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THE IMPACT OF HUMAN DISTURBANCE ON THE ELEVATIONAL PATTERNS OF BRYOPHYTE DIVERSITY

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Abstract:-*Bryophytes have been proposed as ideal indicators of ecosystem change, because they are important components of forest integrity, and considerable research indicates that some groups are sensitive to the changes associated with specific human disturbances. Bryophyte richness and abundance have been found to vary predictably along elevational gradients, but the role of human impacts on these distribution patterns remains unclear. The aim of this study is to explore the impact of human disturbance on the elevational patterns of bryophyte diversity. The data collected three areas (sets) in the following sites: Preserved Area (PA), forest track roadsides area (RA) and disturbed by agriculture/silviculture practices area (D A). Two survey areas of 200 m^2 were established at every 300 m elevational step for each areas PA, RA, DA, and in each area bryophytes were sampled in a stratified manner. At each area recorded all species on available substrates and estimated their percentage cover. The study results showed that species number did not differ among studied areas, but that species diversity pattern differs among the three gradient types and species life strategy composition along the elevational gradient showed a clear response to the disturbance of mature communities. The study concludes that human impact has strongly changed the elevational pattern of diversity, and that these changes vary depending on the ecological and taxonomical group considered.*

Introduction

Disturbances are defined as changes in the biotic or abiotic environment that alter the structure and dynamics of ecosystems[1]. Whether natural or human-induced, disturbances play an important role in shaping global vegetation [2].

Since prehistoric times humans have shown a great ability to colonies new environments and drastically modify them. No ecosystem on Earth's surface is free of pervasive human influence. There is a growing impulse to estimate the human effects in the future. However, the importance of the past and current human influence is not always recognized. This factor is frequently underestimated or ignored in ecological studies, and thus, described patterns of species distribution might be misunderstood[3]. For example, changes that are attributed to environmental filters may be instead due to past or present human activities. Several studies provide evidence that the effects of past human disturbance remain in the ecosystems even after long periods of natural regeneration of the forest, as has been observed for plants, butterflies and small mammals.

Species richness and elevation often show complex relationships, which are dependent on the taxonomic group and locality considered. Biodiversity patterns along elevational gradients have mostly been related with climatic conditions, area of elevational belts and thus size of source populations, environmental heterogeneity and ecological isolation[4]. However, spatial variation in natural resources along the gradient is usually related to human disturbances, which may modify dispersal, colonization and species distributions. Studies on species diversity along elevational gradients date back to the origin of biogeography. However, the relationship between human impact and diversity along elevational gradients has seldom been considered[5]. In a review of the literature on species–elevation relationships, Nogués-Bravo et al.[3], found that a high number of the elevational analyses contained disturbed areas. However, few of these studies included a measure of human impact as a potential predictor.

Bryophytes are the most diverse group of land plants after the flowering plants. They are distributed in almost every terrestrial ecosystem in the globe, so they are ideal candidates for latitudinal and altitudinal studies. Due to their poikilohydric nature, bryophytes are very sensitive to environmental changes and can be used as bioindicators of environmental and microclimatic conditions. Bryophytes have been found to be affected at both habitat and landscape-scale by human disturbances[6]. However, the effect of other types of disturbance on bryophyte communities remains unknown.

The importance of human impact along elevational gradients has been recently observed in a study with vascular plants in Maredumilli forest areas of Andhra Pradesh in the Eastern Ghats, where influence of past disturbances was found to affect processes such as speciation and invasion along the gradient. However, few studies include the anthropogenic factor as a direct variable in studies of species distribution. Here the study diversity patterns of bryophytes along a complete elevational gradient from sea level to high mountain peaks in the Maredumilli forest areas At 1,350 feet above the Mean Sea Level. The Forest Department recorded a temperature as low as 40 C in November 2018. Our general aim is to explore the impact of human disturbances on the elevational patterns of bryophyte diversity.

Material and methods

Study area

The study was conducted on Maredumilli forest area is considered to be one of the most scenic spots in south-eastern India located in Andhra Pradesh. The Maredumilli forest area is situated at a *Latitude*: 17° 35' 44.6496"., Longitude: 81° 43' 6.69". *Latitude*: N 17° 35.7442'. Longitude: E 81° 43.1115'. *Latitude*: 17.595736°. Longitude: 81.718525° . The Maredumilli Forests of East Godavari District are rich in biodiversity and are filled with undulating terrain, which forms part of the Eastern Ghats. It is a place of wildlife, nature, trekking camps, waterfalls and of tribal people who are out to win your heart with their hospitality. This forest area is conserved and developed by the tribal who have habituated the lands for generations. Fed by the waters of the Godavari River, the semi-evergreen forests of the village make it a wonderful place to have some adventure in the wild and immerse oneself with nature. Maredumilli is famous for its bamboo chicken which savours the surrounding beauty of that place.

The study established an elevational transect on the north-east slopes of the Maredumilli, where the studied three different types of areas: preserved area (PA areas), roadsides (RA areas) and disturbed by agricultural/sylvicultural practices (DA areas) (Table 1). The transect started at the Ranpa (40 ma.s.l) and ended at the highest elevation possible. The PA areas were located at the best preserved areas (Table 1), which are not pristine forests, but correspond to the least disturbed forests present on the Maredumilli. The RA areas are established in forest tracks that traverse well preserved areas. In these tracks, trees are initially cut for the road installation, and due to the high degree of light exposure following the cutting, herbaceous and shrubby species largely dominate the track margins, although young trees are sometimes present. In addition, borders are periodically cut for the maintenance of the roads. The DA areas included areas where the original vegetation was removed and replaced by fruit tree plantations in the lower elevations, e.g., banana, papaya, avocado and timber tree plantations in the middle and upper elevations.

Table 1
Description of the number of plots and the type of vegetation at each elevational belt at each site.

Elevational range	Plots per area	Potential vegetation (P Areas)	Vegetation on R Areas	Vegetation on D Areas
0–200	2	Euphorbia shrubland	Roadsides with shrubs and young trees	Fruit trees plantations
200–400	2	Dry *Apollonias barbujana* forest	Roadsides with shrubs and young trees	Fruit trees plantations
400–1200	10	Laurel forests *s.l.*	Roadsides with shrubs and young trees	Fruit trees plantations and timber extraction
1400–1800	6	*Pinus canariensis* forests	Roadsides with shrubs and young trees	Tree plantation for timber extraction and prescribed burning
2000–2200	4	Subalpine shrub vegetation	Roadsides with shrubs and young trees	Prescribed burning and livestock

The fieldwork was conducted from November 2021 to December 2022. The sampling design followed BRYOLAT methodology[32]. Within each area studied: areas, subareas and micro-areas. Areas were established approximately at each 200 m, thus resulting in 12 and 11 elevational levels respectively for PA and for RA and DA. Two areas of 10 m x 10 m were established at each elevational level. Areas in PA areas included only well-preserved laurel forests. Areas in area RA included the total track area as well as 1 m. of the track margin, in which vegetation was present. Areas in area DA were selected where human activity was the most pronounced at each elevational level. These were either fruit plantations or areas managed for forestry.

Sampling method

Within areas, the study randomly selected three subareas of 2x2 m and within each one, bryophyte species were recorded in three micro-areas of 10x5 cm on each substrate present (soil, rocks, humus and decaying wood; epiphyllous species were absent). Epiphytic bryophytes were also recorded, but in this case 3 individuals of each one of the tree species present in the areas were selected, and 3 micro-areas were sampled on each tree trunk at three different heights (TA: 0–50 cm, TB: 50–100 cm; TC: 100–200 cm). Number of trees sampled on each site varied from 46 on areas PA, to 22 on areas DA and no tree was sampled on transect RA, due to an absence of epiphytes on the trees that were present on the margins of the tracks. At each micro-area, bryophyte samples were first identified in the field to estimate relative cover of each species on each micro-area, and then taken to the lab for confirmation. All samples are deposited in the herbarium of Andhra University (Visakhapatnam). As a result of this stratified sampling, the study sampled a total of 68 micro-areas along the elevational gradient (PA areas: 24 micro-areas; RA and DA: each 22 micro-areas), and within these a total of 194 sub-areas (PA: 70 sub-areas, RA: 65, DA: 59). The number of sub-areas sampled in the different transects varied because bryophytes were not always present on every substrate or the particular substrate was absent. For analyses, data from micro-areas on each substrate were pooled to the level of these sub-areas by averaging mean cover values for each species. At each area, we took a detailed description of the vegetation, recording all vascular species present, their relative cover and whether they were herbs, shrubs or trees. In addition, the following potentially informative environmental variables were recorded: elevation, canopy cover, percentage of rocks, percentage of litter layer, and percentage of bare soil.

Data analysis

Bryophytes were assigned to categories reflecting their life-history strategy (Table 2). Life strategy classification followed Düring (1979)[7]. Total number of species was calculated for areas PA, RA and DA. For analyses, micro-area data for each substrate was pooled within subplots by averaging mean cover values for each species.

Table 2
Life strategy classification based on Düring (1979)

Life strategy	Spore size	Spore persistence	Sporophyte production	Life span
Fugitives	<20 µm	very persistent and long lived	High	Short
Colonists	<20 µm	very persistent	High	Moderately short
Annual	>20 µm	Several years	High	Short

shuttles				
Short-lived shuttles	>20 µm	Several years	Rather high	Few years
Long-lived shuttles	>20 µm	Short	Moderate	Long
Perennial stayers	<20 µm	Variable	Low	Many years (>20)

The study calculated number and percentage cover of mosses, liverworts (with regarding of families) in PA, RA and DA areas and also percentage of life forms in each area type. To highlight elevational trends of species richness, the study applied non-parametric locally weighted scatter-area smoothing by using function *lowess* in RA. It fits trend lines to data subsets in order to produce a smoothed curve making the species richness trend in the figures directly visible.

Separately, for each of the different areas are used Indicator Species Analysis which weights relative frequencies and relative cover of species within and between each area to search for important diagnostic species. The analysis determines both fidelity and consistency of species, providing a statistic and an associated *p*-value. Only species significant at the $p < 0.05$ level were selected as indicator species. Indicator species were investigated for elevational belts based on the main type of potential vegetation (Table 1). To analyse elevational range distributions of colonist and perennial species, we took the minimum and maximum elevational range of the respective species, and used the median as the range centre to account for accidental outliers.

In order to assess vegetation similarity and heterogeneity between areas and gradients, it performed ordination techniques based on Bray-Curtis similarity index, with sub-areas as cases and mean cover of species as a variable. Cover of each species at each micro-area was pooled together to obtain the mean value for sub-area, for species in every substrate. In order to reduce noise in the dataset, the study down weighted rare species. Environmental characteristics recorded in the sampling areas were fitted to the ordination result in order to assess their possible contribution to community assemblage patterns. To assess the separation of areas and vegetation belts within the ordination pattern, it fitted the respective variable onto the ordination scores with 999 permutations, which provides a goodness-of-fiter^2 and significance p, indicating whether the score centroids are significantly separated. All analyses were performed with the statistical platform RA and packages vegan and labdsv.

Results

Along the three area types a total of 178 species were recorded (131 mosses, 44 liverworts and 3 hornworts), belonging to 94 genera and 52 families. Pottiaceae (37 species) was the most common family, followed by Brachytheciaceae (15 species) and Bryaceae (12 species). Regarding each considered transect, for the PA sites we found a total of 118 species (86 mosses and 32 liverworts), with Pottiaceae and Brachyteciaceae being the most abundant families. One hundred and ten species were recorded in RA areas (76 mosses, 31 liverworts and 3 hornworts), with Pottiaceae as the most common family, followed by Bryaceae. In DA areas, 99 species were found (69 mosses, 29 liverworts and one hornwort) and Pottiaceae was again the most common family encountered followed in this case by Grimmiaceae. Regarding life strategies, colonists were the most abundant group: 60 species (50%) in PA areas; 69 species (63%) in RA areas; and 61 species (61%) in DA areas. Colonists were followed by perennials: 34 species (28%) in PA; 18 species (16%) in RA; and 20 species (20%) in DA. The other categories were found at a lesser extent in all areas. Among the studied areas some interesting macaronesian endemic species were recorded, such as *Homalothecium mandonii*, *Leptodon longisetus*, and *Exsertotheca intermedia*, all found exclusively in the areas of PA areas.

Elevational patterns of species richness showed differences across all three areas types. Distribution of species richness in well preserved vegetation showed a hump-shaped relationship with elevation, with maximum species richness at mid-elevation areas at about 1000 m, thus corresponding to the laurel forest. RA areas also showed a hump-shaped pattern, but not as clear as in PA areas, and in this case the maximum species richness shifted towards higher elevations. In DA areas, the hump-shaped pattern was replaced by an increase of species richness up to 400 m a.s.l. followed by a plateau above with a more or less constant number of species until the end of the transect.

Elevational patterns of species richness in every area.

Trend lines set by distance weighted least square smoothing using *LOWESS* function in RA. Bar areas indicate proportion of each taxonomic group, life strategy and substrate type at each elevational band. Number of species along y-axis is different when considering substrate as one species can be present in several substrates, thus total number of species considered increases.

Regarding taxonomic groups in PA areas, the number of moss species was higher in the lower and upper parts of the gradient, while at mid-elevation, liverworts had a more pronounced contribution. In RA areas, mosses were more abundant than liverworts along the entire gradient. The number of mosses was more or less constant, while liverworts showed a hump-shaped pattern. In DA areas, the number of moss species was higher in the upper part of the gradient, although no clear pattern is shown. Liverworts, however, showed a mid-elevation peak with higher species number at elevations corresponding to potential areas of laurel forests.

Life strategy patterns along the elevational gradient also showed strong differences among all three areas types. A stronger shift was found regarding colonists and perennials between PA and RA areas. In PA areas colonists were dominant in the lower and upper part of the gradient, while at mid-elevations, perennials (together with long-lived shuttles) became more species-rich. The opposite pattern was found in RA areas, in which perennials at mid-elevations decreased in favour of colonists, which showed a uniform pattern along the whole gradient. A closer look at these life forms revealed that the proportion of perennial species is remarkably less in DA and RA sites than PA areas; similarly, their elevational range is also reduced, while colonists follow the opposite pattern. Long-lived shuttles strongly

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decreased in potential areas of laurel forest between 200 m and 1200 m. In RA areas, annual species showed a hump-shaped pattern, but they were virtually absent in the other two areas. For DA areas there was again no clear pattern for life strategies, and colonists were the most common category along the entire transect.

Patterns of elevational ranges for colonists and perennials along the three areas.

Each dot represents the presence of a species within each 200 m band, each species gets as many dots as elevational steps between its upper- and lower recorded elevation. For clarity, dots were given transparency and a little jitter to depict local clustering. In this way, elevational ranges are depicted for colonists and perennials along the respective areas.

If we consider substrate affinities then differences in the elevational distribution of substrates need to be accounted for between the three types of sites. In PA areas, epiphytes were an important group, and most species occupying this substrate were present between 400 and 1200 m a.s.l. (corresponding to the well preserved laurel forest). In the same way, species growing on decaying wood were restricted to the mid-elevation areas, while terrestrials and rupicolous species were more homogeneously distributed along the elevational gradient. In PA areas species are able to colonize different substrates. On the contrary, this was not found for species in the RA and DA areas, indicating species are restricted to one substrate. Most important change was the complete absence of epiphytes in RA areas, in which bryophytes growing on soil, humus and rocks) were the most common group. In DA areas epiphytes were present in mid-elevation areas, although less widespread, while rupicolous and terrestrial species were dominant throughout the transect.

The first axis of a DCA ordination area showed a higher heterogeneity of the PA areas, indicating higher ß-diversity, which was also observed on the box-area graph. RA areas showed lower variability and thus lower ß-diversity. Separation of the three types of areas, although significant, is not very strong (r^2 = 0.09; $p<0.001$), however, vegetation belts are significantly and well separated (r^2 = 0.47; $p<0.001$). Higher species richness (SR) was associated with high herbaceous and tree cover. On the contrary, elevation and percentage of bare soil were related to lower species richness. Communities in laurel forest and shrub belts are well differentiated, whereas pine forest and subalpine belt communities are very similar. Elevation was related to axis 1, where high-elevation samples are located in the right side of the graph and lower elevation samples in the left side. The opposite pattern was found for species richness, showing that the highest number of species is found on areas at mid and low-elevations.

Ordination analysis (DCA) of sub-areas.

(a) The main figure panel shows ordination positions of each subplot with different symbols for each area. Separation of sub-areas is high, indicated by axis length, and both axes together have an explained variance of 58.2%. Arrows indicate the score load of subplot characteristics. The box-areas above the main panel show the distribution of sub-areas along first axis, again separated for areas. The smaller panels on the right side highlight (b) the assignment of sub-areas to vegetation belts (centre of distribution indicated by ellipses), (c) elevation (symbol size according to elevation), and (d) species richness (symbol size according to species richness).

Results obtained after a Indicator Species Analysis, showed differences in indicators species in each type of vegetation (elevational belt) for each area type. Important differences were observed on the elevational levels corresponding to the laurel forest potential areas. On PA areas, perennial species like *Isothecium myosuroides*, *Lejeunea mandonii*, *Marchesinia mackaii* or *Rhynchostegium megapolitanum*, were indicators for this type of vegetation (Table 3). On RA areas, however, indicator species were annual species (*Anthoceros caucasicus and Phaeoceros laevis*). No species was indicator of the laurel forest potential areas on DA areas.

Table 3
The indicator species analysis for vegetation belts considered and for each area (P: Preserved Areas, R: Roadside Areas, D: Disturbed Areas).

		Species	Moss / Liverwort	Life Strategy	Indicator value
Lowland vegetation potential areas					
	Area P	*Frullania ericoides*	L	L	0.5892
		Tortella inflexa	M	C	0.2168
	Area R	*Plagiochasma rupestre*	L	S	0.4567
		Leptophascum leptophyllum	M	C	0.3769
		Tortula muralis	M	C	0.3298
		Ptychostomum imbricatulum	M	C	0.2777
	Area D	*Tortella flavovirens*	M	C	0.5208
		Tortella tortuosa	M	C	0.3788
Laurel forest potential areas					
	Area P	*Lejeunea mandonii*	L	L	0.4969
		Marchesinia mackaii	L	P	0.3531
		Heteroscyphus denticulatus	L	P	0.3419
		Frullania tamarisci	L	L	0.3266
		Rhynchostegium megapolitanum	M	P	0.2804
		Chiloscyphus coadunatus	L	L	0.2667
		Metzgeria furcata	L	C	0.2652
		Isothecium myosuroides	M	P	0.2503
		Thamnobryum alopecurum	M	P	0.1905
	Area R	*Phaeoceros laevis*	A*	A	0.2619
		Anthoceros caucasicus.	A*	A	0.2089
Pine forest potential areas					
	Area P	*Hedwigia stellata*	M	L	0.2040
	Area R	*Didymodon fallax*	M	C	0.4903
		Ptychostomum pallescens	M	C	0.3457

		Anacolia webbii	M	L	0.1685
	Area D	*Orthotrichum rupestre*	M	C	0.3559
		Dryptodon trichophyllus	M	C	0.3058
Subalpine vegetation potential areas					
	Area P	*Grimmia montana*	M	C	0.4361
		Pohlia cruda	M	C	0.3626
		Schistidium flaccidum	M	C	0.2727
		Oxyrhynchium schleicheri	M	P	0.2613
	Area R	*Grimmia meridionalis*	M	C	0.4846
		Syntrichia montana	M	C	0.3730
		Polytrichum juniperinum	M	C	0.2127
	Area D	*Tortula inermis*	M	C	0.8000

Only species with significant indicator value are shown (p-value < 0.05). Life strategies are: P: Perennial; L: Long lived shuttle; S: Short lived shuttle; C: Colonist; A: Annual.

Discussion

Our results showed that the hump shaped pattern obtained along the well preserved elevational gradient disappears in the case of both types of disturbed sites. Total species number did not differ among studied sites, but species composition and life strategies showed a clear response to the disturbance of mature communities. Specifically, certain groups, strictly depending on undisturbed shady regimes in natural forests are the first to disappear, especially when the canopy is opened and microhabitats lose balanced humid and shady conditions. Changes in species composition after different land use changes depending on light exposure has been also observed for bryophytes and vascular plants. With these trends, colonist species are able to expand their distributional ranges as narrow-ranged species as *Exsertotheca intermedia*, *Homalothecium mandonii or Leptodon longisetus*, which are also macaronesian endemics, decreases.

Bryophytes in our study sites showed different patterns of species richness with elevation. On the sites where preserved vegetation was studied, bryophyte species richness showed a marked hump-shaped relationship with elevation, as has been also observed for bryophytes in other islands and also in continental settings[4]. However, this markedly unimodal pattern changes when considering sites affected by human activities. In this case we found a slightly hump-shaped pattern on sites that includes forest tracks and no clear pattern at all on the disturbed areas corresponding to silvicultural practice areas.

Major land-use changes have already occurred in the areas with highest biodiversity. In this case, our richest ecosystem, the laurel forest, is the most sensitive to both types of human impact analyzed. The dense evergreen canopy of the preserved laurel forest prevents most light from penetrating to the ground. This canopy cover provides optimal conditions for species sensitive to environmental changes and alterations of their habitat, so that they are specific and restricted to these forests. Those changes are not so strong at lower and upper elevations, where canopy cover is low even in preserved sites.

The loss of the hump-shaped pattern in DA and RA areas may be attributable to the dominance of cosmopolitan colonist species on those two treatments. Many of these species are more tolerant to disturbed open habitats, so they can colonize open or modified habitats in a wide elevational range. Colonist species are much more dependent on light exposure conditions than on temperature and humidity, and also of the presence of unstable habitats[7]. Thus, the removal of the forest canopy in both types of the altered sites favours colonists, which are generally more widespread. This in turn results in more homogeneous species assemblages along all the elevational belts. In contrast, perennials are very abundant on preserved sites, especially at mid-elevations, corresponding with well-preserved laurel forests. On disturbed and roadside sites, with the destruction of the forest, this optimal habitat for perennials disappears, and so do most of them, thus losing a great number of species at mid-elevations. In the altered sites, we can still find some perennial species as is the case of *Plasteurhynchium meridionale*, a characteristic epiphytic species in preserved sites that, however, can survive in rupicolous microhabitats in disturbed areas. This case shows complication in usage of bryophytes as bio-indicators after disturbance. There is a delay in their reaction to habitat change, because of their ability to survive in microhabitats after the destruction of their optimal habitat. Mosses are more abundant than liverworts on the two types of degraded sites along the whole gradient, while on preserved sites liverworts are dominant at mid-elevation contributing to the maximum of species richness at the middle of the transect. Liverworts are known to be a group that is highly dependent on moisture conditions[8]. With the increase of light exposure and decrease in humidity after the disturbances the number of liverworts is lower than in preserved areas.

One important result of this study is the fact that epiphytes are not present in RA areas, and drastically decrease on DA areas. Epiphytes in PA areas are mostly perennial pleurocarpic mosses and liverworts. The main factor driving this decrease of the number of epiphytic species in both disturbed areas is the opening of the canopy and removal of mature trees. Many of these epiphytic species exhibit a preference for a given phorophyte. The removal of the original forest is then unfavourable for epiphytes, even if new trees are planted or other host species are present.

Conclusions

The observed differences in distribution patterns along the gradients highlight the importance of taking into consideration human disturbances when assessing biodiversity patterns, as was pointed out by Nogués-Bravo et al. 2008[3]. General studies about biotic processes along elevational gradients might be underestimating human impacts, at least in historically Maredumilli. The study may conclude that human impact strongly changes the elevational pattern of diversity, and these changes differ depending on the ecological and taxonomical group considered.

In fact, our results show that even in a group with few endemic species, as the bryophytes, the loss of endemics is one of the most important consequences of historical disturbances. In this sense, endemic macaronesian endemic species like *Homalothecium mandonii*, *Leptodon longisetus*, or *Exsertotheca intermedia* are indicators of the losses on quality of the bryophyte community. Strong change in community composition after disturbance have been found in elevations corresponding with laurel forests, thus I suggest that the remains of these forests should be of high conservation priority, in order to preserve bryophyte species richness and the uniqueness of these areas.

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