

## **Liana diversity and distribution on host trees in four inland tropical dry evergreen forests of peninsular India**

M. SRIDHAR REDDY & N. PARTHASARATHY\*

*Department of Ecology and Environmental Sciences, Pondicherry University,  
Pondicherry 605 014, India*

**Abstract:** Liana diversity and their distribution on host trees were studied in four 1 ha plots, distributed one in each of the four inland tropical dry evergreen forest sites of peninsular India. A total of 2678 lianas ( $\geq 1$  cm diameter at breast height, dbh) belonging to 35 species in 32 genera and 22 families were inventoried in the four sites. Forty per cent of species were exclusive to individual sites and 25% of species were common to all the four sites. Five predominant liana species formed 56% of the total liana population. *Combretum albidum*, the predominant species across the four sites contributed 28% of total liana density. Majority of lianas (70%) were within 1-3 cm dbh class. Of the four climbing modes of lianas (twiners, tendrils, scramblers and hook climber) the twiners were the most abundant. Ordination analysis based on species abundance differentiated sites along a disturbance gradient. Sixty-three per cent of the total 2785 trees  $\geq 10$  cm girth at breast height (gbh) carried at least one liana. *Albizia amara* and *Manilkara hexandra* were the most preferred host trees, while the dominant trees *Memecylon umbellatum* and *Glycosmis pentaphylla* had lower proportion of trees carrying lianas. The frequency distribution of lianas on trees ranged from 0-10 and the frequency of trees with different number of lianas showed non-random distribution. A significant difference in liana infestation rate as well as mean liana load was observed between trees of 10-30 cm and  $>30$  cm gbh classes. Four host species of  $>30$  cm gbh had a significantly higher proportion of trees supporting lianas than the forest mean. Further, lianas showed a preference for multi-stemmed trees and host trees of  $>30$  cm gbh class with rough bark.

**Resumen:** Se estudió la diversidad de lianas y su distribución en los árboles hospedadores en cuatro parcelas de 1 ha, cada una localizada en uno de cuatro sitios de bosque perennifolio tropical seco de tierra adentro en la India peninsular. El inventario de los cuatro sitios incluyó un total de 2678 lianas ( $\geq 1$  cm diámetro a la altura del pecho, dap), pertenecientes a 35 especies en 32 géneros y 22 familias. Cuarenta por ciento de las especies fueron exclusivas de un solo sitio y 25% de las especies fueron comunes a los cuatro sitios. Cinco especies predominantes conformaron 56% de la población total de lianas. *Combretum albidum*, la especie predominante en los cuatro sitios, contribuyó con 28% de la densidad total de lianas. La mayoría de las lianas (70%) estuvieron en la clase de dap de 1 a 3 cm. De los cuatro modos de trepado de las lianas (enredaderas, trepadoras con zarcillos, escaladoras y trepadoras con ganchos), las enredaderas fueron las más abundantes. Un análisis de ordenación basado en la abundancia de las especies permitió diferenciar sitios a lo largo de un gradiente de disturbio. Sesenta y tres por ciento del total de 2785 árboles  $\geq 10$  cm perímetro a la altura del pecho (pap) sostenía al menos una liana. *Albizia amara* y *Manilkara hexandra* fueron los árboles hospedadores preferidos, mientras que los árboles dominantes *Memecylon umbellatum* y *Glycosmis*

*pentaphylla* tuvieron proporciones menores de individuos con lianas. La distribución de frecuencias de lianas sobre los árboles fluctuó de 0 a 10 y la frecuencia de árboles con diferentes números de lianas mostró una distribución no aleatoria. Se encontraron diferencias significativas en la tasa de infestación de lianas y en la carga media de lianas entre los árboles de las clases de pap de 10-30 cm y de > 30 cm. Cuatro especies hospedadoras de > 30 cm pap tuvieron una proporción significativamente mayor de árboles con lianas que la media para todo el bosque. Además, las lianas mostraron una preferencia por árboles con numerosos tallos y árboles hospedadores de la clases de pap > 30 cm, de corteza rugosa.

**Resumo:** A diversidade em lianas e a sua distribuição nas árvores hospedeiras foram estudadas em quatro parcelas de 1 ha distribuídas em cada uma das quatro estações florestais tropicais secas sempreverdes no interior da Índia peninsular. Para o conjunto das quatro estações foram inventariadas 2678 lianas (diâmetro à altura do peito (DAP)  $\geq$  1 cm de diâmetro, pertencendo a 35 espécies em 32 gêneros e 22 famílias. Cinco espécies de lianas predominantes formaram 56% da população total de lianas. A *Combretum albidum*, a espécie predominante ao longo das quatro estações, contribuiu com 28% da densidade total em lianas. A maioria das lianas (70%) situavam-se entre a classe de DAP dos 1-3 cm. Dos quatro tipos de modos de trepar das lianas (gavinhas, apêndices, enroladoras e enganchadas) foram as mais abundantes. Uma análise de ordenação baseada na abundância de espécies diferenciou as estações ao longo de um gradiente de distribuição. Sessenta e três por cento de um total do total das 2785 árvores de diâmetro à altura do peito (DAP)  $10 \geq$  cm hospedavam pelo menos uma liana. A *Albizia amara* e a *Manilkara hexandra* eram as árvores hospedeiras mais preferidas, enquanto as árvores dominantes a *Memecylon umbellatum* e a *Glycosmis pentaphylla* apresentavam uma baixa proporção de árvores suportando lianas. A distribuição de frequências de lianas nas árvores situou-se entre 0-10 e a frequência de árvores com diferentes números de lianas mostraram um distribuição não casual. Observou-se uma diferença significativa na taxa de infestação em lianas bem como uma carga média de lianas entre árvores da classe 10-30 cm e > 30 cm de DAP. Quatro espécies hospedeiras com DAP > 30 cm apresentavam uma proporção significativamente alta de árvores suportando lianas em comparação com a média da floresta. Além disso, as lianas mostraram uma preferência para as árvores de troncos múltiplos e árvores hospedeiras com DAP > 30 cm com casca rugosa.

**Key words:** Climbing modes, distribution pattern, infestation rate, lianas, ordination, species dominance, tree morphology, tropical dry evergreen forest.

## Introduction

Lianas i.e. woody climbers contribute significantly to the species richness, diversity and structural complexity of tropical forests composing up to 25% of woody individuals and species (Gentry 1991a). Lianas influence forest dynamics by slowing growth rate and increasing the mortality of their host trees (Clark & Clark 1990; Putz 1984) and can alter gap phase regeneration by suppressing sapling growth

(Schnitzer & Carson 2001). Functionally, lianas exhibit diverse patterns of pollination, dispersal and phenological systems, and provide several (e.g. foliar, floral and fruit) resources to the animal communities, and play crucial roles in the maintenance of biological diversity (Burnham 2002; Emmons & Gentry 1983; Nabe-Nielsen 2001; Schnitzer & Bongers 2002). Liana species richness and abundance differ greatly from one forest to another and between forest locations (Balfour & Bond 1993;

Parthasarathy *et al.* 2004). Lianas are most conspicuous in naturally or anthropogenically disturbed areas and their overall abundance increases following forest disturbance (Putz 1984). They are more associated with fertile soils (Putz & Chai 1987), frequently inundated alluvial forests (Proctor *et al.* 1983), disturbed forests, and forest



edges (Laurance *et al.* 2001; Williams-Linera 1990), forests with seasonal rainfall (Gentry 1991a) and regenerating forests (Dewalt *et al.* 2000; Nabe-Nielsen 2002), and the conspicuous presence of lianas in these areas can be assigned to availability of light and trellises (Putz 1984).

Forest structure and host tree features influence the distribution of lianas and their probability to reach the canopy (Chalmers & Turner 1994). Trellis availability is one of the major factors controlling liana access to the forest canopy and thus lianas are more likely to reach the canopy via the edges and treefall gaps (Putz 1984). The mechanism by which a liana climbs (e.g. tendrils, twiners, scramblers) determines in part which trees are suitable supports (Penalosa 1983; Putz & Holbrook 1991) as well as the maximum support diameter of host it can take for climbing (Putz 1984). Various studies on the distribution of lianas on trees have reported that the tree species attributes such as branch shedding (Clark & Clark 1990; Putz 1984), bark characteristics, growth rates (Campbell & Newbery 1993), canopy geometry, climber's association with specific host trees (Carse *et al.* 2000; Carsten *et al.* 2002; Pinard & Putz 1994) and neighborhood characteristics (Perez-Salicrup *et al.* 2001) may determine the number of lianas a tree carries by facilitating or inhibiting liana access, leading to their non-random distribution on trees.

Earlier research in coastal tropical dry evergreen forests over a decade have addressed questions related to biodiversity of trees (e.g. Parthasarathy & Karthikeyan 1997; Venkateswaran & Parthasarathy 2003), lianas (Reddy & Parthasarathy 2003), nutrient cycling (Visalakshi 1992), forest production (Pragasam & Parthasarathy 2005) and reproductive traits and phenology of plant species (Selwyn & Parthasarathy, 2006) to understand the ecosystem structure and functioning of these forests. Lianas contribute substantially to forest biodiversity and play important role in forest functioning, yet they remain unstudied in the inland forests. The present study in inland tropical dry evergreen forests was designed to investigate liana diversity and tree-liana interactions in four short-statured, tropical dry

evergreen forest sites of peninsular India, which experience different degree of human disturbance.

## Study area

The study was conducted at four sites of tropical dry evergreen forests, located ~50 km from the sea coast in Pudukottai district of Tamil Nadu, India. The four sites, viz., Araiypatti (AP), Karisakkadu (KR), Shanmuganathapuram (SP) and Maramadakki (MM) are 3-15 km apart from each other and located within 30 km range of Pudukottai town (latitude 10°16'30"N and longitude 79°03'E). These sites were selected along a varying disturbance gradient and their area ranged from 1.5 to 2.5 ha. These sites are sacred groves juxtaposed with agricultural fields, *Eucalyptus* or cashew plantations and are protected owing to the religious belief of the local people. Anthropogenic activities, such as area used for temple structure, frequency and number of temple visitors, extent of forest resource extraction during temple festivals, cattle grazing, tree felling, collection of fuel wood etc., placed the four sites in an increasing order of disturbance: AP < KR < SP < MM. Site AP is slightly (300 m) away from human habitation and houses a temple endowed with just an idol of God Ganesh; while KR is close (20 m) to human habitation and a thatched temple of Ayyanar is frequented by the local people. Site SP is endowed with Ayyanar deity and surrounded by agricultural fields. It attracts many visitors, particularly on harvesting days, as the villagers believe in a ritual of offering a part of their first harvest to the God. Whereas site MM is close to a village road and lodges a well constructed temple of Goddess Shakthi at one end of the forest and attracts a lot of temple visitors.

The vegetation of the study sites is tropical dry evergreen forest type, being unique type with restricted geographical distribution in peninsular India - the Coromandel (east) coast and the inland areas up to 50 km west from the east coast, northern Sri Lanka (Champion & Seth 1968), Thailand and Jamaica (Bullock *et al.* 1995). The peninsular Indian tropical dry evergreen forests are short-statured (mean tree

height  $10 \pm 2$  m), 2 - 3 layered forests composed of abundant small trees and lianas, with no shrub layer and a sparse ground flora. These forests are composed of 60% evergreen (e.g. *Memecylon umbellatum*, *Drypetes sepiaria* and *Diospyros ebenum*), 31% deciduous (e.g. *Chloroxylon swietenia*, *Strychnos nux-vomica* and *Cassia fistula*) and 9% brevi-deciduous tree species (e.g. *Pterospermum canescens*, *Pongamia pinnata* & *Lepisanthes tetraphylla*; (Mani & Parthasarathy 2005). The climate of this part of peninsular India is monsoonal, marked with unevenly distributed rainfall (mean annual rainfall 861 mm, 57 mean annual rainy days). The rains fall during both the south-west and north-east monsoons (July to September and October to December, respectively), but are distinctly active in the latter monsoon and drastically decrease during the dry season from January to June. The mean annual temperature of the nearest station Pudukottai is 33.4 °C. The topography of the four forest sites is less varied, with more or less flat terrain in three sites, with gentle undulation in site SP. The soil is shallow and characteristically derived from laterites.

## Methodology

### *Liana diversity and distribution*

A 1 ha plot (100 m × 100 m) was established at each study site. The plot was subdivided into one hundred 10 m × 10 m sub-plots and all rooted lianas, free standing as well as climbing individuals within the 1 ha plot having girth 3.1 cm were considered and their girth measured at 1.3 m from the rooting point of the stem. Their climbing mode was noted in the field and voucher specimens were collected, identified and deposited in the Herbarium of School of Ecology, Pondicherry University.

Diversity indices such as Fisher's  $\alpha$ , Simpson's, Shannon's, Hill diversity numbers  $N_1$  and  $N_2$  and evenness indices (as in Magurran 1988) were computed to determine liana species richness and dominance at individual sites as well as for the whole liana community. Species-area curves were plotted by sequential arrangement of 0.1 ha sub-plots. To determine the structural importance of liana species in the community, the importance value

index (IVI) based on Curtis & McIntosh (1950) was calculated as the sum of relative density, relative dominance and relative frequency. Family importance value (FIV) was calculated by the summation of relative dominance, relative density and relative diversity as per Mori *et al.* (1983). The coefficient of dispersion (C.D., Variance/mean) of the number of liana stems in a 10 m × 10 m quadrat was used to assess the spatial pattern of liana community and a 't' test was performed to assess the significant deviation from C.D. =1 (Krebs 1989). Spatial distribution patterns of liana species with >15 individuals and present in at least two sites were determined using standardized Morisita's index of dispersion,  $I_p$  (Krebs 1989) that ranges from -1 to +1. An  $I_p$  of zero indicates a random pattern, above zero indicates a clumped pattern and below zero uniform pattern, with 95% confidence limits at +0.5 and -0.5.

### *Liana distribution on host trees*

Every tree  $\geq 10$  cm girth at breast height (gbh) located within 10 m × 10 m sub-plots was screened for the presence/absence of lianas. The manner in which lianas ascend on trees (such as directly through tree trunk or lower tree branches as primary hosts, or by means of horizontal spread through side canopy as secondary host) was noted in the field to determine the liana load on trees. The number of individual lianas on a particular tree along with tree morphological traits such as branch-free bole height (measured using a 2 m reference pole) and bark texture categorized into smooth and rough were also noted in the field.

The data of the four study sites were combined to analyze tree-lianas interactions. To determine whether a particular tree species had a higher or lower proportion of trees supporting lianas, the mean proportion of trees carrying at least one liana was calculated and contrasted with the observed proportion of specific tree species (> 20 individuals) with lianas by binomial goodness of fit test (Zar 1984). A similar binomial goodness of fit test was performed to evaluate whether the tree species having >20 individuals in the two gbh classes (10-30 cm and >30 cm) had significantly higher or lower proportion of trees with lianas than the forest mean of liana infested trees. Mann-

Whitney t test was performed to evaluate which size class of trees (10-30 cm and >30 cm) was more accessible to lianas to climb onto forest canopy, and for this, the proportion of trees acting as primary hosts and comprising >20 individuals in any size class was considered.

The observed frequency distribution of trees with different number of lianas was compared with expected trees for each category, calculated from Poisson distribution series, by chi-square goodness of fit test to evaluate whether the frequency distribution of trees is either random or clumped (Ludwig & Reynolds 1988). Mann-Whitney t test was used to detect any significant difference in mean liana load between trees categorized into 10-30 cm gbh and >30 cm gbh classes and between trees categorized into smooth and rough bark types.

Contingency table chi-square tests (Zar 1984) were used to test the significant difference in the frequencies of presence and absence of lianas categorized into: (a) twiners, tendril climbers and scramblers (lone hook climber was not included in the analysis); (b) 1 - 3 cm and >3 cm dbh, and (c) 0.1 and >1 number of lianas on the variable- trees in 10-30 cm and >30 cm gbh classes. Similarly, contingency table chi-square test was performed on frequency of presence and absence of lianas on the variable - single and

multi-stemmed trees. While a three-dimensional contingency table test was performed to detect any significant difference in the frequency of presence and absence of lianas on the interactive variables - trees categorized into two size-classes (10 - 30 cm and >30 cm gbh) and bark types (rough and smooth) in each of the four columns.

## Results

### *Liana diversity and distribution*

In the four tropical dry evergreen forest sites a total of 2,678 liana individuals  $\geq 1$  cm diameter at breast height (dbh) representing 35 species, 32 genera and 22 families were enumerated (Table 1). The species richness ranged from 21 (site MM) to 27 species  $\text{ha}^{-1}$  (site AP), while the mean liana density was 669 individuals  $\text{ha}^{-1}$  with a range of 515 (site KR) to 792 individuals  $\text{ha}^{-1}$  (site AP). These individuals accounted for a total liana basal area of 3.88  $\text{m}^2$  (0.97  $\text{m}^2 \text{ha}^{-1}$ ) with a maximum of 1.68  $\text{m}^2 \text{ha}^{-1}$  at site MM. The Shannon index of 2.76 for the whole liana community with an evenness of 0.77 and Hill's  $N_1$  value of 15, against the total of 35 species revealed a varied relative abundance of lianas across the four sites.

Liana abundance was as high as 258 individuals for *Combretum albidum* at site SP to just a single individual each of *Cansjera rheedii*

**Table 1.** Inventory of liana diversity ( $\geq 1$  cm dbh) in four 1-ha plots of inland tropical dry evergreen forest sites (Araiypatti-AP; Karisakkadu-KR; Shanmuganathapuram-SP and Maramadakki-MM) of peninsular India.

Variables	Study site				Total for 4 ha
	AP	KR	SP	MM	
Species richness	26	23	27	21	35
Number of genera	24	22	24	20	32
Number of families	19	19	20	18	22
Population density	792	515	775	596	
Basal area ( $\text{m}^2 \text{ha}^{-1}$ )	1.09	0.67	0.44	1.68	
Diversity indices					
Shannon	2.71	2.56	2.45	2.18	2.76
Simpson	0.099	0.102	0.148	0.166	0.011
Fisher's $\alpha$	5.2	4.9	5.4	4.2	5.7
Shannon evenness	0.83	0.82	0.74	0.72	0.77
Density per quadrat (mean $\pm$ s.d.)	7.92 $\pm$ 6.0	5.15 $\pm$ 3.8	7.75 $\pm$ 5.3	5.96 $\pm$ 3.6	
No. of species per quadrat (mean $\pm$ s.d.)	4.5 $\pm$ 2.7	3.4 $\pm$ 2.1	3.8 $\pm$ 2.3	3.2 $\pm$ 1.5	
Coefficient of variation	0.76	0.74	0.68	0.6	
Coefficient of dispersion ( $S^2/\text{mean}$ )	4.6	2.6	3.7	2.2	

and *Ziziphus oenoplia* across the four study sites (Table 2). Five species *Combretum albidum*, *Derris scandens*, *Strychnos minor*, *Cissus quadrangularis* and *Pyrenacantha volubilis* were predominant (with > 150 individuals) and accounted for 56% of total liana abundance, 19 common species (abundance ranging from 20 to <150 individuals) contributed 41% of liana individuals and eleven species with 3% of total abundance featured in rare category (<20 individuals). About 6% species were represented by a single individual. The distribution of lianas across the four study sites revealed that 40% of liana species were exclusive to individual sites and nearly 25% of species were common to all the four sites.

**Table 2.** List of 35 liana species ( $\geq 1\text{cm}$  dbh) enumerated at four inland tropical dry evergreen forest sites (AP, KR, SP and MM) of peninsular India, along with their population density in descending order of total abundance, climbing type (CT) and dispersal mode (DM).

Species and family	Density						Total for 4 ha
	CT*	DM†	AP	KR	SP	MM	
<i>Combretum albidum</i> G. Don (Combretaceae)	TW	W	198	95	258	191	742
<i>Derris scandens</i> (Roxb.) Benth. (Papilionaceae)	TW	AU	65	52	16	86	219
<i>Strychnos minor</i> Dennst. (Loganiaceae)	TC	A	25	7	86	96	214
<i>Cissus quadrangularis</i> L. (Vitaceae)	TC	A	57	45	39	21	162
<i>Pyrenacantha volubilis</i> Wight (Icacinaeae)	TW	A	42	24	38	51	155
<i>Reissantia indica</i> (Willd.) Halle (Celastraceae)	TW	W	11	75	19	42	147
<i>Coccinia grandis</i> (L.) Voigt (Cucurbitaceae)	TC	A	42	74	9	9	134
<i>Tinospora cordifolia</i> (Willd.) Hook.f. & Thoms. (Menispermaceae)	TW	A	55	16	21	14	106
<i>Acacia caesia</i> (L.) Willd. (Mimosaceae)	SC	AU	56	29	1	4	90
<i>Carissa spinarum</i> L. (Apocynaceae)	SC	A	34	5	38	4	81
<i>Jasminum angustifolium</i> (L.) Willd. (Oleaceae)	TW	A	2	0	75	0	77
<i>Gymnema sylvestre</i> (Retz.) R.Br.ex Schultes (Asclepiadaceae)	TW	W	0	15	49	6	70
<i>Jasminum sessiliflorum</i> Vahl (Oleaceae)	TW	A	10	12	19	7	48
<i>Secamone emetica</i> (Retz.) R.Br. (Asclepiadaceae)	TW	W	0	7	15	23	45
<i>Capparis zeylanica</i> L. (Capparaceae)	SC	A	21	15	3	3	42
<i>Ventilago madraspatana</i> Gaertn. (Rhamnaceae)	TW	W	32	1	6	2	41
<i>Grewia rhamnifolia</i> Heyne ex Roth (Tiliaceae)	TW	A	29	6	1	3	39
<i>Ipomoea staphylina</i> Roemer & Schultes (Convolvulaceae)	TW	AU	31	0	0	3	34
<i>Asparagus racemosus</i> Willd. (Liliaceae)	TW	A	19	8	2	0	29
<i>Pachygone ovata</i> (Poir.) Miers ex Hook. (Menispermaceae)	TW	A	19	0	7	3	29
<i>Hugonia mystax</i> L. (Linaceae)	HC	A	0	1	2	25	28
<i>Rivea hypocrateriformis</i> (Desr.) Choisy (Convolvulaceae)	TW	A	1	2	24	0	27
<i>Derris ovalifolia</i> (Wight & Arn.) Benth. (Papilionaceae)	TW	AU	0	0	26	0	26
<i>Plecosperrum spinosum</i> Trecul (Moraceae)	SC	A	20	0	2	0	22
<i>Premna corymbosa</i> (Burm.f.) Rottl. & Willd. (Verbenaceae)	TW	A	4	10	0	0	14
<i>Capparis brevispina</i> DC. (Capparaceae)	SC	A	5	6	1	2	14
<i>Pterolobium hexapetalum</i> (Roth.) Sant. & Wagh. (Caesalpiniaceae)	SC	W	0	0	13	0	13
<i>Sarcostemma acidum</i> (Roxb.) Voigt (Asclepiadaceae)	TW	W	0	6	3	0	9
<i>Cocculus hirsutus</i> (L.) Diels (Menispermaceae)	TW	A	6	0	0	0	6
<i>Canavalia virosa</i> (Roxb.) Wight & Arn. (Papilionaceae)	TW	AU	0	4	0	0	4
<i>Wattakaka volubilis</i> (L.f.) T. Cooke (Asclepiadaceae)	TW	W	4	0	0	0	4
<i>Salacia chinensis</i> L. (Celastraceae)	TW	A	3	0	0	0	3
<i>Abrus precatorius</i> L. (Papilionaceae)	TW	AU	0	0	2	0	2
<i>Cansjera rheedii</i> Gmel. (Opiliaceae)	SC	A	0	0	0	1	1
<i>Ziziphus oenoplia</i> (L.) Mill. (Rhamnaceae)	SC	A	1	0	0	0	1

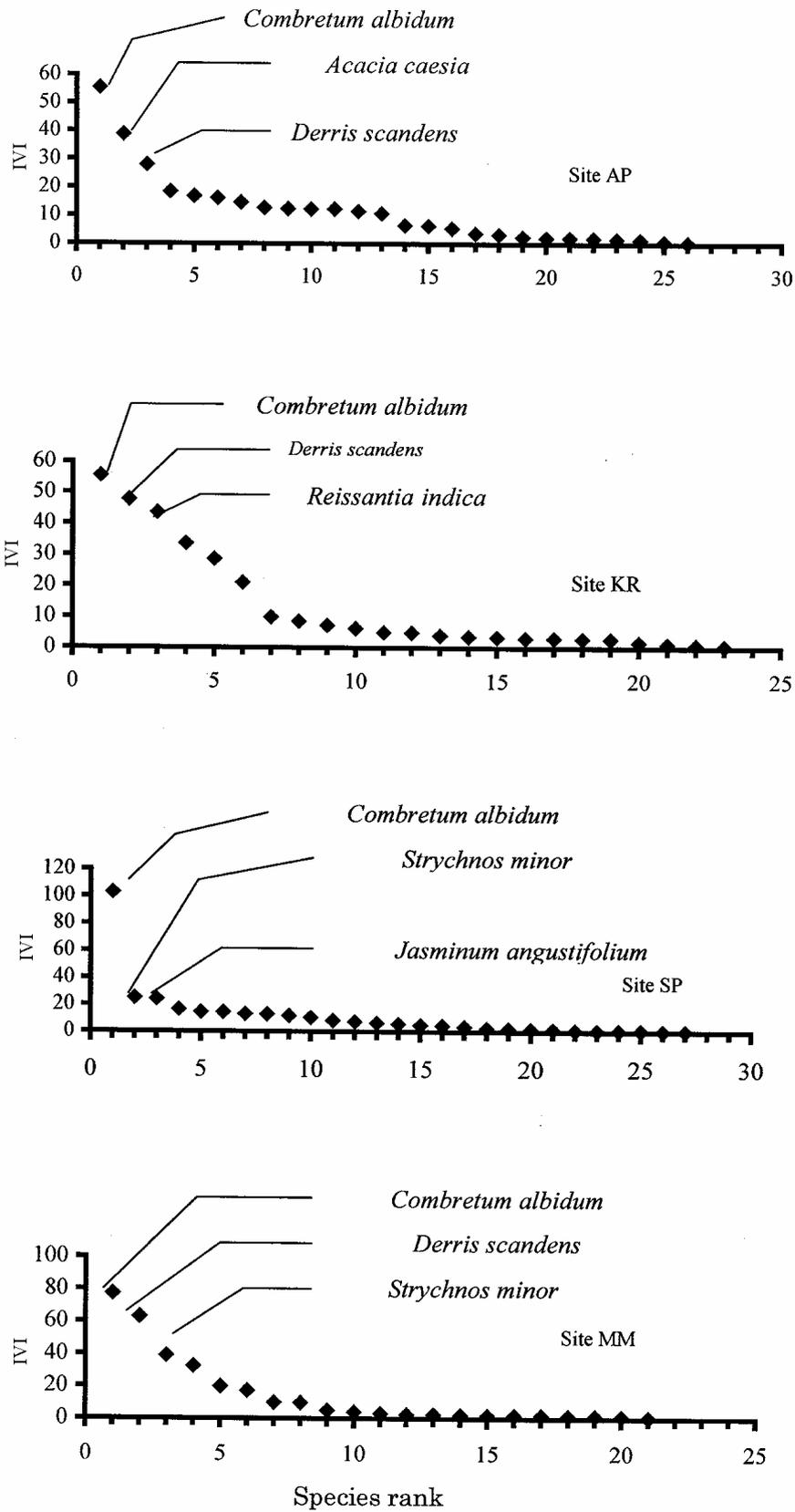
\*CT- climbing type: HC- hook climber; SC- scrambler; TC- tendril climber; TW- twiner.

†DM- dispersal mode: A- animal; AU- autochorous; W- wind.

*Combretum albidum*, structurally the most important species, occurred in nearly 60% sub-plots and accounted for 18-34% of liana abundance and 17-53% total liana basal area in the four study sites. Although it is abundant in

all the four sites, with respect to basal area contribution it ranked first only in site SP, whereas in site AP *Acacia caesia* ranked first, and *Derris scandens* was first in sites KR and MM. Three predominant species at the four

sites cumulatively accounted for importance  
value index (IVI) from 40% at site AP



**Fig. 1.** Liana species ranks based on importance value indices (IVI) and the top three liana species in each of

to as high as 60% at site MM (Fig. 1). Site KR featured the same three species in the order as that of the total liana community IVI. Site SP presented a condition where *Combretum albidum* comprised 34% of the total IVI. At the family level, Combretaceae with its lone predominant species *Combretum albidum* figured as the most dominant family, while the species-rich families, Papilionaceae and Asclepiadaceae were placed in 2nd and 4th position, respectively, in the descending order of family importance value (Table 3).

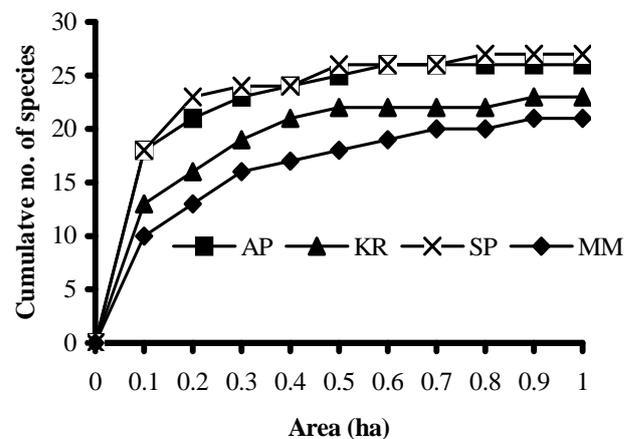
The distribution of liana stems at the four sites at the smaller spatial scale of 0.01 ha (10 m × 10 m sub-plots) revealed 60 to 76% variation among sub-plots having lianas with a range of  $5.15 \pm 3.8$  to  $7.92 \pm 6.0$  individuals belonging to  $3.2 \pm 1.5$  to  $4.5 \pm 2.7$  species. The

**Table 3.** Liana families, their species richness, abundance and family importance value (FIV) pooled for 4 sites of inland dry evergreen forest sites, arranged in descending order of FIV.

Family	Genera	Species	Abundance	FIV
Combretaceae	1	1	742	56
Papilionaceae	3	4	251	48
Celastraceae	2	2	150	21
Asclepiadaceae	4	4	128	18
Mimosaceae	1	1	90	16
Menispermaceae	3	3	141	15
Loganiaceae	1	1	214	15
Oleaceae	1	2	125	11
Capparaceae	1	2	56	10
Vitaceae	1	1	162	10
Rhamnaceae	2	2	42	10
Convolvulaceae	2	2	61	10
Cucurbitaceae	1	1	134	10
Icacinaeae	1	1	155	9
Moraceae	1	1	22	7
Apocynaceae	1	1	81	7
Linaceae	1	1	28	6
Tiliaceae	1	1	39	6
Liliaceae	1	1	29	4
Caesalpinaceae	1	1	13	4
Verbenaceae	1	1	14	4
Opiliaceae	1	1	1	3

species accumulation curve showed a rapid rise up to 0.3 ha, followed by a gradual increment in all the sites, and among the four sites species-area curve stabilized at 0.8 ha scale at sites AP and SP and at 0.9 ha at sites KR and MM (Fig. 2). Analysis of spatial dispersion for all liana individuals, as per the coefficient of dispersion values that ranged from 2.18 in site MM to 4.58 in AP (all showing Variance/mean values >1) indicated a non-random distribution (Table 1;  $t = 8.3$  to  $25.2$ ,  $df = 99$ ,  $P < 0.05$ ). Further, analysis of dispersion for specific liana species revealed that six species were consistently clumped, and among them, *Derris scandens*, *Pyrenacantha volubilis* were prominent. *Combretum albidum*, the predominant liana and four other species showed a varied pattern of dispersion across the four sites. Just one species, *Acacia caesia* at site KR exhibited an uniform distribution (Table 4).

The diameter class structure of liana population revealed that 90% individuals remained below 10 cm dbh (Table 5). Lianas of smaller diameter class (1-3 cm dbh) differed significantly ( $\chi^2_{(3)} = 10.6$ ,  $P < 0.05$ ) among the four sites, with nearly 70-80% of their stems in 1-3 cm dbh, except at site MM wherein 47% belonged to this class. *Combretum albidum* was the dominant liana in 1-3 cm dbh and up to 10-15 cm dbh classes, while *Derris scandens* remained the dominant liana in >10-15 dbh classes (Table 5). Further, all liana species were encountered in the 1-3 cm dbh class itself, except the thorny straggler *Ziziphus oenopia*.



**Fig. 2.** Species-area curves for lianas in the four inland tropical dry evergreen forests.

**Table 4.** Standardised Morisita's index values and the dispersion patterns of lianas at 0.01 ha scale within the 1-ha study plots, for liana species with >15 individuals and present in at least two of the four study sites (AP, KR, SP and MM).

Liana species	AP	KR	SP	MM
<i>Combretum albidum</i>	0.52 (c)	0.262 (c*)	0.505 (c)	0.506 (c)
<i>Strychnos minor</i>	0.57 (c)	–	0.514 (c)	0.504 (c)
<i>Derris scandens</i>	0.509 (c)	0.524 (c)	0.515 (c)	0.515 (c)
<i>Cissus quadrangularis</i>	0.501 (c)	0.500 (c)	0.503 (c)	0.145 (c*)
<i>Pyrenacantha volubilis</i>	0.510 (c)	0.507 (c)	0.508 (c)	0.503 (c)
<i>Reissantia indica</i>	–	0.283 (c*)	0.231 (c*)	0.428 (c*)
<i>Coccinia grandis</i>	0.514 (c)	0.501 (c)	–	–
<i>Tinospora cordifolia</i>	0.506 (c)	0.382 (c*)	0.504 (c)	–
<i>Acacia caesia</i>	-0.028 (u)	0.251 (c*)	–	–
<i>Carissa spinarum</i>	0.050 (c)	–	0.504 (c)	–
<i>Secamone emetica</i>	–	–	0.547 (c)	0.504 (c)
<i>Capparis zeylanica</i>	0.146 (c*)	0.518 (c)	–	–

'c' = clumped at  $P < 0.05$ ; 'c\*' = apparent clumped  $P > 0.05$ ; 'u' = uniform at  $P < 0.05$

**Table 5.** Species richness and density (stems  $\text{ha}^{-1}$ ) of lianas categorized by diameter classes in the four inland dry evergreen forest sites

Dia. class (cm)	Study site									
	AP		KR		SP		MM		Total for 4 sites	
	Species richness	Density	Species richness	Density						
1-3	24	583	22	359	26	652	17	278	34	1872
3-6	16	140	12	114	15	99	14	195	23	548
6-10	11	49	6	33	5	21	10	93	17	196
10-15	7	19	3	7	2	3	4	25	9	54
15-20	1	1	1	2	0	0	1	3	1	6
20-30	0	0	0	0	0	0	1	2	1	2
Total	26	792	23	515	27	775	21	596	35	2678

#### *Climbing mechanism and dispersal modes*

The liana species inventoried at the study sites fall under four different climbing modes – twiners, tendril climbers, scramblers and hook climber (Table 6). The twiners were predominant both by species (66%) and individuals (70%). In site SP, 75% of lianas were twiners, among them *Combretum albidum* was (44%) prominent. The three tendril climbers enumerated, occurred in all the four sites, although in varied proportions. Sites KR and MM had greater representation of tendril climbers and were dominated by *Coccinia grandis* and *Strychnos minor*, respectively. Scramblers were spatially well represented at site AP with a total of six species and 17% of density, while site MM had a poor representation of this mode. *Hugonia*

*mystax*, the lone hook climber occurred at three study sites, except in site AP, but was abundant in site MM.

A variety of diaspores, adapted for wind, animal and autochorous modes of dispersal occurred in the liana community of the four study sites. At least 60% of liana species possess reward-providing diaspores and 20% of species produce wind-dispersed diaspores like samara and seeds with tuft of hairs.

#### *Liana distribution on host trees*

Of the 2,785 trees having  $\geq 10$  cm gbh at four study sites, 63.8% (1,777) trees carried at least one liana. Two species *Memecylon umbellatum* and *Glycosmis pentaphylla* formed the less preferred hosts with a lower proportion

of trees carrying lianas than the mean proportion of host trees at the four study sites based on binomial distribution (Table 7). Four tree species viz., *Albizia amara*, *Manilkara hexandra*, *Strychnos nux-vomica* and *Lepisanthes tetraphylla* had higher proportion of trees carrying lianas.

Mann-Whitney t test between trees categorized into 10 - 30 and > 30 cm gbh classes revealed a significant difference in their infestation rates ( $U_{10,14} = 112$ ,  $P < 0.05$ ; Table 7). In the 10 - 30 cm gbh class, *Albizia amara* alone carried significantly higher proportion of tree individuals with lianas than the forest mean, while in the > 30 cm gbh category none

had a significantly lower proportion of trees with lianas, indicating a high proportion of trees with lianas in this category for all the tree species. The mean number of lianas on a tree species also showed significant difference ( $U_{10,14} = 133$ ,  $P < 0.05$ ) between the two gbh classes, indicating a higher liana load on trees of >30 cm gbh class, although *Albizia amara* and *Strychnos nux-vomica* trees in 10-30 cm gbh class also recorded a mean liana load comparable to the values of >30 cm gbh class.

The frequency distribution of lianas on trees ranged from 0-10 lianas per tree. This frequency distribution on trees, when compared to Poisson distribution series, showed a

**Table 6.** Liana species richness and density (stems ha<sup>-1</sup>) under four different climbing mechanisms in the four inland dry evergreen forest sites.

Site	Twiner		Tendrill climbers		Scramblers		Hook climbers	
	Species	Density	Species	Density	Species	Density	Species	Density
AP	17	531	3	124	6	137	0	0
KR	15	333	3	126	4	55	1	1
SP	17	581	3	134	6	58	1	2
MM	12	431	3	126	5	14	1	25
Total for 4 ha	23	1876	3	510	8	264	1	28

**Table 7.** Total number of individuals in tree species (each with >20 individuals) and individuals of these species separated by two size classes (10-30 cm and >30 cm gbh); percentage of trees carrying lianas is given within parenthesis.

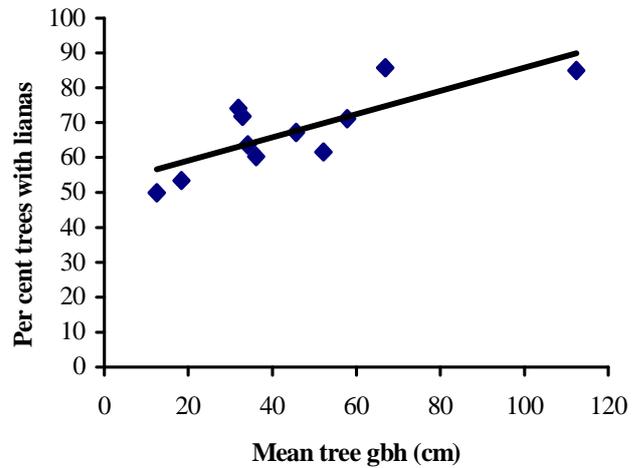
Tree species	≥10 cm gbh	No. of individuals 10-30 cm gbh	>30 cm gbh
<i>Memecylon umbellatum</i>	935 (53.5*)	881 (52.8)	54 (66.6)
<i>Drypetes sepiaria</i>	337 (71.2**)	61 (62.3)	276 (73.2**)
<i>Pterospermum canescens</i>	232 (61.6)	90 (55.5)	142 (65.5)
<i>Strychnos nux-vomica</i>	204 (74**)	149 (68.5)	55 (89.1**)
<i>Albizia amara</i>	155 (85.8**)	54 (79.6**)	101 (89.1**)
<i>Lepisanthes tetraphylla</i>	117 (71.8**)	70 (65.7)	47 (80.8**)
<i>Glycosmis pentaphylla</i>	102 (50*)	-	-
<i>Canthium dicoccum</i>	77 (63.6)	27 (55.5)	50 (68)
<i>Chloroxylon swietenia</i>	88 (60.2)	46 (58.7)	42 (61.9)
<i>Euphorbia antiquorum</i>	76 (61.8)	-	-
<i>Pongamia pinnata</i>	61 (67.2)	22 (59.1)	39 (71.8)
<i>Manilkara hexandra</i>	60 (85**)	-	-
<i>Vitex altissima</i>	45 (66.6)	-	-
<i>Syzygium cumini</i>	26 (73)	-	-
<i>Lannea coromandelica</i>	23 (56.5)	-	-

\*\*P<0.05, Tree species having higher proportion of individuals with lianas than the forest mean of 63.8, based on binomial distribution. \*P<0.05, Tree species having lower proportion of individuals with lianas than the forest mean of 63.8, based on binomial distribution.

significant difference from random pattern  $\chi^2_{(4)} = 62.1, P < 0.05$ ; Table 8). The low value of variance/mean,  $(1.15/0.98 = 1.173)$  suggests less aggregation, as also further authenticated by the observed modal number of lianas i.e. 'one' on trees in the dry evergreen forests. The relative proportion of trees with several lianas showed that trees carrying one liana and  $\geq 4$  lianas occurred more than expected and the expected host trees were higher than the observed hosts at the frequencies 2 and 3 lianas per host (Table 8).

Spearman rank correlation showed a significant positive relationship between mean tree gbh values and their proportion of individuals carrying lianas ( $r_{11} = 0.618, P < 0.05$ ; Fig. 3). Further, a steady increase in the mean tree gbh values (30.8 to 82.6 cm) against the ascending order of 0 -  $\geq 4$  lianas per tree was observed (Table 8). The mean trellis height of trees had no significant relation with infestation rates of tree species ( $r_{11} = 0.473, P > 0.05$ ).

The 2x2 contingency table chi-square tests revealed a significant difference ( $P < 0.01$ ) in liana presence/absence on single and multi-



**Fig. 3.** Relationship between mean tree gbh and their corresponding proportion of trees with lianas.

stemmed trees. Lianas, categorized by climbing mechanisms, viz. twiners and scramblers showed a significant difference, by higher occurrence on trees with  $>30$  cm gbh than on 10-30 cm gbh trees ( $P < 0.01$ ; Table 9). Tendril climbers took hold more on trees of 10-30 cm gbh than  $>30$  cm gbh class ( $\chi^2_{(1)} = 5.06$ ,

**Table 8.** Observed number of trees and their mean gbh value for different frequencies of lianas; the expected number of trees with lianas was calculated from the Poisson distribution.

Frequency of lianas	Mean tree gbh	No. of trees supporting lianas		Poisson
		Observed	Expected	$\chi^2$
0	30.84	1039	10.8	0.00096
1	35.87	1114	1024	7.91
2	50.74	397	506	23.48
3	68.62	146	166	2.41
$\geq 4$	82.65	89	51	28.31
Total				62.11

**Table 9.** Contingency table chi-square tests for presence/absence of lianas categorized by climbing modes, diameter classes and frequency number on trees Vs total number of trees in 10-30 cm and  $>30$  cm girth classes.

Contingency table $\chi^2$ test performed	$\chi^2$ statistic	d f
Presence/absence of lianas Vs single stemmed and multi-stemmed trees	40*	1
Presence/absence of twiners Vs trees in 10-30 cm and $>30$ cm gbh classes	98.02*	1
Presence/absence tendril climbers Vs trees in 10-30 cm and $>30$ cm gbh classes	5.06	1
Presence/absence scramblers Vs trees in 10-30 cm and $>30$ cm gbh classes	46.53*	1
Presence/absence of lianas 1-3 cm dbh class Vs trees in 10-30 cm and $>30$ cm gbh classes	4.5	1
Presence/absence of lianas $>3$ cm dbh class Vs trees in 10-30 cm and $>30$ cm gbh classes	256.5*	1
No. of trees carrying/not carrying 0,1 and $>1$ lianas Vs trees in 10-30 cm and $>30$ cm gbh classes	204.74*	2

\* $P < 0.05$

$P < 0.05$ ). Lianas categorized into 1-3 cm dbh and  $>3$  cm dbh classes showed significant difference in their occurrence on two gbh classes (10-30 cm and  $>30$  cm) of trees; the  $>3$  cm dbh lianas had a significantly higher proportion of occurrence on  $>30$  cm gbh trees ( $P < 0.01$ ; Table 9). Mann-Whitney 't' test revealed a significant difference in trees carrying lianas categorized into smooth and rough bark types ( $U_{7,7} = 39 > 38$ ,  $P < 0.05$ ). Further, the three dimensional contingency table, in which both the two tree size classes and bark types (smooth and rough) were included as interactive variables, revealed a significant difference ( $\chi^2_{(1)} = 136.9$ ,  $P < 0.05$ ).

## Discussion

### *Liana diversity and distribution*

The presence of 21-27 liana species ( $\geq 1$  cm dbh) out of the total 47-62 woody species (trees+lianas) at the 1 ha scale of the presently studied four inland tropical dry evergreen forest sites, and 24-28 liana species  $\text{ha}^{-1}$  (total 50-59 woody species) in four comparable coastal dry evergreen forests (Reddy & Parthasarathy 2003) projects the liana life-form to be an important component of peninsular Indian dry evergreen forests. These figures are comparable to the dry rainforest in Hunter Valley, New South Wales which contained 27 liana species  $\text{ha}^{-1}$  having  $\geq 1$  cm dbh (Chalmers & Turner 1994). In central American dry forests liana species richness ranged 10-21 species at 0.1 ha scale (Gillespie 2000), and in Mexican dry forests, Lott *et al.* (1987) enumerated 8-22 liana species (2.5 cm dbh) within 0.1 ha. However, a direct comparison of liana inventories is complicated because of the lack of uniformity in sampling methods and diameter threshold considered. The dry evergreen forests of peninsular India harbor a moderate species richness of 5-8 liana species at 0.1 ha scale when compared to the above referred neotropical dry forests.

Tropical forests show considerably varying liana density (Gentry 1991a) and lianas tend to occur in high abundance among tree fall gaps (Hegarty & Caballe 1991) and forest margins (Williams-Linera 1990). Besides, anthropogenic disturbances influence liana diversity because lianas with different competitive abilities might

partition the heterogeneous resources that result from a disturbance (Schnitzer & Bongers 2002). In the presently studied dry evergreen forests, where few liana species dominate, liana species richness seems to be influenced by the prevailing disturbance level of a given site. Site MM contained greater number of larger diameter lianas ( $>3$  cm dbh) than the other sites and top five species constituted 78% of total density. These big lianas are prominent in the forest, and a few tree-tops are heavily loaded with them. Although the site SP was the most species-rich and nine species had high abundance compared to other sites, maximum number of lianas remained within small diameter class (1-3 cm dbh). Thus, SP and MM exhibit a holistic picture of inland dry evergreen forests, wherein due to a differential disturbance regime (possibly in addition to other variables such as soil, forest height etc.) the same liana species occurred but in different size classes and abundance levels. The changes in the dispersion pattern of major liana species (from clumped to apparent clumped pattern) across the four study sites reflect the varied abundance and the effects of disturbance at species level (Table 4). Thus, the differences in liana abundance and their dbh distribution can be attributed to disturbance gradient and liana species preference as well as their ability in utilizing a mosaic of undisturbed and disturbed areas in the forest.

Out of the 3 to 5 predominant lianas at the present study sites, *Combretum albidum* was consistently dominant in all the four sites, contributing 28% of all liana stems, owing to its ability to reproduce both vegetatively (by ramets) and by seeds, as also observed for the liana *Machaerium cuspidatum* at Yasuni in both terra firma and flood plain habitats (Burnham 2002). Similarly, *Maripa panamensis* (11%) in central Panama (Dewalt *et al.* 2000) and *Tynanthus schumannianus* (8.5%) in eastern Bolivia (Perez-Salicrup *et al.* 2001) constituted the predominant liana species at the landscape level.

This type of prominent distribution by a single species in a given site indicates the species' ability to utilize available resources. In the studied dry evergreen forests Combretaceae, Papilionaceae, Asclepiadaceae, Apocynaceae

and Menispermaceae were the well represented liana families, while in New South Wales dry forest Vitaceae, Apocynaceae, Leguminosae and Menispermaceae formed the most dominant families (Chalmers & Turner 1994). Bignoniaceae, Asclepiadaceae, Leguminosae and Combretaceae formed the common liana families in neotropical dry forests (Castellanos *et al.* 1989; Gentry 1995; Wikander 1984) implying a low floristic similarity at the family level. Presence of 20% wind dispersed liana species and 60% of animal dispersed species in our dry evergreen forests shows a similarity with the Paleo-tropics where 24-30% species were wind dispersed, while in neotropical dry forests nearly 80% of lianas are reported to be wind dispersed (Gentry 1991b).

#### *Liana distribution on host trees*

Among the available tree-liana studies in peninsular Indian tropical forests, the observed 63.8% of trees supporting lianas in the present study is on the higher side, when compared to 53% trees acting as hosts for lianas in the coastal dry evergreen forests of India, 28% of trees carrying lianas in the tropical wet evergreen forest of Anamalais (Muthuramkumar & Parthasarathy 2001), and 16% of trees doing so in Agumbe (Padaki & Parthasarathy 2000). This can be partly explained by the high liana density. Among several studies on tree-liana interactions including those of the South America - the Venezuelan forests (Putz 1983), Bolivian liana forest (Perez-Salicrup *et al.* 2001) and Bolivian dry forest (Carse *et al.* 2000) reveal that 42%, 86% and 78%, respectively, of trees carried lianas. In south-east Asia, 51% trees in Lambir National Park (Putz & Chai 1987), 57% in lowland Dipterocarp forest, Sabah (Campbell & Newbery 1993) and 46% in La Selva tropical wet forest (Clark & Clark 1990) supported lianas, while in Barro Colorado Island (BCI), Panama 49% (Putz 1984) and in Australian dry rainforest 27% (Chalmers & Turner 1994) of trees carried lianas. Thus, the proportion of trees carrying lianas indicates no marked difference between low gbh and short-statured nature of trees of tropical dry evergreen forests, and those of the largely tall-statured large diameter trees of rainforests in supporting lianas.

The degree of liana infestation on trees has been related to a number of tree morphological characteristics. Tree with big leaves, smooth bark, dense crown, large diameter and tall branch-free bole height usually tend to avoid lianas; while small leaves, rough bark, uneven canopy and prior presence of liana(s) (Campbell & Newbery 1993; Putz 1984) make trees more vulnerable to climber colonization. Notably, in our sites *Albizia amara* (with smooth bark and less dense canopy) and *Manilkara hexandra* (with rough bark and dense crown) recoded high infestation rates. While the most dominant tree *Memecylon umbellatum* and *Glycosmis pentaphylla* with their smooth bark and occurrence in lower-storey remained the least preferred hosts. In the inland dry evergreen forest, the proportion of trees that supported lianas increased with tree gbh class as also reported by Nabe-Nielsen (2001) at Yasuni, Ecuador, while the lack of a definite relation with mean branch-free bole height of trees can be assigned to the narrow range of mean bole heights of trees (1-3 m) and the overall short-stature of the dry evergreen forests. That rough-barked trees supported lianas in higher proportion in this study is in conformity with the report of Carsten *et al.* (2002) in Queensland rainforest. Thus, host tree morphological features as well as forest stature seem to influence the host trees' support for lianas in Indian forests.

All trees which are strong enough to support liana mass can be a potential trellis for lianas (Putz 1984). The modal frequency number of lianas, i.e., 'one' suggests the adequacy of trellis availability in the forests. While the presence of significant difference in liana infestation rates and mean liana load between trees of the two gbh classes (10-30 cm and >30 cm) indicates that lianas utilize smaller trees as succession path way to ascend on to the larger canopy trees. The lianas which take support of >30 cm gbh trees have a chance to increase their girth increment, as well as to form trellis for other lianas to climb upon to forest canopies leading to their aggregation - *albeit* to a lesser degree; may be that lianas in our forests are able to project their photosynthetic canopy leaves in appropriate position in the canopy within the horizontal spread on even canopies of two to

three trees. Thus, an array of tree traits, site attributes as well as liana size class distribution appear to influence liana infestation, and a combination of these factors seems to determine the degree of liana aggregation in tropical dry evergreen forests.

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