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Bryophyte diversity along a gradient of human disturbance in the southern Western Ghats

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Evergreen forests, degraded evergreen forests, clove and rubber plantations were sampled for bryophyte species diversity in the Southern Western Ghats. Evergreen forests have the highest diversity followed by degraded evergreen forests, clove and rubber plantations. Besides, evergreen forests have the highest number of exclusive species whereas degraded evergreen forests, clove and rubber plantations have more generalized and light-tolerant species such as *Fissidens ceylonensis*, *Hyophila comosa*, *H. involuta* and *Frullania acutiloba*. Monoculture plantations and degraded evergreen forests as a result of human interference enable the invasion of such generalized and light-tolerant species which would sooner or later replace species with restricted distribution in evergreen forests if human interference continues unabated.

Keywords: Bryophytes, diversity, human disturbance, natural forests, plantations, Western Ghats.

BRYOPHYTES are nonvascular plants generally reproducing by spores. They are considered to be pioneers that colonize terrestrial habitats from an aquatic environment. They are the simplest and the most primitive of the land plants as they do not have a well developed conductive tissue system. Though basically terrestrial, there are a few aquatic forms such as *Riccia fluitans*, *Ricciocarpus natans* and *Riella* spp. *Cryptothallus* and *Buxbaumia* are saprophytic genera of liverworts and mosses respectively. Bryophytes are more common in humid areas and during rainy seasons, but usually show a preference for microclimatic niches such as crevices of rocks and trees and the vicinity of small shady springs. However, they can grow on a wide range of substrata. They may be found on old discarded/abandoned leather goods, rubber tyres, wooden articles, tiled and asbestos roofs and mortar of stone and mud walls. They also grow as epiphytes on barks of trees (corticolous), leaves (folicolous), rocks (rupicolous), stones and pebbles (saxicolous), fallen logs (lignicolous), river banks and roadside cuts (terricolous). Since water is inevitable for completing their life cycle, they are known as the 'amphibians' of the plant kingdom. However, many are drought-tolerant and are secondary colonizers on barren rocks in a xerosere after lichens. With a remarkable capacity to absorb water they turn fresh in no time and hence are also known as 'resurrection plants'.

India, one of the 12 megabiodiversity countries of the world, possesses a large area and a variety of phytoclimatic conditions which contribute to the great diversity of the flora. Pandé[1] divided these zones into seven bryogeographical regions, namely the Western and Eastern Himalayas, Punjab and West Rajasthan, Gangetic Plains, Central India, Deccan Plateau, and the Western and Eastern Ghats. The flora of the Western Ghats has been studied with emphasis on flowering plants and even pteridophytes. However, knowledge on the taxonomy, ecology and distribution of bryophytes is still far from adequate[2]. Moreover, questions like whether monoculture plantations lead to reduction of species diversity and ultimately local extinction of species remain unanswered. The present study is an effort to answer such questions and to highlight the need, for conservation of natural ecosystems.

Kanyakumari District, Tamil Nadu is situated at the southernmost tip of Peninsular India. It lies between 8°5′ and 8°30′N lat.; 77°10′ and 77°36′E long. The geographical position of the district is such that it receives both southwest and northeast monsoons. Normally during December

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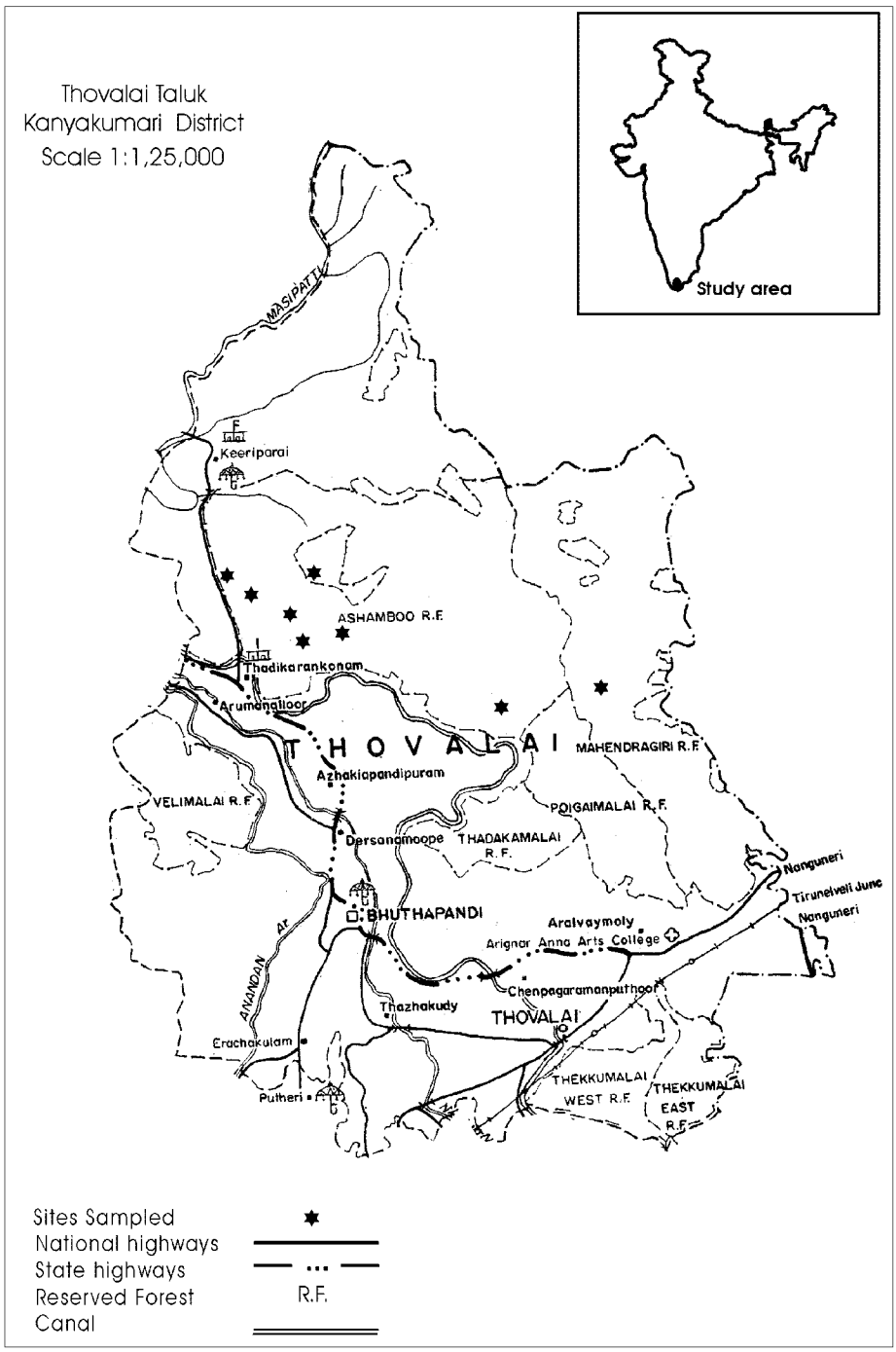

Figure 1. Map of the study area.

and January, there is heavy dew with occasional showers. Thus, it is obvious that the district remains moist for a greater part of the year. The average rainfall is about 3000 mm. The total area is 1684 sq. km with 446 sq. km under forest cover as the Western Ghats terminate here.

The present study area, the Mahendragiri hill (Figure 1), lies on the northeastern side of the Kanyakumari District and has the highest peak in the south, with an elevation of 1645 m, next to the Agasthyar peak with an elevation of 1868 m in the adjoining Tirunelveli District. The vegetation types vary from southern tropical thorn forests in the drier zones at the foothills to montane evergreen forests and grassy swards above 900 m. However, large tracts of monoculture plantations have made the natural forests patchy. Some of the main plantations are rubber (*Hevea braziliensis*), coffee (*Coffea arabica*), coconut (*Cocos nucifera*), tea (*Camellia sinensis*) and clove (*Syzygium aromaticum*).

Sampling was carried out over a period of ten months from September 2004 to June 2005. 50 m long transects with three 10 × 10 m quadrat alternating with an interval of 10 m were laid. In each vegetation type six transects were laid. Altitude was noted using an altimeter (YCM, Japan). The vegetation types sampled are clove plantations in Valayathuvayal (250 m) and Devagiri (520 m); rubber plantations in Valayathuvayal (160 m) and Devagiri (420 m); degraded evergreen forests in Injikkadavu (320 m) and in the vicinity of Manchalthittai (710 m), and evergreen forests in Injikkadavu (480 m) and Manamedai cholai (1000 m).

The method adopted was stratified random sampling because the habitats were pre-decided as they are representatives of different human interferences and altitudes within the landscape. The transects were laid randomly in such a way that each quadrate was visited and sampled only once. They were thoroughly searched for bryophytes and collections were made in various habitats such as bark, rock, stones and soil. Bryophytes were scraped with the help of a knife or razor blade. The collected plants were numbered, labelled and kept in polythene bags for determination. Determinations were made with the help of Gangulee[3] and other related works including Daniels[4] as well as more recent revisions and monographs.

The diversity of bryophytes of the four vegetation types at different altitudes was assessed using Shannon–Weiner index[5,6]

$$H' = -\sum p_i \ln p_i$$

where H' is the measure of diversity, and P_i the proportion of the ith species in the landscape element sampled.

On the whole 2580 collections were made from 144 quadrates laid on 48 transects. The total number of collections made in different plantations are given in Table 1.

Evergreen forests host 56 genera and 105 species followed by degraded evergreen forests with 29 genera and 58 species, clove plantations with 17 genera and 33 species and rubber plantations with 14 genera and 34 species.

The substrata colonized by bryophytes are corticolous, rupicolous, saxicolous and terricolous. In all the vegetation types terricolous colonies were predominant except in rubber plantation (160 m). Corticolous colonies are higher in rubber plantation (160 m) and lesser in clove (520 m) and degraded evergreen forest (710 m). Saxicolous colonies are lesser in evergreen forest (480 m). Rupicolous colonies are highest in evergreen forests (Table 2).

Table 1. Total number of collections made in different plantations

Plantation (altitude, m)	Number of collections
Rubber plantation (160)	338
Rubber plantation (420)	312
Clove plantation (250)	272
Clove plantation (520)	219
Degraded forest (310)	401
Degraded forest (710)	294
Evergreen forest (480)	324
Evergreen forest (1000)	420

Four vegetation types, viz., rubber plantations, clove plantations, degraded forests and evergreen forests were studied. In order to find out whether altitude has any influence on the diversity of bryophytes each of the four vegetation types was sampled at two altitudes with a minimum difference of at least 250 m. Thus transects were laid in eight sites. In all the eight vegetation types studied equal number of quadrates were laid and the species diversity is as follows: rubber plantation 160 m; H' = 2.428; rubber plantation 420 m, H' = 2.490; clove plantation 250 m, H' = 2.016; clove plantation 520 m, H' = 2.511; degraded evergreen forest 320 m, H' = 2.771; degraded evergreen forest 710 m, H' = 3.362; evergreen forest 480 m, H' = 3.041, and evergreen forest 1000 m, H' = 3.764; (Tables 3 and 4). The above data indicate that evergreen forests have the highest species diversity followed by degraded evergreen forests, clove plantations and rubber plantations.

Concerning the number of colonies, barring the evergreen forests all the vegetation types show a higher colony number from lower elevations (Tables 3 and 4). This may be due to the colonization of more light-loving species, since degraded evergreen forests and plantations have a comparatively more open canopy than evergreen forests. Species like *Fissidens ceylonensis* appear to be a light-loving and are found to be with the highest number of colonies (142) in the lower elevation clove plantations and with just one colony in the higher elevation evergreen forest. Similarly, *Frullania acutiloba* shows highest number of colonies (37) in the lower elevation rubber plantation and just 2 and 1 in the lower elevation evergreen and higher elevation evergreen forests respectively. *Hyophila comosa* has 27 colonies in degraded forests, 26 each in rubber and clove plantations, and just 14 and 6 in evergreen forests. *Hyophila involuta* has 105 and 66 colonies in degraded evergreen forests and rubber plantations respectively, and just 5 and 13 colonies in evergreen forests. Thus it is evident that these are light-loving species and have a higher number of colonies in monoculture plantations and degraded evergreen forests. But more shade and moisture-loving species such as *Bryum wightii*, *Calymperes graeffeanum*, *Lophocolea bidentata*, *Distichophyllum schmidtii*, *Cheilolejeunea khasiana*, *Cheilolejeunea serpentina* and *Phaeoceros laevis* are restricted to evergreen forests (Table 5).

The number of exclusive species in each habitat type [rubber plantation (160 m) = 2, rubber plantation (420 m) = 6, clove plantation (250 m) = 3, clove plantation (520 m) = 3, degraded evergreen forest (320 m) = 5, degraded evergreen forest (710 m) = 3, evergreen forest (480 m) = 15 and evergreen forest (1000 m) = 24; Table 5] supplement the above-mentioned distribution pattern. Considering the

Table 2. Number of colonies on different substrata in percentage

Vegetation type (altitude, m)	Rupicolous	Corticolous	Saxicolous	Terricolous
Rubber plantation (160)	9.4	33.1	27.6	29.9
Rubber plantation (420)	20.9	24.2	15.3	39.6
Clove plantation (250)	0.72	15.8	16.5	66.9
Clove plantation (520)	21.7	5.9	10.4	61.9
Degraded forest (320)	26.8	21.4	4.8	46.9
Degraded forest (710)	27.4	9.9	8.4	54.2
Evergreen forest (480)	30.3	18.5	2.1	49.1
Evergreen forest (1000)	31.2	18.2	5.1	45.6

Table 3. Species richness, abundance and diversity of bryophytes across the four vegetation types

Vegetation type (altitude, m)	No. of quadrates	No. of species	No. of colonies	Shannon–Weiner Index
Rubber plantation (160)	18	17	341	2.428
Rubber plantation (420)	18	30	326	2.490
Clove plantation (250)	18	25	278	2.016
Clove plantation (520)	18	20	221	2.511
Degraded forest (320)	18	32	462	2.771
Degraded forest (710)	18	46	321	3.362
Evergreen forest (480)	18	44	340	3.041
Evergreen forest (1000)	18	87	507	3.764

Table 4. Summary of number of colonies and species of bryophytes per quadrate in the four vegetation types

			No. of colonies/quadrates				No. of species/quadrate			
Vegetation type (altitude, m)	Number of quadrates	Total count	Range	Average	Standard deviation	Coefficient of variation	Range	Average	Standard deviation	Coefficient of variation
Rubber plantation (160)	18	338	13–26	19	4.256	22.40	4–10	7.17	1.383	19.289
Rubber plantation (420)	18	312	12–29	18.11	5.546	30.62	4–10	7.22	1.896	26.26
Clove plantation (250)	18	272	10–20	15.44	3.091	20.02	1–9	5.11	2.193	42.92
Clove plantation (520)	18	219	10–15	12.28	1.841	14.99	4–9	6.44	1.381	21.44
Degraded forest (320)	18	401	15–35	25.67	5.247	20.44	6–15	10.06	2.279	22.65
Degraded forest (710)	18	294	15–22	17.83	2.203	12.36	5–13	9.78	2.211	22.61
Evergreen forest (480)	18	324	11–26	18.89	3.969	21.01	4–12	7.722	2.372	30.73
Evergreen forest (1000)	18	420	22–36	28.33	3.742	13.21	10–22	15.33	3.710	24.20

types of substrata (Table 2) on which bryophytes colonize, in evergreen forests and degraded evergreen forests terricolous forms were the highest. This may be attributed to the fact that the forest floor in evergreen forests is rich in humus and remains so throughout the year. In degraded evergreen forests, in spite of the comparatively more open canopy several microhabitats or niches such as small springs or crevices or an evergreen tree protecting a considerable area of plants from direct sunlight are seen which may support the growth of terricolous forms. The reason for the lower diversity and lower terricolous forms in plantations is due to the regular intercultural practices, such as weeding and manuring carried out, and also the use of pesticides. Hence, there is no humus and the soil remains moist only during monsoon. The number of rupicolous forms was also the highest in evergreen forests followed by degraded evergreen forests. This is because in these two vegetation types the rocks are usually partly soil-covered and have a considerable amount of moisture capable of supporting a luxuriant growth of bryophytes.

Rubber plantations show the highest number of corticolous forms though evergreen forests possess a denser growth of trees and shrubs. This may be because the plantation is more suitable only for the growth of corticolous forms since the soil and rock are drier and are suitable for the growth of drought-tolerant species. Moreover, most of the larger rocks are blown up with dynamite for making boundary and retaining walls in plantations. Hence, the number of saxicolous forms is higher in rubber and clove

Table 5. Occurrence of bryophyte species in different vegetation types

Species	Rubber (160 m)	Rubber (420 m)	Clove (250 m)	Clove (520 m)	Degraded forest (320 m)	Degraded forest (710 m)	Evergreen forest (480 m)	Evergreen forest (1000 m)
Acanthorrhynchium papillatum	–	–	–	–	–	–	–	+
Anoectangium bicolor	–	+	–	–	–	+	+	+
A. stracheyanum	–	–	–	–	–	+	–	+
Aneura pinguis	–	–	–	–	–	–	+	–
Anthoceros subtilis	–	–	–	+	–	–	–	–
Archilejeunea apiculifolia	–	+	+	–	+	–	+	–
A. minutilobula	–	+	+	–	+	–	+	+
Archilejeunea sp.	–	–	–	–	+	–	–	–
Atrichum undulatum var. *subseratum*	–	–	–	–	–	+	–	+
Barbula indica	–	–	–	–	–	+	–	+
B. javanica	–	–	+	–	–	–	–	–
Barbula sp.	–	–	–	–	–	–	–	+
Brachilejeunea sp.	–	–	–	–	–	–	–	+
Brachythecium buchanani	–	–	–	–	–	–	–	+
B. procumbens	–	–	–	–	–	–	–	+
Bryum apiculatum	–	+	+	+	+	+	–	+
B. billardierei	–	+	–	–	–	+	–	+
B. caespiticium	–	+	–	–	–	–	–	–
B. coronatum	–	+	–	–	–	–	–	–
B. paradoxum	–	+	–	–	–	–	–	–
B. pseudotriquetrum	–	+	–	–	–	–	–	–
B. wightii	–	–	–	–	–	–	–	+
Calymperes afzelii	–	–	–	–	+	+	+	+
C. erosum	–	–	+	–	+	+	–	+
C. graeffeanum	–	–	–	–	–	–	–	+
C. taitense	–	–	–	–	–	–	+	–
C. tenerum	+	–	–	–	–	–	–	–
Calyptothecium recurvulum	–	–	–	–	–	–	–	+
Campylopus savannarum	–	–	–	–	–	–	–	+
Cephalozia sp.	–	–	–	–	+	–	–	–
Cephaloziella sp.	–	–	–	–	–	–	–	+
Cheilolejeunea khasiana	–	–	–	–	–	–	–	+
C. serpentina	–	–	–	–	–	–	+	–
Cololejeunea furcilobulata	–	–	–	–	–	–	+	–
C. lanciloba	–	–	–	–	–	+	–	–
Cyathodium aureonitens	–	–	–	–	–	–	–	+
C. smaragdinum	–	–	–	+	–	–	–	–
Dichranolejeunea sp.	–	–	–	–	–	–	+	–
Distichophyllum schmidtii	–	–	–	–	–	–	+	–
Entodon rubicundus	–	–	–	–	–	–	–	+
Eriopus sp.	–	+	–	–	–	–	–	–
Erpodium biseriatum	–	–	+	+	–	–	–	–
E. mangiferae	–	–	+	–	–	–	–	–
Fissidens auriculatus	–	+	–	–	+	–	–	+
F. ceylonensis	+	+	+	+	+	+	–	+
F. crenulatus	+	+	–	–	+	+	+	+
F. crispulus	–	–	–	–	–	+	+	+
F. diversifolius	–	–	–	–	–	–	–	+
F. ganguleei	–	–	–	–	+	+	+	+
F. flaccidus	+	+	+	+	+	+	–	+
F. griffithii	+	–	+	–	–	–	–	–
F. incognitus	–	–	–	+	–	+	+	+
F. involutus subsp. *curvato-involutus*	–	–	–	–	+	+	–	+
F. involutus subsp. *involutus*	+	+	+	–	+	–	+	–
F. javanicus	–	–	–	–	–	–	+	
F. kalimpongensis	+	+	+	+	+	+	+	+
F. macrosporoides	–	–	–	–	+	–	–	–
F. obscurus	–	–	–	–	–	–	+	–
F. pokhrensis	–	–	–	+	+	+	+	+

(Contd...)

Table 5. (*Contd...*)

Species	Rubber (160 m)	Rubber (420 m)	Clove (250 m)	Clove (520 m)	Degraded forest (320 m)	Degraded forest (710 m)	Evergreen forest (480 m)	Evergreen forest (1000 m)
F. polysetulus	–	–	–	–	–	–	–	+
F. pulchellus	–	+	–	–	+	–	+	–
F. subpalmatus	+	+	+	–	+	–	–	–
F. subpulchellus	–	–	–	–	+	–	–	–
F. teraicola	–	–	–	–	+	–	+	+
F. virens	–	–	–	+	–	–	–	–
F. zollingeri	+	+	+	+	+	+	+	+
Fossombronia himalayensis	–	–	–	–	–	+	–	+
Frullania acutiloba	+	+	+	+	+	+	+	+
F. campanulata	+	+	+	–	–	+	–	–
F. muscicola	+	+	+	–	+	+	–	–
Heteroscyphus argutus	–	–	–	–	–	–	+	–
H. orbiculatus	–	–	–	–	–	–	+	–
Hydrogonium amplexifolium	–	–	–	–	–	–	–	+
H. javanicum	–	–	+	–	–	+	–	+
Hymenostylium recurvirostre	–	+	–	+	+	+	+	+
H. aurantiacum	–	–	–	–	–	–	+	+
Hyophila comosa	+	+	+	+	+	+	+	+
H. involuta	+	+	+	+	+	+	+	+
H. rosea	+	–	–	–	–	+	–	+
H. spathulata	–	–	–	–	–	+	–	+
Isopterygium albescens	–	–	–	–	–	+	+	+
I. andamanicum	–	–	–	–	–	–	–	+
I. lignicola	–	–	–	–	–	–	–	+
Jungermannia sp.	–	–	–	–	–	+	–	+
J. tetragona	–	–	–	–	–	+	–	+
Lejeunea cocoes	–	–	–	–	–	–	–	+
L. obfusca	–	–	–	–	–	–	+	–
L. olivacea	–	–	–	–	–	–	–	+
L. punctiformis	–	–	–	–	–	–	–	+
L. tuberculosa	–	–	+	+	–	–	+	+
Leucobryum juniperoideum	–	–	–	–	–	–	–	+
Leucoloma amoene-virens	–	–	–	–	–	–	–	+
L. tenerum	–	–	–	–	–	–	+	+
Lophocolea bidentata	–	–	–	–	–	–	–	+
L. heterophylla	–	–	–	–	–	–	–	+
L. minor	–	–	–	–	–	–	–	+
Macromitrium hamatum	–	–	–	–	–	+	–	+
M. sulcatum	–	–	–	–	–	–	–	+
Mastigolejeunea auriculata	+	+	+	–	+	–	–	–
Meteoriopsis ancistrodes	–	–	–	–	–	–	–	+
M. formosanum	–	–	–	–	–	–	–	+
M. reclinata	–	–	–	–	–	–	–	+
M. squarrosa	–	–	–	–	–	–	–	+
Meteorium buchanani	–	–	–	–	–	–	–	+
Metzgeria sp.	–	–	–	–	–	–	–	+
Neckeropsis submarginata	–	–	–	–	–	–	+	–
Octoblepharum albidum	–	–	–	–	–	–	+	+
Pallavicinia lyellii	–	–	–	–	–	–	–	+
Pelekium versicolor	–	–	–	–	–	–	+	–
Phaeoceros laevis	–	–	–	–	–	–	–	+
Philonotis fontana	–	–	–	+	+	+	+	+
P. hastata	–	–	–	–	–	+	–	–
P. thwaitesii	–	+	–	–	+	+	+	+
Pohlia flexuosa	–	–	–	–	–	–	–	+
P. longicollis	–	+	–	+	–	+	–	+
Porella campylophylla subsp. *lancistipula*	–	–	–	–	–	–	–	+
Pterobryopsis orientalis	–	–	–	–	–	–	–	+
Racopilum cuspidigerum	–	–	–	–	–	–	–	+

(*Contd...*)

Table 5. (*Contd...*)

Species	Rubber (160 m)	Rubber (420 m)	Clove (250 m)	Clove (520 m)	Degraded forest (320 m)	Degraded forest (710 m)	Evergreen forest (480 m)	Evergreen forest (1000 m)
R. othocarpum	–	–	–	–	–	+	–	+
Radula sp.	–	–	–	–	–	+	–	–
Riccardia levieri	–	–	–	–	–	+	+	–
Riccia billardieri	–	+	–	+	–	–	–	–
R. crozalsii	–	+	–	–	–	–	–	–
R. discolor	–	–	+	+	–	–	–	–
Schiffneriolejeunea indica	+	–	–	–	–	–	–	–
Scopelophila ligulata	–	–	–	–	–	+	–	–
Sematophyllum subpinnatum	–	–	–	–	–	–	–	+
Stereophyllum confusum	–	–	–	–	–	+	–	+
S. wightii	–	–	–	–	–	–	–	+
Taxiphyllum minutirameum	–	–	–	–	+	+	+	+
Thuidium cymbifolium	–	–	–	–	–	–	+	–
Trematodon longicollis	–	–	–	–	–	+	–	+
Trichosteleum punctipapillosum	–	–	–	–	+	–	+	+
Trichostomum teneuirostre	–	–	–	–	–	+	–	+
Weissia edentula	–	–	+	–	–	–	–	–

plantations as there are invariably such protective constructions.

From Table 3 it is evident that altitude does influence the growth and diversity of bryophytes, as the species diversity is consistently higher in all the higher altitude habitats. Similar observations have been made by Negi and Gadgil[7] on terricolous liverworts in the Himalayas.

However, the above analyses it is clear that there is a tendency for plantations and degraded evergreen forests to accommodate more generalized and robust species than species with restricted distribution. Similar observations have been made by Daniels *et al.*[5] on birds and Devy and Davidar[8] on butterflies.

From this study it is evident that natural forests, particularly the evergreen forests with a wealth of specialized endemic species are giving way to the invasion of more generalized and light-tolerant bryophyte species as a result of human interference. The existing evergreen forests and the introduced monoculture plantations are far apart in terms of similarity of species. *F. ceylonensis*, *H. comosa*, *H. involuta* and *F. acutiloba* are light-tolerant species and can serve as indicators of human interference. Unless natural forests, particularly the evergreen forests, are preserved, there is a danger of losing a number of endemic, rare and specialized bryophytes, which will be sooner or later be replaced by the more robust, light-tolerant generalists. Moreover, evergreen forests possess the highest number of species diversity of bryophytes and therefore there is an urgent need to protect and preserve them.

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