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Influence of disturbance regime on liana species composition, density and basal area in the tropical montane evergreen forests (sholas) of the Western Ghats, India

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Abstract: Lianas have been shown to respond to natural and anthropogenic disturbances in many tropical forests worldwide. However, little is known about how disturbance affects liana composition, density and basal area in the tropical montane evergreen forests (sholas) of the Western Ghats, India. We used a large dataset from permanent monitoring plots across four sites to examine whether liana composition, stem density and basal area were influenced by moderate level disturbance. Vegetation data were collected from four sampling sites that cover 13.58 ha in the southern montane evergreen forests (sholas) of the Western Ghats. All liana individuals with diameter at breast height (dbh) ≥1 cm were tagged, counted, mapped and identified to species level. A total of 1658 individuals belonging to 18 families, 24 genera and 33 species were recorded. Species richness did not differ significantly between disturbed and undisturbed sholas in Amaggal (AG), Kukkal (KK) and Upper Bhavani (UB) sites, but it differed significantly in Korakundah (KR) site (P < 0.05). Species composition of lianas responded to disturbance at lower percentage (9 %) among four sites. Density of lianas was significantly higher in disturbed than in undisturbed sholas across all four sites. Mean densities were 10.19 ± 6.10 and 5.69 ± 3.35 in disturbed and undisturbed sholas, respectively, while the proportions of stem densities were 66 % and 34 % in disturbed and undisturbed sholas, respectively. Surprisingly, basal area showed contrasting trends in disturbed and undisturbed sholas. In KR and UB sites, mean basal area was significantly higher in undisturbed than in disturbed sholas, while in AG and KK sites, mean basal area was significantly higher in disturbed than undisturbed sholas. The findings of the study indicate that moderate level human disturbance influenced liana composition, abundance and basal area within the studied region.

Resumen: Se ha mostrado que las lianas responden a los disturbios naturales y antropogénicos en muchos bosques tropicales de todo el mundo. Sin embargo, poco se sabe

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acerca de cómo eldisturbio afecta la composición, la densidad y el área basal de las lianas en los bosques perennifolios tropicales montanos (sholas) de los Ghats Occidentales, India. Usamos una base de datos grande de parcelas de monitoreo permanente en cuatro sitios para examinar si la composición, la densidad de tallos y el área basal de las lianas estaban influenciados por un disturbio de nivel moderado. Se obtuvieron datos de vegetación de cuatro sitios de muestreo que cubren 13.58 ha en los bosques montanos perennifolios (sholas) sureños de los Ghats Occidentales. Todos los individuos de lianas con diámetro a la altura del pecho (DAP) ≥ 1 cm fueron marcados, contados, mapeados e identificados a nivel de especie. Se registró un total de 1658 individuos pertenecientes a 18 familias, 24 géneros y 33 especies. La riqueza de especies no difirió significativamente entre sholas perturbados y no perturbados en los sitios Amaggal (AG), Kukkal (KK) y Upper Bhavani (UB), pero sí difirió en el sitio Korakundah (KR). La composición de especies de lianas respondió aldisturbio en menor proporción (9 %) entre los cuatro sitios. La densidad de lianas fue significativamente mayor en sholasperturbados que en los inalteradas los cuatro sitios. Las densidades medias fueron 5.69 ± 6.10 y 10.19 ± 3.35 en bancos perturbados y no perturbados, respectivamente, mientras que las proporciones de la densidad de tallos fueron de 66 % y 34 % en sholas perturbados y no perturbados, respectivamente. Sorprendentemente, el área basal mostró tendencias contrastantesen sholas perturbados y no perturbados. En los sitios KR y UB, el área basal promedio fue significativamente mayor en sholas no perturbados que en los perturbados, mientras que en los sitios AG y KK el área basal media fue significativamente mayor en los sholasperturbados que en los inalteradas. Los hallazgos del estudio indican que el disturbio humano de nivel moderado afecta la composición, la abundancia y el área basal de las lianas en la región de estudio.

Resumo: Foi mostrado que as lianas respondemàs perturbações naturais e antrópicas em muitas florestas tropicais de todo o mundo. No entanto, pouco se sabe sobre como a perturbação afeta a composição das lianas, a densidade e a área basal nas florestas tropicais sempre verdes de altitude (sholas) dos Gates Ocidentais, na Índia. Usámos um grande conjunto de dados de parcelas permanentes de controlo em quatro locais para examinar se a composição das lianas, a densidade de caules e a área basal foram influenciados por um nível moderadode perturbação. Os dados da vegetação foram coletados em quatro estações de amostragem que cobriam 13,58 ha nas florestas montanas sempre verdes (sholas) do sul dos Gates Ocidentais. Todas as lianas com diâmetro à altura do peito (DBH) ≥ 1 cm foram marcadas, contadas, mapeadas e identificadas ao nível da espécie. No seu conjuntoforam registados 1.658 indivíduos pertencentes a 18 famílias, 24 géneros e 33 espécies. A riqueza de espécies não diferiu significativamente entre sholasdisturbadas e inalteradas em Amaggal (AG), Kukkal (KK) e na zona de topo da estação deBhavani (UB), mas diferiram significativamente na estação de Korakundah (KR). A composição de espécies de lianas respondeu à perturbação em menor proporção (9 %) entre as quatro estações de amostragem. Em todos as quatro estações, a densidade das lianas foi significativamente maior nas estações perturbadas do que em sholas inalteradas. As densidades médias foram de 10,19 ± 6,10 e 5,69 ± 3,35 em sholas disturbadas e inalteradas, respectivamente, enquanto as proporções das densidades de troncosforam de 66 % e 34 % em sholasperturbadas e inalteradas, respectivamente. Surpreendentemente, a área basal mostrou tendências contrastantes em sholasperturbadas e não perturbadas. Nas estações KR e UB, a média da área basal foi significativamente maior nas sholasnão disturbadas do que nas disturbadas, enquanto que nas estações AG e KK, a média da área basal foi significativamente maior nas estações perturbados do que nas sholas não perturbadas. As conclusões do estudo indicam que na região estudada a perturbação humana de nível moderado influenciou a composição das lianas, a abundância e a área basal.

Key words: Forest management, human forest destruction, liana diversity, Nilgiri hills, Palni hills.

Introduction

Lianas constitute an important structural component of tropical forests and their biomass has increased during the past several decades (Addo-Fordjour *et al.* 2012; Anbarashan & Parthasarathy 2013; Schnitzer & Bongers 2002; Schnitzer & Bongers 2011). Recent studies indicate that liana abundance and distribution are determined by various abiotic factors such as climate, topography and disturbance (DeWalt *et al.* 2010; Gentry 1991; Hegarty & Caballe 1991; Schnitzer 2005; Schnitzer & Bongers 2011). However, little is known about the effects of disturbance on liana abundance and distribution at regional scales, especially in montane tropical forests of the Western Ghats. Moreover, liana abundance, diversity and biomass are higher in disturbed areas due to increasing forest disturbances by humans for various reasons (Addo-Fordjour *et al.* 2013a; Homeier *et al.* 2010; Putz 1984; Rice *et al.* 2004; Schnizter & Bongers 2011). Various anthropogenic disturbances can strongly affect plant communities (Sultana *et al.* 2014) and play an important role in influencing liana abundance, diversity, and productivity (Laurance *et al.* in press). Consequently, we tested whether liana stem density and basal area increased with disturbance in montane forests.

Montane evergreen rainforests of the Western Ghats, locally known as 'sholas' (hereafter referred to as sholas) are confined to valleys and hollow depressions and form many discrete patches at high elevations (1500 - 2400 m). Plant inventories have been conducted in these mountains across several sites in different years (Davidar *et al.* 2007a; Mohandass & Davidar 2009; Mohandass & Davidar 2010). Sholas naturally represent a fragmented forest ecosystem of tropical origin with moderate frost and fire tolerance. The effects of shola size and habitat distribution on species composition have been previously studied (Mohandass 2007; Mohandass & Davidar 2010). However, there is no ecological information on lianas in the area, especially information on the effects of human disturbance on liana composition, abundance and basal area. In this study, we aim to examine the influence of disturbance on liana species composition, stem density and basal area in the higher elevation montane forests of the Western Ghats.

Materials and methods

Study area

The study was carried out in two mountain hills namely Nilgiri (11° 13. 840' N and 76° 35.115' E) and Palni hills (10° 16' N and 77° 22' E) in the Western Ghats. We sampled three regions (Amaggal Reserve forest (AG), Korakundah (KR) and Upper Bhavani (UB) Reserve forest) in Nilgiri hills and one region (Kukkal ReserveForest) in Palni hills (Fig.1). The elevation ranged between 2200 and 2400 m a.s.l. The geological infor-mation of these areas is found in previous studies (Davidar *et al.* 2007a; Mohandass & Davidar 2009; Mohandass & Davidar 2010). The mean annual rainfall (1996 - 2007) at Korakundah Tea Estate ranged from 1368 to 3245 mm in Nilgiri hills. The southwest (SW) monsoon occurs from June to September and the northeast (NE) monsoon occurs from October to November. The mean annual temperature (1996 - 2007) ranged between 0 °C and 23 °C. The dry season lasts from December to March and frost occurs from December to January. In Palni hills, rainfall is received from both the SW and NE monsoon winds. Mean annual rainfall for Kodaikanal over a four-year period (2001-2004) was 1690 mm (Davidar *et al.* 2007a). In all studied regions, patches of sholas have been disturbed for about five decades by local people. Some of these patches are exploited for firewood, timber, shifting cultivation and other uses, while the majority of patches are surrounded by exotic (e.g. *Acacia dealbata* Link., *Eucalyptus globulus* Labill., and *Pinus patula* Schiede ex Schltdl. & Cham.) plantations.

Sampling and data collection

We selected twenty one shola patches with different sizes from four sites including three from Nilgiri hills and one from Palni hills. We inventoried tree and liana species during 2002-2004 in Korakundah (KR; 7.43 ha), Upper Bhavani (UB; 4.07 ha), Kukkal (KK; 1.08 ha), and during 2007 in Amaggal Reserve forest (AG; 1 ha). Prior to sampling, we assessed the disturbance level in each shola and corresponding plots. In each shola, we randomly set up a 30 x 30 m plot and subdivided it into nine 10 x 10 m subplots in three sites (KK, KR, UB) while ten 10 × 100 m transects were laid down randomly in AG site (sampled size one ha; total shola size about 30 ha). In all four

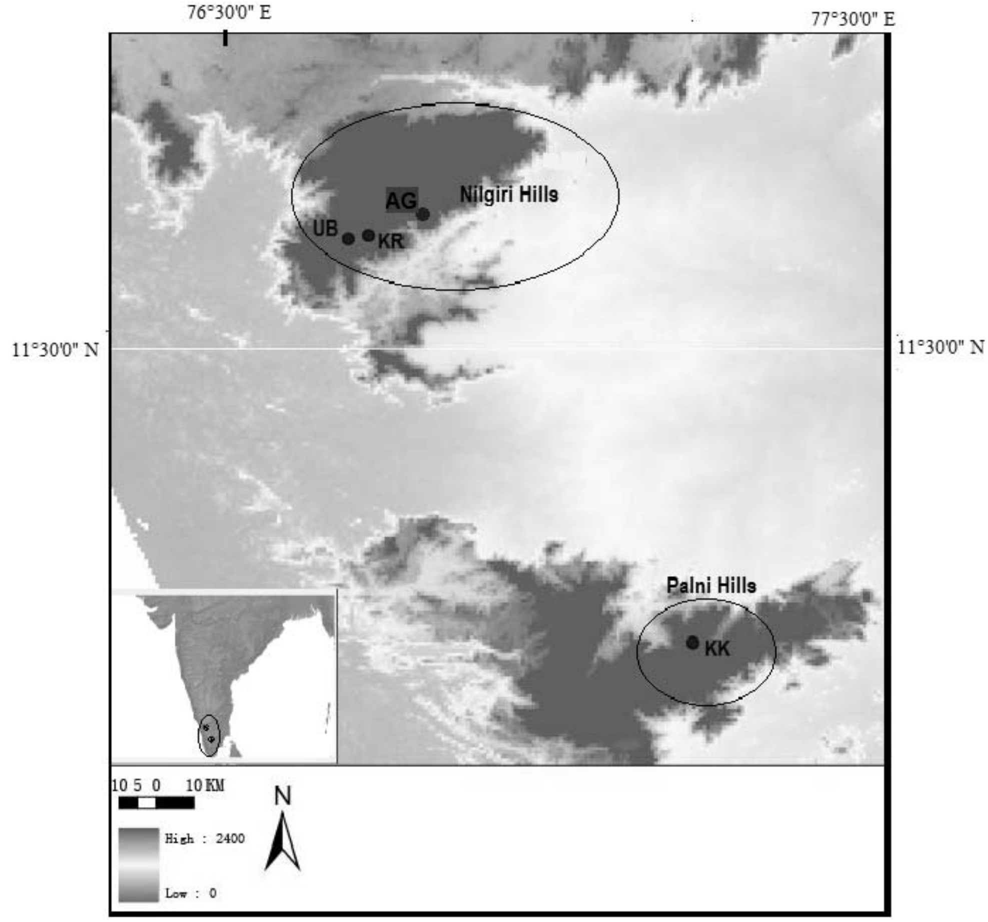

Fig. 1. Map of the study location showing four study sites; Amaggal (AG), Kukkal (KK) and Korakundah (KR), Upper Bhavani (UB) Reserve forest of Nilgiri and Palni hills, Western Ghats, India.

sampling sites, the sampling effort was terminated when the species area curves reached an asymptote (see Davidar *et al.* 2007a; Mohandass & Davidar 2009). The total sampled area was 13.58 ha from four study sites. In each subplot, lianas (woody climbers) with diameter at breast height (dbh) $\geq$ 1 cm were tagged, counted, mapped, and identified to species level. The diameter of each liana was measured at 1.3 m above ground level with a measuring/ diameter tape. Voucher specimens of all sampled lianas were collected and later identified to species level (Fyson 1932; Matthew 1999). The taxonomic ranks (species, genus and family) were then revised following the APG III Classification (Bremer *et al.* 2009).

Assessment of disturbed and undisturbed sholas

In this study, disturbed sholas moderately were defined as those highly exploited by humans for firewood collection and other purposes (Table 1). Most of the disturbed sholas were found inside the private tea estate (KR), and few disturbed sholas were found near the human habitation and water reservoir. Undisturbed sholas were defined as those farther away from human inhabited areas and surrounded by exotic plantations for at least six decades (see details in Table 1).

Data analyses

Mean species richness was calculated from all quadrats of disturbed and undisturbed plots within the sites. In each site, mean liana stem density (number of individuals ha^{-1}) and mean basal area (m^2 ha^{-1}) were calculated from total number of individuals of each species in disturbed and undisturbed sholas. Basal area was calculated using the formula: $(Dbh)^2 *(\pi/4)$ (Adekunle *et al.* 2013; Mohandass & Davidar 2009). Fisher's alpha (a measure of diversity) was used to assess species

Table 1. Name of site (abbreviation), disturbance classification, disturbance factors and area of shola sites (ha) sampled in the Nilgiri and Palni hills, Western Ghats, India.

Site name	Disturbed factors	Undisturbed factors	Area of sampled disturbed sholas (ha)	Area of sampled undisturbed sholas (ha)
Amaggal (AG)	Frequent access by humans for various purpose; firewood collection, nearby human habitation, surrounded exotic tree plantation and tea plantation	Infrequent access by humans; not surrounded by exotic tree plantation and tea plantation	0.4	0.6
Kukkal (KK)	Frequent access by humans; edge shrinkage due to agricultural expansion	Infrequent access by human and not surrounded by exotic tree plantation and agricultural practices	0.45	0.63
Korakundah (KR)	Frequent access by humans; fire wood collection and nearby human habitation , forest fragments, surrounded by tea plantation	Infrequent access by humans; not firewood collection, however, many of the shola patches are surrounded by exotic tree plantation	2.39	5.04
Upper Bhavani (UB)	Frequent access by humans; fire wood collection and nearby human habitation, forest fragments, patches that are found nearby dam constructed in 1950s.	Infrequent access by humans; not firewood collection, however, none of the shola patches are not surrounded by exotic tree plantation	1.72	2.35

Table 2. Summary statistics, including total number of taxa (species, genera and families), number of individuals, stem density (ha^{-1}), basal area (m^2 ha^{-1}) and Fisher's alpha per site for all lians with diameter at breast height (dbh) $\geq$ 1 cm recorded in 21 shola es in the Nilgiri and Palni hills, Western Ghats, India.

Variables	Amaggal (AG)	Kukkal (KK)	Korakundah (KR)	Upper Bhavani (UB)
No. of species	23	17	14	10
No. of genera	18	13	10	7
No. of family	14	11	9	7
Sampled area (ha)	1	1.08	7.43	4.07
No. of individuals	202	154	692	610
Stem density (ha$^{-1)}$	202	143	93	150
Basal area (m^2 ha$^{-1)}$	1.21	0.72	2.7	2.33
Fisher's alpha	6.68	4.88	2.49	1.70

diversity since it is fairly independent of plot size (Condit *et al.* 1998; Fisher *et al.* 1943; Mohandass & Davidar 2010). To quantify species turnover, we calculated Sorensen similarity index value between sites (Davidar *et al.* 2007b; Magurran 2004; Sultana *et al.* 2014). A distance matrix of group average clustering (UPGMA) was used to generate the dendrogram in the software R version 3.01 (R Development Core Team 2013). The species richness, density and basal area of lianas were computed and a two-sample test (F-test) was performed to find significant differences in these parameters between disturbed and un-disturbed sholas. Moreover, the percentage of stem density

Table 3. Similarity in species composition between pairs of sites calculated using the Sorensen similarity index across four sites.

Site name	Sorensen similarity index value
AG-KK	0.20
AG-KR	0.28
AG-UB	0.21
KK-KR	0.30
KK-UB	0.20
KR-UB	0.74

and basal area (m^2 ha^{-1}) of each species were calculated from a pooled dataset of all four sites and tested by chi-square for comparison between disturbed and undisturbed sholas. Apart from Sorensen similarity index, all other statistical analyses were performed using MedCalc Version 12.2.1.0 (MedCalc statistical software 2012).

Results

Floristic composition, density and basal area

A total of 1658 liana stems (≥ 1 cm dbh) belonging to 33 species, 24 genera and 18 families were identified across four sites including disturbed and undisturbed sholas covering an area of ~ 13.58 ha (Appendix 1). The Amaggal site had 23 species (69.7 % of total), followed by the Kukkal site (17 species; 51.5 %), the Korakundah site (14 species; 42.4 % of total) and the Upper Bhavani site 10 species (30.3 %) of the total species, respectively (Table 2). The mean stem density across the four sampling sites was about 147 individuals ha^{-1} while the stem density per site ranged from about 93 to 202 individuals ha^{-1} (Table 2). Basal area ranged from 0.70 to 2.70 m^2 ha^{-1} and Fisher's alpha ranged from 1.70 to 6.68 (Table 2). The total density of lianas in all plots combined (13.58 ha) was highest for *Gardneria ovata* Wall. (31.4 %; 521 total individuals). Other dominant species included *Elaeagnus conferta* Roxb. (18 %*), Pipertri-chostchyon* (Miq.) C. DC. (14 %), *Toddalia asiatica* (L.) Lam. (7 %), *Cissamelopsis walkeri* (Arn.) C. Jeffrey & Y. L. Chen (4 %), *Tetrastigma leucostaphylum* (Dennst.) Balakrishnan. (3 %), *Ventilago maderaspatana* Gaertn. (3 %) and *Piper mullesua* Buch-Ham. ex D. Don (3 %) which together accounted for 85 % of the overall density (Appendix 1). Four genera (*Piper, Rubus, Derris* and *Celastrus*) were dominant and 6 genera were rare (Appendix 1; with species having only a single individual each). Piperaceae and Rosaceae were the most dominant families. Only three species (9 %) namely *Gardneria ovata, Elaeagnus conferta* and *Toddalia asiatica* were shared among the four study sites. Sorensen similarity indices showed that the study sites had similar species composition and low species turnover rates (0.19 - 0.30) except between KR and UB (0.74) (Table 3; Fig.2).

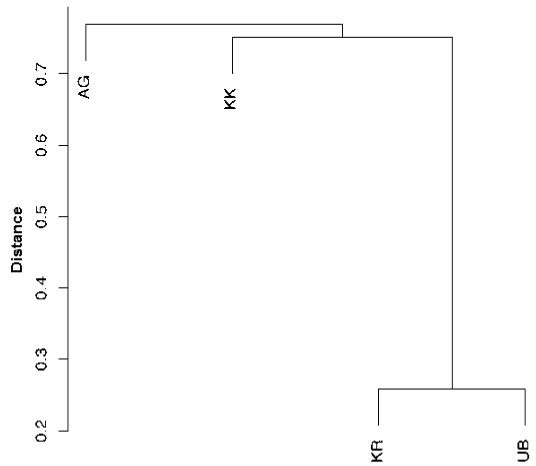

Fig. 2. Dendrogram showing the distance of species similarity among four shola sites in the tropical montane evergreen forest (sholas) of the Western Ghats, India calculated using Sorensen similarity index.

Effect of disturbance on liana composition

Species richness did not differ significantly between disturbed and undisturbed sholas in AG, KK and UB sites ($P > 0.05$), but differed significantly ($P < 0.05$) in KR site. *Elaeagnus conferta*, and *Gardneria ovata* were predominantly found in disturbed sholas. In the AG site, it was apparent that *Connarus wightii* Hook.f., *Rhamnus wightii* Wight & Arn., and *Tetrastigma leucostaphylum* increased in density due to disturbance. In the KR and UB sites, *Elaeagnus conferta*, *Gardneria ovata*, and *Piper trichostychon* highly responded to disturbance, while in the KK site, *Ventilago maderaspatana* density highly increased due to disturbance (Appendix Table 1). Species composition was similar between disturbed and undisturbed plots within each shola site (Fig. 3).

Effect of disturbance on liana density and basal area

In all four sites, the mean density of lianas was significantly higher in disturbed than undisturbed

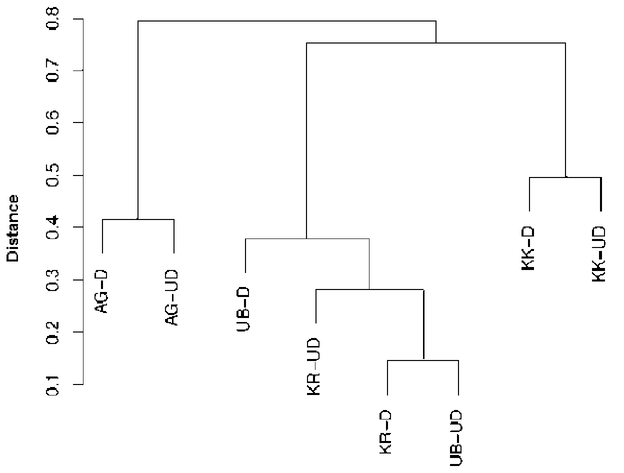

Fig. 3. Dendrogram showing the distance of species similarity between disturbed and undisturbed sites calculated using Sorensen similarity index.

sholas (Table 2) suggesting that disturbance results in high density of lianas in high-elevation evergreen montane forests. Mean liana density was 10.06 ± 6.20 and 5.46 ± 3.58 in disturbed and undisturbed sholas, respectively, while the percentage of stem density was 66 % and 34 % in disturbed and undisturbed sholas, respectively. Surprisingly, basal area showed contrasting trends in disturbed and undisturbed sholas. In the Korakundah (KR) and Upper Bhavani (UB) sites, mean basal area was significantly higher in undisturbed than in disturbed sholas, while in the Amaggal (AG) and Kukkal (KK) sites, mean basal area was significantly higher in disturbed than in undisturbed sholas. This indicates that moderate level disturbance (Addo-Fordjour *et al.* 2013a) arising from human interference influences density and basal area of lianas.

The percentage of density was significantly higher in disturbed than undisturbed sholas (significant level ranged from $P < 0.05$ to $P < 0.0001$; Table 5) in all four sites, whereas basal area was significantly ($P < 0.0001$) lower in disturbed sholas of KR and UB sites ($P < 0.0001$; Table 5). This also indicates that bigger lianas are prevalent in undisturbed sholas, whereas smaller lianas are commonly found in disturbed sholas.

Discussion

Our results suggest that liana species richness differed across the four sites. However, species richness was higher in AG and KK sites compared with KR and UB sites. This indicates that medium-elevation sholas (> 1800 - 2005 m) have high number of lianas than high-elevation sholas (> 2200 m). Our findings suggest that lianas are more diverse in medium elevation forests than in high elevation forests. However, species richness of lianas were similar between disturbed and undisturbed plots of four sites (Table 4), this pattern is similar to that reported in Similipal Tiger Reserve of Sal forests (Sahoo & Davidar 2013). A possible explanation could be due to increased cloud and fog at higher elevation which affects water balance and reduce energy availability to plants (Bruijnzeel & Proctor 1998; Jiménez-Castillo *et al.* 2007). Moreover, lianas are more vulnerable to lower temperatures than other life-forms, and this cold intolerance plays a key role in their global distribution (Jiménez-Castillo *et al.* 2007). Dominant lianas (15 %) are similar in species composition and constitute 74 % of total liana density shared among three to four study sites. However, among the sample sites, liana species similarity was relatively low but this pattern is similar to that reported in Restinga forests (Moraes *et al.* 2014). The similarities in liana species composition among four sites were similar in species composition irrespective of disturbance level. Species richness was higher in undisturbed sholas in three sites (AG, KK, and UB) but lower in disturbed sholas (KR site). This suggests that disturbance influences species richness in KR site.

The major finding of this study demonstrates that liana abundance significantly increased due to various disturbance regimes and levels of forest utilization by humans. These results are consistent with findings from Neotropical and Amazonian forests (Phillips *et al.* 2005; vander Heijden & Phillips 2008) but differ from the results of Addo-Fordjour *et al.* (2013b) in which liana density decreased with human disturbance in a tropical forest reserve in Ghana. Interestingly, we found that liana basal area significantly decreased with increasing human disturbance, which is consistent with the findings of Addo-Fordjour *et al.* (2013b). These findings show that human disturbance pose differential effects on different aspects of liana structure (density and basal area).

Among the sholas, few species such as *Gardneria ovata, Elaeagnus conferta, Toddalia asiatica* increased in density due to several disturbance regimes including firewood and timber collection, decreasing forest edges and frequent usage of forest paths. Interestingly, several studies have shown that liana abundance often increase

Table 4. Effect of disturbance on mean species richness, mean density ha^{-1} and mean basal area m^2 ha^{-1} among four study sites in the tropical montane evergreen forest (sholas) of the Western Ghats, India.

Site name	Variables	Disturbed (Mean ± SD)	Undisturbed (Mean ± SD)	F-test
Amaggal (AG)	Species richness	8.8 ± 1.3	8.6 ± 2.41	1.85^{ns}
	Density (ha^{-1})	6.23 ± 7.86	2.95 ± 4.28	3.37**
	Basal area (m^2 ha^{-1})	0.05 ± 0.08	0.01 ± 0.04	4.17***
Kukkal (KK)	Species richness	5.5 ± 1.73	6.0 ± 1.63	1.06^{ns}
	Density (ha^{-1})	6.94 ± 2.65	3.49 ± 3.40	7.27*
	Basal area (m^2 ha^{-1})	0.04 ± 0.06	0.01 ± 0.03	4.04**
Korakundah (KR)	Species richness	7.2 ± 0.45	7.17 ± 2.14	4.76*
	Density (ha^{-1})	8.35 ± 13.55	6.03 ± 7.71	3.09*
	Basal area (m^2 ha^{-1})	0.07 ± 0.12	0.12 ± 0.20	2.87^{ns}
Upper Bhavani (UB)	Species richness	7.33 ± 1.53	7 ± 2.55	1.66^{ns}
	Density (ha^{-1})	19.25 ± 27.12	10.30 ± 12.24	4.91*
	Basal area (m^2 ha^{-1})	0.04 ± 0.08	0.08 ± 0.35	21.06****

ns = not significant; Significant at *< 0.05, **< 0.01, ***0.001 and ****0.0001.

Table 5. Comparison between disturbed and undisturbed on percentage of liana density and basal area across four sites.

	Density (ha^{-1})			Basal area (m^2 ha^{-1})		
Site names	Disturbed (%)	Undisturbed (%)	*χ^2-test	Disturbed (%)	Undisturbed (%)	*χ^2-test
AG	68 (137)	32 (65)	21.34**	76 (1.00)	24 (0.32)	15. 13**
KK	72 (83.33)	28 (33.33)	16.51**	74 (0.48)	26 (0.17))	19.82**
KR	58 (117)	42 (84)	4.5*	36 (0.98)	64 (1.72)	17.77**
UB	65 (192.5)	35 (103)	23.19**	15 (0.35)	85 (1.97)	72.72**

Significant at *< 0.05, **< 0.0001.

due to human induced pressure, especially selective logging, fuelwood collection, agriculture, and edge disturbance associated with tree extraction (Addo-Fordjour *et al.* 2013a; Laurance *et al.* 2001; Schnitzer & Bongers 2011). In the AG site, some parts of the forest were particularly disturbed following the intensification of human activities, deforestation and urbanization. However, these disturbances did not cause significant forest loss but stimulated the mass recruitment of small lianas in the disturbed plots. Since some sites are part of the protected area network, they experienced moderate levels of disturbance that stimulated high liana stem density and basal area. High density of lianas may affect tree species recruitment and composition due to failure of gaps formation, which in turn affect forest structure (Addo-Fordjour *et al.* 2013c; Schnitzer & Carson 2010). Conversely, removal of lianas can facilitate tree recruitment and growth resulting to about 45-65 % increase in species richness (Schnitzer & Carson 2010). In the KR site, three sholas are located inside the tea estate and are frequently disturbed by local people. Initially, sholas were exploited and their trees were cut, especially in the fringes and edges for timber and construction of houses. Subsequently, more lianas colonized the area and occupied the host trees. In the UB site, exotic trees (e.g. *Acacia dealbata*) were introduced during the 1950s. During this period, people highly exploited forest resources near the edge of the sholas, thereby stimulating increased liana recruitment. In the KK site of Palni hills, sholas are equally surrounded by exotic tree plantations. However, major parts of the sholas were disturbed for agricultural purposes that caused the shrinkage of shola edges. Due to influence of disturbance, shola edges increased the liana density and basal area in the KK site (Laurance *et al.* 2001). The importance of our study results suggest that disturbance slightly changes species composition, liana density increased due to moderate disturbance factors and basal area influenced by various disturbance level across the four study sites.

There is a hypothesis suggesting that lianas are light-demanders (Gilbert *et al.* 2006; Schnitzer & Bongers 2002) because they perform well in high light conditions. Consequently, liana regeneration is favored in disturbed areas as they are able to take advantage of elevated levels of resources, particularly light, and higher temperatures in gaps that facilitate more liana recruitment (Foster *et al.* 2008; Schnitzer 2005). Gaps do not favor other plant forms due to limited seed dispersal and resource partitioning, preventing tree species from recruiting, growing and surviving (Hubbell *et al.* 1999; Brokaw & Busing 2000). But recent evidence shows that gaps promote the rapid recruitment and growth of lianas, which are inimical to shade-tolerant tree species (Schnitzer & Carson 2010). In disturbed sholas, heavy liana invasion may reduce tree regeneration (Laurance *et al.* 2001; Schnitzer *et al.* 2005), because disturbance may promote above and belowground competition through mechanical stress. For instance, above ground, lianas reduced light in gaps and below ground, lianas appear to be good competitors for water (Schnitzer *et al.* 2005; Toledo-Aceyes & Swaine 2008) which may limit tree growth in gaps, particularly during the dry season (Schnitzer & Carson 2010). In the disturbed sholas, *Elaeagnus conferta* in particular can reduce the abundance of tall trees and increase tree mortality by pulling down neighboring forest trees during a treefall (Mohandass pers.obs.). Therefore, increased liana stem density and basal area may reduce tree diversity and density due to anthropogenic disturbance in the Nilgiri and Palni hills.

Conclusions

In sholas of the Western Ghats, liana density and basal area increased significantly due to the impact of moderate level anthropogenic disturbances (firewood collection by humans, stem cutting for house construction, and edge shrinkage due to agriculture expansion). These disturbance factors form more gaps which induce more liana proliferation in the disturbed plots. A high proportion of liana species did not significantly respond to disturbance. Only few species (e.g. *Gardneria ovata, Elaeagnus conferta* and *Toddalia asiatica*) showed significant patterns in both disturbed and undisturbed sholas. These species are mainly fast-growing, light demanding and shade tolerant species distributed across the sholas. Moreover, the effects of these lianas are far reaching as their proliferation can reduce tree regeneration causing changes in tree species composition, diversity and forest structure (Laurance *et al. in press*; Ledo & Schnitzer *in press*). We, therefore, urge that management plans for sholas should be a high priority for the conservation of tree diversity. Particularly, more attention should be directed towards the control of human induced pressure to prevent more liana proliferation and enhance the maintenance of tree diversity. Moreover, removal of some lianas would be a potential tool to facilitate more tree recruitment and sustain floristic diversity (Kainer *et al.* 2014; Schnitzer & Carson 2010).

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Appendix Table 1. Species name, family name, density (ha^{-1}) and basal area ($m^2\ ha^{-1}$) of lianas recorded in the disturbed and undisturbed sholas at the four sites in the tropical montane evergreen forest (sholas) of the Western Ghats, India.

		Amaggal (AG)				Kukkal (KK)				Korakundah (KR)				Upper Bhavani (UB)			
		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area	
Species	Family	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD
Baeolepis nervosa (Wight & Arn.) Decne. ex Moq.	Apocynaceae	-	1	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-
Celastrus paniculatus Willd	Celastraceae	5	2	0.02	0.01	-	-	-	-	-	-	-	-	-	-	-	-
Celastrus paniculatus subsp. *aggregatus* T. Matthew	Celastraceae	1	0	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cissampelopsis walkeri (Arn.) C. Jeffrey & Y.L. Chen	Compositae	-	2	-	0.00	1.85	2.8	0.01	0.01	5.00	2.00	0.04	0.01	11.00	5.00	0.00	0.06
Connarus wightii Hook. f.	Connaraceae	14	9	0.07	0.02	-	-	-	-	-	-	-	-	-	-	-	-
Derris brevipes var. *brevipes* (Benth.) Baker	Leguminosae	-	-	-	-	0.93	0.93	0.00	0.00	-	-	-	-	-	-	-	-
Derris scandens (Roxb.) Benth	Leguminosae	4	3	0.05	0.02	-	-	-	-	-	-	-	-	-	-	-	-
Desmos lawii (Hook. f. & Thoms.) Safford	Annonaceae	-	-	-	-	20.37	4.63	0.10	0.01	-	-	-	-	-	-	-	-
Elaeagnus conferta Roxb.	Elaeagnaceae	9	3	0.05	0.03	11.11	1.85	0.07	0.01	22.00	15.00	0.38	0.67	45.00	21.00	0.24	1.08
Embelia tsjeriam-cottam (Roemer & Schult) A.DC.	Primulaceae	13	4	0.27	0.18	-	-	-	-	-	-	-	-	-	-	-	-
Cardneria ovata Wall.	Loganiaceae	18	7	0.27	0.00	0.93	0.93	0.00	0.01	48.00	26.00	0.29	0.38	82.00	41.00	0.00	0.53
Jasminum brevilobum A. DC.	Oleaceae	2	3	0.01	0.00	4.63	1.85	0.01	0.07	-	0.40	-	0.00	-	-	-	-

Contd...

Appendix Table 1. Continued.

		Amaggal (AG)				Kukkal (KK)				Korakundah (KR)				Upper Bhavani (UB)			
		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area	
Species	Family	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD
Lonicera ligustrina Wall.	Caprifoliaceae	-	-	-	-	-	-	-	-	4.00	0.80	0.04	0.01	-	-	-	-
Mussaenda hirsutissima (Hook. f.) Hutch. ex Gamble	Rubiaceae	-	-	-	-	-	0.93	-	0.00	-	-	-	-	-	-	-	-
Parsonsia alboflavescens (Dennst.) Mabberley	Apocynaceae	-	-	-	-	-	-	-	-	-	-	-	-	3.00	4.00	0.00	0.01
Passiflora leschenaultii DC.	Passifloraceae	-	-	-	-	-	-	-	-	-	0.20	-	0.00	-	-	-	-
Piper argyrophyllum Miq.	Piperaceae	-	-	-	-	0.93	1.85	0.00	0.00	-	-	-	-	-	-	-	-
Piper hymenophyllum Miq.	Piperaceae	1	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Piper mullesua Buch.-Ham. ex D. Don	Piperaceae	3	1	0.01	0.00	3.7	5.56	0.02	0.01	0.00	6.00	0.00	0.03	-	-	-	-
Piper schmidtii Hook. f.	Piperaceae	2	1	0.00	0.00	-	-	-	-	6.00	3.00	0.03	0.03	3.00	5.00	0.00	0.02
Piper trichostachyon (Miq.) C. DC.	Piperaceae	-	-	-	-	0.92	11.11	0.00	0.01	21.00	14.00	0.05	0.11	37.00	12.00	0.05	0.14
Rhamnus wightii Wight & Arn.	Rhamnaceae	14	5	0.14	0.01	-	4.63	-	0.00	-	-	-	-	-	-	-	-
Rosa leschenaultiana Red. & Thory ex Wight & Arn.	Rosaceae	-	1	-	0.00	1.85	0.93	0.00	0.00	0.00	0.40	0.00	0.01	-	-	-	-

Contd...

Appendix Table 1. Continued.

		Amaggal (AG)				Kukkal (KK)				Korakundah (KR)				Upper Bhavani (UB)			
		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area		Density ha^{-1}		Basal area	
Species	Family	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD	D	UD
Rubus ellipticus Sm.	Rosaceae	2	-	0.00	0.00	0.93	1.85	0.003	0.00	3.00	2.00	0.01	0.02	2.00	6.00	0.00	0.02
Rubus niveus Thunb.	Rosaceae	1	1	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-
Rubus racemosus Roxb.	Rosaceae	-	1	-	0.00	-	0.93	-	0.00	0.50	0.60	0.00	0.00	0.50	1.00	0.00	0.00
Rubus rugosus Sm. var. *rugosus*	Rosaceae	-	-	-	-	-	1.85	-	0.00	0.50	3.00	0.00	0.06	1.00	2.00	0.00	0.01
Strychnos wallichiana Steud. ex A. DC.	Loganiaceae	3	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetrastigma leucostaphylum (Dennst.) Balakrishnan	Vitaceae	32	19	0.10	0.04	-	-	-	-	-	-	-	-	-	-	-	-
Toddalia asiatica (L.) Lam.	Rutaceae	7	-	0.01	-	6.48	4.63	0.03	0.01	7.00	11.00	0.14	0.38	8.00	6.00	0.05	0.10
Tylophora ovata (Lindl.) Hook. ex Steud.	Apocynaceae	5	2	0.01	0.00	-	-	-	-	-	-	-	-	-	-	-	-
Ventilago maderaspatana Gaertn.	Rhamnaceae	-	-	-	-	29.63	12.04	0.17	0.15	-	-	-	-	-	-	-	-
Dregea volubilis (L.f.) Benth	Apocynaceae	1	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-

D; Disturbed sholas, UD; Undisturbed sholas.