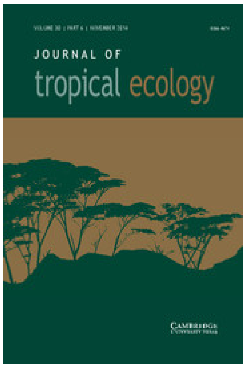

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Effects of patch size on liana diversity and distributions in the tropical montane evergreen forests of the Nilgiri Mountains, southern India

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Abstract: We investigate the effect of patch size on liana diversity and distribution in 19 patches of montane evergreen forest in the Nilgiri hills, Western Ghats, southern India. Additionally, we examined how liana species richness and community assemblage in both edge (within 10 m of the forest edge) and interior regions of forest patches respond to patch size, in order to infer the impact of forest expansion or reduction on the liana communities. A total of 1276 woody liana individuals of 15 species were identified, belonging to 10 genera and nine families. Total species richness of lianas was significantly positively related to forest-patch area, both when analysed for the entire patch, in addition to both core and edge regions when examined separately. Species richness of larger lianas also showed a significant positive relationship with increasing forest patch area. Community assemblage varied with respect to forest edge, with shade-dependent species only occurring in interior patch regions, shade-averse species in edge regions, and shade-tolerant species occurring throughout. Disturbance also played a role in determining the response of liana diversity to patch size, with heavily disturbed patches showing no relationship between patch size and diversity, whereas positive relationships exist in low to moderately disturbed patches. The most significant result is the change in liana community composition between small and larger fragments. Many species present in smaller patches are also present in edge zones of larger fragments. This suggests that lianas are important structural components of montane forest ecosystems, and their compositional patterns are possibly driven by succession. Moreover, this study reveals the importance of edge effect and patch size in influencing liana species richness and compositional patterns.

Key Words: community assemblage, disturbance, fragment size, shade tolerance, species-area relationships

INTRODUCTION

Many studies have used species-area relationships (SARs) to evaluate the effect of patch size on species richness in a variety of habitats, including natural forest patches (Estavillo *et al.* 2013, Gignac & Dale 2007, Mohandass & Davidar 2010). Studies suggest that lianas and trees show positive relationships between species richness and patch area (Liu *et al.* 2013, Morgan *et al.* 2011). However, the exact nature of the relationship between forest patch area and species richness of lianas has received much less attention.

Within forest patches, the forest edge and interior zones differ considerably in their localized environmental and disturbance conditions (Laurance & Yensen 1991, Laurance *et al.* 2002). Consequently the edge and interior zones are often populated by vegetation at different successional stages, different species assemblages and with different species richness (Harper *et al.* 2005, Ries *et al.* 2004). Though the effects of forest patch size and shape on tree and herbaceous diversity has been investigated in numerous studies around the world (Agra & Néeman 2012, Gonzalez *et al.* 2010, Wulf & Kolk 2014, Yineger *et al.* 2014, Zmihorski *et al.* 2010), liana communities have largely been neglected in these former studies, despite their known roles in ecosystem functioning in tropical forests (Laurance 2008, Schnitzer & Bongers 2002). Therefore, further research is required

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to understand the relationship between patch area and edge effects on liana diversity within forest patches.

Liana abundance may either increase or decrease as a direct and indirect consequence of various disturbance levels, depending on the exact nature and duration of the disturbance (Addo-Foudjour *et al.* 2013, Anbarashan & Parthasarathy 2013, Laurance *et al.* in press). In former studies disturbance was found to increase liana abundance (Mohandass *et al.* in press) and high disturbance decreased liana diversity (Addo-Fordjour *et al.* 2013).

In the Nilgiri Mountains, previous studies show that tree species richness within montane forest patches increases with forest patch area (Mohandass 2007, Mohandass & Davidar 2010), but the relationship between patch size and liana richness has yet to be investigated. This study aims to provide a comprehensive survey of how lianas respond to patch size, and to determine how edge and forest interior communities vary with fragment size. Many forest patches in and around the study areas have been disturbed through tea cultivation and exotic tree plantations (such as *Acacia dealbata* Link., *Eucalyptus globulus* Labill. and *Pinus patula* Schiede ex Schltdl. & Cham.), which have fragmented the formerly more extensive forest and degraded some forest regions. This landscape modification has created a landscape mosaic, which offers an ideal setting to explore how patch size affects the distribution and diversity of lianas under a number of conditions.

The aim of the study is to test the following hypotheses: (1) Total species richness of lianas and species richness in forest edge and interior zones will increase with increasing patch size (both in total and when examined separately); (2) The within-patch distribution and species richness of lianas as delineated by various eco-physiological guilds (shade tolerance, dispersal mode, climbing mechanism etc.) will respond to increasing patch size; (3) Disturbance influences liana species richness, especially as patch size increases.

METHODS

Study area

The study occurred in the Nilgiri Biosphere Reserve (NBR), which represents a component of UNESCO's Man and the Biosphere Programme (Puyravaud & Davidar 2013). The study was carried out in the tropical montane evergreen rain forest of Korakundah (11°13.840′N, 76°35.115′E) and Upper Bhavani Reserve Forest (*c.* 11°14′N, 76°33′E, Figure 1). We sampled 19 forest patches of various sizes in the Korakundah and Upper Bhavani Reserve Forests (Figure 1). The total area of all 19 patches was 39.2 ha, of which 11.5 ha was sampled.

The area ranges from 2200 to 2400 m asl, with varying slope. Climatic and topographic information for this region have been recorded during former studies (Mohandass 2007, Mohandass & Davidar 2010).

Montane forests within the Nilgiri region usually exist as small, discrete patches of vegetation, although they do occasionally occur as larger stands. Montane forests in the region are largely evergreen and generally stunted (10–20 m height) with a densely crowned canopy.

Sampling procedure

All sampling occurred between November 2002 and September 2004. The forest patches were selected randomly from across the study region, but were all separated by a minimum distance of 100 m, and fell into three distinct size classes. Selected forest patches were classed as large (> 5 ha), medium ($> 1 - < 5$ ha) or small (< 1 ha). Sampling of lianas was terminated where the species area curves reached their asymptote in the two large (GOLD2 and UPMD1) and three medium (ESHD, GDMD and KOMD) patches.

A quadrat of 30 × 30 m was placed randomly within each medium-large patch, and subdivided into 10 × 10-m subplots. In small patches all lianas were inventoried, and later sampling area was corrected to 30 m^2 by removing forest areas of under 30 m^2 from analysis. Though forest patches in the area showed a number of different shapes, there were approximately equal numbers of elongated and rounded patches, and we therefore did not differentiate between shapes for the purpose of analysis.

All individual lianas of ≥ 1 cm dbh were measured, tagged, identified to species level, and geo-referenced to the nearest metre. Diameter at breast height of each individual liana was measured at 1.3 m above ground level and each was tagged using sequentially numbered aluminium tags (Gerwing *et al.* 2006, Muthuramkumar & Parthasarathy 2000). Liana specimens were identified to species using various local and regional floras (Fyson 1932, Gamble & Fischer 1915–1935, Matthew 1999) and identification of each sample was confirmed by the Botanical Survey of India, Coimbatore. Voucher specimens were deposited at the Department of Ecology and Environmental Sciences, Herbarium section, Pondicherry University.

The effect of total forest patch area

After field sampling, the area of small forest patches were corrected to ensure an equal sample area size (30 m^2) and therefore a total of 10.98 ha sampled area was used for data analysis. After the sampled area correction a total of 4.41 ha was sampled from 13 small forest patches (> 1 ha), 4.32 ha from four medium forest patches

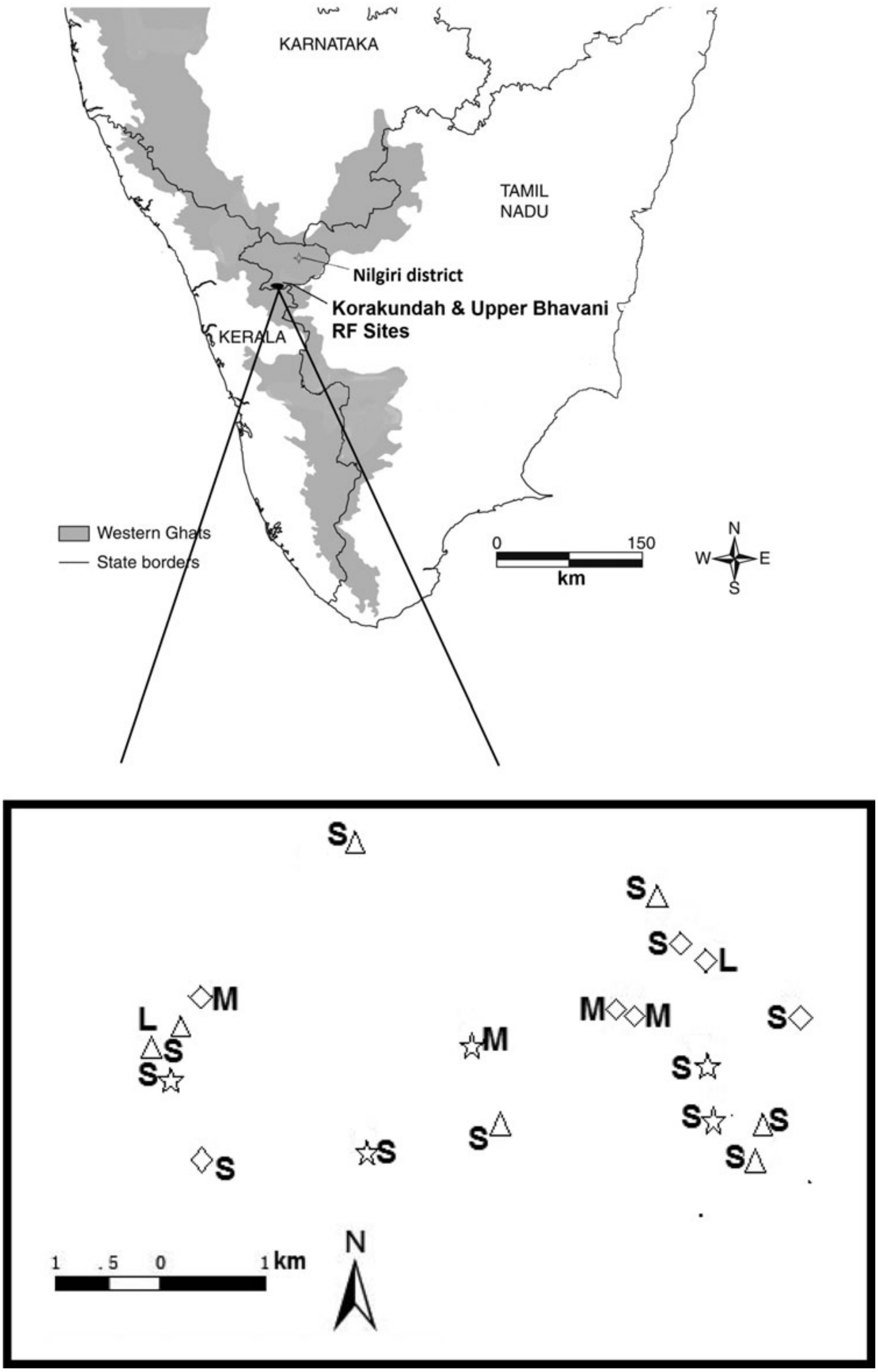

Figure 1. Map of the study area in Korakundah and Upper Bhavani regions of the Nilgiri Mountains, southern India. Marking points: L, large patches; M, medium patches; and S: small patches. Symbols indicate various disturbance levels: diamond, low disturbance; triangle, moderate disturbance; and star, highly disturbed.

(> 1 ha to < 5 ha) and 2.25 ha from two large forest patches (> 5 ha). The corrected sampled area was logarithmically transformed for each forest patch.

The effects of edge and forest interior in relation to patch size on liana species richness

Within each forest patch, the liana species richness in the forest edge zone and forest interior zone were recorded separately. The forest edge zone was defined as a 10-m-wide strip starting from the border of each forest patch and extending into the forest, and the forest interior zone as the remaining forest area. The community composition, and selected eco-physiological traits (species shade tolerance, dispersal modes and climbing mechanism) of species within forest edge and forest interiors were also recorded.

Shade tolerance and dispersal mode

Shade tolerance of liana species was divided into three categories, depending on their tolerance to different levels of available light: (a) shade-dependent: species which were only found in the forest interior and shaded conditions; (b) shade-tolerant: species found in both forest interior and edge zones; (c) shade-averse: species only found in edge zones and open conditions.

For data analysis, we used the frequency of occurrence of each liana species (with a minimum of 10 occurrences) found in each forest patch in a particular habitat, and compared abundance in the forest and edge zones to investigate habitat specificity.

The fruit dispersal method of each liana species was categorized as one of four types, depending on the dominant dispersal agent/agents. Mammal dispersal was normally by Nilgiri langur (*Trachypithecus johnii*) or dhole (*Cuon alpinus*); bird dispersal was from various frugivorous birds; explosive dispersers used an explosive dehiscent method, and wind-dispersed species relied on air-currents. No water-dispersed species were found within the study region.

Based on climbing guild descriptions in other studies (Muthuperumal & Parthasarathy 2009, Muthuramkumar & Parthasarathy 2000) we identified five commonly occurring climbing mechanisms for lianas in this study: hook climbers, root climbers, scramblers, tendril climbers and twiners. The frequency of each of these in both edge and interior zones were inventoried and relative abundance compared.

Effects of disturbance factors

During 1950s, the local government introduced exotic plantations around many of the forest patches across the Nilgiri region. These plantations included a considerable number of species, but *Acacia dealbata*, *Eucalyptus globulus* and *Pinus patula* plantations were among the most common. Between the 1970s and 1990s there was considerable logging of these exotic trees around the montane forests. Remaining forest fragments are now protected under nature reserve forest and protected area network agreements. However, severity and frequency of various forms of disturbance (both present and historical) varies between forest patches in the region. Therefore in the present study we categorized all forest patches within the study area into three distinct current disturbance categories: (1) Low disturbance (LD): past disturbances i.e. exotic tree logging occurred in the 1950s to 1990s, although there was little other human-induced disturbance pressures. Currently there is no longer any overt anthropogenic disturbance in patches defined as LD; (2) Moderate disturbance (MD): past disturbance effects greater than that of LD sites, minimal ongoing disturbance by humans (normally only firewood collection); (3) High disturbance (HD): higher levels of past disturbance than either LD or MD sites; high levels of disturbance continue to the present, with regular tree-cutting and other forms of disturbance. Highly disturbed forest patches are normally smaller and located near human habitation. Species richness of seven relatively undisturbed forest patches (LD), seven moderately disturbed forest patches (MD) and five highly disturbed forest patches (HD) were analysed.

Data analyses

As montane forest fragments represent isolated patches we tested whether liana species richness would increase linearly with area on a log-log scale as assumed by the theory of island biogeography (MacArthur & Wilson 1967). Species richness and patch size were log-transformed, and species richness (total and for large lianas separately) of various areas (edge and interior) normalized before further analysis using the arcsine transformation. We also used principal component analysis in Spatial Analysis for Macroecology (Rangel *et al.* 2010), followed by ANOSIM to determine if community composition varied significantly in patches of different sizes. Degree of similarity in liana community composition was analysed using ANOSIM in PAST (http://folk.uio.no/ohammer/past/) using the Bray–Curtis metric. Numbers of each species found in the forest edge and interior of different patch sizes (small, medium and large) were compared to examine if patches of different sizes had the same or different species communities in their edge and interior zones.

A Pearson correlation (r) was used to assess the relationship between patch size and species richness of lianas in forest edge and interior zones. The relationship between the number of species of different eco-physiological guilds (i.e. shade tolerance) in forest edge and interior zones in relation to patch size was analysed using a linear regression. An analysis of variance (ANOVA) was used to test whether mean species richness of lianas with different dispersal modes and climbing mechanisms showed any relationship with patch size. A t-test was then used to compare mean species richness of dispersal mode and climbing mechanism in forest edge and interior zones. The relationship between degree of disturbance, species richness and patch size was analysed using a linear regression analysis. All the statistical analyses were performed using the software SPSS® Statistics version. 17.0.

RESULTS

Liana sampling

Within the examined 10.98 ha of montane forest from 19 discrete forest patches (Appendix 1) we recorded a total of 1276 individual (≥ 1 cm dbh) woody lianas, belonging to 15 species, 11 genera and 10 families. The number of lianas in each forest patch ranged from 9–262 (Appendix 1). Species richness varied from 12 (in a large patch: 1.17 ha) to four species (in a small patch of 0.09 ha) (Appendix 1).

The effect of patch size on liana species richness

Both total species richness of lianas overall and of large lianas (log*n* species richness) increased significantly with increasing forest patch size ($R^2 = 0.43$, $N = 18$, $P = 0.002$; Figure 2a; $R^2 = 0.44$, $N = 11$, $P = 0.01$; Figure 2b). Species richness of lianas in both edge and interior zones also increased significantly with increasing forest patch size ($R^2 = 0.29$, $N = 15$, $P = 0.02$; Figure 2c; $R^2 = 0.395$, $N = 16$, $P = 0.004$; Figure 2d).

The effect of edge and forest interior in relation to patch size on liana species richness

Species richness of lianas in forest edge ($r = 0.68$, $P = 0.001$) and interior zones ($r = 0.74$, $P = 0.0003$) was significantly positively related to patch size. Species richness in the forest edge zones (4.89 ± 0.55) and interior zones (4.94 ± 0.33) do not differ significantly ($t = 0.07$, $df = 28$, $P = 0.94$). The species richness of lianas ranged from 2–11 in edge zones and 2–7 in interior zones in patches overall, therefore edge zones are frequently more diverse than interior zones.

Of the 15 liana species, eight were more frequent in the edge zone than in the interior zone. Of these, four species were found only in the edge zone, and were absent from the forest interior (*Jasminum brevilobum*, *Lonicera ligustrina*, *Decaloba leschenaultii* and *Rosa leschenaultiana*; Appendix 2). However, seven species were more common in the interior zone than the edge zone, and four species were equally abundant in the edge and interior zones (*Cissampelopsis walkeri*, *Elaeagnus conferta*, *Gardneria ovata*, *Toddalia asiatica*).

Shade tolerance

In the edge zone, shade-averse and shade-tolerant species showed significant positive responses to increasing patch area. In the forest-interior zone however, both shade-tolerant species and shade-dependent species showed no significant response to increasing patch area (Table 1). There were more shade-averse and shade-tolerant lianas found in the edge zone (12 species including seven shade-averse and five shade-tolerant) than shade-dependent species found in the interior zone (three species).

Dispersal mode

The species richness of lianas with different modes of dispersal was significantly related to patch size ($F_{3,75} = 13.5$, $P = 0.0001$). Lianas dispersed by mammals and birds were the most species rich in both the edge and interior patch zones, whilst lianas dispersed by the wind or an explosive mechanism were the least diverse (Figure 3a).

Climbing mechanisms

The climbing mechanism used by species of liana also varied significantly with increasing patch area ($F_{3,11} = 69.7$, $P = 0.0001$). Of the five types of climbing mechanism identified, hook climbers were significantly more abundant in the edge zone, whereas root climbers were more abundant in the forest interior ($t = -2.33$, $df = 36$, $P = 0.03$, $t = 3.67$, $df = 36$, $P = 0.001$; Figure 3b).

The effect of disturbance level and patch size on liana species richness

There was no significant difference in liana diversity between each category of habitat disturbance (LD: 7.14 ± 0.94 species; MD: 6.71 ± 0.60; HD: 7.20 ± 0.80: Table 2). However, species richness within areas with low to moderate levels of disturbance significantly increased

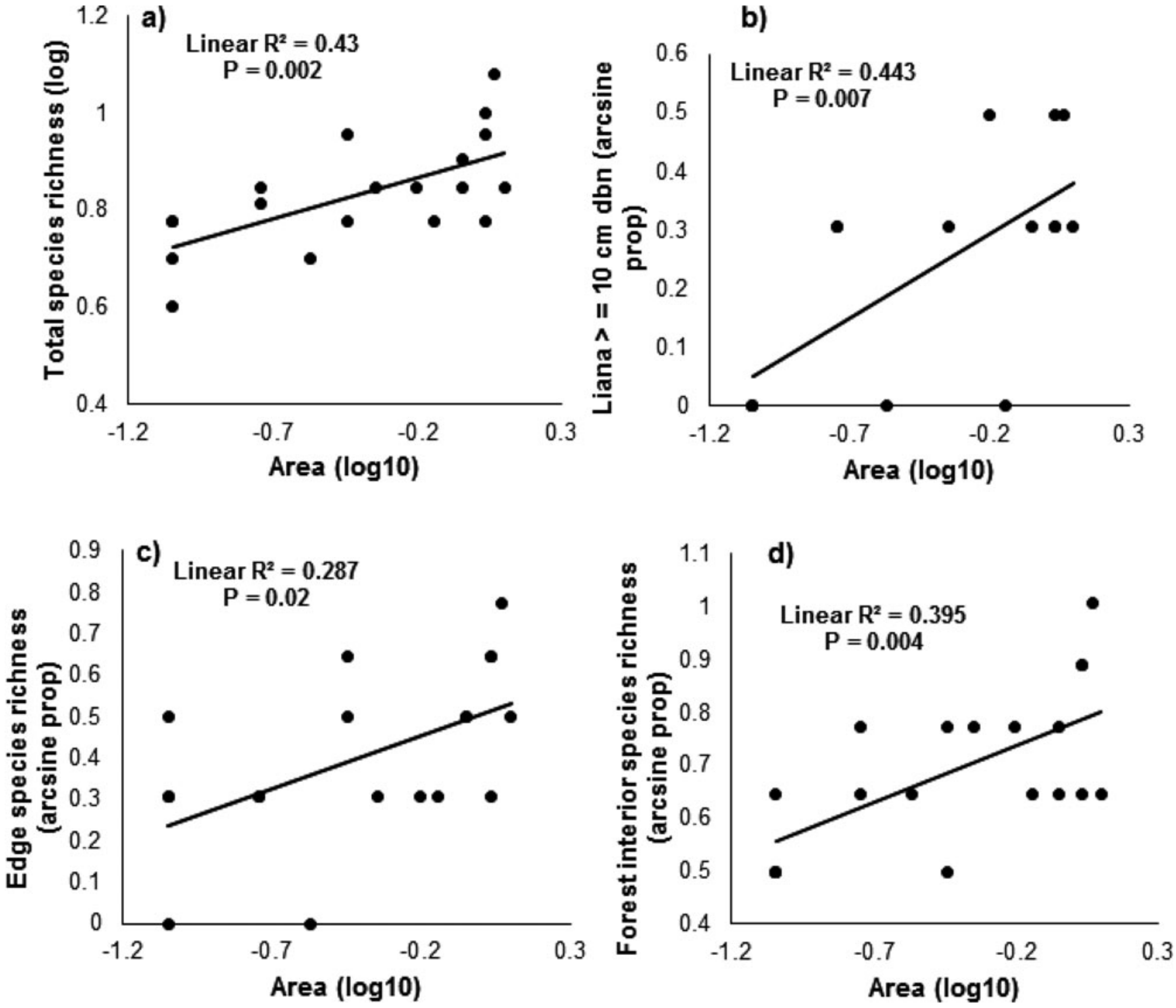

Figure 2. The relationship between total species richness of lianas (≥ 1 cm dbh) (a), larger lianas (≥10 cm dbh) (b), total species richness of lianas in forest edge-zones (c) and interior zones (d), and patch area (log transformed, in ha) were examined in the tropical montane evergreen forest patches of the Nilgiri Mountains, southern India. Significant regression lines are shown.

with increasing patch size, though no significant relationship was found in highly disturbed areas (R^2 = 0.40, P = 0.25) (Table 2).

Community compositional change in different-sized patches

Small patches had significantly different liana communities (in both edge and interior zones) from the communities in large and medium patches (forest interior: Bray–Curtis similarity R = 0.52, P = 0.001; Small patch: Medium patch, P = 0.003, small patch: large patch, P = 0.008, medium patch: large patch, P = 0.67) (forest edge zone: R = 0.47, P = 0.002; small patch: medium patch, P = 0.04, small patch: large patch, P = 0.01, medium patch: large patch P = 0.14). This indicates that a size threshold exists between small and medium patches below which a patch can no longer sustain the original community and therefore small patches hold different communities from larger-sized fragments.

DISCUSSION

Species-area relationships

Positive species-area relationships have previously been found in many fragmented forests globally (Gonzalez *et al.* 2010, Laurance 2008, Mohandass & Davidar 2010). In our study species richness overall, and in both forest edge and interior zones increased with increasing forest patch

Table 1. Regression statistics of the species-area relationship (with log area) for the examined liana species related to patch size, and the forest edge and interior zones in the tropical montane evergreen forest patches of the Nilgiri Mountains, southern India. Species are grouped according to the shade tolerance (N = 19 patches).

Variables	Parameter	Estimate	SE	t-test	P (> t)
Forest patch size					
Shade-dependent	Intercept	1.82	0.15	1.34	0.20
Adj $r^2 = 0.096$; $P = 0.20$	Slope	0.34	0.26		
Shade-averse and shade-tolerant	Intercept	− 1.11	0.29	2.56	0.015
Adj $r^2 = 0.278$; $P = 0.02$	Slope	0.88	0.34		
Edge zone					
Shade-averse and shade-tolerant	Intercept	− 0.76	0.23	2.58	0.016
Adj $r^2 = 0.281$; $P = 0.019$	Slope	0.59	0.16		
Forest interior zone					
Shade-dependent	Intercept	1.79	0.18	1.67	0.113
Adj $r^2 = 0.142$; $P = 0.112$	Slope	0.53	0.32		
Shade-tolerant	Intercept	− 0.85	0.25	1.91	0.069
Adj $r^2 = 0.177$; $P = 0.073$	Slope	0.83	0.43		

Table 2. Effect of disturbance on liana species richness related with (log10) forest patch area according to disturbance level: low disturbance (LD), moderate disturbance (MD) and highly disturbed (HD) patches in the tropical montane evergreen forest patches of the Nilgiri Mountains, southern India.

Variables	Parameter	Estimate	SE	t	P (>t)
Species richness (Log10)					
Low disturbance	Intercept	− 3.60	1.20	3.06	0.028
Adj $r^2 = 0.651$, $P = 0.028$	Slope	4.35	1.43		
Moderate disturbance	Intercept	− 5.35	1.42	3.53	0.031
Adj $r^2 = 0.713$, $P = 0.017$	Slope	6.10	1.73		
High disturbance	Intercept	− 2.15	1.38	1.40	0.256
Adj $r^2 = 0.396$, $P = 0.255$	Slope	2.27	1.62		

area, however there was no significant difference in the average diversity of the two zones. Similar trends have been identified in a number of forests in the western hemisphere (Echeverría *et al.* 2007, Gonzalez *et al.* 2010, Lawesson *et al.* 1998).

We found significant differences in the communities of liana present between small and larger patch sizes. Small forest patches differ from larger patch sizes due to changes in biotic and abiotic parameters resulting from forest fragmentation (Farmilo *et al.* 2013, Laurance *et al.* 2002). These alterations of biotic and abiotic parameters particularly impact the interior regions of small forest patches. These smaller forest patches show the greatest relative loss in interior forest area, whereas edge-zone area is more closely tied to perimeter length. Not only does the creation of a small forest patch dramatically shift the edge : core area ratio, but furthermore it may increase disturbance, vulnerability to invasion, microclimatic conditions, air currents, light availability and therefore plant species survival and turnover (MacDonald *et al.* 2014). Smaller forest patches are also at the greatest risk of drying out, and are therefore especially vulnerable to fire during the dry season (Caner *et al.* 2007). The loss of liana interior-specialist species in smaller forest patches may result at least in part from the high frequency of disturbance in addition to the decreased area of suitable forest in many of these smaller fragments (Caruso *et al.* 2011, Hill & Curan 2003, Laurance 2008). Other than species eco-physiology, minimum viable populations for some liana species or dependencies on interacting species such as pollinators which require larger fragments may also require larger fragments to maintain communities over time.

Dispersal agent and distributions

Most liana species were found to require vertebrate dispersal agents, both overall and in edge and interior areas. This may in part be due to the greater dispersal distance possible when a vertebrate disperser is used. Birds often drop seeds and defecate in the forest and are therefore good dispersal agents (Gonzalez *et al.* 2010), thus it is no surprise that 80% of liana species in the study region were dispersed by birds.

Liana species confined to forest-edge regions are likely to be in part the result of the deposition of liana propagules from outside sources, which may in many cases be from avian dispersers (Ewers & Didham 2006). Birds may therefore facilitate transfer of propagules between forest

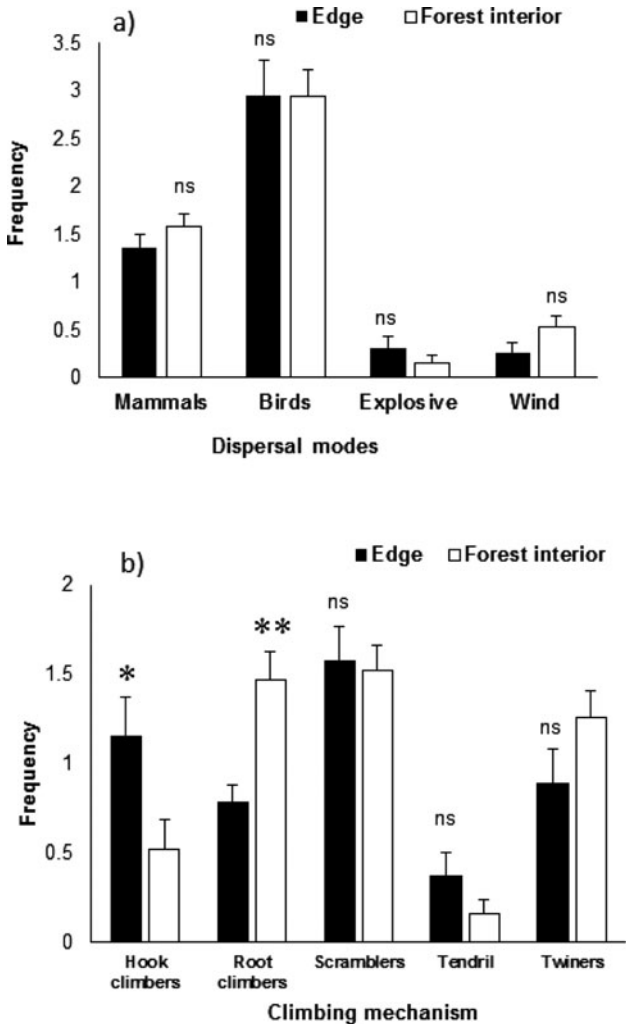

Figure 3. Differences in frequency (number of lianas) of different dispersal modes (a) and climbing mechanisms (b) in forest edge-zones (black bars) and the interior zones (white bars) were examined in the tropical montane evergreen forest patches of Nilgiri Mountains, southern India. Significance levels are $^{*}P < 0.05$; $^{**}P < 0.001$; and ns = not significant.

patches, and thus play a role in maintaining connectivity in a seemingly fragmented landscape, though this may be more evident in edge than interior zones.

Shade tolerance and distributions

Degree of shade tolerance appears to have a major role in determining the distribution of liana species in relation to distance from the forest edge. Shade-tolerant species, such as *Cissampelopsis walkeri*, *Elaeagnus conferta*, *Gardneria ovata* and *Toddalia asiatica* occurred at much higher frequencies in the forest edge zone, as did species classed as shade-averse. Shade-averse species (though less common than shade-tolerant species) such as *Decaloba leschenaultii*, *Jasminum brevilobum*, *Lonicera ligustrina*, *Parsonia alboflavescens* and *Rosa leschenaultiana* were common in edge zones, and occurred at lower frequencies in the forest interior (Laurance *et al.* 2001). These changing ratios of species in accordance with their light and shade-tolerance levels may have important consequences in forest succession, with the gradual replacement of initially shade averse, and then shade-tolerant species by shade-dependent species with increasing distance from the forest edge.

Diversity of shade-dependent species was lower than either that of shade-tolerant or shade-averse species, and this may in part relate to less access to avian dispersal agents. Smaller patches will suffer disproportionate loss of shade-dependent species due to the greater relative loss of the interior regions of the patch, as the edge zone area relates to the length of the perimeter rather than simply the volume. As patch area decreases, the area of forest core decreases more rapidly than that of forest edge, and therefore species dependent on shady conditions are likely to be rarer overall than those capable of tolerating brighter conditions. As a consequence, overall diversity of shade-dependent species is also likely to be lower.

Climbing mechanism and distributions

Four types of liana climbing mechanisms were common in both edge and interior zones (Figure 3b). At the early stages of liana colonization, species favoured show rapid growth and proliferation which is often determined by their climbing mechanism. In forest edges, tendril and hook climbers are more frequent. Root climbers and twiners were found at greater frequencies in forest interiors, and increased in abundance and diversity with increasing area. Some scramblers (e.g. *Elaeagnus conferta*) grew well in both edge and interior zones. However other guilds, such as hook climbers, are more abundant at patch edges, and are sensitive to various disturbances.

Disturbance

Lianas show different assemblages in forests with differing degrees of disturbance, depending on the sensitivity of each species and type of disturbance (Rice *et al.* 2004, Schnitzer & Bongers 2011). Disturbance levels in the study patches were relatively low impact, and caused by the harvesting of plant parts by local people for firewood and other resource harvesting. Human encroachment into montane forest patches (i.e. road and path development) influences liana success by changing light levels and microclimates of areas. The removal of larger trees for firewood collection or for house construction purposes forms larger gaps in the middle of the forests, and thus simulates natural light gaps from tree fall, and initiates natural successional processes.

Liana species richness increased in the low-disturbance patches and moderate-disturbance patches in response to increasing patch area, but did not increase with increasing forest area in the highly disturbed patches (Table 2). Therefore high disturbance and over-usage of montane forests may negatively affect liana species establishment and growth, and therefore may hinder succession.

CONCLUSIONS

We demonstrate that liana species richness of montane forests in the Nilgiri Mountains increases with forest patch size. Liana prevalence and the existence of different species at forest edge zones suggests they play a possible role in forest expansion and forest succession, as has been found in a previous study on trees in the Western Ghats (Mohandass & Davidar 2010, Puyravaud *et al.* 2003). Overall, to maintain diversity and aid natural successional processes, the protection of both large and small forest patches is necessary, and additionally the minimization of disturbance in their outer forest margin. In conclusion, lianas play a key ecological role in montane forest ecosystems, however further experimental study is needed to fully understand their ecological role in the processes of patch size expansion and plant community succession.

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Appendix 1. Site code, corrected sampled area (ha), total patch area (ha), species richness of lianas, species richness in edge zone, species richness in forest interior zone, number of occurrence of lianas in each site and the disturbance regime of the studied 19 montane forest patches in the Korakundah and Upper Bhavani Reserve forest, Nilgiri Mountains, southern India.

Site code	Corrected area (ha) sampled	Total patch area (ha)	No. of plots (30 × 30 m)	Species richness	Species richness in edge zone	Species richness in forest interior zone	Number of lianas occurring in each site	Disturbance status
CALD	0.09	0.14	1	6	2	4	13	Low disturbance
DOHD	0.27	0.3	3	5	1	4	10	High disturbance
EALD	0.9	0.9	10	8	3	5	26	Low disturbance
ESHD	1.08	3	12	9	4	6	100	High disturbance
FOLD	1.26	1.26	14	7	3	4	76	Low disturbance
GDMD	0.18	0.18	2	7	2	4	57	Moderate disturbance
GDLD1	1.08	4	12	6	2	5	82	Low disturbance
GOLD2	1.17	15	13	12	5	7	149	Low disturbance
KOMD	0.09	0.1	1	7	3	4	14	Moderate disturbance
KOLD	0.9	2	10	7	3	3	103	Low disturbance
MAHD	0.45	0.5	5	7	2	5	27	High disturbance
NAMD	0.72	0.82	8	6	2	4	94	Moderate disturbance
PYHD1	0.36	0.4	4	9	4	5	30	High disturbance
PYMD	0.09	0.12	1	5	2	3	28	Moderate disturbance
SIHD	0.36	0.4	4	6	3	3	20	High disturbance
TUMD	0.63	0.72	7	7	2	5	129	Moderate disturbance
UPMD1	1.08	9	12	10	4	6	262	Moderate disturbance
UPMD2	0.18	0.24	2	6	2	4	47	Moderate disturbance
UPLD	0.09	0.09	1	4	1	3	9	Low disturbance

Appendix 2. Frequency of the 15 liana species in forest edge and forest interior zones, including their shade tolerance, dispersal modes and climbing mechanism in the examined tropical montane forest patches of the Nilgiri Mountains, southern India.

			Frequency in montane forest patch zones			
Species	Family	Shade tolerance	Forest edge	Forest interior	Dispersal mode	Climbing mechanism
Cissampelopsis walkeri (Arn.) C.Jeffrey & Y.L.Chen	Compositae	Shade-tolerant	15	37	Wind	Twiners
Elaeagnus conferta Roxb.	Elaeagnaceae	Shade-tolerant	95	168	Mammals	Scrambler
Gardneria ovata Wall.	Loganiaceae	Shade-tolerant	126	363	Birds	Twiners
Jasminum brevilobum DC.	Oleaceae	Shade-averse	2	0	Birds	Twiners
Lonicera ligustrina Wall.	Caprifoliaceae	Shade-averse	12	0	Birds	Scrambler
Parsonsia alboflavescens (Dennst.) Mabb.	Apocynaceae	Shade-tolerant	10	3	Explosive	Tendril
Decaloba leschenaultii (DC.) M.Roem.	Passifloraceae	Shade-averse	1	0	Birds	Tendril
Piper mullesua Buch.-Ham. ex D. Don	Piperaceae	Shade-dependent	2	28	Birds	Root climbers
Piper schmidtii Hook.f.	Piperaceae	Shade-dependent	5	40	Birds	Root climbers
Piper trichostachyon (Miq.) C. DC.	Piperaceae	Shade-dependent	50	164	Birds	Root climbers
Rosa leschenaultiana (Redout, & Thory) Wight & Arn.	Rosaceae	Shade-averse	2	0	Explosive	Scrambler
Rubus ellipticus Sm.	Rosaceae	Shade-averse	17	12	Birds	Hook climber
Rubus racemosus Genev.	Rosaceae	Shade-averse	4	2	Birds	Hook climber
Rubus rugosus Smith var. *thwaitesii* Focke.	Rosaceae	Shade-averse	16	3	Birds	Hook climber
Toddalia asiatica (L.) Lam.	Rutaceae	Shade-tolerant	23	76	Mammals	Scrambler