The Asian and Australasian Journal of Plant Science and Biotechnology ©2008 Global Science Books

Pattern of Bryophyte Richness in Relation to Landscape Features

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ABSTRACT

The bryophyte communities in the Rishikesh area, India were analyzed with respect to species diversity, frequency, life strategies and adaptation. The adaptive trends and life strategies were generally subjected to different types of habitats in a zone of disturbances. The prominent life strategies were colonist and shuttle forms which were found to be in frequently disturbed sites. In sub-humid communities colonists with high asexual reproduction are prominent. The analysis of life forms, life strategy and morphological adaptation indicate that common adaptive trends arise convergently but independently in unrelated taxa when they evolve under similar habitat conditions. This also provides insight into the establishment of species, habitat maintenance and dispersal strategy and highlights the most important habitat type for bryophyte species richness in various types of landscapes in term of climatic and land use while discerning the most influential factor for distribution of species in these habitats.

Keywords: adaptive traits, colonist, ecological amplitude, life strategy, microhabitat, mosses, shuttle, species distribution

INTRODUCTION

The bryophytes contain some of the most species-rich lineages of land plants presenting a challenge for understanding diversification through adaptation. They help to increase the nutrient status of a bare site and make it possible for colonization by higher plants and small animals (Longton 1992). Bryophyte species tend to be highly specific for a particular micro-environment, responding to such features as temperature, light and water availability, substrate chemistry etc., and making them good ecological indicator species, i.e. they appear to be an ecological keystone group in various ecosystems (Uniyal *et al*. 2007). Bryophytes in a tropical system provide a major buffer allowing measured loss of minerals from trees to soil – a loss slow enough to allow almost complete re-absorption of minerals by the trees (Oechel and Van Cleve 1986).

Historical, physical and ecological constraints influence dispensability, establishment and persistence of bryophytes over time. Bryophytes, being small, economically unimportant plants and unlikely to have been introduced by humans prove to reflect a natural biogeographical pattern of dispersal and vicariance (Tan and Pócs 2000; Vanderpoorten and Engels 2003). Bryophytes serve as model organism for studies and biogeographical patterns on islands. The combination of clonal growth, poikilohydry and external water conduction indicate that the plants in clumps are subject to natural selection as a group. Bryophytes often appear transiently within communities that represent stages in succession or cycling processes (During 1992). Although bryophytes form a minor component of the total biomass, they play an important role in nutrient cycling (Brown and Bates 1990) and there is an urgent need to prepare a data base and protect them in the fragile ecosystem.

The important role of substrates in bryophyte species diversity and composition has been well established (Pharo and Beattie 2002). This study aims to prepare an inventory of bryophytes of the site and study the effect of soil conditions and landscape features on bryophyte diversity and rarity, which can serve as predictive models of distribution. Further analysis is required to identify the ecological conditions that control diversity and rarity pattern of bryophytes and to synthesize the relation between bryophytes diversity and landscape features at a regional scale.

MATERIALS AND METHODS

The Rishikesh area in Uttarakhand state, India was selected for the study because of already available information on the soil conditions. The area consists of low hills and plains and valley (average altitude = 400 m) in the Shivalik ranges on the bank of the Ganges River. As a consequence of frequent visits by tourists, the natural habitat is patchy and fairly reduced in size. The soil is mostly sandy-loam. A comprehensive species inventory was made by examination of the collected material in different seasons with help of the literature (Chopra 1975; Gangulee 1980; Singh 2001). The scale of species rarity was built based on species frequencies through the quadrat (50 × 50 cm) method. Fifty quadrats were placed randomly in the study. The species which occurred in less than 10% of the quadrats were considered to be rare. The occurrence of species was measured by total soil cover by the species. Measurement of abundance of a species was based on the average percentage cover of a species in quadrats. Frequency was calculated by the following formula:

$$F = \frac{n}{N} \times 100$$

where F = frequency, n = total number of quadrats in which species occurred and N = total number of quadrats studied.

RESULTS

A total of 52 species of bryophytes were recorded (**Table 1**). Species diversity varied between 8 and 14 species per quadrat with a median of 10 species. Locally rare species (species occurring in less than 10% of the quadrat) accounted for 30% of the total number of species in the area. Species diversity was significantly correlated with vegetation cover.

Received: 7 May, 2008. Accepted: 13 July, 2008.

Original Research Paper

Table 1 List of thalloid taxa recorded in study site with their growth forms and life strategies.

Taxa	Locality	Growth form	Life strategy	Substrate	Frequency %
Notothylaceae					
Notothylas indica Kash.	Someshwar	TM	SS	soil	5.7
N. levieri Schiff.	Garur Chatti	TM	SS	soil	5.0
Marchantaceae					
Marchantia palmata Nees.	Garur Chatti	TM	MS	old wall	25.5
M. polymorpha L.	Phool Chatti	TM	MS	old wall	35.2
Targioniaceae					
Cyathodium tuberosum Kash.	Someshwar	TM	CL	rock	20.8
Targionia hypophylla L.	Garur chatti	TM	MS	rocks	15.0
Aytoniaceae					
Asterella angusta St.	Garur chatti	TM	MS	old wall	60.0
Reboulia hemispherica (L.) Raddi	Phool chatti	TM	MS	rocks	15.7
Plagiochasma articulatum Kash	Garur chatti	TM	MS	rock	30.6
P. appendiculatum Lehm..et Lindb.	Garur chatti	TM	MS	wall	35.6
P. simlensis Kash.	Garur Chatti	TM	MS	wall	20.0
P intermedium Lindb.et Gotts.	Garur Chatti	TM	MS	rocks	25.5
Ricciaceae					
Riccia fluitans L. et Mull	Manu swamp	TM	SS	soil	10.6
R. sanguinea Kash.	Geeta Bhawan	TM	SS	soil	5.0
R. melanospora Kash.	Garurchatti	TM	SS	soil	10.6
R. cruciata Kash.	Phool chatti	TM	SS	rock	25.3
R. himalayensis St.	Kailash inn	TM	SS	old wall	15.5
R. robusta Kash.	Manu swamp	TM	SS	soil	15.0
Pelliaceae					
Pellia calycina (Tayl). Nees	Manu swamp	TM	MS	wet rocks	15.1
P. neesiana (G) Limpr.	Manu swamp	TM	MS	rock	10.5
Aneuraceae					
Aneura levieri Schiff.	Manu Swamp	TM	SS	stones	5.0
Porellaceae					
Porella plumosa Inoue	Phool Chatti	LM	CL	stones	10.6
Plagiochilaceae					
Plagiochila mittenii St.	Garur chatti	LM	CL	Stones	10.8
Plagiochila sp.	Phool chatti	LM	CL	stones	5.0

CL = colonist, LM = leafy mat, MS = medium shuttle, SS = short shuttle, TM = thalloid mat

Table 2 List of moss taxa recorded in study site with their growth forms and life strategies.

Taxa	Locality	Growth form	Life strategy	Substrate	Frequency %
Dicranaceae					
Trematodon capillifolius C. Muell.	Neelkanth	TR	CL	soil	10.0
Fissidentaceae					
Fissidens pulchellus Mitt.	Garur Chatti	LM	CL	soil	10.0
Pottiaceae					
Molendoa roylei (Mitt.) Broth.	Garur Chatti	TR	CL	rocks	5.5
Anoectangium stracheyanum Mitt.	Nelkanth	TR	CL	rocks	15.0
A. thomsonii Mitt.	Garur Chatti	TR	CL	walls	15.0
Hymentostomum tortile (Schwaegr.) B.S.G.	Manu swamp	CS	CL	rocks	30.6
Gymnostomum aurantiacum (Mitt.) Jaeg.	Hardwar Road	CS	CL	rocks	30.6
G. calcareum Nees. et Hornsch.	Garur Chatti	CS	CL	rocks	25.0
Hymenostylium recurvirostre (Hedw.) Dix.	Phool Chatti	CS	CL	rocks	30.6
Hyophila involuta (Hook.) Jaeg.	Phool chatti	TR	CL	wall	70.0
Hydrogonium arcuatum (Grif) Wijk.	Laxman Jhula	CS	CL	rocks	40.4
Barbula horricomis C. Muell.	Laxman Jaula	TR	CL	rock	50.0
B fallax Hedw.	Garur Chatti	TR	CL	stones	10.0
B acuta (Brid.) Brid.	Garur Chatti	TR	CL	stones	20.0
B. icmadophilla (C. Muell.) Amann	Garur Chatti	TR	CL	stones	10.6
B. unguiculata Hedw.	Neelkhanth	TR	CL	stones	20.0
B vinealis Brid.	Neelkahnth	TR	CL	stones	10.0
Funariaceae					
Physcomitrium japonicum Hedw. (Mitt.)	Garur Chatti	TR	SS	soil	50.0
Funaria hygrometrica Hedw.	PG College	TR	FG	wall	70.0
F wallichii (Mitt.) Broth	PG College	TR	FG	wall	20.0
Bryaceae					
Bryum argenteum Hedw.	Neelkhantn	TR	CL	rocks	30.6
B. porphyroneuron C. Muell.	Garur Chatti	TR	CL	rocks	25.4
Bartramiaceae					
Bartramia subpellucida Mitt.	Phool Chatti	TR	PS	rocks	15.0
Bartramidula roylie (Hook) BSG.	Garur Chatti	TR	PS	rocks	15.0
Philonotis falcata (Hook) Mitt.	Garur Chatti	TR	PS	rocks	25.0
Cryphaeaceae					
Forsstroemia mussooriensis Dix.	Garur Chatti	LM	PS	bark	5.0
Plagiotheciaceae					
Stereophyllum anceps (Bosch et Lac.) Broth.	Garur Chatti	LM	PS	soil	10.0
Hypnaceae					
Pylaisia aurea (Schwaegr.) Broth.	Phool Chatti	LM	PS	rocks	5.0

CL = colonist, CS = cushion, FG = fugitive, LM = leafy mat, PS = perennial stayers, SS= short shuttle, TR = turf

In most of the quadrats only one to three species were recorded. A wide range of investigation on bryophyte distribution was performed in a landscape.

Most of the recorded moss species show a turf and cushion growth form (**Table 2**). In the turfs the individual shoots and branches stand erect and parallel to each expanding in large areas. This form is represented by *Molendoa*, *Anoectangium*, *Hyophila*, *Barbula*, *Physcomitrium*, *Funaria*, *Bryum*, *Bartramia*, *Bartramidula* and *Philonotis.* In cushion forms the shoots have frequent branching, so the upper portions of the shoots expand more making dome-shaped masses. The cushion form was observed in *Hymenostomum*, *Gymnostomum*, *Hymenostylium* and *Hydrogonium.* The advantage of these growth forms is that they stand firmly on the substrate and are able to retain much water in between the individual shoots. Life strategies of a species are of great importance for habitat establishment and maintenance which are based on life span, reproductive efforts, size and number of spores and dispersal strategy (During 1979). Members of the Pottiaceae are mostly deeply embedded in the substrate during the dry season. As a general tendency, an increase in solitary plants, short turf and cushions, which is typical for numerous acrocarpous mosses (Kurschner 2004), were observed in sunny, dry and xeric habitats. All thalloid forms were found on old moist walls as the soil is not able to retain water for long. In the terrestrial communities the species with a colonist strategy often consist of truly pioneering colonizing species such as *Trematodon*, *Anoectangium*, *Gymnostomum*, *Hymenostylium*, *Hyophila* (**Fig. 1A**), *Barbula* and *Bryum* (**Table 2**) that were found to appear in early successional series. The short-lived shuttle species occupy an unstable and frequently disturbed common habitat. Their dispersal distance is reduced by the larger size of spores or cleistocarpic capsules that restrict their establishment at another site. They show an ephemeral habit and appear year after year on the same site. Their life cycle is often strongly determined by seasonal fluctuation. This strategy is shown by *Riccia* (**Fig. 1A**), *Notothylas* and *Physcomitrium* (**Tables 1, 2**). They grow in such sites which are frequently passed by tourists and animals. These disturbances help to break their cleistocarpic capsules and disperse the spores. It is quite obvious that species following the shuttle strategy have a competitive advantage.

The high proportion of colonist species such as *Byrum*, *Barbula*, *Trematodon* and *Cyathodium* within the community is a strategy typical for pioneers. They occupy barren or disturbed habitats and their multiplication may be brought about by gemmae and rhizoidal tubers. The drought-resistant xeromorphic species such as *Plagiochasma*, *Asterella*, *Anoectangium* and *Barbula* are characterized by cushions and short turf (in leafy forms). In these species sexual as well as asexual reproduction produces a wide range of genotypes among the spores. Some of the species like *Stereophyllum*, *Pylaisia*, *Philonotis* and *Forestromia* following a perennial stayer and perennial shuttle strategy by occupying the habitat throughout the year.

The majority of the thalloid forms of the site exhibit a variety of structural adaptation for the retention of water and maintenance of photosynthesis under dry conditions. *Asterella*, *Plagiochasma*, *Reboulia*, *Riccia* and *Targionia* have a non-wettable thallus surface and have pegged rhizoids for water absorption (**Fig. 1D**). They have well-developed air pores and air chambers for efficient gas exchange (**Fig. 1C**). The mosses of the site show crisps and contorted leaves accompanied by a considerable shrinkage of the lamina and increased rolling and recurred margin (**Fig. 1B**). Leaves become adpressed to the stem and have papillose lamina cells (**Fig. 1E, 1F**).

DISCUSSION

The alarming loss of biological diversity in landscapes demands the development of appropriate strategies for sustainable land management. Recent studies showed that there was a correlation between land use intensity and overall

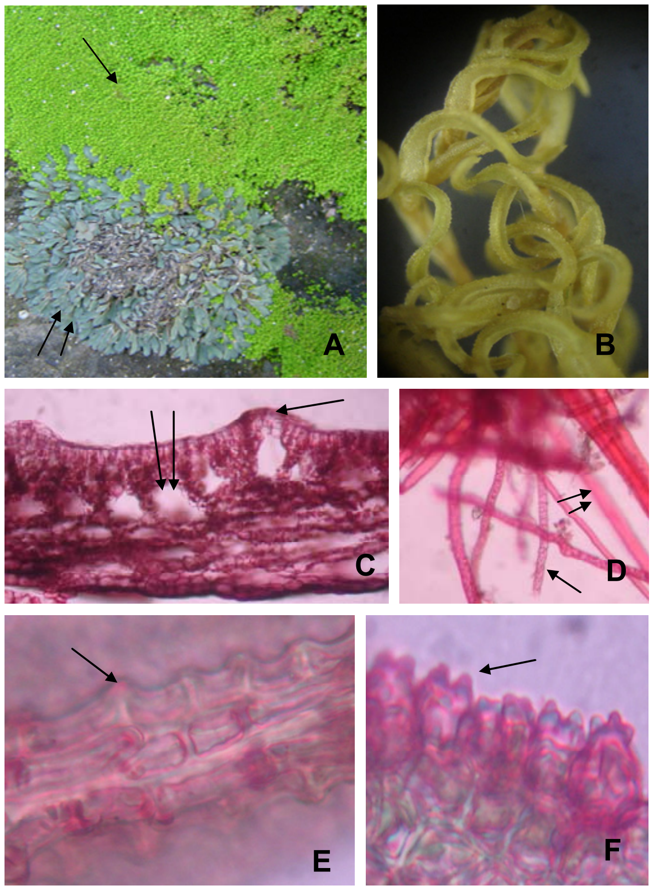

Fig. 1 (**A**) *Riccia cruciata* (double arrows) and *Hyophila involuta* (single arrow) on a rocky substratum. (**B**) *Barbula fallex* showing rolling lamina and recurved margins of leaves. (**C**) *Asterella angusta* showing epidermal pore (single arrow) and air chambers in the vertical section of thallus. (**D**) Pegged (single arrow) and smooth-walled rhizoids of thalloid forms. (**E**) Pappilose laminal cells (arrow) of *Barbula horicomis*. (**F**) Bipapillose marginal cells of the lamina of *Barbula acuta*.

bryophyte richness (Zechmeister *et al.* 2003). The general appearance of colonies of mosses is largely governed by the growth pattern of their shoots. The usual pattern of growth forms are transformed by environmental factors. The growth pattern is closely connected with light and water conditions. High light inhibits the elongation of axes and promotes short turf and cushion forms. Shade and humidity favour tall turfs, mats and dendroids (Uniyal *et al.* 2007). Ah-Peng *et al.* (2007) stated that along the altitudinal transect on a homogenous substrate the heterogeneity of a bryophyte community exists at a very small scale which is strongly linked to the nature of the microhabitat. Such studies contribute towards elocution of the ecological significance of growth form and its influence upon the ecological amplitude of moss species (Dierssen 2001). Gimingham and Birse (1957) described the classification of growth form based on the morphology as turf, cushion, dendroid, mat, weft, pendant and feather. A strong macrozonation of morphological adaptation and life strategies were observed along a gradient of soil texture, moisture temperature and irradiance. The exposed conditions bring cushions and turf into prominence while shade and humidity favour thalloid forms. Shoot growth tends to be vertical when illumination is even all around. The significance of turf and cushion growth form is that the individual shoots remain in large groups, adhere firmly to the substrate and retain much water in the capillary system formed in between the shoots.

Ah-Peng *et al*. (2007) observed that species show different life strategies along a transect and in the microhabitat. They found *Campylopus aureonitens* to be the most common species which posses long hyaline hair-pointed leaves and thick-walled laminal cells to prevent desiccation. In the present study mainly four types of strategies were observed. The shuttle forms such as *Riccia* avoid drought by growing only when there is adequate moisture and they quickly produce spores during a favourable period. They have long spore viability and remain in the soil for a longer time as a diaspore bank. Fugitive species such as *Funaria hygrometrica* colonize on a briefly available habitat patch and spread their spores to distant sites and colonize there in the next favourable season. The colonist forms appear on the same site year by year. They have a moisture-conserving morphology and high reproductive potential, forming spores and gemmae frequently (Pottiaceae and *Bryum* sp.). The closely packed parallel shoots and branches store enough capillary water. Perennial stayers are found only at the untouched sites and where moisture remains available throughout the year indicating that they avoid competition and disturbances (Uniyal 2007; Uniyal *et al.* 2007). Short-lived or shuttle forms with drought-resistant gametophytes show a high incidence of sexual reproduction. Most of the spores remain near the parent plants after dispersal and may permit the survival of a population. The majority of taxa present in the site have a moderately short life span. They have a small spore size that performs long-range dispersal. There is a strong correlation between life form, community structure and ecological site conditions (Kurschner 2004) and it is obvious with regards to sun-exposed, epilithic communities where acrocarpous short turfs and cushions dominate.

This study provides richness and ecological amplitude of bryophyte species. It also indicates the importance of bryophytes as successful colonizers which accumulate minerals, enhance microbial activity and make the site suitable for the establishment of higher plants.

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