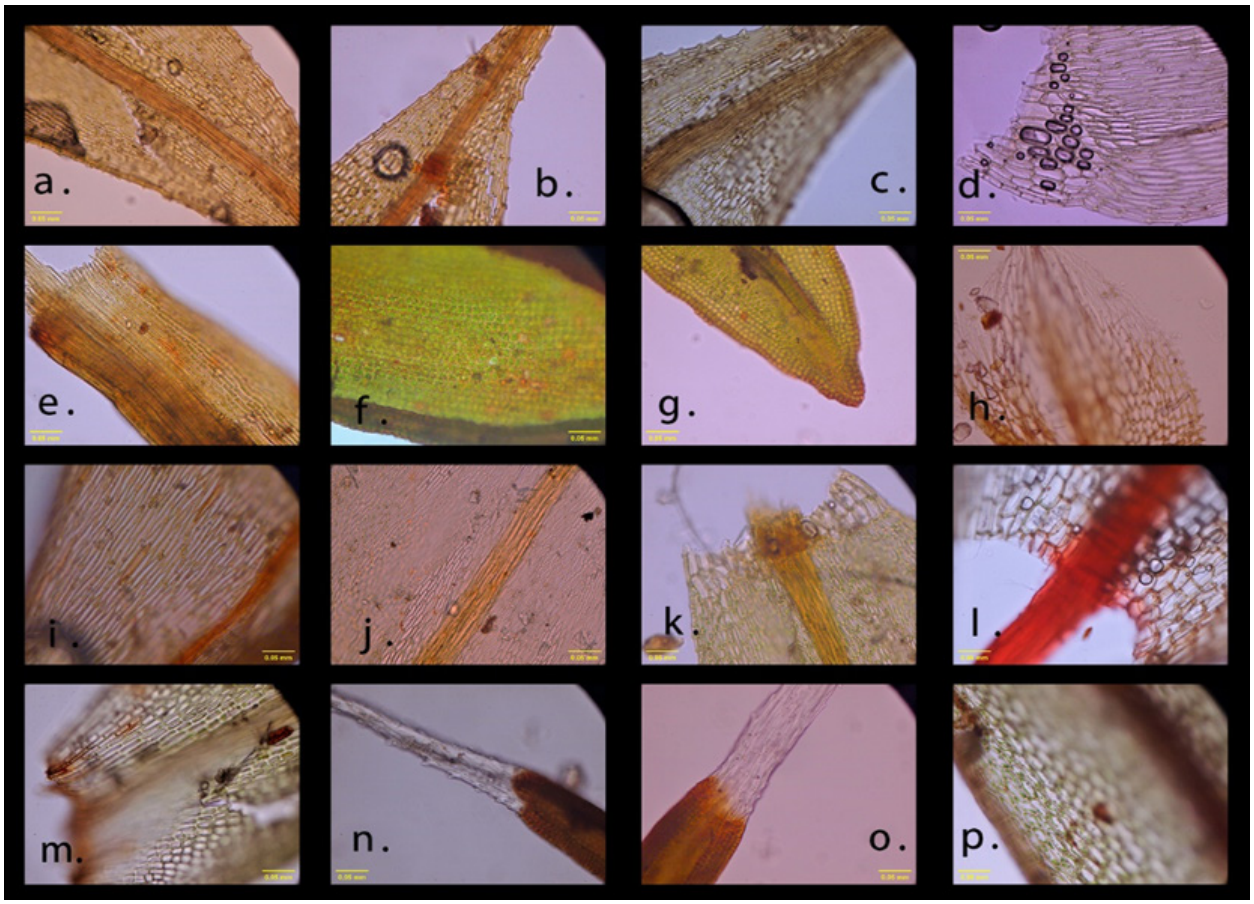

Image 3. Variations in leaf cell types in upper, middle, and basal leaf regions in different moss taxa: a—*Anacolia menziesii* | b—*Philonotis bartramioides* | c—*P. roylei* | d—Differentiated alar cells of *Brachythecium kamounense* | e—Basal leaf cells of *Grimmia fuscolutea* | f—Multipapillose quadrate cells in *Encalypta vulgaris* | g—Apical leaf cells of *Cynodontium polycarpon* | h—Apical rhombic cells of *Bryum argenteum* | i—Basal cells of *B. kashmirense* | j—Middle leaf cells of *Palustriella decipiens* | k—Basal cells and differentiated alar cells of *Cratoneuron filicianum* | l—Basal cells of *Bryum capillare* | m—Basal cells of *Hymenostylium recurvirostrum* | n—Hyaline tip of *G. donniana* | o—Hyaline tip of *G. funalis* | p—Middle leaf cells along with marginal cells of *Ptychostomum pseudotriquetrum*. © Anshul Dhyani.

of a long, hyaline tip which covers ca. 20–40% of leaf length; abaxial papillae which varies from branched to stellate and leaf margin either recurved on lower half or plane. *H. ciliata* has been previously reported from Himachal Pradesh and Uttarakhand (Asthana & Sahu 2014). *H. stellata* has been reported from Kashmir and the distribution of *H. emodica* was previously found in Jammu & Kashmir (Dalton et al. 2013). The presence of *H. emodica* in Himachal Pradesh, therefore, implies the range extension of this taxon. Present populations were found growing on sand rocks, boulders, and creeks as well as the lower trunks of *Cedrus* trees. It appears that *Hedwigia* prefers to grow on acidic substratum.

Bryophyte distribution is affected by the macroclimatic conditions, including precipitation and temperature. However, moisture is considered as an important growth stimulator more than any other factor for bryophyte productivity (Skre & Oechel 1981; Porley & Hodgetts 2005). The dominance of families such as Pottiaceae and Grimmiaceae, generally growing in exposed sites on granite-mica rocks, indicate that the area has harsh and extreme climatic conditions. Wide distribution of members of Bartramiaceae shows presence of calcareous substrata (Tewari & Pant 1994). The average bryophyte cover was higher in exposed sites and under coniferous forest patch, and thus considered as important ground cover in the area. The area is dominated by the acrocarpous turfs and cushion forming mosses in comparison to the pleurocarpous mosses. A deep bryophyte layer thickness is commonly associated with species groups that often have large cover, which therefore, produce a high biomass (Sun et al. 2013). This area harbours rich plant diversity. Less population, low developmental activities, and remote location of the area gives the opportunity to have the high regeneration rate of the species. Moreover, the harsh

environmental conditions stimulate the adaptations in the species, hence the species occurring in the area remain unique. It is important to understand the plant communities, especially of lower plant groups, of such sites for comparative study and distribution modelling in future. There is an abundance of rocky bulges and depressions, which provide refuge to species with morphological adaptations to stressful climates and to rare communities of plants, including bryophytes.

The existence of 21 distinct families in this region serves as a clear indication of the considerable diversity in terms of bryophyte richness and composition. This underscores the importance of conducting expeditions in the surrounding areas to compile a cumulative checklist. Such an endeavour will contribute to the formulation of effective policy management and conservation approaches. Although the area is remote, but the small hydroelectric units and camps on ground may make the habitat vulnerable. These anthropogenic disturbances may pose a threat to the survival of many different moss taxa. Poor dispersal range of bryophytes not only limits the population recruitment but also leads to conservation implications. The niche specificity and the role of associated species together with genetic diversity need to be studied further.

CONCLUSIONS

Bryophytes constitute an important component of the ecosystem and contribute a significant portion of species richness and biomass as well as ground cover. Although, they play a significant role in ecosystem functioning yet they receive less attention in biodiversity mapping. These interesting groups of plants are very sensitive to environmental perturbation and fairly used as indicator species. The present study revealed the species diversity of mosses in Pangi Valley (Himachal Pradesh, India) which will help in forest policies and management to conserve the biodiversity of the area. The developmental projects in the area may cause destruction of habitats of these mosses and thus can be a potential threat to their survival. Therefore, efficient and sustainable forest practices should be adopted to safeguard this economically important plant group.

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