CHAPTER - 5

RESULTS
&
DISCUSSION

1.1 Diversity and Distribution of Bryophytes

The present study investigated the diversity and distribution of bryophytes in the Eastern Part of Central Gujarat. The study area encompassed a large diversity of habitat types and included forest areas, riverine areas, urban areas, agricultural areas and was home to several monuments. This diversity of habitats harbored a good diversity of bryophytes which could be recorded during the present study. As discussed in the methodology care was taken to visit diverse habitat sites all over the study area. A total of 53 sites were visited during the study periods which were covered in 121 days of field work.Table. 5.1 below enumerates the district wise locations of the locations visited and their GPS coordinates. The distribution of the locations across the study area has been depicted in Fig. 5.1 below.

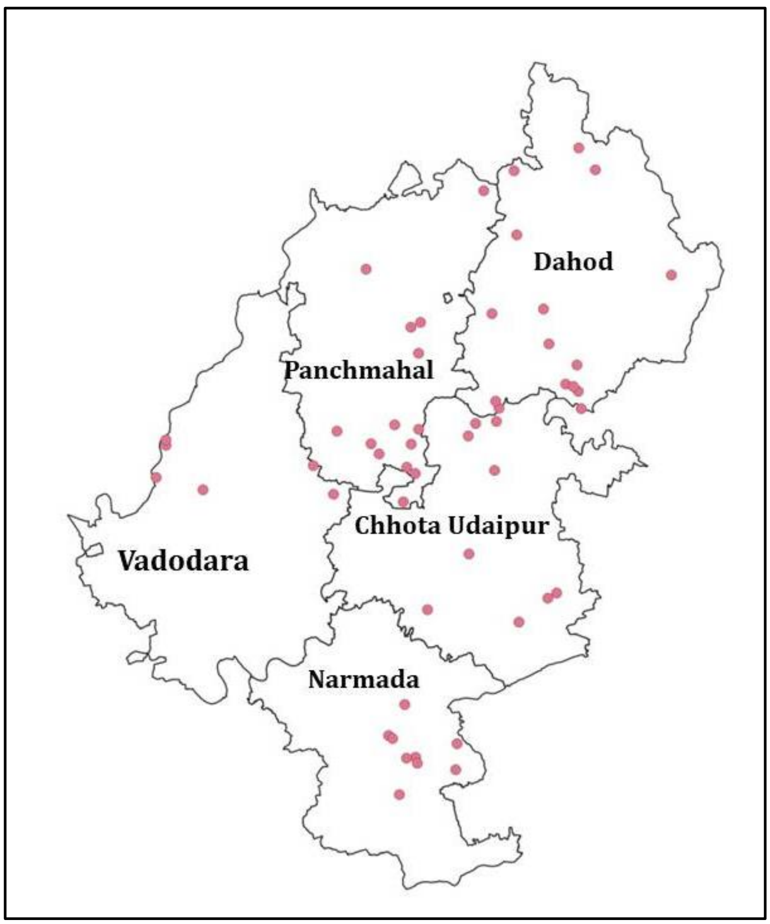

Fig. 5.1: The distribution of the locations across the study area

Table. 5.1 District wise locations of the locations visited and their GPS coordinates

Chhota Udepur district			
Sr. No.	Location	Coordinates	
		Lat (°N)	Long (°E)
1	Acchala	22.37258	73.91497
2	Nana Amarda	22.175255	73.851943
3	Ambadungar	22.015459	73.978997
4	Dungarbhint	22.488204	73.918751
5	Durgarvant	22.453305	73.847839
6	Sukhi dam & Surrounding	22.519263	73.925082
7	Ghata	22.482712	73.866105
8	Kawant	22.084674	74.073433
9	Palaskuva	22.072384	74.051423
10	Piplej	22.043157	73.748694
Narmada district			
Sr. No.	Location	Coordinates	
		Lat (°N)	Long (°E)
1	Ghichad	21.745801	73.653532
2	Junaraj	21.695205	73.721721
3	Juna Mosda	21.692939	73.699131
4	Ninai	21.666732	73.822731
5	On the way to Dediapada	21.738908	73.663491
6	Sagai	21.727915	73.825546
7	Sagbara	21.606862	73.681781
8	Zarwani	21.819217	73.693435
9	Karjan Reservior surrounding	21.681135	73.726273
Vadodara district			
Sr. No.	Location	Coordinates	
		Lat (°N)	Long (°E)
1	Chipat and surrounding	22.313265	73.50919
2	on the way to Dev Dam	22.380243	73.457436
3	Fajalpur	22.424047	73.085226
4	M S University	22.320355	73.18003
5	Mahi ravines_Rayka	22.436827	73.084806
6	Mahi ravines_Sindhrod	22.348055	73.061557
Dahod district			
Sr. No.	Location	Coordinates	
		Lat (°N)	Long (°E)

1	Chhaparvad	22.928087	73.966817
2	Kanjeta	22.577147	74.092933
3	Khalta garabdi	22.622324	74.121301
4	Khokhbed	22.671708	74.050188
5	Mal	22.519476	74.132669
6	Nalada campsite	22.560128	74.124852
7	Pipargota	22.571577	74.1125
8	Sagtala	22.535706	73.916418
9	Sanjeli	23.079066	73.958838
10	Dungar (Northern border Rajasthan)	23.133778	74.122593
11	Jhalod	23.082394	74.165021
12	Kharoda	22.835339	74.358957
13	Devgadh baria	22.741957	73.905438
14	Piplodra	22.753832	74.035788
Dahod district			
Sr. No.	**Location**	**Coordinates**	
		Lat (°N)	**Long (°E)**
1	Bhat	22.409188	73.623285
2	Dhanpuri	22.363802	73.714872
3	hathni mata waterfall	22.468096	73.722608
4	Kada Dam	22.37849	73.693443
5	On the way to zand	22.432987	73.602558
6	Pavagadh	22.46188	73.516219
7	Shivaraj forest patch	22.478116	73.661881
8	Targol	22.432951	73.704097
9	Zand hanuman	22.296672	73.685327
10	Navagam	23.031234	73.88215
11	Karsana	22.844232	73.585859
12	Goyasundal	22.647229	73.720598
13	Acchala	22.720149	73.724936
14	Rinchhya	22.708395	73.700676

5.1.1 Diversity of Bryophytes

The study revealed the presence of 45 species of bryophytes which included 13 liverworts, 6 hornworts and 26 mosses. This number represents more than half of the reported bryophyte diversity of the state (Shah & Gujar, 2016). This also highlights the importance of the eastern part of central Gujarat to the bryophyte diversity of the state. Table 5.2 below shows the list of bryophytes that have been recorded.

Table 5.2: List of bryophytes recorded in the current study.

Sr. No.	Family	Species
LIVERWORTS.		
1.	Aytoniaceae	*Asterella angusta*(Steph.) Kachroo
2.	Aytoniaceae	*Plagiochasma rupestre* (Forst) Steph.
3.	Aytoniaceae	*Plagiochasma appendiculatum* Lehm. & Lindenb.
4.	Aytoniaceae	*Plagiochasma intermedium* Lindenb. & Gottsche
5.	Aytoniaceae	*Plagiochasma microcephalum* (Stephani) Stephani
6.	Cyathodiaceae	*Cyathodium cavernarum* Kunze.
7.	Cyathodiaceae	*Cyathodium tuberosum* Kash.
8.	Lejeuneaceae	*Rectolejeunea aloba* (Sande Lac.) Stephani
9.	Ricciaceae	*Riccia billardieri* Mont. & Nees ex Gottsche, Lindenb. & Nees
10.	Ricciaceae	*Riccia cavernosa* Hoffm.
11.	Ricciaceae	*Riccia discolor* Lehm. & Lindenb.
12.	Ricciaceae	*Riccia gangetica* Ahmad
13.	Targioniaceae	*Targionia hypophylla* L.
HORNWORTS		
1.	Anthocerotaceae	*Anthoceros bharadwajii*Udar & A. K. Asthana
2.	Anthocerotaceae	*Anthoceros subtilis* Stephani
3.	Notothylaceae	*Notothylas pfleidereri* Udar & D.K. Singh
4.	Notothylaceae	*Notothylas khasiana* Udar & D.K. Singh
5.	Notothylaceae	*Notothylas levieri*Schiffner
6.	Notothylaceae	*Notothylas udarii* D.K. Singh & Semwal
MOSSES		
1.	Bartramiaceae	*Philonotis hastata* (Duby) Wijk & Margad
2.	Bartramiaceae	*Philonotis mollis* (Dozy & Molk.) Mitt.
3.	Bartramiaceae	*Philonotis thwaitesii* Mitt.
4.	Bryaceae	*Brachymenium turgidum* Broth. ex Dixon
5.	Bryaceae	*Bryum cellulare* Hook.
6.	Bryaceae	*Bryum coronatum* Schwagr.
7.	Bryaceae	*Bryum paradoxum* Schwagr
8.	Bryaceae	*Ptychostomum capillare* (Hedw.) D. T. Holyoak & N. Pedersen.
9.	Fissidentaceae	*Fissidens kurzii* Mull. Hal.
10.	Fissidentaceae	*Fissidens zollingeri* Mont.
11.	Fissidentaceae	*Fissidens curvatoinvolutus* Dixon
12.	Fissidentaceae	*Fissidens involutus* Wilson ex Mitt.
13.	Funariaceae	*Funaria hygrometrica* Hedw.
14.	Funariaceae	*Physcomitrium eurystomum* Sendtn.

Sr. No.	Family	Species
15.	Pottiaceae	*Hydrogonium arcuatum* (Griff.) Wijk & Margad.
16.	Pottiaceae	*Hydrogonium consanguineum* (Thwaites & Mitt.) Hilp.
17.	Pottiaceae	*Hyophila involuta* (Hook.) A. Jaeger
18.	Pottiaceae	*Hyophila nymaniana* (M. Fleisch.) M. Menzel
19.	Pottiaceae	*Hyophila spathulata* (Harv.) A. Jaeger
20.	Pottiaceae	*Hyophila walkeri* Broth.
21.	Pottiaceae	*Semibarbula orientalis* (F. Weber) Wijk & Margad.
22.	Splachnaceae	*Gymnostomiella vernicosa* (Hook. ex Harv.) M. Fleisch.
23.	Stereophyllaceae	*Entodontopsis nitens* (Mitt.) W.R. Buck & R.R. Ireland
24.	Stereophyllaceae	*Stereophyllum decorum* (Mitt.) Wijk & Margad.
25.	Stereophyllaceae	*Stereophyllum setschwanicum* Broth.
26.	Stereophyllaceae	*Stereophyllum tavoyense* (Hook. ex Harv.) A. Jaeger

The most commonly occurring bryophytes was *Gymnostomiella vernicosa* (moss) which occurred in all the five district while *Cyathodium tuberosum* (liverwort) occurred only in a single district (i.e. Panchmahal).

5.1.2 Species description of bryophytes

The description of the species has been broadly adapted from Bapna and Kachroo (2000) for liverworts and hornworts. For family Notothyladacee from Singh (2002) and mosses from Gangulee (1969-1980), Chaudhary and Deora (1993) and Chaudhary *et al.* (2006 and 2008). Characters which are useful for the identification of the species have been given preference. The floras can be referred to for detailed descriptions.

Species description.

1. ***Asterella angusta* (Steph.) Kachroo:** Thallus was dioecious. It was light green, prostrate about 15-20 mm long, 5-7 mm broad, light green in colour, dichotomously branched with long lanceolate appendage. It occurred in regular or irregular rosettes. Scales were to lunate in shape, purple in colour and in two rows. Both type of rhizoids was found - smooth walled and tuberculate. Female receptacle was terminal, lobed (2-6), stalked, disc shaped or hemispherical. Antheridia were found on the dorsal surface

in the form of raised cushion. Spores were brown, 70-100 µ diameter. Elaters were branched, yellow with single spiral thickenings, 180-260 µm in length. (Plate 2)

Habitat: Wall, Rock.

2. ***Plagiochasma rupestre*** **(G. Forst.) Stephani:** Thallus was monoecious or dioecious. Thallus was about 8-9 mm long and 3-5 mm broad. It was oblong, unbranched and bluish green in colour. Dorsal surface was occupied by purple scales. Appendages were 1-2 and triangular in shape. Upper epidermal cells were thin with trigones. Pores were simple surrounded by ring of 4-5 cells. Female receptacle was present in the centre of the thallus. Female receptacle occurred in the median part of thallus. Archegoniophore was stalked and stalk was about 6 mm in length. Spores were brown and about 90-120 µm in diameter. (Plate 3)

   Habitat: Rock, Wall. Walls were calcareous.

3. ***Plagiochasma appendiculatum*** **Lehm. & Lindenb.**: Thallus was monoecious. It was about 15-25 mm long and 6-8 mm broad., oblong and dichotomously branched. Both the type of rhizoids were present i.e. smooth walled and tuberculated. Purple scales occurs on both the side of the midrib with one – two appendages, Appendages were purple in colour. Male receptacle was roundish or lobed or horse shoe shaped. Female receptacle occurs on a stalk with rhizoidal furrow. Appendages were broad, ovate and 2 in number. Male receptacle was located on dorsal surface, horse shoe shaped and sub-sessile. Female receptacle was also sub-sessile and dorsal surface. (Plate 4)

   Habitat: Wall, Rock

4. ***Plagiochasma intermedium*** **Lindenb. & Gottsche:** Thallus was monoecious, green and found in dense patches. It was about 10-15 mm long and 4-6 mm broad. Thallus was linear, with purple and wavy margin. Pores were simple, bounded by 2-4 ring of cells of 6-10 cells. Thallus was strap shaped with crenate margin. Scales were purple, overlapping and in two rows. Male receptacle was horse-shoe shaped located on the dorsal surface surrounded by scales. Scales were ovate with acute apex. Female receptacle was sub-sessile, located on the dorsal surface. Carpocelphalum was concave, lobes were apiculate. Spores often 80-100 µm. (Plate 5)

   Habitat: Wall, Rock

5. ***Plagiochasma microcephalum* (Stephani) Stephani:** Thallus was about 20-25 cm long and 3-5 mm wide with a purple margin. It was greenish yellow in colour. Cuticle was smooth. Scales were purple, in 2 rows with a sinuate margin and had single appendage. Appendage generally single, triangular with pointed apex. Male receptacle was roundish or kidney shaped located on median ventral surface of thallus. Female receptacle also occurred on median ventral surface of thallus. (Plate 6)

   Habitat: Wall, Rock.

6. ***Cyathodium cavernarum* Kunze:** Plant was monoecious. Thallus was yellowish green in colour. It was about 4-7 mm long and 3-4 mm broad. It was thin, delicate and dichotomously branched. Pores were present towards the dorsal surface of the thallus. Dorsal pores more numerous at the anterior end than at the posterior end. Smooth walled rhizoids and simple ventral scales occurred towards the ventral side. Spores were blackish brown in colour, about 35-55 μm in diameter, baculate and spinate. Capsule was black, about 0.8-1.2 mm in diameter and located towards the apex of the dorsal surface. Elaters were bispiral (sometimes trispiral) and reddish brown in colour.

   Habitat: Soil, Wall. It was found in association with different species of *Riccia*. (Plate 7)

7. ***Cyathodium tuberosum* Kashyap:** Plant was dioecious. Thallus was about 8-100 mm long and 3-5 mm broad, pale green and branched. Smooth and tuberculated rhizoids were present on ventral side. Scales were irregularly distributed. Capsule was black and located towards the apex of the dorsal surface. Sporangium was differentiated into short foot, medium seta and capsule. Spores were spherical, dark brown and spinate. Elaters were reddish brown in colour, pointed at one end and blunt at other end. (Plate 8)

   Habitat: Soil, Wall

8. ***Rectolejeunea aloba* (Sande Lac.) Stephani:** It was dioecious. The plant was about 1 cm long. It was pale yellow or yellowish green in colour. The leaves were thin, ovate having a rounded apex. Perianth was large with lanceolate lobule. Rhizoids were unicellular and smooth. Reproductive body not observed. (Plate 9)

   Habitat: Bark of *Ficus glomerata*.

9. ***Riccia billardieri* Mont. & Nees ex Gottsche, Lindenb. & Nees:** Thallus was monoecious. Thallus was about 10-15 mm long, 6-8 mm broad, ovate, dichotomously branched with prominent apical notch, entire margin and obtuse apex. Both the type of rhizoids (smooth walled and tuberculated) occurred. Scales were purple, semilunar, overlapping with curved margin. Antheridial papillae were projecting from the surface of thallus and in group of 2-3. Archegonia was not found. (Plate 10)

   Habitat: Soil, Wall

10. ***Riccia cavernosa* Hoffm.:** Thallus was about 3 cm in diameter, yellowish green in colour and occurred in rosette form. The dorsal surface perforations and grooves. Ventral surface had hyaline scales and smooth walled rhizoids. (Plate 11)

   Habitat: Soil, Wall

11. ***Riccia discolor* Lehm. & Lindenb.:** Thallus was dioecious. Thallus was about 12-20 mm long, 4-6 mm wide, green, broad and twice forked. Margin was distinctly purple. Both the type of rhizoids i.e. smooth walled and tuberculate rhizoids occurred on the ventral surface. Small semilunar scales also occurred on the ventral surface extend slightly beyond the margin. Antheridia occurred on the median row and the antheridial papillae were colourless or pinkish in colour. The blackish purple colour neck of the archegonia projects above the surface of thallus. (Plate 12)

   Habitat: Soil, Wall

12. ***Riccia gangetica* Ahmad:** Thallus was monoecious. Thallus was 13-18 mm long, 2-4 mm broad, dichotomous brand with prominent mid dorsal groove, lobes were linear. Smooth and tuberculate rhizoids were present on the dorsal side. Purple scales also occurred on the ventral side on the margin but not extending beyond the margin. Pinkish antheridial papillae were present on the dorsal surface and the archegonial neck protrude out from the dorsal surface. Spores were tetrahedral, brownish black with crenate margin having 100-125 μm diameter. (Plate 13)

   Habitat: Soil, Rocks. Often found in association with other species of *Riccia.*

13. ***Targionia hypophylla* L.:** It was found both as monoecious and as dioecious. Plant is light to dark green in colour and found in clusters. Thallus was 10-12 mm long, 4-5 mm wide, oblong, prostrate growing and dichotomously branched. The dorsal surface shows presence of polyhedral areas called areole. Ventral surface had pink margin and

bears rhizoids. Rhizoids were tuberculate and smooth walled both. Sporophyte was present on the ventral side towards the apical notch. Sporophyte was surrounded by black involucre with small teeth on its inner wall. It was having a vertical slit that splitted it into two valves. (Plate 14)

Habitat: Wall, Rock. It is found in association with *Gymnostomilla vernicosa*, *Riccia* sp, *Cyathodium*.

14.*Anthoceros bharadwaji* Udar & A. K. Asthana: Thallus was moneocious. Thallus (female) was about 10-15 mm long, 18-20 mm broad, with highly dissected fan shaped lobes. Epidermal cells are having single chloroplast. Spores were dark brown to blackish in colour, tri-radiate ridge reached to the periphery, boarded un-sculptured stripe. The spores have spinulate blunt projections that form a reticuloid pattern. Diameter of the spores was about 32-50 µm. Elaters had diameter of about 150-250 µm, thin, branched, light brown and 4 celled sometimes 5 also. (Plate 15)

Habitat: Soil. It was generally found on the shaded slopes.

15.*Anthoceros subtilis* Stephani: Thallus was monoecious. Thallus (female) was about 10-12 mm long, 2-3 mm broad, spongy and formed rosette. The lobes of the thallus had highly dissected margin. Thallus had many morphological variants. Cells of the epidermis had single chloroplast with dark central pyrenoid. Spores were brown in colour with tri-radiate ridge that reached to the periphery of spore wall having 33-41µm. Spores had baculate projections on its surface with distal surface being densely spinulate in comparison to the proximal surface. Elaters had diameter of about 95-150 µm, thin, light brown and 4 celled and with presence of thin dark bands. (Plate 16)

Habitat: Soil

16.*Notothylas pfleidereri* Udar & D.K. Singh: Plant was monoecious. Thallus was about 8-12 mm in diameter, lobed, long and compact. The dorsal cells of the epidermis were quadrate to subquadrate near the apex. *Nostoc* colonies were spherical, bluish green and irregular distributed. Sporangia was inserted with distinct foot and capsule. Columella is absent. Spores was yellowish brown in colour ranging from 25 to 40 µm in diameter. (Plate 17)

Habitat: Soil

17. ***Notothylas khasiana* Udar & D.K. Singh:** Plant was dioecious. Female thallus was about 3-5 mm long and 2-4 mm wide. It was growing prostrate, dichotomously branched and lobes having crenulate margin. Sporophyte was single with distinct foot. Sporophyte lacked columella. Spores were 30-50 µm in diameter and brownish yellow in colour. Pseudoelaters were mostly 2 celled with distinct spiral thickening. (Plate 18)

    Habitat: Soil

18. ***Notothylas levieri* Schiffner:** Plant was monoecious. It formed overlapping rosettes. Thallus was pale yellow, dichotomously branched and 5-8 mm in diameter. Dorsal surface was sometimes found to be lamellate near the base of the involucres. The capsule was slender, oblong cylindrical, bivalve with prominent line of dehiscence. The capsule wall non stomatiferous, splits longitudinally along the line of dehiscence. Spores were about 30-40 µm in diameter, dark brown and arranged in tetrahedral. The psuedoelaters were light brown in colour, 1-3 celled either linear or quadrate with prominent tranverse to spiral thickening bands. (Plate 19)

    Habitat: Soil.

19. ***Notothylas udarii D*.K. Singh & Semwal:** Thallus was moneocious. Thallus is prostrate, about 10 mm long, 5-7 mm broad, lobed, dark green in colour, formed rosette, dorsal surface smooth. Spherical *Nostoc* colonies were distinctly visible on the dorsal surface. Sporophyte was located on the junction of the two thallus with lamellate involucre. Capsule had well developed persistent columella and dehiscence longitudinally along the single longitudinal suture. Spores were 30-50 µm in diameter, brownish yellow, with wavy tri-radiate ridge. Psuedoelaters were 18- 35 µm in size, rectangular in shape with spiral thickenings. (Plate 20)

    Habitat: Soil

20. ***Philonotis hastata* (Duby) Wijk & Margad.:** Stem was about 1.5-3 cm in length, branched with sub floral innovations long, slender. Leaves were lanceolate, acuminate apex, margin slightly reflexed. They were appreased to stem when dried. Cells of the leaves were thin-walled, rhomboidal to hexagonal and mamillose at the tip. Sporophyte not found. (Plate 21)

    Habitat: Soil, Wall. It was generally found near the flowing water/water fall.

21.*Philonotis mollis* (Dozy & Molk.) Mitt.: Stem was small about 1-1.5 cm in length and unbranched. Leaves were lanceolate, tapering towards the apex, acuminate apex, upper margin serrulate while rest margin entire. The upper cells were narrow-elongated while the lower cells were rectangular. Margin was serrulate in the upper half portion, rest entire. Costa was excurrent. Upper and middle leaf cells were elongated rectangular while the basal cells narrow rectangular Sporophyte was no found. (Plate 22)

Habitat: Soil, Wall. It was generally found near the flowing water/water fall.

22.*Philonotis thwaitesii* Mitt.: Stem was about 1-1.5 cm in length, stout, branched. Leaves were errecto-patent, ovate to lanceolate, acuminate apex, revulate margin, upper 2/3 portion of margin was serrurate. Costa was excurrent ending into short spine. The upper cells were mamillose, narrow-elongated while the lower cells were rectangular. Sporophyte was no found. (Plate 23)

Habitat: Wall, Rock. It was generally found near the flowing water/water fall.

23.*Brachymenium turgidum* Broth. ex Dixon: Stem was about 1-1.5 cm long. Leaves were lanceolate, smooth, entire margin, midrib 4-5 cells thick. Leaves become curled and twisted when dried. It had erect urn shaped capsule with long seta. Costa was excurrent. Upper leaf cells were hexagonal while the lower leaf cells were elongated. Capsule was erect, sub pendulous with distinct apophysis. Length of the seta was about 1.5 cm. Spores were 40-60 μm in diameter, oval and brown in colour. Peristome teeth were double. (Plate 24 & 47)

Habitat: Bark, Rock.

24.*Bryum cellulare* Hook.: Stem was erect, about 10 mm in length, reddish, branched with sub-floral innovations. Leaves were smooth, lanceolate, acute apex and entire margin. Younger leaves were reddish in colour. Costa was reddish, percurrent and ending much below the apex. Upper and middle cells were hexagonal while the lower cells were rectangular. Margin of the lamina was bordered by row of long linear cells. Sporophyte was not found. (Plate 25)

Habitat: Soil, Rock.

25.*Bryum coronatum* Schwägr.: Stem was about 1.5-2 cm long, branched. Leaves were ovate to lanceolate, smooth, with acuminate apex, entire margin. Costa was stout, reddish and excurrent. Upper and middle cells were hexagonal while the lower cells were rectangular. Capsule was thick, pendulus with 1-1.5 cm long seta. Seta was long, reddish in colour and arcuate. Apophysis was distinct thick and spongy. Operculum was big, conical and thick walled. Peritome teeth were reddish. Spores were yellowish and 5-10 µm in diameter. (Plate 26 & 47)

Habitat: Wall, Rock. It was found in association with *Riccia* species.

26.*Bryum paradoxum* Schwägr.: Stem was 1-2 cm long, branched with several sub-floral innovations. Leaves were 2-3 mm long and 0.5-1 mm wide, linear to lanceolate, with acuminate apex and crowded at apex. Costa is excurrent. Apical and middle cells were rhomboidal to hexagonal in shape and basal cells were rectangular. Capsule was errect with 0.8- 1 cm long reddish seta. Peritome teeth were reddish. Spores were yellowish and 5-10 µm in diameter. (Plate 27)

Habitat: Wall, Rock. It was found in association with *Riccia* species.

27. *Ptychostomum capillare (*Hedw.) D. T. Holyoak & N. Pedersen.: Stem was about 10 mm in length bearing many sub floral innovations. It is light to dark green in colour above while at the base it is reddish. Leaves were smooth, lanceolate, acute apex and with entire margin. They were crowded at apex and were errecto-patent when moist and become spirally twisted when dry. Upper and middle cells were hexagonal while the lower cells were rectangular. Costa was stout and tapering towards the apex and excurrent into a sharp point. Sporophyte was not found. (Plate 28)

Habitat: Soil, Rock.

28.*Fissidens curvatoinvolutus* Dixon: Plant was about 2 cm in height. Leaves without limbidium. It was ovate to lanceolate, tip acuminate and lamina sheathing. Dorsal lamina sharply rounded portion at base & decurrent with fold also at base. Costa 4-5 cells below apex and dentate margin absent. Cells of leaves were hexagonal and the cells towards the costa were longer. Marginal cells were mamillose. (Plate 29)

Habitat: Wall

29.*Fissidens involutus* Wilson ex Mitt.: Plant was about 10-12 mm long and unbranched. Leaves were oblong, acute apex, margin serrulate unbordered and with sheathing lamina. Dorsal lamina was long and decurrent. Costa was percurrent and light brown in colour. Leaf cells were hexagonal. Upper cells were wider than the lower cells. Sporophyte not found. (Plate 30)

Habitat: Soil

30.*Fissidens kurzii* Müll. Hal.: Plant was about 6-8 mm in height with light green in colour, unbranched with reddish brown stem. Leaves were oblong, lingulate and broad towards the base. It did not curled or twisted when dried. Cells of the leaves were translucent and papillate**.** Costa brown, percurrent and slightly sinous at the apical portion. Leaves were with incomplete limbidium and percurrent costa. Sporophytes not found. (Plate 31)

Habitat: Wall

31.*Fissidens zollingeri* Mont.: Plant was about 5-7 mm in length and unbranched. Leaves are oblong, acuminate apex, margin entire but slightly undulate. Vaginant lamina was reaching upto the mid leaf. At the point of insertion, the dorsal lamina had a rounded lobe. The margin of the leaf was entire and undulated. Leaves were curled twisted, when dry. Cells of leaf were hexagonal and polygonal. Costa brown, excurrent, ending into cuspidate point. Capsule was erect, cylindrical and constricted below mouth. Operculum was conic to rostrate. Spores were 10-15 μm in diameter, smooth and rounded. (Plate 32)

Habitat: Bark

32.*Funaria hygrometrica* Hedw: Plant was about 8-12 mm long. Leaves were thin, yellowish green in colour, ovate and with acuminate apex. The upper and middle cells of the leaves were hexagonal while the lower cells were rectangular. Lower leaves were small in comparison to upper middles leaves. Capsule was sub-errect, pyriform, curved with distinct annulus. Seta was long, erect and about 2 cm in length. Operculum was large with wide mouth and having 2 rows of teeth- outer and inner teeth. Spores were spherical, 14-16 μm in diameter, yellow. Calyptra was persistent and cucullate. (Plate 33 & 47)

Habitat: Wall, Rock

33.*Physcomitrium eurystomum* Sendtn.: Stem was about 8-10 mm long, slender and unbranched. Stem is short, slender sometimes branched. Leaves ovate to lanceolate, acute apex and with entire margin. Laminar cells were short to long rectangular bordered by one row of elongated cells. Leaves were slightly serrated on the margin at the apex. Costa was distinct and percurrent. Cells of lamina were smooth, thin walled and a row of narrow elonagated cells on the border. Capsule was short pyriform in shape and had short apophysis. Seta was small, slender about 2-4 mm in length. Operculum was wide and about 1 mm in diameter. Spores were about 25-30 μm in diameter, brownish and papilose. (Plate 34)

Habitat: Soil.

34.*Hydrogonium arcuatum* (Griff.) Wijk & Margad.: Dioecious. Plants robust, in dense tufts, green to yellowish-green, rarely brown below. Stems erect, brownish, cm tall, 1 mm wide with leaves, lower portion radiculose with thick rhizoids. Leaves when dry erect and appressed slightly flexuose to lanceolate to triangular base, long acuminate, apex acute, margin slightly revolute from base to the apex, rarely up to the middle and very rarely plane, with few projections near the tip. Cells short rectangular, hyaline to pellucid, smooth. Costa moderately thick, yellowish brown to reddish brown and percurrent. Sporophyte was not recorded. (Plate 35)

Habitat: Soil, Brick, Rock

35.*Hydrogonium consanguineum* (Thwaites & Mitt.) Hilp.: Dioecious. Plant robust, caespitose, yellowish green, to green above, greenish brown below. Stem erect, brown,1-2 cm tall, 0.5-1 mm wide with the leaves, sparsely radiculose below. Leaves were lanceolate, apex obtuse, margin crenulate. Cells quadrate to rectangular, papillose on both the surface with many c-shaped papillae. Costa yellowish-green to yellowish and excurrent. Sporophyte was not recorded. (Plate 36)

Habitat: Soil, Brick, Rock

36.*Hyophila involuta* (Hook.) A. Jaeger: Dioecious. Plants robust, green above, brown to dark brown below. Stem was erect brown to dark brown, 1.5 – 2.5 cm tall, simple or branched, tips curled or incurved (dry), errecto-patent, erect (moist). Cells of the upper part of leaves were quadrate in shape while on the lower part it is rectangular, mamillose, yellowish green in colour. Costa is thick to brownish in colour, percurrent. Capsule was erect, cylindrical, brownish. Peristome teeth were absent. Spores were yellowish, brown and about 8-12 μm in diameter. (Plate 37)

Habitat: Wall, Rock

37. ***Hyophila nymaniana* (M. Fleisch.) M. Menzel**: Plant was about 1.5-2 cm in length and formed rosette at regular intervals. Leaves were spatulate, with acuminate apex and slightly recurved at the apex. The cells were papillose, on the upper part of leaves were quadrate in shape while the basal cells were rectangular in shape. Costa was reddish brown and percurrent. Capsule was erect and cylindrical. (Plate 38)

    Habitat: Wall, Rock

38. ***Hyophila spathulata* (Harv.) A. Jaeger:** Plant was about 5-8 mm length; upper part was green while the lower part was reddish brown in colour. Leaves were spatulate in shape, mamillose, with quadrate shaped cells in the upper part of leaves and basal part with rectangular cells. Leaf cells rectangular, thin walled and transparent. Costa was reddish brown and percurrent. Capsule was erect and cylindrical. Spores were yellowish, brown and about 8-12 µm in diameter. (Plate 39)

    Habitat: Wall, Rock

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39. ***Hyophila walkeri* Broth.:** Plant was dioecious. Plants was very small, upto 2.5 mm in length. Stem was erect, unbranched and simple. Leaves were oblong with acute apex and entire margin. Cells were quadrate towards the upper part of leaf while basal cells were rectangular in shape. They were rectangular, transparent and broad at the base. Costa was prominent, smooth, percurrent, reddish brown in colour. Capsule was erect and cylindrical. Peristome teeth was absent. Spores were spherical, brown in colour and 16-20 µm in diameter. (Plate 40)

    Habitat: Wall, Rock

40. ***Semibarbula orientalis* (F. Weber) Wijk & Margad.:** Plant was about 1.5-2.5 cm long, unbranched, yellowish green in colour. Stem was erect, brown, and long. Leaves were oblong lanceolate, papillose, with obtuse apex, entire margin slightly curved at the middle. Costa was yellowish brown, ending just below the apex and having steroidal band on one side. Plant was sterile. Gemmae were recorded. Sporophyte was not found. (Plate 41)

    Habitat: Rock.

41. ***Gymnostomiella vernicosa* (Hook. ex Harv.) M. Fleisch.:** Plant was very small about 5-8 m long. Leaves were small, oval to spatulate in shape, entire margin crowded at

apex , crumpled when dry. Cells of the leaves were hyaline, transparent. Asexual reproductive bodies *viz* gemma was also found. Asexual reproduction was more common in comparison to the sexual reproduction. Sporophyte was globose dark brown in colour. Sporophytes was also found. (Plate 42)

Habitat: Brick, Wall, Rock.

42. ***Entodontopsis nitens*** **(Mitt.) W.R. Buck & R.R. Ireland:** Plant was yellowish green in colour. It was about 0.8-1.2 cm long. Stem was long branched and flattened. Leaves were ovate, suddenly tapers into pointed tip, obtuse apex and revolute margin. Costa reaches upto half the length of leaf. Upper and middle cells were elongated rhomboidal while the lower cells differentiated into quadrate alar cells. Sporophyte was not found. (Plate 43)

Habitat: Bark

43. ***Stereophyllum decorum*** **(Mitt.) Wijk & Margad.:** Plant was growing parallel to the substratum. It was about 1.5-2 cm long, thin slender, branched, yellowish green in colour. Leaves were ovate to lanceolate with acute apex and entire margin. Upper and middle cells were quadrate to rectangular while the distinct square shaped alars were present. Perichaetal leaves were narrow and erect. Capsule was cylindrical with slender seta. (Plate 44)

Habitat: Bark

44. ***Stereophyllum setschwanicum*** **Broth.:** Plant was yellowish green in colour. Stem was about 1-1.5 cm long, creeping and branched. Leaves were ovate to lanceolate with acute apex and entire margin. Upper and middle cells were quadrate to rectangular while the distinct squarish alars were present. n reached upto half the length of leaf. Sporophyte was not found. (Plate 45)

Habitat: Bark

45. ***Stereophyllum tavoyense*** **(Hook. ex Harv.) A. Jaeger:** Plants was light green to dark green in colour. Stem was creeping, branched and flattened. Costa ends just below the tip. Leaves were oblong, with acute tip, entire margin and occurred in asymmetrical row. Alars cells were rectangular in shape. Upper and middle cells were elongated rhomboidal in shape while the lower cells differentiated into quadrate alar cells. Sporophyte was located towards the base of the stem. Capsule was sub-erect,

cylindrical with long, slender reddish seta. Operculum was conical. Apophysis was short and tapering. Peristome teeth was well developed. (Plate 46 & 47)

Habitat: Bark

5.1.3 Familywise status of Bryophytes

In the study total 14 families were recorded in which Pottiaceae was the most diverse family having 7 species (*Hydrogonium arcautum, Hydrogonium consanguineum, Hyophila involuta, Hyophila nymmaniana, Hyophila spatulata, Hyophila walkeri, Semibarbula orientalis*) while Lejeuneaceae is the least diverse as it has only single species i.e *Rectolejeunea aloba.* Members of Pottiaceae were mostly found on the rocks or stones while the *Rectolejeunea aloba* was an epiphyte. (Table 5.3 & Fig. 5.2). Past studies reveals that among mosses Pottiaceae (6 to 34 species) Fissidentaceae (7 species) and Bryaceae (10-30 species) were predominant families in Gujarat, Southern Rajasthan, Madhya Pradesh, Chhattisgarh and Jharkhand, Rajasthan and Punjab plains, Konkan region of Maharashtra. (Shah and Gujar, 2014; Chaudhary *et al*., 2006; Alam *et al*., 2015).

In the present study among liverworts, the dominant family was Ayotoniaceae represented by 5 Species (*Asterella angustata, Plagiochasma rupestre, Plagiochasma appendiculatum, Plagiochasma intermedium* and *Plagiochasma microcephalum,*). Ayotoniaceae (5 species) and Ricciaceae (5 to 10 species) were the dominant families recorded in the Gujarat and its neigbouring states like Maharashtra (Chaudhary *et al*., 2006, 2008; Shah and Gujar, 2014, 2016;).

Similarly, in hornworts, Notothylaceae was dominant consisting of 4 species (*Notothylas indica, Notothylas kashypii, Notothylas leiveri* and *Notothylas udarii*). Notothylaceae (4 to 7 species) and Anthocerotaceae (3 to 8 species) were the dominant families recorded in the Gujarat and its neigbouring states like Maharashtra (Chaudhary *et al.,* 2006, 2008; Shah and Gujar, 2014

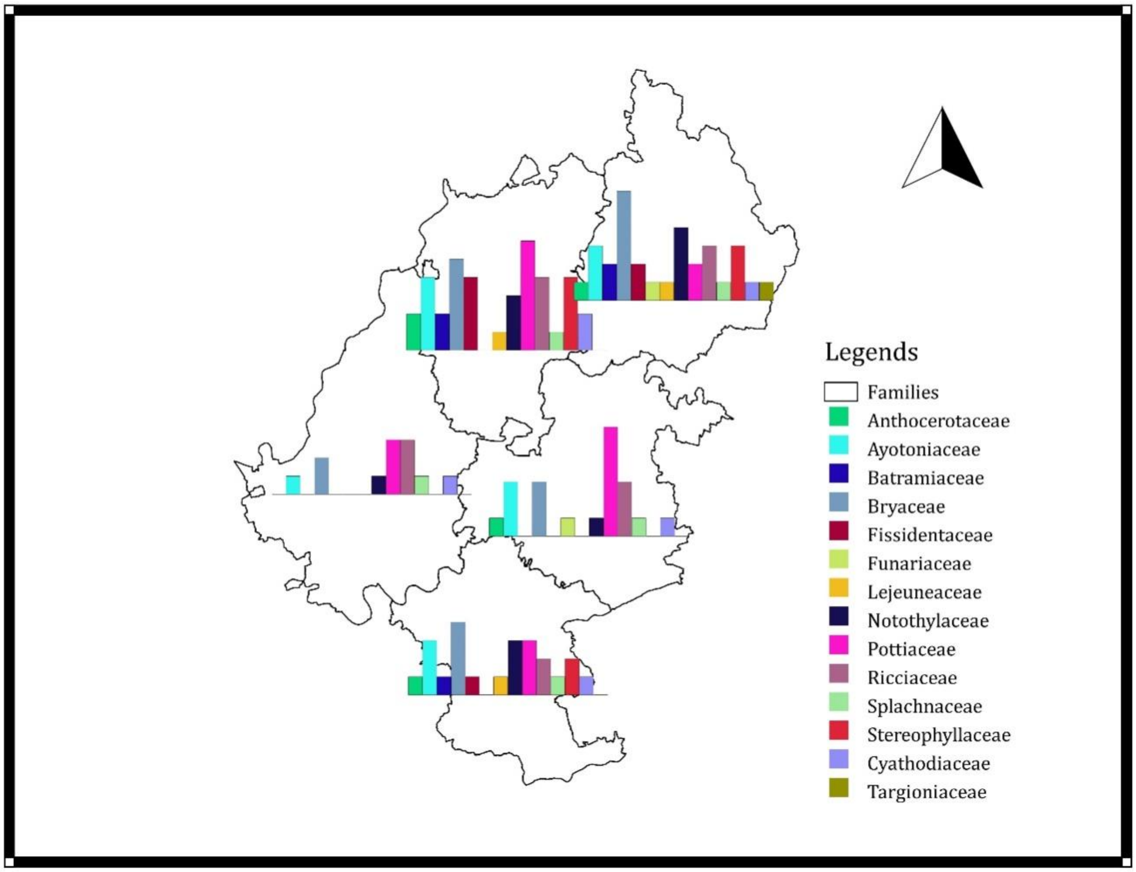


Fig. 5.2 Map showing the distribution of families in different districts of the study area.

Table 5.3: Family wise distribution in different district

Sr. No	Family	Number of species in different district				
		Chhota Udepur	Dahod	Narmada	Panchmahal	Vadodara
1.	Anthocerotaceae	1	1	1	2	-
2.	Aytoniaceae	3	3	3	4	1
3.	Bartramiaceae	-	2	1	2	-
4.	Bryaceae	3	6	4	5	2
5.	Cyathodiaceae	1	1	1	2	1

Sr. No	Family	Number of species in different district				
		Chhota Udepur	Dahod	Narmada	Panchmahal	Vadodara
6.	Fissidentaceae	-	2	1	4	-
7.	Funariaceae	1	1	-	-	-
8.	Lejeuneaceae	-	1	1	1	-
9.	Notothylaceae	1	4	3	3	1
10.	Pottiaceae	6	2	3	6	3
11.	Ricciaceae	3	3	2	4	3
12.	Splachnaceae	1	1	1	1	1
13.	Stereophyllaceae	-	3	2	4	1
14.	Targionaceae	-	1	-	-	-
Total		**20**	**31**	**23**	**38**	**13**

5.1.4 District-wise distribution of Bryophytes

In Panchmahal district, highest number of bryophytes (i.e. 38 species) were recorded that included 5 hornworts, 11 liverworts, and 22 mosses (Fig. 5.3). In Vadodara district, least number (13 species) of bryophytes were recorded that comprised of 1 hornwort, 5 liverworts, and 7 mosses. In other district like Dahod 31 species, in Narmada 23 species and in Chhota Udepur 20 species were recorded. In Panchmahal, Chaudhary *et al.* (2006) had recorded total 28 species that included 8 liverworts, 3 hornworts and 17 mosses while Shah and Gujar (2014) had recorded total 18 species that included 11 liverworts, 2 hornworts, 5 mosses. These were the only two major district wise work carried out. Chaudhary *et al.* (2006) had not investigated the Dahod, Narmada and Vadodara district of Gujarat. Moreover, they had considered Vadodara and Chhota Udepur as single district, since the partition between them occurred later in 2013. This was the only district wise study on the bryodiversity was carried in the state till the present work was intiated. However, later Shah and Gujar (2014) had visited these district and noted 12 species in Dahod, 10 species in Vadodara and 8 species in Chhota Udepur. Chhota Udepur and

Vadodara district falls in the arid region, hence the diversity of bryophytes was less. Moreover, Vadodara is the most developed urban area among the other study areas with very less forest cover. The diversity of the bryophytes also depends on the terrain. Like in Chhota Udepur, most of the members of Pottiacaeae (6 species) were found and was also dominant as it falls in the arid to semi-arid region, hence the diversity of bryophytes was less. Similarly, in Panchmahal district, highest number of epiphytes (4 species) have been documented as it has several highly elevated hilly outcrops and these outcomes in line with the past study (Chaudhary *et al*., 2006, Shah and Gujar, 2014). In case of Vadodara, most of the bryophytes were recorded on the walls or old building like MSU campus, Kirti, Mandir etc.

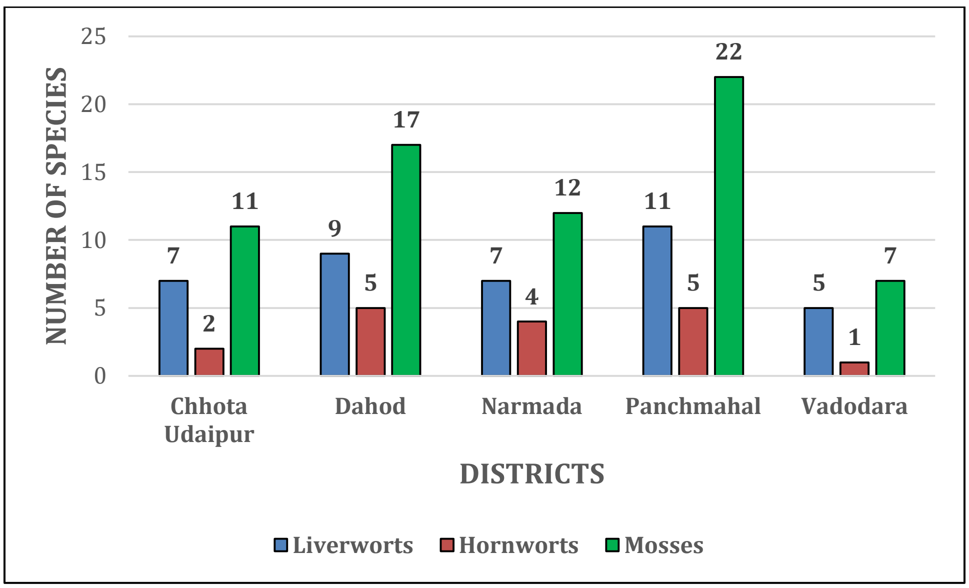


Fig 5.3: Distribution of groups in different district.

5.1.5 Habitat-wise distribution of bryophytes

In the study area, bryophytes were recorded on 5 different habitats *viz.* soil, bark, brick, rock and wall. Habitat preferences of the hornworts and liverworts had always remained monotonous. Hornworts were mostly found on only soil, while liverworts were mostly noted on soil while the mosses occupy a wide range of habitats like soil, bark, rock etc. Most dominant habitat was the rock (=24 species) while the least number species were found in brick (7 species) (Table 5.4). The rocks were inhabited by the 6 liverworts and 17mosses

The barks of *Ficus* spp.,*Diospyrous melanoxylon* were commonly used by the epiphytic species. They were mostly found in the hills of Pavagadh, Mal (Plateau, Ratanmahal), hills of dediapada. They were mainly comprised of different species of *Stereophyllum* and leafy liverwort i.e *Rectolejeunea aloba.* Rocks were mainly inhabited by the members of Pottiaceae as it retains very least moisture and they are the one better adapted for the such condition. Some species also found in dual habitats like Brick+Wall (5 species), Brick + soil (2 Species) or Rock+ Brick (6 species), Rock + soil (2 species) or Soil + wall (2 Species).

The habitat diversity of bryophytes depends greatly on the substratum and the mosses are especially adapted to occupy wide range of habitat in comparison to liverworts or hornworts (Bansal and Nath, 2012). Study of the mosses of Rajasthan (like *Bryum corantum, B cellulare)* were found in the similar habitat as recorded by many workers of central India in the past (Bansal and Nath, 2014). However, the mosses of Madhya Pradesh (Amarkanthak) were predominantly found as epiphyte on the tree bark (Nath *et al.,* 2007). In the past study, the members of Pottiaceae were mainly found on barren rocks or wall covered with soil. Similarly, in the present study they were recorded on the wall as well as some were on rock and brick. In the past, member of all liverworts were recorded on wall or rock or soil except epiphyte liverwort *Rectolejenuea aloba,* while the hornworts were recorded only on soil. In case of mosses, members of bryaceae were recorded on varied habitats like wall, soil and brick whereas *Brachymenium turgidium* was also recorded on tree bark, members of Pottiaceae and Plagiothiaceae were recorded mainly on rocks and tree bark respectively (Chaudhary and Deora, 1993; Chaudhary *et al.,* 2006, 2008; Shah and Gujar, 2014)

Table 5.4: Habitat wise distribution of Species.

Sr. No.	Species	Soil	Bark	Wall	Rock	Brick
1.	*Anthoceros bharadwajii* Udar & A. K. Asthana	+				
2.	*Anthoceros subtilis* Stephani	+				
3.	*Asterella angusta* (Steph.) Kachroo			+	+	
4.	*Brachymenium turgidum* Broth. ex Dixon		+	+	+	
5.	*Bryum cellulare* Hook.	+		+	+	+
6.	*Bryum coronatum* Schwagr.			+	+	
7.	*Bryum paradoxum* Schwagr			+	+	

Sr. No.	Species	Soil	Bark	Wall	Rock	Brick
8.	*Cyathodium cavernarum* Kunze.	+				
9.	*Cyathodium tuberosum* Kash.	+				
10.	*Entodontopsis nitens* (Mitt.) W.R. Buck & R.R. Ireland		+			
11.	*Fissidens kurzii* Mull. Hal.				+	+
12.	*Fissidens zollingeri* Mont.		+			
13.	*Fissidens curvatoinvolutus* Dixon				+	+
14.	*Fissidens involutus* Wilson ex Mitt.				+	+
15.	*Funaria hygrometrica* Hedw.			+	+	
16.	*Gymnostomiella vernicosa* (Hook. ex Harv.) M. Fleisch.			+	+	+
17.	*Hydrogonium arcuatum* (Griff.) Wijk & Margad.			+		+
18.	*Hydrogonium consanguineum* (Thwaites & Mitt.) Hilp.			+		+
19.	*Hyophila involuta* (Hook.) A. Jaeger			+	+	
20.	*Hyophila nymaniana* (M. Fleisch.) M. Menzel			+	+	
21.	*Hyophila spathulata* (Harv.) A. Jaeger			+	+	
22.	*Hyophila walkeri* Broth.			+	+	
23.	*Notothylas levirelli* Schiffner	+				
24.	*Notothylas udarii* D.K. Singh & Semwal	+				
25.	*Notothylas khasiana* Udar & D.K. Singh	+				
26.	*Notothylas pfleidereri* Udar & D.K. Singh	+				
27.	*Philonotis hastata* (Duby) Wijk & Margad			+	+	
28.	*Philonotis mollis* (Dozy & Molk.) Mitt.			+	+	
29.	*Philonotis thwaitesii* Mitt.			+	+	
30.	*Physcomitrium eurystomum* Sendtn.	+				
31.	*Plagiochasma rupestre* (Forst) Steph.			+	+	
32.	*Plagiochasma microcephalum* (Stephani) Stephani			+	+	
33.	*Plagiochasma appendiculatum* Lehm. & Lindenb.			+	+	
34.	*Plagiochasma intermedium* Lindenb. & Gottsche			+	+	
35.	*Ptychostomum capillare (Hedw.) D. T. Holyoak & N. Pedersen.*	+		+	+	+
36.	*Rectolejeunea aloba* (Sande Lac.) Stephani		+			
37.	*Riccia billardieri* Mont. & Nees ex Gottsche, Lindenb. & Nees	+				
38.	*Riccia cavernosa* Hoffm.	+				
39.	*Riccia discolor* Lehm. & Lindenb.	+				

Sr. No.	Species	Soil	Bark	Wall	Rock	Brick
40.	*Riccia gangetica* Ahmad	+				
41.	*Semibarbula orientalis* (F. Weber) Wijk & Margad.			+	+	
42.	*Stereophyllum decorum* (Mitt.) Wijk & Margad.		+			
43.	*Stereophyllum setschwanicum* Broth.		+			
44.	*Stereophyllum tavoyense* (Hook. ex Harv.) A. Jaeger		+			
45.	*Targionia hypophyla* L.			+	+	
Total		**15**	**7**	**23**	**24**	**8**

5.1.6 Distribution of Bryophytes at different altitudes.

The species richness of bryophytes increases with the increase in the altitude (Grau *et al*., 2007; Wolf, 1993). In the present study, *Stereophyllum, Fissidens zollingeri* in case of mosses and single epiphyte liverwort i. e. *Rectolejeunea aloba* were recorded only at the higher altitude (800 m and above). Some of the species are cosmopolitan and were recorded at wide range of altitude i.e. low like memebers of pottiaceae as they were recorded at lower as well as the higher altitude. Members of Pottiaceae were recorded at wide range of altitude (0-1000 m). Other such members include *viz.Targionia hypophylla, Bryum cellulare, Bryum coronatum* etc. Liverworts like different species of *Plagiochasma, Asterella angusta* and moss like *Hyophila nymaniana*, were found at a moderate elevation (200-600 m). Liverworts like *Riccia discolor*, *R. billadeiri*, *R. cavernosa*, *Semibarbula indica* etc. were found at very low altitude (below 200 m). Pattern of the distribution of species varied with the change in the altitude. At lower altitude the richness of the bryophytes is less compared to the higher altitude. Thus, this is also one of the important reason for the lower richness of bryophytes (Grau *et al*.; 2007). Similar results were obtained in the Nepal (Bhattarai and Vetaas, 2003, 2006; Bhattarai *et al.,* 2004).

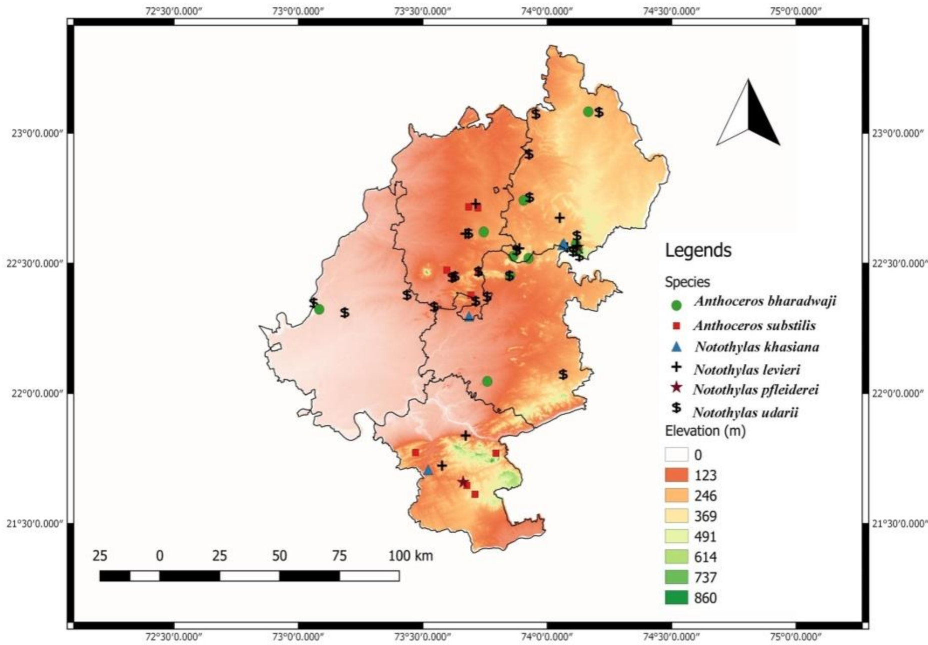


Fig. 5.4: Elevation distribution map of *Anthoceros* spp and *Notothylas* spp.

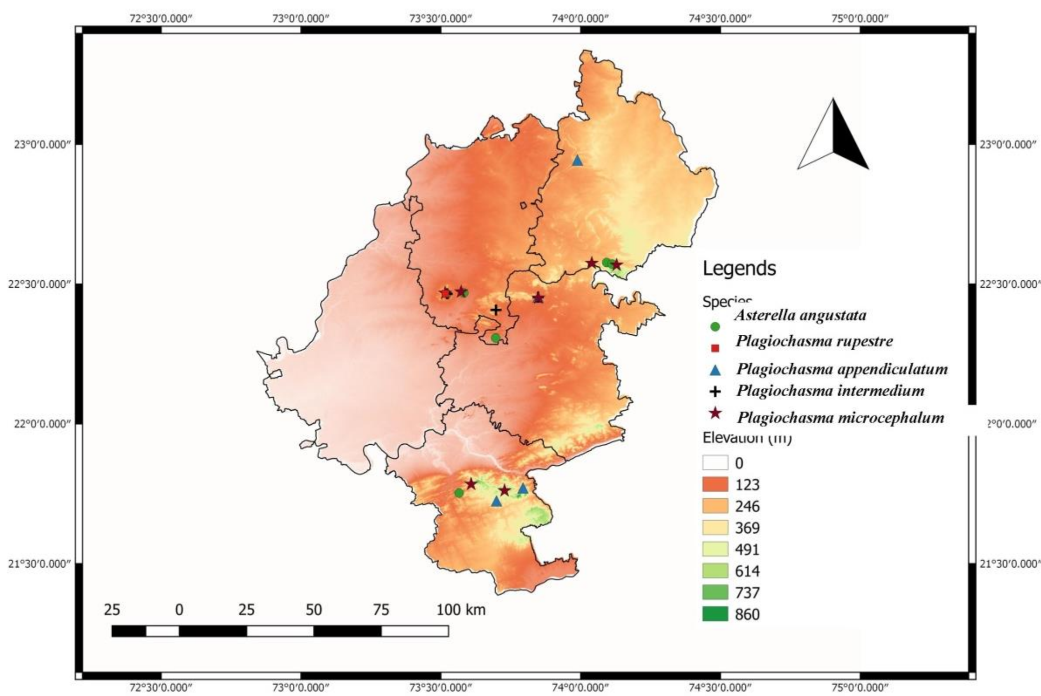


Fig 5.5: Elevation distribution map of *Asterella angusta* and *Plagiochasma* spp.

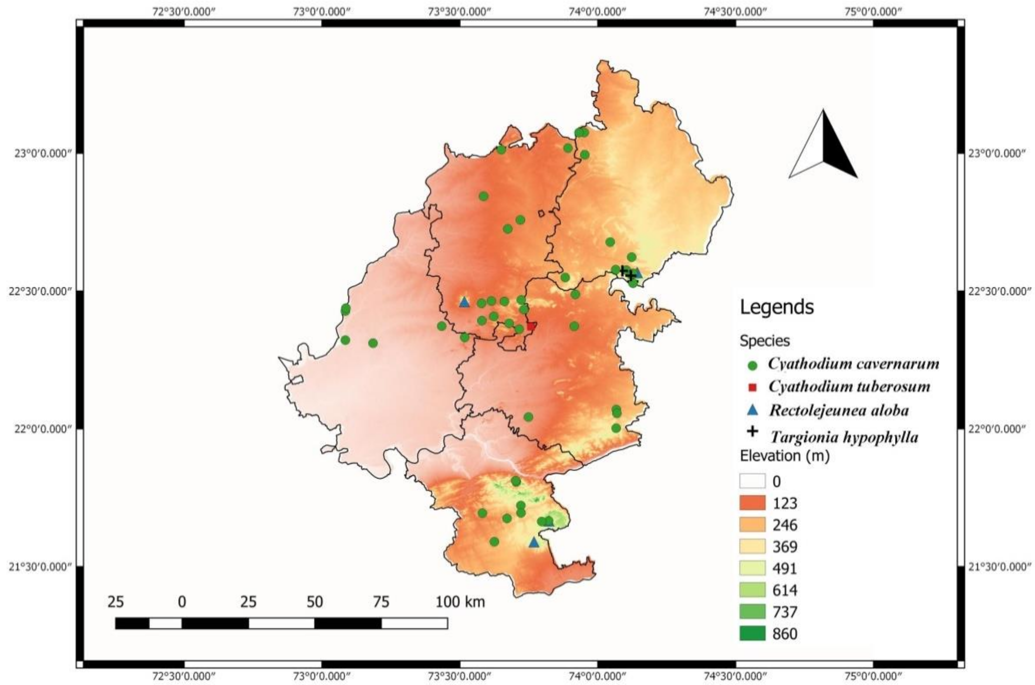


Fig. 5.6: Elevation distribution map of *Cyathodium* spp, *Targiona hypophylla* and *Rectolejunea aloba*

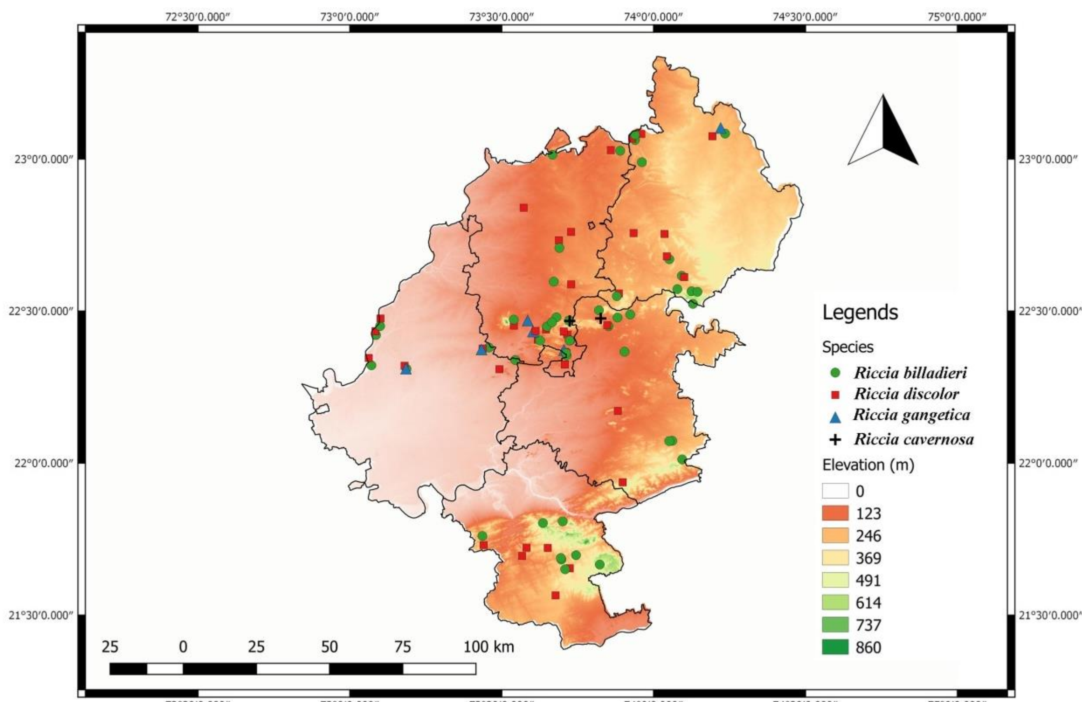


Fig. 5.7: Elevation distribution map of *Riccia* spp.

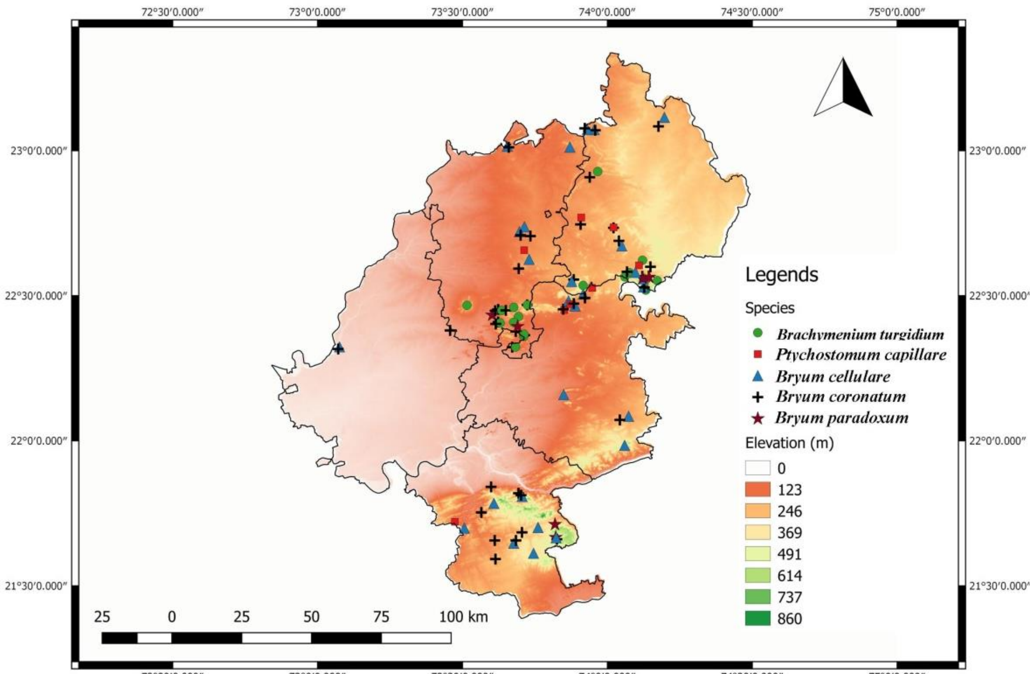


Fig. 5.8: Elevation distribution map of *Brachymenium turgidum,Bryum* spp. and *Ptychostomum capillare*.

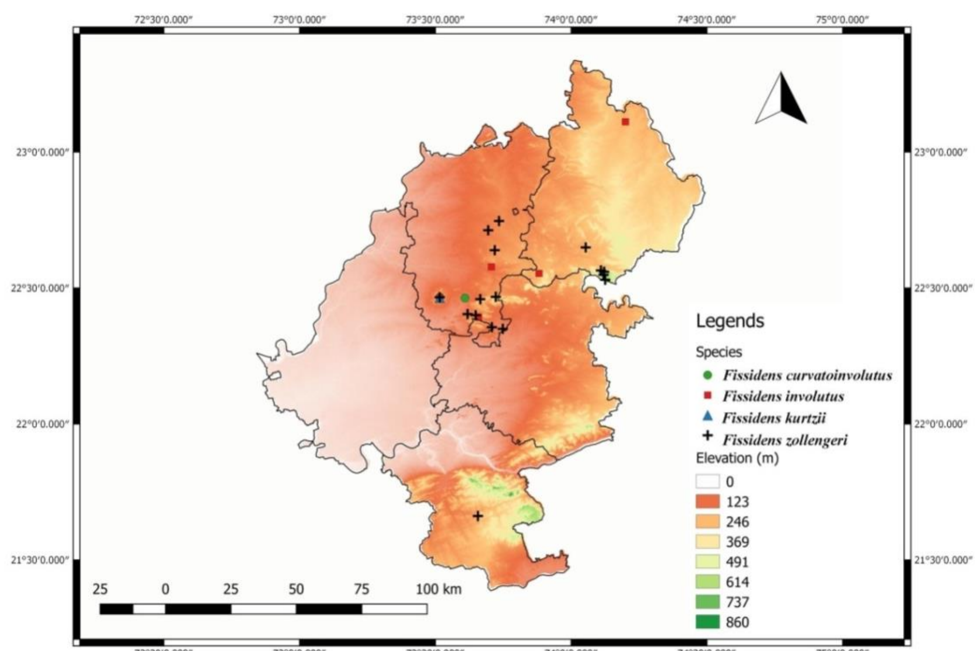


Fig. 5.9: Elevation distribution map of *Fissidens* spp.

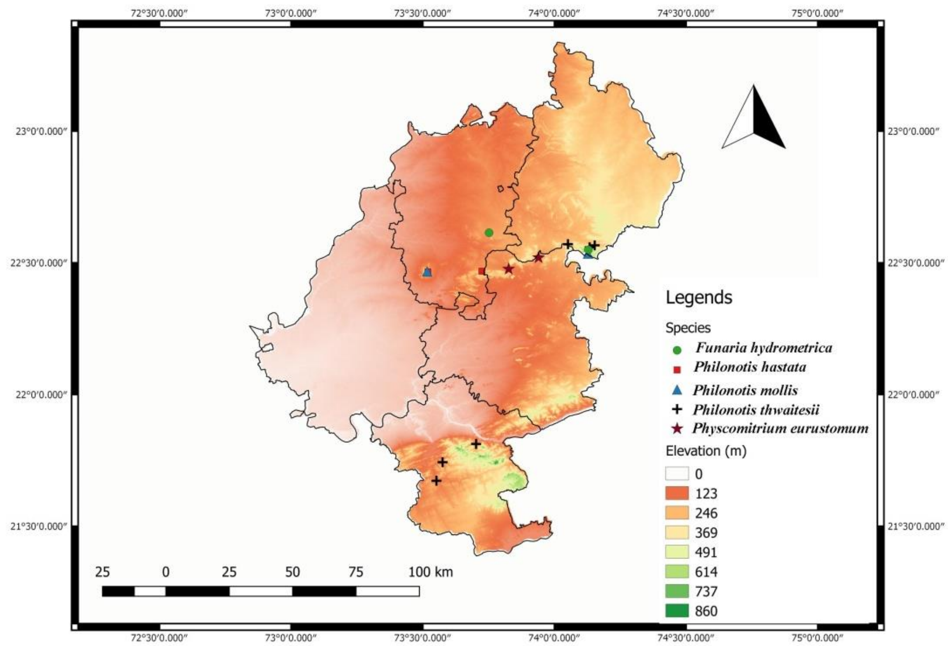


Fig. 5.10 Elevation distribution map of *Funaria hygrometrica*, *Phillonotis* spp and *Physcomitrium eurystomum*.

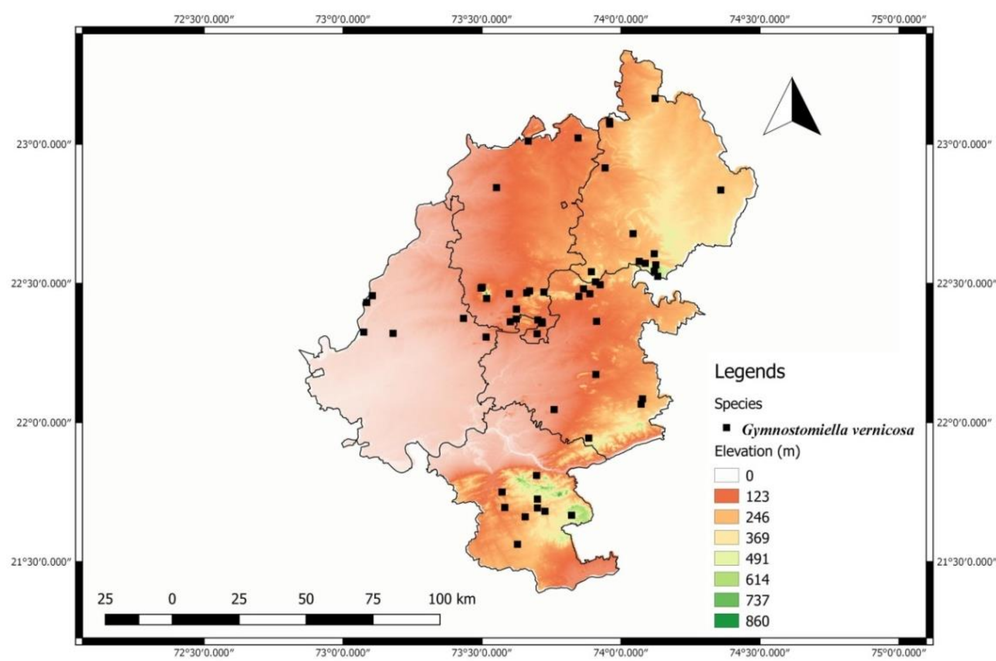


Fig. 5.11: Elevation distribution map of *Gymnostomiella vernicosa.*

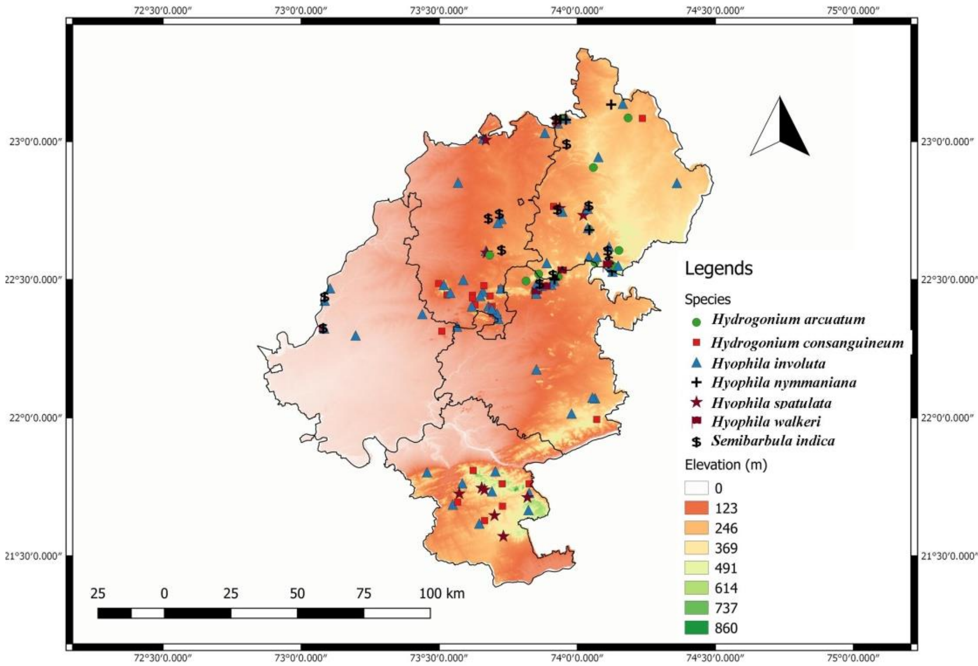


Fig. 5.12: Elevation distribution map of *Hydrogonium* spp, *Hyophila* spp. and *Semibarbula orientalis*

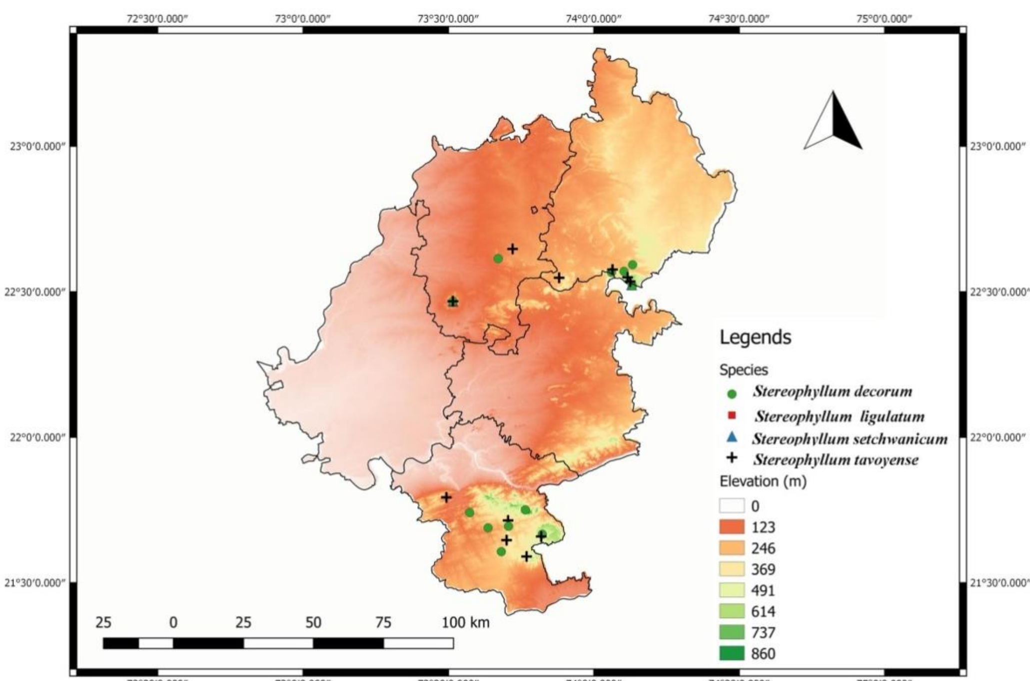


Fig. 5.13: Elevation distribution map of *Stereophyllum* spp

The climatic conditions and the topography of the study area aligns with the climatic conditions and the topography of neighboring states. Like, the Chhota Udepur and Vadodara districts being semi-arid resembles the Rajasthan and some part of Madhya Pradesh while Narmada, Panchmahal and Dahod districts resembles western part of Maharashtra. Hence, many of the species recorded in the present study was found in the literature of the past study. There were several researchers worked on the bryophyte diversity of Gujarat and these neighboring states. Similar studies carried are: Chaudhary and Deora (1993) had recorded 27 species of mosses from Rajasthan, Chaudhary *et al*.(2006) had recorded 67 species of bryophytes from Gujarat, Alam *et al.*(2015) 210 species from Gujarat, Southern Rajasthan, Madhya Pradesh, Chhattisgarh and Jharkhand, Alam *et al.*(2011) 20 species from Rajasthan (Ranthambore tiger reserve), Nath *et al.* (2007) 28 species of mosses from Madhya Pradesh (Amarkanthak), Rawat *et al.* (2015) listed 51 species from Rajasthan and Punjab plains and Chaudhary *et al.*(2008) had recorded 6 species of liverworts, 4 species of hornworts, and 34 species of mosses from North Konkan region of Maharashtra. They were found on different habitats like soil, bark, brick, wall, brick+wall, brick + soil, rock+ brick, rock + soil and soil + wall and at different altitude ranging from 50 m to 1400 m.

Based on information from the following different references Chaudhary (1993), Bapna and Kachroo (2000), , Aziz and Vohra (2008), Chaudhary *et al*. (2006, 2008), Nath *et al.* (2011), Bansal and Nath (2014), the following table 5.5 has been created which discusses the biogeography of the different species found in the current study.

Table 5.5: Bryophytes recorded in Gujarat and Its neighbouring states.

Sr. No.	**Species**	**Other Parts Gujarat**	**Rajasthan**	**MP**	**Maharashtra**
	LIVERWORTS				
1.	*Asterella angusta*	+	+	+	+
2.	*Plagiochasma rupestre*	+			
3.	*Plagiochasma appendiculatum*	+	+	+	+
4.	*Plagiochasma intermedium*	+	+	+	+
5.	*Plagiochasma microcephalum*	+			
6.	*Cyathodium cavernarum*	+	+	+	+

Sr. No.	Species	Other Parts Gujarat	Rajasthan	MP	Maharashtra
7.	*Cyathodium tuberosum*	+	+	+	+
8.	*Rectolejeunea aloba*	+			
9.	*Riccia billardieri*	+	+	+	
10.	*Riccia cavernosa*	+		+	
11.	*Riccia discolor*	+	+	+	+
12.	*Riccia gangetica*	+	+	+	+
13.	*Targionia hypophylla*	+	+	+	+
HORNWORTS					
1.	*Anthoceros bharadwajii*	+			
2.	*Anthoceros subtilis*	+	+		+
3.	*Notothylas indica*		+	+	+
4.	*Notothylas kashypii*				
5.	*Notothylas levieri*	+	+	+	+
6.	*Notothylas udarii*	+			
MOSSES					
1.	*Philonotis hastata*	+			+
2.	*Philonotis mollis*	+	+		+
3.	*Philonotis thwaitesii*	+	+		+
4.	*Brachymenium turgidum*	+			
5.	*Ptychostomum capillare*	+	+		
6.	*Bryum cellulare*	+	+		
7.	*Bryum coronatum*	+	+		
8.	*Bryum paradoxum*		+		
9.	*Fissidens involutus*			+	
10.	*Fissidens kurzii*				
11.	*Fissidens zollingeri*	+			+
12.	*Fissidens curvatoinvolutus*		+		+
13.	*Funaria hygrometrica*	+	+	+	+
14.	*Physcomitrium eurystomum*	+			
15.	*Hydrogonium arcuatum*	+	+		+
16.	*Hydrogonium consanguineum*	+	+		+
17.	*Hyophila involuta*	+	+	+	+
18.	*Hyophila nymaniana*	+			+
19.	*Hyophila spathulata*	+			+
20.	*Hyophila walkeri*	+			
21.	*Semibarbula orientalis*	+	+	+	+
22.	*Gymnostomiella vernicosa*	+	+	+	+

Sr. No.	Species	Other Parts Gujarat	Rajasthan	MP	Maharashtra
23.	*Stereophyllum decorum*	+	+		+
24.	*Entodontopsis nitens*	+	+		+
25.	*Stereophyllum setschwanicum*	+	+		+
26.	*Stereophyllum tavoyense*	+			+

5.2 Culturing of bryophytes

In the current study, while micropropagation of *Funaria hygrometrica* as the taken up as one of the objectives however due to major contamination despite sterilization and use of anti biotics. Hence the current study was restricted to the study of the growth of the protonema stage in the presence as well as absence of sugar.

5.2.1 Growth in presence of sugar

The protonema is a filamentous, elongated cylindrical structure formed during the germination of moss spores. It has two stages of development viz chloronema stage and caulonema stage. The former is having small size cells, perpendicular cross wall, large number of chloroplasts, colourless cell wall and irregular branching. The latter have longer cells, diagonal cross walls, brownish cell wall and with few choloroplasts. In mosses two type of protonema are found i.e. Thalloid protonema and filamentous protonema. Members of Sphagnopsida and Andreopsida have thalloid protonema while Bryopisda have filamentous protonema and *Funaria hygrometrica* belongs to Bryopsida class (Glime, 2017). In this study, *Funaria hygrometrica* was used for the study of germination of *Funaria hygrometrica* using knop medium.

Moss was cultured on the solid agar medium as the liquid inhibits the formation of caulonema leading to reduction in bud formation, especially in case of *Funaria hygrometrica* . This is because studies had shown that the wet condition’s negatively effects the development of gametophyte. (Johri and Desai, 1973). Successful germination of spores is the important step in the invitro culture and insitu conservation of rare or endangered or other important species of bryophytes.

The spore of Moss was brown in colour. The growth and development of mosses begins with the germination of spores. Germination (of mosses) spores means swelling of spores due to absorption of water followed by rupturing of cell and formation of germ tube. However, some researchers consider phenomenon of the swelling of spores due to absorption of water as germination, however physiologically this is not germination since it is passive process while the germination is active process (Bauer and Mohr, 1959; Mogensen, 1978, Glime, 2017). In germination the thickness of the cell walls changes and in case of *Funaria hygrometrica* it involves thickening of intine and thinning of exine (Olesen and Mogensen, 1978; Glime, 2017). The germination of the spore initiated on 4-5 day of inoculation in all the replicates at all the concentrations. In 5-6 day the swelling in the spore increased in size and formed a germ tube. The germ tube elongated forming short cylindrical cells with cross-walls and having large amount of chloroplast called as Chloronema cells in 10-15 days. After 10-15 days, brown cylindrical filaments with oblique septa called caulonema. The few Chloronema were found to be growing positively geotrophic while rest were found growing horizontally. Both the filaments were having abundant choloroplast. Further, buds were not formed in either of them i.e Chloronema and Caulonema. Thus, the growth was restricted only to the formation of theses filaments as further development and differentiation terminated after 35 days.

Unipolar germination of spores very dominant, however, bipolar was also recorded. However, the bipolar germination was was very rare. Bipolar germination of spore was also observed by Basile *et al*. (2008). Plate 5.14 B shows the bipolar germination of the spore. Plate 5.14 shows the development of the protonema in nutrient media with sugar.

5.2.2 Protonema grown without sugar

In culturing, addition of sugar is not requisite in agar because it only accelearates the growth and development of the explant (Bopp and Knoop, 1984). In another experiment, spores were grown in absence of sugar in same condition of temperature for the studying time needed for full growth of protonema. In this experiment, the germination of the spores began after 10-15 days while the chloronemal and caulonemal branch was formed in 40-45 days. It was found that the full growth of protonema in the form of erect filament was recorded after 90 days. In absence of sugar growth of protonema occurs but it very slow (Vujicic *et al.,* 2011). Hence, the growth was slow as the sugar was not added in the medium but contamination was not recorded in any of the replicates. However, variation in the growth of protometal was recorded in few replicates, in some replicates the growth did not last longer while in some it not initiated. The best growth was recorded in knop full strength.

The diameter of the germinated spores was measured in all the replicates. The spores grown in half strength knop medium were broader (19 μmdiameter) in comparison to those grown in full and one-fourth strength media (17.1 μm and 18.4 μm diameter respectively). After the complete development of the protonema (i.e. approx. 90 days), diameter measurement of the filaments was carried out. The Chloronemal diameter of the replicate in full strength knop medium was the highest at 13.78 μmwhile that of half strength knop medium was having narrow diameter 19 μm. Similarly, the diameter of the caulonemal branch of the replicate in full strength knop medium was broader at 12.56 μm in comparison to half strength knop medium at 9.59 μmand one fourth strength knop medium at 9.26 micron. Figure 5.15 shows details of the spore and the different parts of the protnema. The details of the measurement have been given in the table 5.6 below

Table 5.6. Dimensions of Spore, chloronema and caulonema filaments of *Funaria hygrometirca* protonema in different concentrations of Knop's media

	Diameter (μm)								
	Knop			**1/2 Knop**			**1/4 knop**		
Organ	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Spore	17.1 ± 2.26	16.75 ± 2.20	17.45 ± 2.32	18.84 ± 2.94	19 ± 2.71	19.19 ± 2.46	19.19 ± 3.39	19.19 ± 1.83	18.14 ± 2.20
Chloronema	13.78 ± 3.89	16.05 ± 3.75	11.51 ± 4.04	11.16 ± 2.04	10.64 ± 4.61	10.12 ± 2.57	9.42 ± 1.59	10.29 ± 1.98	9.42 ± 1.68
Caulonema	12.56 ± 2.52	14.65 ± 2.20	10.47 ± 2.84	9.42 ± 2.34	9.59 ± 3.12	9.77 ± 1.56	9.07 ± 1.91	9.42 ± 1.56	9.30 ± 1.80

1.1 DNA barcoding

5.3.1 Barcoding of Bryophytes

DNA Barcoding of samples belonging to 14 species of bryophytes were undertaken during the current study. This constituted approximately 30 % of species recorded in the present study. This included 5 liverworts, 1 hornwort and 8 species of liverworts. For DNA extraction fresh gametophyte was taken for analysis. In some cases, to make up the necessary quantity, small amount of sporophyte was included in the sample. The table 5.7 below lists the species and the plant part used for the analysis.

Table 5.7. Plant species taken up for barcoding study.

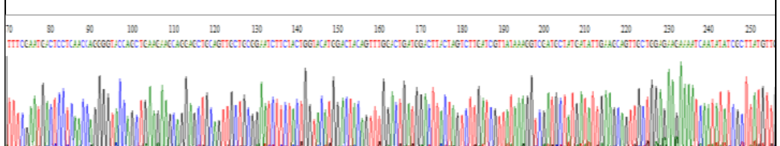
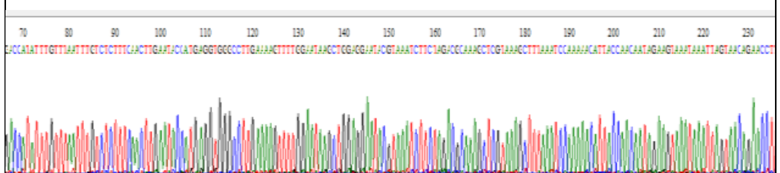
Sr. No	Species	Plant Part used
	Liverwort	
1.	*Riccia discolor*	Thallus
2.	*Asterella angustata*	Thallus and Sporophyte
3.	*Plagiochasma appendiculatum*	Thallus and Sporophyte
4.	*Plagiochasma intermedium*	Thallus
5.	*Cyathodium cavernarum*	Thallus
	Hornwort	
6.	*Anthoceros substilis*	Thallus
	Moss	
7.	*Bryum coronatum*	Leaves
8.	*Hyophila involuta*	Leaves
9.	*Fissidens zollengeri*	Leaves
10.	*Stereophyllum decorum*	Leaves
11.	*Stereophyllum tavoyense*	Leaves
12.	*Funaria hygrometrica*	Leaves
13.	*Hydrogonium arcuatum*	Leaves
14.	*Philonotis thwaitesii*	Leaves

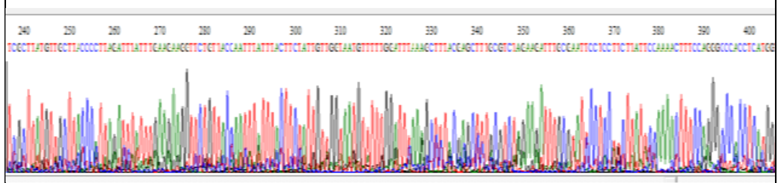
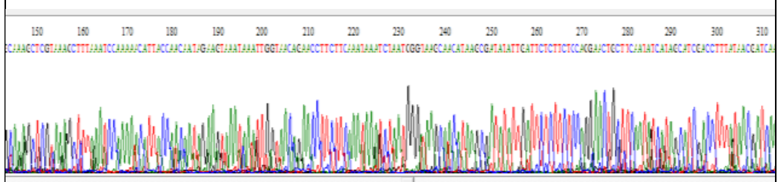
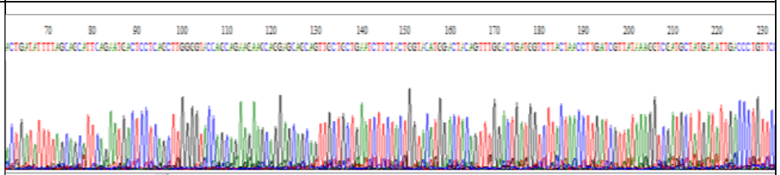
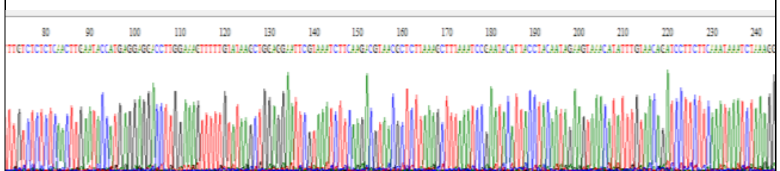
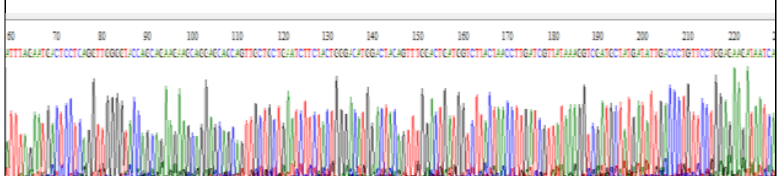
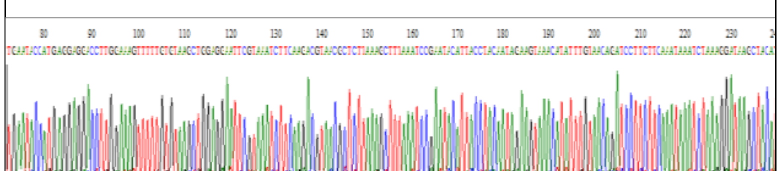
Of the attempted species, barcodes could be successfully generated for 5 species only. They included 2 species of mosses and 3 species of liverworts as shown in table 5.8 below along with their barcode sequence ID. As discussed in the methodology as well as the review of literature *rbcL-a* (CBOL, 2009) was selected as the gene of interest. However adequate quantity and purity of DNA as well as the availability of suitable primers were two main reasons that contributed to the failure of obtaining barcoding of some species. A few additional primers were tried but success in obtaining adequate quality and purity of DNA was not acheived. Also bryophyte being very small plants, which grew intermixed with other bryophyte species as well as algae and cyanobacteria, difficulty was faced in obtaining pure specimens and that to in good enough quantity. Hence the barcoding study is restricted to these 5 species. The sequence chromatograms of the barcodes as well as their collection details have been given in table 5.9.

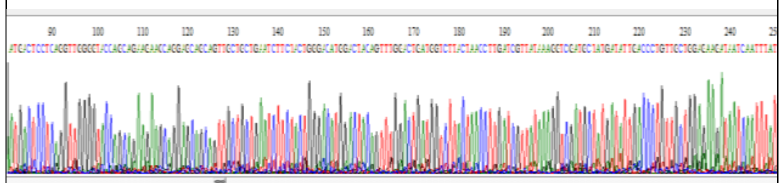
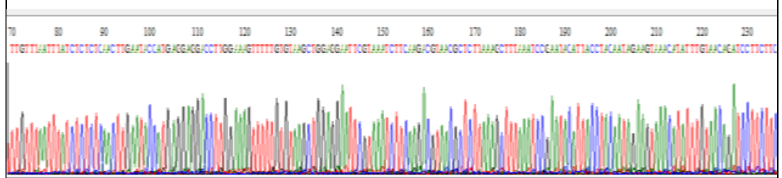
Table 5.8 Species which were barcoded successfully along with their details.

Sr. No	Species	Sequence Quality	Barcode Sequence ID
1.	*Asterella angustata*	**High**	GENG239-14
2.	*Plagiochasma appendiculatum*	High	GENG241-14
3.	*Plagiochasma japonicum*	High	GENG240-14
4.	*Bryum coronatum*	High	GENG461-14
5.	*Fissidens zollengeri*	Low	GENG242-14

Table 5.9. The bold Chromatogram of the different species.

Sr. No	Name of species	Site of Collection	Family	Chromatogram
1.	*Bryum coronatum*	Pavagadh	Bryaceae	 Forward  Reverse

Sr. No	Name of species	Site of Collection	Family	Chromatogram
2.	*Fissidens zollengeri*	Pavagadh	Fissidentaceae	 Forward  Reverse
3.	*Asterella angusta*	Pavagadh	Aytoniaceae	 Forward  Reverse
4.	*Plagiochasma* rupestre	Pavagadh	Aytoniaceae	 Forward  Reverse

Sr. No	Name of species	Site of Collection	Family	Chromatogram
5.	*Plagiochasma japonicum*	Pavagadh	Aytoniaceae	 Forward  Reverse

5.3.2 Phylogenetic analysis of three important families

Based on the DNA sequence available for the barcoding, constructing of phylogenetic relationship was attempted. The relationship of different members within the family was studied. In the present, the phylogenetic analysis of the species barcoded with other species matched with the blast results in the NCBI database is discussed below. The species recorded in India by the different researcher and present in NCBI database were considered for blast analysis (Chaudhary *et al*., 2006; Chaudhary *et al*., 2008, Alam *et al*., 2015).

5.3.2.1 Fissidentaceae

Phylogenetic analysis of *Fissidens* was carried out (Fig 5.16). An earlier analysis had shown that the *Fissidens* is a monophyletic group (Suzuki *et al*., 2018). Maximum likelihood classification was carried out for 11 species. Comparing the morphological characters with the phylogenetic tree of different genera of *Fissidens* following logical inferences can be driven. Some species of *Fissidens* have well differentiated elongated, smooth and thick walled hyaline marginal cells called as limbidum. This is an important character for the identification of the species as they provide information about the evolutionary pattern of the *Fissidens*. In evolutionary lineage, limbiate species are evolved from the elimbiate species (Suzuki *et al.*, 2018). *F.zollingeri* is separated from the other due to absence of limbdium as rest of the species have presence of the limbidium. Moreover, *F. zollingeri* is small in size while the rest species are moderate to long in height. The habitat of the species also plays an important role in it segregation as it can be seen that *F. nobilis* – an aquatic species is segregated from terrestrial species; in addition, it has an apical sporophyte while separates it from the rest of the genera. Similarly, *F. grandifrons* which is an aquatic or semiaquatic species is having different clade than *F.s taxilfolius* and *F,s geminiflorus* which is a terrestrial species. The leaves of *the F. grandifrons* elongated julaceous, with thickened leaf margin. This is present as a morphological adapatation to the aquatic submerged habitat as these characters provide them mechanical strength to withstand the pressure of the water current (Akiyama, 1993; Shevock *et al.*, 2017). In *F. taxifolius* the sporophytes are on lateral shoot while in *F. nobilis* the sporophytes are apical. Hence *F. zollingeri* was close to *F. nobilis* than *F*. t*axifolius* as it also has apical sporophyte. The margin of the leaf of *F. anomalous* was differentiated while that of *F. obscura. F. obscurus* and *F. anomalus* have same ancestor as they have common character of having single layered leaf margin. The clades of all the species of *Fissidens* were closely related to each other while the clade *of Bryum capillare* is far from clade of *Fissidens spp.* Accession number of sequence used from NCBI database is given below in Table 5.10.

Table 5.10 Accession number of species used from NCBI database for phylogenetic analysis of Fissidentaceae.

Species	NCBI Accession NO.
Fissidens anomalus	LC271957
Fissidens crispulus	LC271966
Fissidens dubius	LC271968
Fissidens geminiflorus	LC271977
Fissidens grandifrons	LC271979
Fissidens involutus	LC271984
Fissidens nobilis	LC271990
Fissidens obscurus	LC271992
Fissidens subangustus	LC272005
Fissidens taxifolius	LC272008

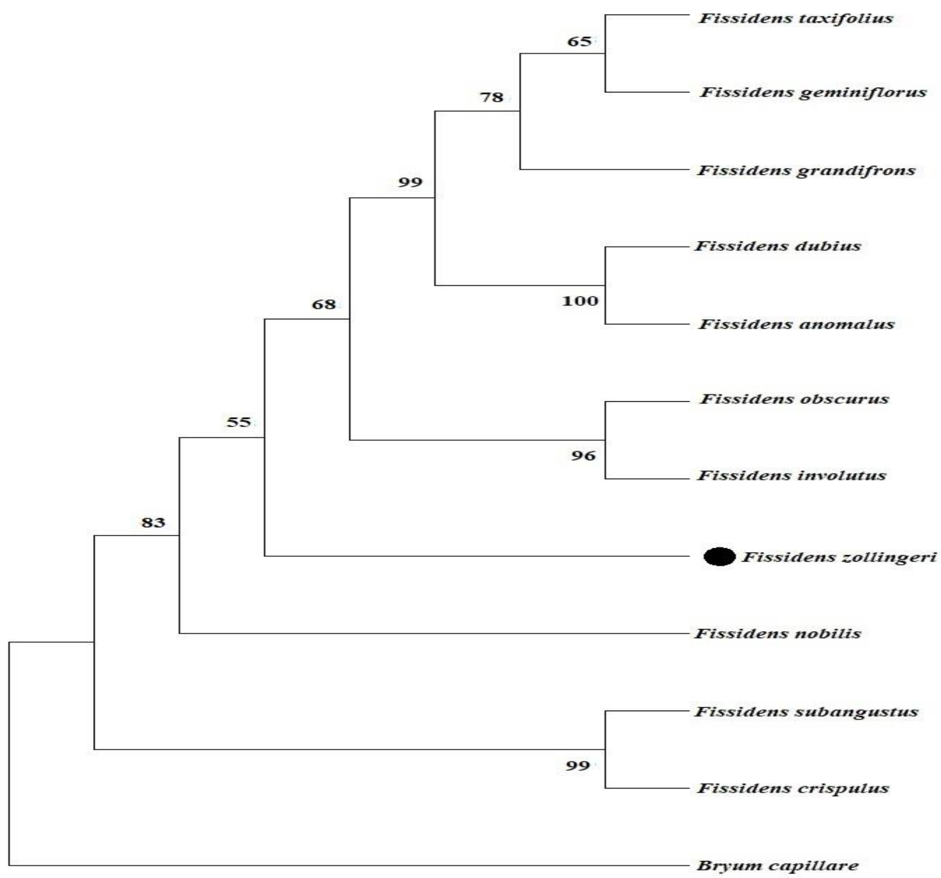


Fig 5.16: Evolutionary analysis by Maximum Likelihood method of *Fissidens zollengeri* with different members of Fissidentaceae (● species barcoded during the current study) found in India

5.3.2.2 Bryaceae

The evolutionary analysis of member of Bryaceae family consisting of 4 genera viz. *Bryum,. Brachymenium, Plagiobryum, Anomobryum* and 12 species was constructed (Fig. 5.17). The analysis showed that the genera/species which mainly has larger leaves like *Anomobryum, Brahcymenium* and *Bryum pseudotriquetrum* were separated from the other species.*B. caespiticum*, *B. atrovirens* and *B. capillare* had common lineage as all of them had entire margin. However, *B. atrovirens* and *B. capillare* have same node with different branch due to the difference in their size. *B. capillare* is medium to large *and B. atrovirens* is small in size. *B. alpinum*, *B. capillare* and *B. atrovirens* have common lineage as their leaf have a distinct border.

Polytomy between the different genera like *Anomobryum, Bryum,*, and *Plagiobryum* can be clearly observed in the figure. From the figure it is evident that *the Anomobryum , Bryum, Brachymenium* and *Plagiobryum* are polyphyletic and is supported by the past study (Pedersen *et al*., 2003). However, *Haplodontium* genera were a monophyletic genus. Though the it was also reported to be having a polyphyletic lineage (Pedersen *et al*., 2003). The phylogenetic analysis shows that most of the all the branches are unresolved and thus weakly supported due to small sampling size. Hence, for the phylogenetic analysis of the species the sampling size need to be large. Similar phylogenetic relationship between were observed in different species like *Brahcymenium pulchrum*, *B. acuminatum, Rhodobryum keniae, Bryum capillare, B. capillare, B. alpinum, B. pseudotriqutrum Haplodontium megalocarpum* and *H. reticulatum* are validated by the work done in the past (Pedersen and Hedenas 2003, 2005; Pedersen *et al*, 2007). The clades of all the species of *Bryum,. Brachymenium, Plagiochasma, Anomobryum* were closely related to each other while the clade *of Hyophila involuta* which was an outcrop is quite far from the others. Accession number of sequence used from NCBI database is given below table 5.11.

Table 5.11 Accession number of species used from NCBI database for Phylogenetic analysis of bryaceae

Species	NCBI Accession NO.
Anomobryum filiforme	MH670651
Brachymenium acuminatum	AY163017
Brachymenium pulchrum	AY163021
Bryum alpinum	AY163023
Bryum argenteum	LC270450
Bryum bicolor	AY163025
Bryum caespiticium	AY163026
Bryum capillare	AY163027
Bryum cellulare	AY163029
Bryum pseudotriquetrum	MK134891
Plagiobryum zieri	AY163045
Hyophila involuta	AY950312

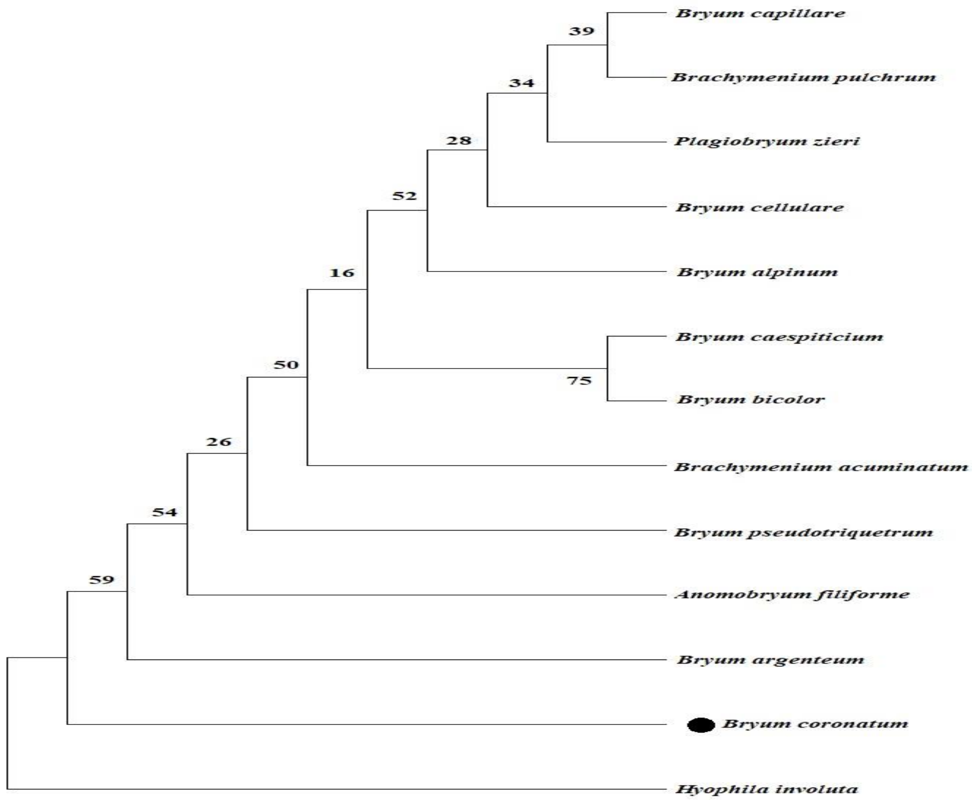


Fig. 5.17: Evolutionary analysis by Maximum Likelihood method of of *Bryum coronatum* with different members of Bryaceae (● species barcoded during the current study) found in India.

5.3.2.3 Aytoniaceae

Evolutionary analysis of 4 genera viz. *Asterella, Mannia, Plagiochasma* , *Reboulia* and 12 species were carried out (Fig. 5.18). The phylogenetic analysis of the available data revealed that *Asterella angusta* has very close relationship with the *Asterella wallachiana*, in comparision other species i.e. to *A.musuriensis*. *A. wallichiana* is mostly reported from the western Ghats or in the northeastern region and similarly *A. musuriensis* was reported from the north eastern region (i.e. Himachal Pradesh) (Dandotiya *et al.*, 2011). Polytomies of *Asterella* with other genera like *Reboulia, Mannia* and *Plagiochasma* was also recorded. Different species of *Mannia, Asterella, Plagiochasma* are easily distinguishable. The analysis was very limited due to the data deficiency in NCBI database of Indian species. Very few Indian species of *Asterella* have been barcoding and uploaded in the NCBI.

The phylogenetic tree of the members of Ayotoniaceae family consisted 5 species of *Plagiochasma* have been studied. The phylogenetic analysis of of *Plagiochasma* shows that the clade A is the most closely related clade.

The phylogenetic analysis of *Plagiochasma pterospermum* showed close resemblance with the *P japonicum.* However, both of them belong to different parts of country *P japonicum* is commonly occurring species of eastern region while *Plagiochasma pterospermum* occurs in the southern India or in some parts of northern India (Dandotiya *et al.*, 2011). Different genera like *Plagiochasma, Mannia, Reboulia* and *Asterella* are linked though poorly as they all belong to same family i.e Aytoniaceae. The different genera like *Plagiochasma, Mannia* and *Asterella* are grouped together

The analysis shows that only *Plagiochasma japonicum* and *Plagiochasma rupestre*relationship is the best (98% similarity). The low value of bootstrap is indicating a poor lineage. Thus, the proper phylogenetic analysis could not be interpreted due to lack of the proper sequence data.

It is evident from that *Plagiochasma rupestre*, *P. apendiculatum*, and *P. intermedium*. are phylogenetically apart This is also supported by the difference in their morphological characters. *P rupsetre* is having narrow epidermal pores, absence of hyaline ring and water repellant granules on the cuticle. Contrary, later two species have broad epidermal pores, presence of concentric hyaline rings and smooth cuticle. Similarly, divergence of *P. appendiculatum* and *P. intermedium* is also supported by the morphological characters. *P. appendiculatum* is having non articulated thallus with 1- 2 appendages and spirally thickened elaters while *P. intermedium* is having articulated thallus with 2-3 appendages and elaters with absence of incomplete thickening

The clades of all the species of *Asterella, Mannia, Plagiochasma* , *Reboulia* were closely related to each other while the clade *of Riccia gangetica* which is an outcrop is far from clade of former species. Accession number of sequence used from NCBI Database is given below table 5.12

Table 5.12 Accession number of species used from NCBI database for Phylogenetic analysis of Aytoniaceae

Species	NCBI Accession NO.
Asterella khasyana	AM920279
Riccia gangetica	KX468610
Asterella leptophylla	AM920278.
Asterella mussuriensis	AM920284
Asterella wallichiana	FJ173696
Mannia androgyna	FJ173702
Mannia fragrans	FJ173712
Plagiochasma appendiculatum	FJ173715
Plagiochasma intermedium	AM920293
Plagiochasma pterospermum	AM920282
Reboulia hemisphaerica	AY688788

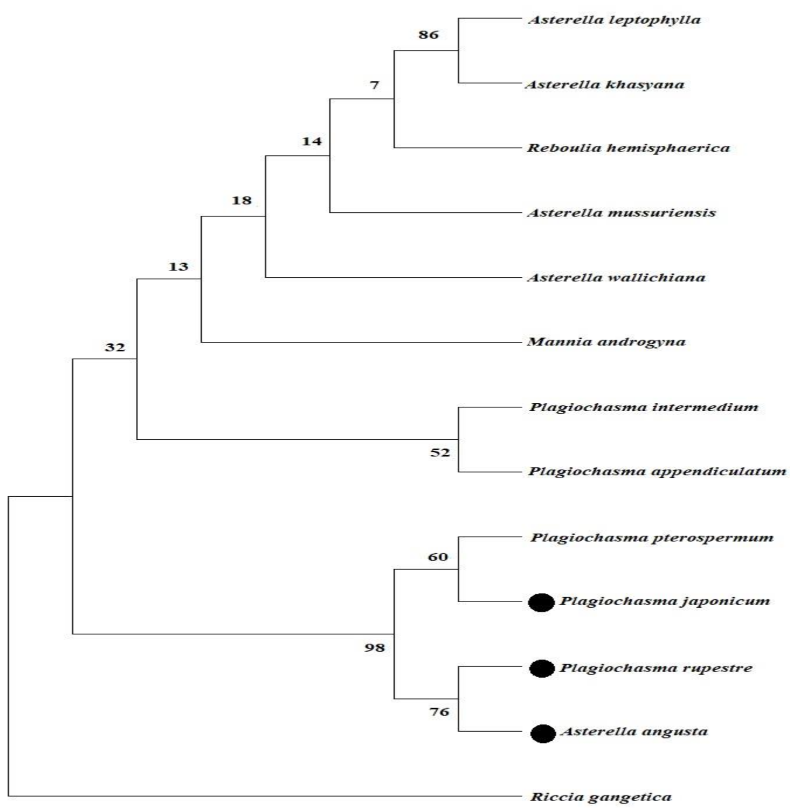


Fig. 5.18: Evolutionary analysis by Maximum Likelihood method of different member of Aytoniaceae (● species barcoded during the current study) found in India.

5.3.3 Practical problems in DNA Barcoding and its outcomes

In this study, DNA barcoding was analaysed as a method to supplement the identification of different bryophyte species using the rbcL. While barcoding was accomplished for a few species for a majority of species it could not be done. The results that have been depicted above show that while it is possible to discern a few species from one another, using a single locus, there are difficulties in identifying the different species of the same genera. We had also tested how relevant sequences available in GenBank matched and grouped with the sequences obtained in this study. All the sequences downloaded from GenBank clustered with congeneric species in our data set, but there was a clear mismatch with some *Fissidens* species. The erroneous clustering of some of the GenBank sequences could be due to inability of the studied markers to discriminate between bryophyte species, or could be due to identification error. Barcode studies totally or partially based on single locus GenBank sequences hence need to take these limitations into consideration and be cautious of the potentially uneven taxonomic quality in public databases.

The identification of bryophytes is a tough task because of its small size and its inconspicuous morphological characters. They also possess variation in their morphological features in response to environmental factors (Lodge, 1959; Mishler, 1985; Bergamini and Peintinger, 2002; Buryova and Shaw, 2005; Hassel *et al*., 2005). DNA barcoding by standardized gene regions as internal species tags was believed to be of great help in the study of bryophyte species diversity. For successful barcoding, the barcode should have following qualities like universality of primers with high sequencing success, high interspecific divergences and clear separation and distinguishing ability between the same group of species. These properties lead to effective discrimination of closely related taxa and the possibility of using barcodes in species identification. Based on these characters, several markers like rbcL, rpoC1, rps4, trnH–psbA and trnL–trnF, atpF–atpH, the nuclear ITS2, matK etc were proposed by various researchers for DNA barcoding of bryophyte because of ease of amplication and due to interspecific genetic variability (Liu *et al.,* 2010, 2011; Hassel *et al.,* 2013). From the various plastid regions, the two gene regions matK and rbcL had been proposed as general two locus barcode regions for land plants (CBOL Plant Working Group 2009). Unfortunately, these regions have been found to have low discriminative power at the species level in certain land plants such as the Araucaria and Bryophytes according to several researchers (Hollingsworth *et al.* 2009; Von Crautlein *et al.* 2011; Liu *et al.* 2011). Previously, rbcL has been found to show a high degree of monophyly at the species level (90%) for the thalloid liverwort family Aytoniaceae (Hollingsworth *et al*., 2009). However, Stech and Quandt (2010) concluded that for bryophytes in general, rbcL shows low sequence variation at family level and below and claim that the marker is not useful for DNA barcoding and low-level phylogenetic analyses. Liu *et al.* (2010), in their taxonomically broad study of Bryophyta, found 89% monophyly for the taxa analysed by rbcL (79% for trnH–psbA and 66% for ITS2), but most of the specimens included in their analysis were not congeneric. Thus, the general usefulness of rbcL as a bryophyte barcode region is still questionable. In bryophytes, a stand-alone barcoding marker is unlikely to be found among the standard plastid markers used for phylogeny reconstruction (Hollingsworth *et al.,* 2011). In addition, it also needs some supplementary markers such as trnH-psbA and ITS. Moreover, in closely related and cryptic taxa DNA barcoding is always ambiguous and demands more group specific markers. Hence, the rbcL used in the current study as it has been used and suggested by several researchers for the bryophytes (CBOL Plant Working Group 2009; Liu *et al*., 2010, 2011; Hassel *et al*., 2013).

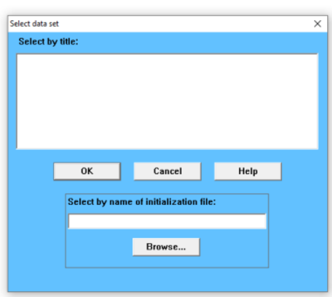
The all above discussion highlights the fact that the barcoding of the bryophytes for species level identification needs more that a general marker like rbcL and for several families, specific and different markers are needed. Moreover, during the course of the current study, the anticipated funding support for DNA barcoding could not be obtained and hence additional specimens collected and identified during the later part of the study were not attempted for barcoding.

5.4 Computer Aided Identification

This Delta (Description Language for taxonomy) INTKEY software module was generated for developing interactive keys for identification of the three different groups of bryophytes. Mosses, liverworts and hornworts can be easily separated from their gross morphological features. Also the characters useful for identification are different for all the three groups as has been indicted in the methodology chapter and hence three different software modules were prepared for the three different groups of bryophytes. They key would help in the identification of bryophytes found in the study area even if all the stages of the plant are not found. This is one of the major benefits of using a Multiple access key system over the dichotomous identification key system used in traditional taxonomy. The currently developed module helps in the identification of the bryophyte species in the study area. The software module is present in the folder entitled "Bryophyte Software" which is present in the DVD attached with this thesis. As can be seen the whole software module does not occupy a size of more than 40 Mb.

5.4.1 Using the Software Module:

Browse to the 'Bryophyte Software" folder either in the DVD or after copying it into any computer system. In the folder double click the Open the Intkey module by double clicking the 'intkey5_shortcut' icon which is shown by this symbol .The program will open and a window as indicated below will open. The window will need the selection of a specific dataset.



Using the browser select the file "Bryophyte Software/Liverwort_key/Liverwort/intky.ink" and click ok. This will open the software module for the identification of liverworts. Similarly opening the file "Bryophyte Software/Hornwort_key/Hornwort/intky.ink" will open the module for hornwort identification and the moss identification module can be opened by opening the "Bryophyte Software/Mosses_key/Mosses/intky.ink" file.

5.4.2 Introduction to INTKEY Window

The INTKEY window will be divided into four different panels and you will have two rows of icons and shortcuts at the top left corner of the window. The window which gets displayed is shown in fig. 5.19 below and the description of the four panels is as below,

1) The top left panel (A) named as "Best Character" list the characters that have been used in creation of this database. Based on the specimen or its part available different characters are selected from this panel for the identification of the species. At the upper right corner of the panel clicking on the square blue box will list the characters in their natural order (sequence of characters while creating the database) and clicking on the blue "equals to" sign will list the characters according to their importance in the identification of the species. The symbol ~ indicates the error tolerance and can be set as desired
2) The top right panel (B) named as "Remaining Taxa" shows the list of species that are available for identification. As the characters and their states are selected the list in this panel keeps of reducing till only one remains which indicates the identified taxa.
3) The Lower right panel (C) named as "Eliminated taxa" panel: This panel is initially blank and as the characters and their states are selected a list of species starts appearing in this panel. This list indicates taxa which do not match with the characters that have been selected. Species not matching the selected characters can be viewed in this panel.
4) Lower left panel (D) named as "Used Characters" panel: The characters selected from the top left panel (A) that have been used for the identification of the specimen are listed in this panel.

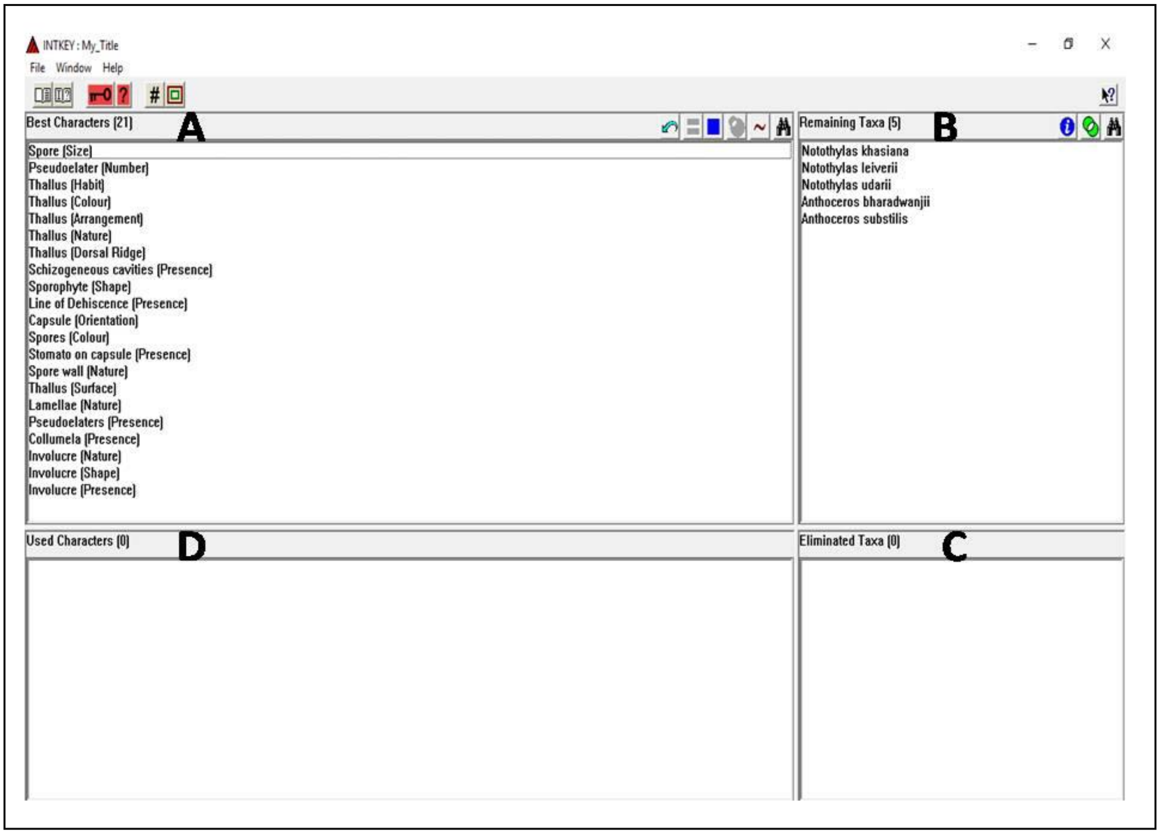


Fig. 5.19: The INTKY Window Panel in Normal Mode.

5.4.3 Using the INTKEY software module

a. **Selection of characters for the identification of species:** The characters for the identification are selected from the upper left panel (Fig 5.19 A). Based on the selection of characters some species will the removed for the list of available species and will be seen in the lower right panel. The species matching the selected characters will appear in the upper right panel. The characters state used for the identification of species, can be changed by doubling the character state listed in “Used characters” panel, selecting it and click ok. This will remove the characters from the “Used characters” panel to “Best Characters” panel.
b. **Subset of characters:** This function is used for creating a smaller group of characters from the complete list of characters that will help in the identification of species. This is specially used when a large number of characters have been used to

create the database and this will enable the speedy identification of species and save time. Creating subset of character also helps in easy identification of species. For creating a subset, select desired characters and click subset icon in the upper left panel. Fig 5.20 shows the subset of characters on the upper left panel creating using the subset function.

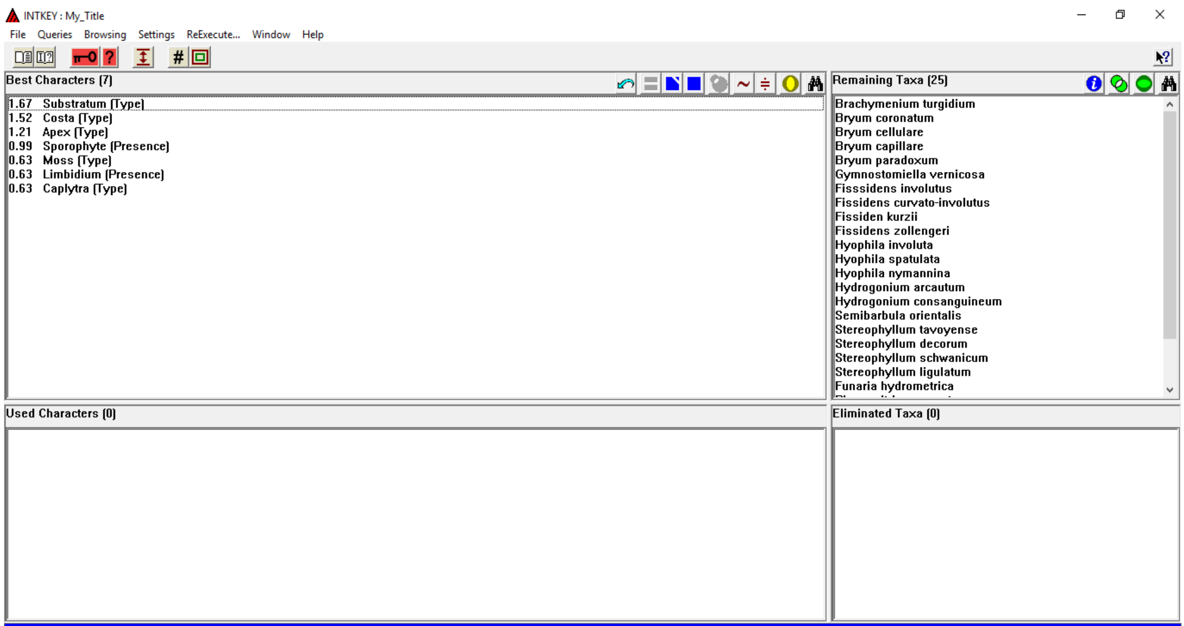


Fig. 5.20: Subset of characters considered for the identification of sporophyte possessing members of Bryaceae.

c. **Difference between the taxa:** This functions can be used to know the difference in the characters between the two or more species as per the description available in the database. This helps in detailed identification of specimens where even overlapping of characters is present. To use this function, the required species are selected and the icon “ ” is clicked. This opens a dialog box showing the difference in characters between the selected species. Fig. 5.21below shows the difference in characters of the two species, *Bryum coronatum* and *Sterophyllum tavoyense*.

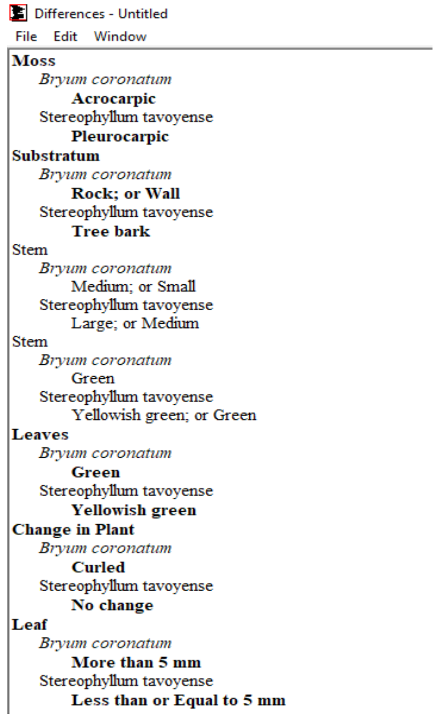


Fig.5.21: Difference in characters between the moss species *Bryum coronatum* and *Stereophyllum tavoyense*

d. **Description of species:** The Delta INTKEY provides an automated system generated description of the species based on the characters used during the creation of the database. This is provided in the same sequence of characters and their states as was input during the creation of the database. This helps in identification of the species and even having the whole description of the species as per the database even though only a few characters have been used in the identification of the specimen. For this the desired specimen is clicked and in the resultant dialog box 'Full description' is selected and then display is clicked.

e. **Illustrations:** Bryophyte morphology is not as well-known as angiosperm morphology and hence there are several characters which are difficult to understand for untrained workers in bryophyte taxonomy. Illustrations help in understanding these characters. As these characters and illustrations are directly linked to species in the database, they also help in the identification of the species. They also reduce errors due to misunderstanding of characters states. For this the desired species is selected as indicated above and instead of 'Full description', 'illustrations' are selected before clicking display.

f. **Error tolerance:** Difference in the micro climatic conditions where the species grow can result in differences in morphological states within the same species. This can sometimes lead to misidentification of specimens. To overcome this problem, the current software module allows for setting up tolerance values (no of characters states in the specimen which can vary from those in the database). This helps in overcoming subtle variations in the morphology of species.

g. **Species Identification:** Using the character states exhibited by the specimen on hand, the module can be used to identify the specimen. Generally fewer characters are required for the identification of a specimen using this module than using the traditional dichotomous keys. The fig. 22, fig. 23 and fig. 24 depict the identification of different species belonging to the different groups of bryophytes. They also depict the characters and the total number of characters used in completing the identification of the specimen.

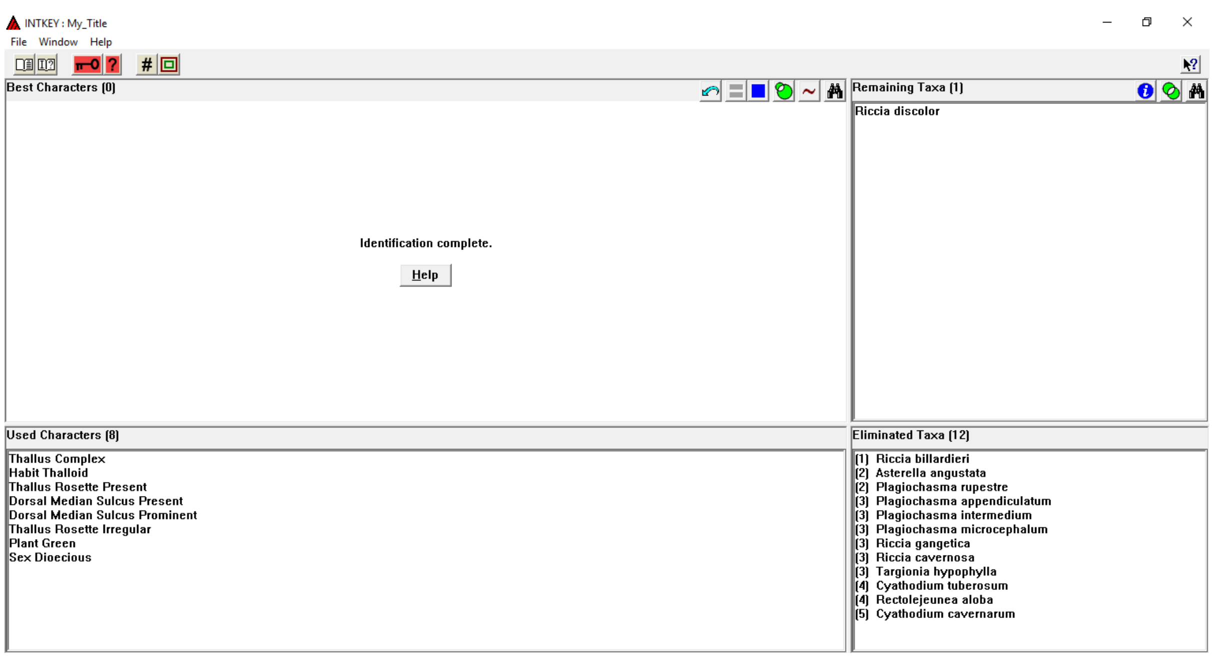


Fig. 5.22: Liverwort *Riccia discolor* identified using DELTA INTKEY

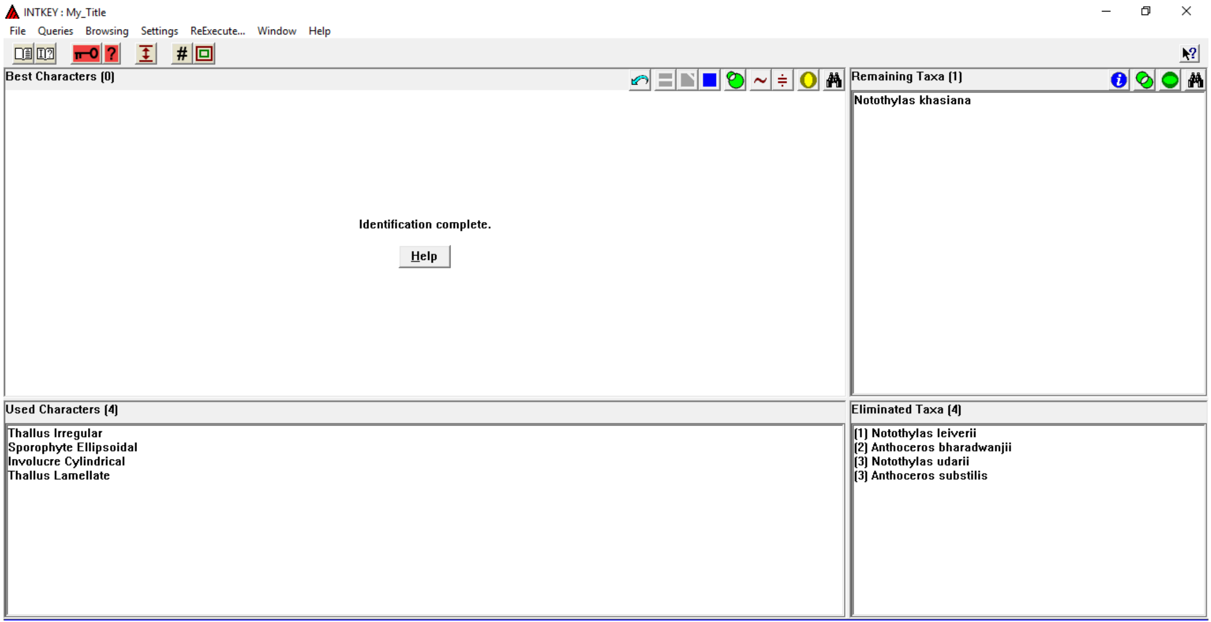


Fig. 5.23: Hornwort *Notothylas khasiana* identified using DELTA INTKEY

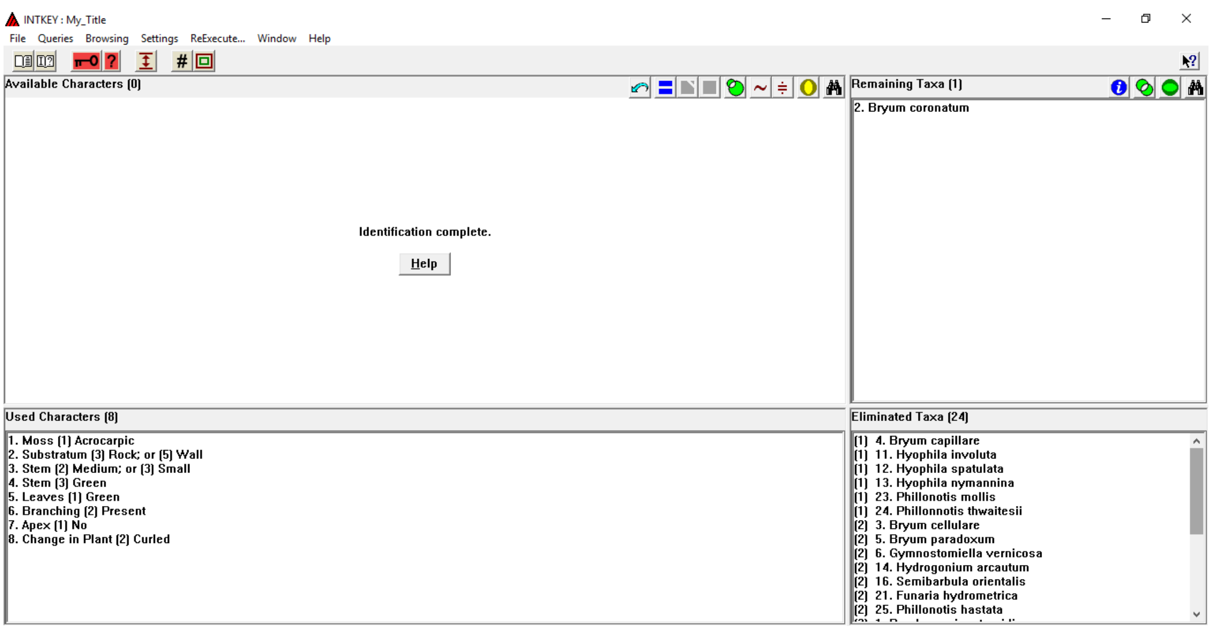


Fig. 5.24: Moss *Bryum coronatum* identified using DELTA INTKEY

h. Generation of Region specific Dichotomous Keys for identification: Dichotomous keys have been extensively used for the taxonomic identification of taxa (Cruz *et al.*, 2012). In this software module, the dichotomous key is automatically generated using the best set of characters and specimens within the database. This is specific to the database which pertains to a specific geographical area and helps in reducing the number of characters needed to complete an identification compared to a standard flora or monograph. The keys can be generated in either a bracketed form or in a tabular form (Dallwitz, 1993). INTKEY develops a dichotomous key by using the best characters (i.e. having the high value). Dichotomous keys are produced as text outputs using confor directive key “tokey” within the editor mode of the database. The keys developed for the three different groups of bryophytes are shown below

5.4.4 Dichotomous Key

Liverwort Key

1(0) Male Receptacle Not Found..*Plagiochasma rupestre*
Male Receptacle Absent... 2
Male Receptacle Present...9
2(1) Dorsal Median Sulcus Absent......................................3
Dorsal Median Sulcus Present.....................................6
3(2) Plant Green...4
Plant Yellowish green... 5
4(3) Scale Below the margin...…….*Asterella angustata*
Scale On the margin...*Targionia hypophylla*
5(3) Plant More than 5 mm.............................………………*Rectolejeunea aloba*
Plant Less than or equal to 5 mm................………….*Cyathodium cavernarum*
6(2) Plant More than 5 mm... 7
Plant Less than or equal to 5 mm................................. 8
7(6) Scale Beyond themargin...*Riccia discolor*
Scale On the margin...*Riccia billardieri*
8(6) Dorsal Median Sulcus Inconspicous.............................*Riccia cavernosa*
Dorsal Median Sulcus Prominent...................................*Riccia gangetica*
9(1) Articulate Thallus Absent..10

Articulate Thallus Present...11

10(9) Plant More than 5 mm........................ ……………………..*Plagiochasma appendiculatum*

Plant Less than or equal to 5 mm................................*Cyathodium tuberosum*

11(9) Branching Absent..*Plagiochasma microcephalum*

Branching Present...*Plagiochasma intermedium*

Hornworts Key

1(0) Spore 150 to 250 micron...*Anthoceros substilis*

Spore 50 to 150 micron..*Anthoceros bharadwanjii*

Spore Less than 50 micron...2

2(1) Thallus Rosette..*Notothylas udarii*

Thallus Irregular...3

3(2) Thallus Lamellate..*Notothylas khasiana*

Thallus Smooth...*Notothylas leiverii*

Mosses Key

1(0) Costa Percurrent...2

Costa Excurrent...12

Costa Not applicable...18

2(1) Leaves Green...3

Leaves Dark Green...6

Leaves Yellowish green..8

3(2) Leaf cells Mamillose...*Phillonnotis thwaitesii*

Leaf cells Papillose...*Semibarbula orientalis*

Leaf cells Smooth..4

4(3) Leaf More than 5 mm...*Physomitrium eurystomum*

Leaf Less than or Equal to 5 mm..5

5(4) Leaf Margin Toothed...*Phillonotis hastata*

Leaf Margin Smooth...*Bryum cellulare*

6(2) Leaf More than 5 mm..*Hyophila nymannina*

Leaf Less than or Equal to 5 mm...7

7(6) Leaf Margin Toothed...*Hyophila involuta*

Leaf Margin Smooth..*Hyophila spatulata*

8(2) Leaf More than 5 mm..9

Leaf Less than or Equal to 5 mm...10

9(8)Leaf Dithicous...*Fissidens curvato-involutus*

Leaf Spiral...*Hydrogonium arcautum*

10(8) Leaf cells Papillose...*Fisssidens involutus*

Leaf cells Smooth...11

11(10) Leaf Dithicous...*Fissiden kurzii*

Leaf Spiral..*Phillonotis hastata*

12(1) Caplytra Non-Persistent...13

Caplytra Persistent..15

13(12) Leaf More than 5 mm..*Bryum coronatum*

Leaf Less than or Equal to 5 mm..14

14(13) Leaf Margin Toothed..*Bryum paradoxum*

Leaf Margin Smooth...*Brachymenium turgidium*

15(12) Leaf More than 5 mm...16

Leaf Less than or Equal to 5 mm...17

16(15) Leaf cells Mamillose...*Phillonotis mollis*

Leaf cells Smooth...*Hydrogonium consanguineum*

17(15) Leaves Green...*Bryum capillare*

Leaves Yellowish green...*Fissidens zollingeri*

18(1) Costa More than half the length of leaf...*Stereophyllum decorum*

Costa Half the length of Leaf...19

Costa upto the apex..21

19(18) Leaf Arising from one side...*Stereophyllum schwanicum*

Leaf Spiral...20

20(19) Sporophyte Absent...*Stereophyllum ligulatum*

Sporophyte Present...*Stereophyllum tavoyense*

21(18) Leaf cells Papillose..*Gymnostomiella vernicosa*

Leaf cells Smooth...*Funaria hygrometrica*

This technique have been used for different groups like mushrooms (Lebbe, 1984; Pasarell, 1999) lichen (Zeltyn and Pchelkin, 1993), bryophytes (Stagg *et al*., 2015), ferns (Thomas and Franceschi, 2013), gymnopserms (Watson and Dallwitz, 2008), angiosperms (Watson and Dallwitz, 1992a&b; Watson *et al*., 1992; Prosperi *et al*., 2005; Sasidharan, 2006; Ramesh *et al*., 2010). Thus, such technique of Computer aided identification (CAI) of species have not been widely explored for lower group of plants like bryophytes and ferns. This key is important for bryophytes as the identification of the bryophyte need an expertise and availability of the experts in these field are difficult. Moreover, bryophytes are small plants with their size ranging from 10 mm to 2-3 cm and appearance of their sporophyte stage is also many times uncertain. The sporophytic stage is an important phase in identification and its absence makes the identification more difficult even for the experts. On the contrary, such CIA tools makes use of several gametophytic characters that helps in the knowing the taxon even in sterile stage.

CIA have less explored in identification of bryophytes as against the traditional method. The traditional identification method uses the dichotomous key while the CIA technique used the multi-access key (Legg, 1992; Pankhurst, 1991). The most important feature of the CIA is that the users can select the character states as per theirs choice unlike the dichotomous key as well can tolerate some errors. So the user can select the easily observable characters making the process of identification easy and interesting. Also, it allows the users to start the identification from any characters without following the definite sequence like traditional single – access keys (dichotomous or Polytomous) (Dallwitz *et al*., 2011). Multi access key occurs in two forms i.e. printed form and the interactive key, used in the present study. Of these the later one is most widely used, also called as computer aided interactive key.

The CIA used in the present study used the morphological features of the bryophytes like leaf shape, leaf size, leaf texture, sporophyte length, capsule shape, spores colour, spore size etc for the identification. However, the CIA also used other features like leaf probabilistic neural network (Wu *et al.,* 2007), anatomy of stem (Thomas and Franceschi, 2013), leaf morphological traits (Aakif and Khan, 2015) for identification of plants.

The leaf and its morphological traits like leaf shape, colour, texture, margin etc were used for identification of species employing different algorithms and approaches like multi-scale fractal dimension, contour based approach, volumetric fractal dimension etc (Backes and Bruno, 2009; Backes *et al.,* 2009; Priya *et al.,* 2012; Asrani and Jain, 2013).

Cho (2012) had developed CAI tool using the floral content for the identification of flower with the help of probabilistic based recursive model.

Vallianmmal (2013) had used CAI technique with the help of vegetative part of plant i.e. leaves using leaf area recognition method for the identification of higher plants. In this method 28 different features of plants grouped into 5 categories were studied that included geometry, colour, texture, newline fractal and leaf feature. Genetic Algarithm (GA) and Principal Component Analysis (PCA) was also used for identification.

The CIA is not just limited to using, studying and analyzing the morphological traits of plants for the identification. But the development of Science and Technology had also helped to used the microscopic features in identification. Fataniya (2019) had applied the

CAI technique for identifying the herbal plants using the microscopic features present in the powder of the herbal plants. Researcher had used the shape and texture of the microscopic features of the herbal powder along with several algorithms like Support Vector Machine (SVM), K- Nearest Neighbour (KNN) etc for the identification.