



## Research article

## Assessment of liana diversity and carbon stock in differently disturbed tropical dry evergreen forests of southern India

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**Abstract:** Lianas are important components of tropical forests that play a crucial role in forest dynamics. We investigated biodiversity and carbon stock of lianas in two tropical dry evergreen forest (TDEF) sites, the relatively undisturbed Sendhirakillai (SK) and disturbed Palvathunnai (PT) by establishing one-hectare plot in each site. All lianas  $\geq 1$  cm diameter (measured 1.3 m from rooting point) and trees  $\geq 10$  cm girth (measured at 1.3 m from ground) were enumerated to ascertain species richness and stem density of lianas and trees with respect to site disturbance. Liana diversity totaled 24 species (16 in SK and 20 in PT) in the two studied sites. Liana density totaled 1182 individuals ( $744 \text{ ha}^{-1}$  in SK and  $438 \text{ ha}^{-1}$  in PT). Fifty percent of species were shared between the two sites. A considerable variation in the density, dominance and basal area of different species was found between the sites. No dominant family was common to both the sites. Stem twining and zoochory was predominant in both disturbed and undisturbed sites. Lianas comprised 36.4% (SK) & 48.8% (PT) of the total woody species richness (lianas + trees) and 37% (SK) and 38.3% (PT) of the total woody species density. The mean aboveground biomass and carbon stock of lianas were  $7.2 \text{ Mg ha}^{-1}$  and  $4.5 \text{ Mg ha}^{-1}$ , accounting for 1.94% of total woody species community (trees + lianas). The aboveground biomass and carbon stocks were highest in undisturbed site SK compared to disturbed site PT. The extent of liana diversity and their contribution to the total woody plant abundance and biomass highlight the importance of lianas in forest functioning, dynamics and mitigating climate change. Considering the biodiversity TDEFs hold and the current level of human disturbance, a holistic approach in conservation is emphasized.

**Keywords:** Liana - Biomass - Disturbance - Wood specific density - Allometric equation - Woody species diversity - Conservation.

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### INTRODUCTION

Lianas (woody climbers) represent one of the dynamic life-forms, which are prominent and abundant throughout the world but they are more conspicuous and characteristic in tropical forests of three continents (Tropical America, Africa and Asia), having high taxonomic diversity and species richness (Gentry 1991, Schnitzer & Bongers 2002, Mascaro *et al.* 2004). Like other life-forms, these woody plant climbers germinate at the ground, root permanently in soil and possess the capacity to climb host plants (trees) by their specialized climbing structures to reach the forest canopy (Gerwing 2004). Lianas have relatively little structural support and typically have a very high canopy, stem biomass ratio, resulting in a higher proportion of assimilating biomass than other woody plants (Schnitzer & Bongers 2002).

Lianas comprise up to 35% of species diversity and between 10%–45% of total woody stem density (Gentry 1991, Senbeta *et al.* 2005, Addo-Fordjour *et al.* 2009a, DeWalt *et al.* 2015). They contribute about 10% of tropical forests aboveground biomass due to their thin stems and low wood density with up to 30 % of total aboveground biomass in liana-dense areas (DeWalt & Chave 2004) that help in the ramification of tropical forest dynamics and functions (Schnitzer & Bongers 2002). Lianas have potential to reduce aboveground carbon

storage by up to 50 % (Duran & Gianoli 2013). Although lianas account for less than 10% of total woody species biomass they contribute up to 40% of forest leaf biomass and canopy leaf cover (Putz 1984, Rodriguez-Ronderos *et al.* 2016).

Lianas can rapidly colonize the open habitats such as canopy gaps, forest edges and clearings in the forests that provide more light for their growth and proliferate in heavily disturbed areas (Putz 1984, Laurance *et al.* 2001). Lianas depend on trees to support their biomass and compete for both above and below ground for resources. Trees with heavy liana loads often show decreased growth and increased mortality, reduced biomass, fecundity (Kainer *et al.* 2006) and survivorship. It is estimated that lianas could reduce tree growth as much as 84% and increase tree mortality risks by two to three folds (van der Heijden *et al.* 2013). They act as key ecological components of the whole forest in transpiration, carbon sequestration and forest regeneration.

With the exacerbation of forest fragmentation, natural and anthropogenic disturbances and global environmental changes, an increase in liana abundance and biomass are witnessed across all tropical regions (Wright *et al.* 2004, Schnitzer & Bongers 2011) which will consequently influence forest structure and composition, and functions especially carbon sequestration potential. For example in the seasonal tropical rainforests of Panama, liana biomass and abundance have been increasing over the past 40 years (Ingwell *et al.* 2010). Moreover, reduction in forest-level carbon in the presence of lianas was also found (van der Heijden *et al.* 2015), as lianas themselves do not seem to compensate for the loss in tree biomass that they cause (Roels 2016).

Evidences are still accumulating about the effect of disturbance on liana community. Some studies suggest that density, abundance and biomass of lianas increase with an increase in disturbance (Schnitzer & Bongers 2011) and sometimes liana basal area and aboveground biomass also depend on the structural characteristics of the forest and physical environment (van der Heijden & Phillips 2008). Moreover a significant increase in human disturbance by various means especially logging lead to a reduction in liana abundance (Addo-Fordjour *et al.* 2008). It is also reported that liana density and basal area are positively related to disturbance particularly on the local scale (Putz 1984) and frequently correlated with trees having low basal area and wood density (Laurance *et al.* 2001).

Similar to many tropical forest ecosystems, lianas form one of the major structural components of tropical dry evergreen forest (TDEF) in India. As per the recent reports (DeWalt *et al.* 2015), TDEFs are one of the liana-dense forests in Asian tropics. Although there are studies carried out in TDEFs on lianas, an integrated research on liana diversity and their contribution to woody species abundance and carbon stocks are negligible. And many researchers quantified the biomass and carbon stock potential of trees in tropics but lianas have got very less importance and there exist very few studies. Hence, this study is aimed at investigating liana biodiversity, carbon stock, and its share to total woody species abundance and biomass in selected tropical dry evergreen forests experiencing varied disturbance regimes.

## MATERIALS AND METHODS

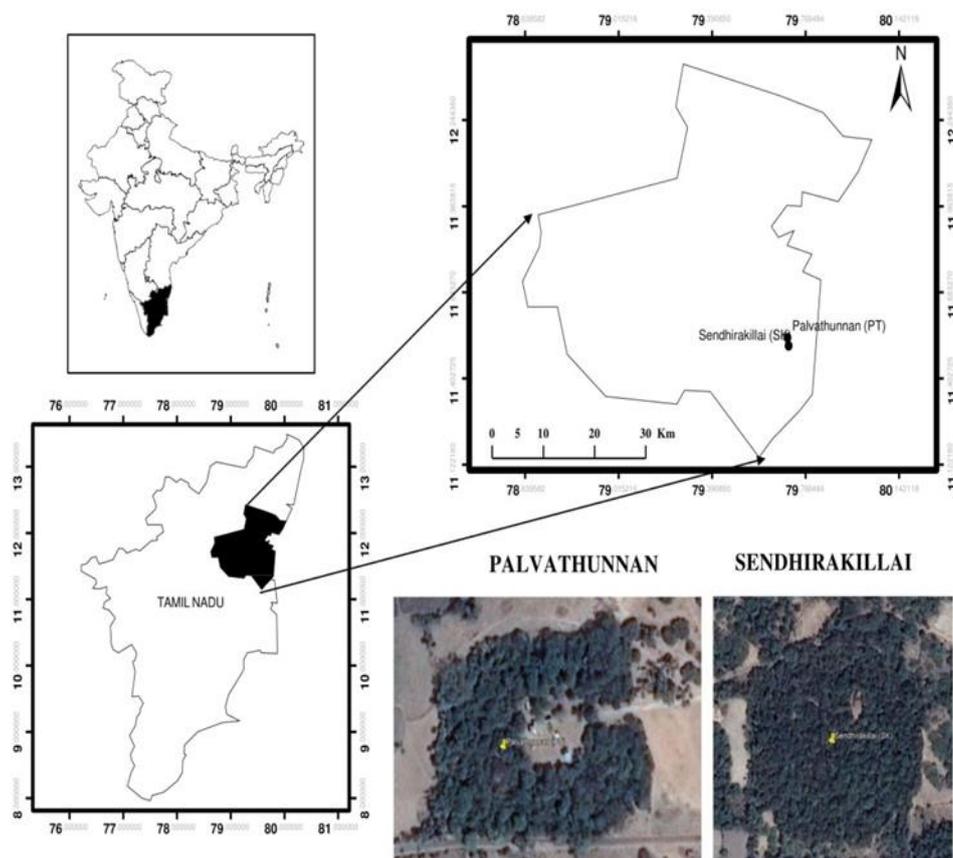
### Study area

**Table 1.** Characteristics of two tropical dry evergreen forest sites on the Coromandel Coast of India. [Climate data source: Meteorological observatory, Cuddalore, Tamil Nadu, India]

Variable	Study area	
	Sendhirakillai (SK)	Palvathunnan (PT)
Location (Lat. & Long.)	11° 30' 07" N 79° 41' 49" E	11° 31' 58" N 79° 41' 51" E
Forest area	3 ha	1.4 ha
Mean annual rainfall	1184 mm	1184 mm
Mean annual temperature	28.85°C	28.85°C
Soil	Alluvial; sandy loam	Alluvial; sandy loam
Distance to human settlement	~100 m	~300 m
Forest stature	Tall (~ 8 m); 3-layered	Short (~ 5 m); 2-layered
Disturbance level	Relatively Undisturbed (Score- 13)	Much disturbed (Score- 30)

Two 1-ha plots were surveyed for liana species in two tropical dry evergreen forest sites Sendhirakillai (SK) and Palvathunnan (PT) located in Cuddalore district ( lat. 11° 44' 40.91"N and long. 79°46' 4.87"E) of Tamil Nadu, south India (Fig. 1; Table 1). These sites are situated at 54 km south of Puducherry town on the Coromandel Coast. Though the inter-site distance is 6 km, the two study sites are unique in terms of dominant woody species, forest stature, level of disturbance and cultural aspects. These are sacred groves and encompass temples within the forest and protected by the local communities. Both the study sites are prone to varying level

of anthropogenic disturbances (Table 1). The climate here is tropical dissymmetric with heavy rains received during north-east monsoon followed by dew formation for six months (mid-October to mid-March) and then a little inconsistent rainfall during south-west monsoon (Parthasarathy *et al.* 2008). The mean number of rainy days in the annual cycle is 55.5. Both the sites' vegetation is characterized as tropical dry evergreen forest [TDEF; Type 7/CI of Champion & Seth (1968)] which is short-statured, 2- to 3- layered form, tree-dominated, liana-dense with sparse ground flora (Parthasarathy *et al.* 2008).



**Figure 1.** Map showing the location of study sites (SK- Sendhirakillai; PT- Palvathunnan) along the Coromandel Coast in Tamil Nadu state of India and the Google earth image of SK and PT sites.

#### Field inventory

Two 1-ha plots, one in each study site were entrenched. Each one hectare plot was further subdivided into one-hundred 10 m × 10 m quadrats to facilitate liana species inventory. All lianas  $\geq 1$  cm diameter (measured 1.3 m from rooting point) were enumerated systematically within the 10 m × 10 m quadrat. All trees  $\geq 10$  cm girth (measured at 1.3 m from ground) were also enumerated to ascertain lianas' share to total woody richness (trees + lianas), density and carbon stock. In the case of trees with multi-stems, their girth was measured separately and the basal area was calculated and added up. The specimens were identified on site and using regional flora (Gamble & Fisher 1915–1935), then cross-checked with herbarium lodged in the Department of Ecology and Environmental Sciences, Pondicherry University. The climbing mechanism and dispersal mode of liana species were noted down.

Human disturbance was determined for both the sites SK and PT, and the disturbance score was calculated using standard protocol (Veblen *et al.* 1992), with modifications (Mani & Parthasarathy 2005) by on-field observations and also by participatory rural appraisal tools. The scores were summed up to validate the level of disturbance in both the sites. High scores indicate the high level and low score signifies a low level of disturbance.

#### Data analysis

Diversity indices (Shannon, Simpson index and Fisher's) were computed using PAST 3.1 software (version 3.1; Øyvind Hammer, Natural History Museum, University of Oslo) (Naveenkumar & Sundarapandian 2018). The modified importance value index (IVI) and family importance value (FIV) were calculated (Mori *et al.* 1983). The diameter values were considered to calculate aboveground and belowground biomass (AGB, BGB).

Liana contribution to the forest structure was determined by calculating the ratios of woody species (trees + liana) richness and density as well.

Liana above ground biomass was estimated following allometric equation developed by Schnitzer *et al.* (2006):

$$AGB = \exp [- 1.484 + 2.657 \ln (D)]$$

Where, D is the liana diameter

Tree aboveground biomass was estimated following allometric equation provided by Chave *et al.* (2005) using two variables, wood specific density (WSD) and diameter:

$$AGB_{est} = \rho \times \exp (-1.499 + 2.148 \ln (D) + 0.207(\ln (D))^2 - 0.0281(\ln (D))^3)$$

Where, D is the diameter of tree species and  $\rho$  is their wood specific density (WSD)

The WSD of each tree species was obtained from the global wood database (Zanne *et al.* 2009) and the available literature (Mani & Parthasarathy 2007). The woody species for which wood specific density value was not available; a generalized allometric equation (Pearson *et al.* 2005) was used using D as the only variable.

The belowground biomass for both the life-forms was determined by multiplying aboveground biomass with 0.26 (IPCC 2003) and the carbon stock (CS) was computed to be 50% of the total biomass (AGB+BGB) (IPCC 2005).

The liana diversity data of the present two sites were compiled with the data of eighteen other tropical dry evergreen forest sites (Parthasarathy *et al.* 2015) to compare liana richness, density, basal area and carbon stock against disturbance. The scores that had 1–9 designated as undisturbed sites (UND), 10–18 as relatively undisturbed (RUD), 19–27 as moderately disturbed (MOD), and 28–36 as heavily disturbed (HD) (Table 5). A simple regression was performed to test the relationship between the disturbance score with the liana species richness, tree density, and basal area.

## RESULTS

### Liana diversity

A total of 1182 liana individuals (stems  $\geq 1$  cm dbh), that belonged to 24 liana species, 22 genera and 18 families were inventoried in two tropical dry evergreen forest sites SK and PT (Table 2). The mean species richness was 18 species per one-hectare plot. Site PT had greater liana species richness (20 species, 18 genera and 14 families) than site SK (16 species, 15 genera and 13 families; Table 2). Twelve species (50%) were common to both the sites. The diversity indices varied between the two sites and the values increased with increase in site disturbance (Table 2).

**Table 2.** Summary of liana diversity inventory in two tropical dry evergreen forest sites (SK- Sendhirakillai; PT- Palvathunna) on the Coromandel Coast of India.

Variable	Study site		Total for 2 ha (average)
	SK	PT	
Species richness (number ha <sup>-1</sup> )	16	20	24 (18.00)
Number of genera	15	18	22 (16.50)
Number of families	13	14	18 (13.50)
Liana contribution to total woody species (trees + lianas) richness (%)	36.4	48.8	
Liana density ( stems ha <sup>-1</sup> )	744	438	
Liana contribution to total woody species (trees + lianas) density (%)	37	38.3	1182
Basal area (m <sup>2</sup> ha <sup>-1</sup> )	1.007	0.506	1.50 (0.75)
<i>Diversity indices</i>			
Shannon index	1.99	2.22	
Simpson index	0.81	0.86	
Fisher's alpha	2.88	4.32	

### Liana density, dominance and basal area

The density, dominance and basal area of different liana species varied between the two study sites. Less disturbed site SK harbored more than one and a half times greater liana density (744 individuals) and basal area (1.007 m<sup>2</sup> ha<sup>-1</sup>) than heavily disturbed site PT (438; 0.506) (Table 3). Site SK was dominated by *Strychnos lenticellata* (Dennst.) S.Hill with 240 individuals (32% of total liana stems) followed by *Reissantia indica* (Willd.) Halle (164; 22%), *Tinospora cordifolia* (Willd.) J.D.Hook.& Thoms. (79; 10%) and *Combretum albidum* G.Don (74; 9.9%), whereas site PT was dominated by *Coccinia grandis* (L.) Voigt (97; 22%) followed

by *Tinospora cordifolia* (73; 16%), *Grewia rhamnifolia* Heyne ex Roth (68; 15.5%) and *Pachygone ovata* (Poir.) Miers ex Hook. (68; 15.5%) (Table 3). Among these dominant species *Tinospora cordifolia* was found in both the sites. The dominant species accounted for a remarkable share of 75% of total stems and 79% of total basal area in site SK; while in site PT they made up to 70% of total stems and 56.4% of total basal area. Interestingly, the two highest contributors in terms of density and basal area namely *Strychnos lenticellata* and *Combretum albidum* at site SK were not represented in site PT.

**Table 3.** List of liana species enumerated in two tropical dry evergreen forest sites (SK- Sendhirakillai; PT- Palvathunnan), with their stem density, important value index (IVI), aboveground biomass (AGB) in kg, carbon stock (CS) in kg, climbing mechanism (CM), and dispersal mode (DM).

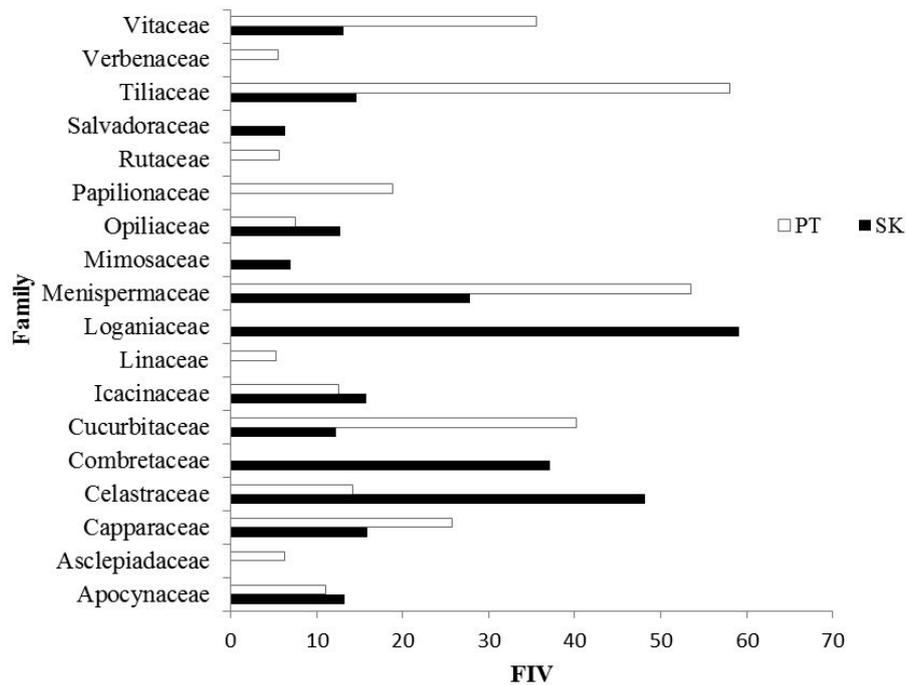
Species	Family	CM	DM	SK				PT			
				Density	IVI	AGB	CS	Density	IVI	AGB	CS
<i>Acacia caesia</i> (L.) Wild.	Mimosaceae	SA	AU	1	1.16	73.73	46.45	0	0	0.00	0.00
<i>Aganosma cymosa</i> (Roxb.) G.Don var. <i>cymosa</i> Hook. f.	Apocynaceae	ST	W	2	0.89	0.54	0.34	3	2.19	1.23	0.77
<i>Azima tetracantha</i> Lam.	Salvadoraceae	SA	A	1	0.46	0.56	0.35	0	0	0.00	0.00
<i>Cansjera rheedii</i> Gmel.	Opiliaceae	ST	A	30	14.73	198.03	124.76	4	3.46	51.51	32.45
<i>Capparis brevispina</i> DC.	Capparaceae	SA	A	3	1.83	41.55	26.18	1	0.81	1.96	1.23
<i>Capparis zeylanica</i> L.	Capparaceae	SA	A	11	5.81	93.10	58.65	26	22.58	485.98	306.17
<i>Carissa spinarum</i> L.	Apocynaceae	SA	A	3	1.40	3.18	2.00	1	0.77	1.38	0.87
<i>Cayratia pedata</i> (Lam.) Juss.ex Gagnep.	(Vitaceae)	TC	A	0	0	0.00	0.00	2	1.45	0.68	0.43
<i>Cissus quadrangularis</i> L.	Vitaceae	TC	A	0	0	0.00	0.00	5	3.78	5.39	3.39
<i>Cissus vitiginea</i> L.	Vitaceae	TC	A	23	11.63	387.05	243.84	23	24.85	666.45	419.87
<i>Coccinia grandis</i> (L.) Voigt	Cucurbitaceae	TC	A	23	10.55	91.41	57.59	97	56.24	199.49	125.68
<i>Combretum albidum</i> G.Don	Combretaceae	ST	W	74	45.85	2994.98	1886.84	0	0	0.00	0.00
<i>Derris scandens</i> (Roxb.) Benth.	Papilionaceae	ST	AU	0	0	0.00	0.00	4	15.28	1434.90	903.99
<i>Grewia rhamnifolia</i> Heyne ex Roth	Tiliaceae	SU	A	14	14.08	993.76	626.07	68	67.8	1804.82	1137.04
<i>Hugonia mystax</i> L.	Linaceae	HC	A	0	0	0.00	0.00	1	0.77	1.17	0.74
<i>Lantana camara</i> L.	Verbenaceae	SA	A	0	0	0.00	0.00	2	1.48	1.04	0.65
<i>Leptadenia reticulata</i> (Retz.) Wight & Arn.	Asclepiadaceae	ST	AU	0	0	0.00	0.00	4	2.72	9.43	5.94
<i>Pachygone ovata</i> (Poir.) Miers ex Hook.	Menispermaceae	ST	A	10	3.37	29.26	18.43	68	32.37	202.97	127.87
<i>Pyrenacantha volubilis</i> Wight	Icacinaceae	ST	A	66	20.01	28.61	18.03	30	15.73	12.64	7.97
<i>Reissantia indica</i> (Willd.) Halle	Celastraceae	SU	W	164	67.99	2229.26	1404.43	23	15	123.17	77.59
<i>Strychnos lenticellata</i> (Dennst.) S.Hill	Loganiaceae	ST	A	240	78.48	1897.86	1195.65	0	0	0.00	0.00
<i>Tinospora cordifolia</i> (Willd.) J.D.Hook. & Thoms.	Menispermaceae	ST	A	79	21.77	206.41	130.04	73	30.27	109.69	69.11
<i>Toddalia asiatica</i> (L.) Lam.	Rutaceae	SA	A	0	0	0.00	0.00	2	1.65	4.93	3.11
<i>Trichosanthes tricuspidata</i> Lour.	Cucurbitaceae	TC	A	0	0	0.00	0.00	1	0.73	0.40	0.25

**Note:** SA- Scrambler-armed; ST- Stem twinner; TC- Tendril climber; SU- Scrambler-unarmed; HC- Hook climber; A- Animal; W- Wind; AU- Autochorus.

#### Importance value index (IVI) and family importance value (FIV)

In site SK, *Strychnos lenticellata* with an IVI of 78.48 was the most important species whereas *Grewia rhamnifolia* (IVI – 67.8) was the most important species in site PT. Nine families (50%) were common to both the study sites and four families were exclusive to site SK and five families were exclusive to site PT. The three dominant and important families in terms of density and FIV were Loganiaceae, Celastraceae and Combretaceae

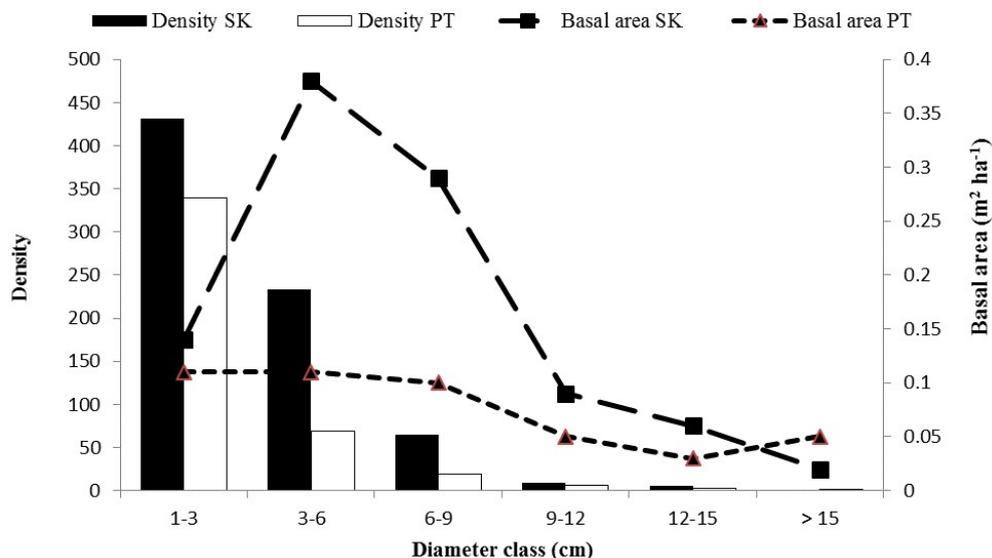
in site SK, while in PT Menispermaceae, Cucurbitaceae and Tiliaceae were the most dominant families (Fig. 2). The Menispermaceae was taxonomically diverse and formed the most speciose family, represented by two genera and two species each in both the sites. The three dominant families contributed 64.2% of total liana stems and 75.4% of the total basal area in site SK, while in PT they contributed 70% of total stems and 55.4% of the total basal area.



**Figure 2.** Family importance value (FIV) of liana families in two tropical dry evergreen forest sites (SK- Sendhirakillai; PT- Palvathunnan).

*Diameter class distribution of lianas*

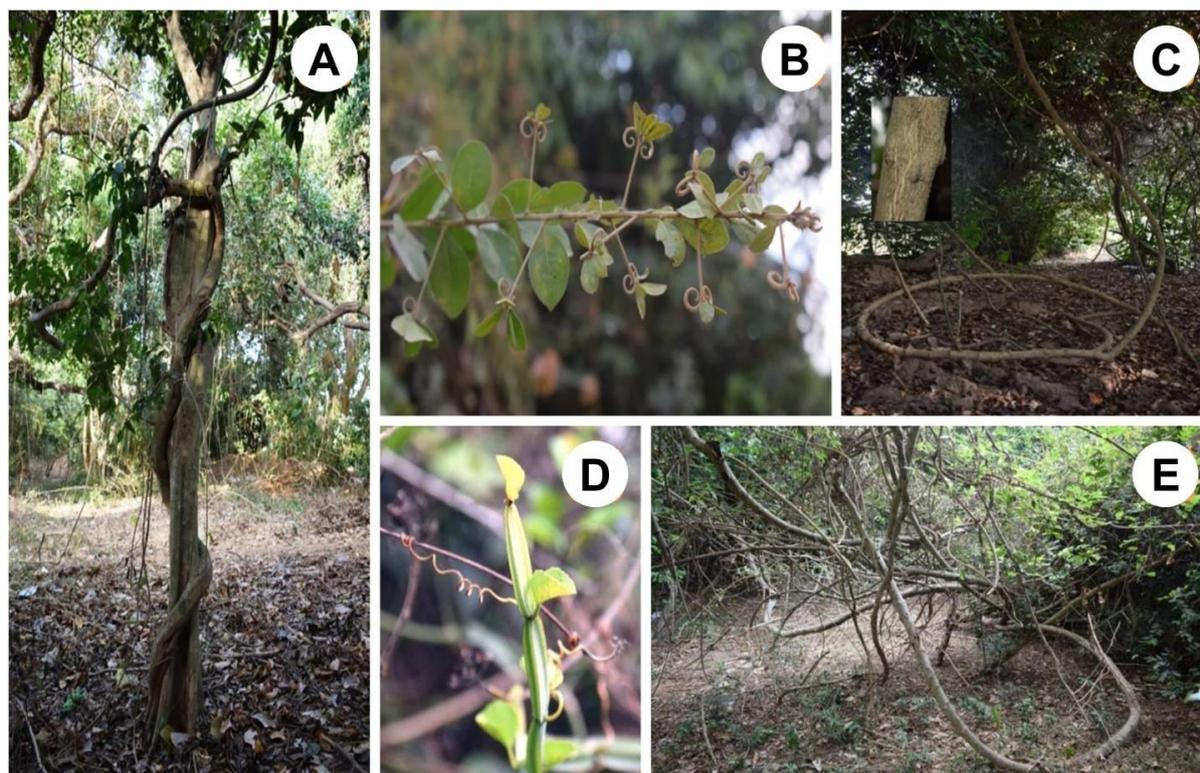
In both the sites liana density decreased with increase in diameter class. In less disturbed site SK, 89 % of liana density was contributed by 1–6 cm dbh class and 58% of liana stems were restricted to the lowest diameter class of 1–3 cm. The lower and middle diameter classes (1–3 cm and 3–6 cm) contributed 13.9% (0.14 m<sup>2</sup> ha<sup>-1</sup>) and 37.7% (0.38 m<sup>2</sup> ha<sup>-1</sup>) to their respective total basal area. In the highly disturbed site PT, 93.4% of liana density fell within 6 cm dbh and 77.6% of liana individuals were represented in the lowest diameter class 1–3 cm. The lower and middle diameter classes (1–3 cm and 3–6 cm) contributed 21.73% (0.11 m<sup>2</sup> ha<sup>-1</sup>) respectively, to their total basal area. The density of large lianas (≥ 6 cm) was maximum in less disturbed site SK (with 80 stems) than the highly disturbed site PT (with 29 stems). In the highest diameter class (>15 cm), basal area was notably higher in site SK than PT (Fig. 3).



**Figure 3.** Liana density and basal area by diameter classes in two tropical dry evergreen forest sites (SK- Sendhirakillai; PT- Palvathunnan).

*Climbing mechanisms and dispersal modes*

Among the 24 liana species recorded in the two study sites, four climbing mechanisms (Fig. 4) and three dispersal modes were identified (Table 3). Stem twining was predominant in both the sites in terms of richness (7 species) and density (67.3% of total density in SK and 42.6% in PT); whereas in terms of richness alone, both stem twiners and scramblers were dominant (Table 3). The highly disturbed site PT had a higher proportion of species richness (6 species) and density (29%) of tendrill climbers than the undisturbed site SK (2 species; 6%). The lone hook climber *Hugonia mystax* L. was found only in the disturbed site PT. Zoochory was predominant over autochory and anemochory in both the sites. At site SK, 75% (12 species) of lianas are dispersed by animals followed by wind dispersed (18% - 3 species) and self dispersed (6% - 1 species). At PT, the proportion of lianas with wind and self dispersed diaspores are similar to site SK (3 and 1 species), but the number of lianas dispersed by animals are greater (80% -16 species) than PT. (Table 3).



**Figure 4.** Climbing mechanisms possessed by lianas in two tropical dry evergreen forests (SK- Sendhirakillai; PT- Palvathunnan): **A**, Stem twiner - *Strychnos lenticellata* - anti-clockwise twining around *Drypetes sepiaria* (host tree); **B**, Hook climber - *Hugonia mystax* with paired hooks; **C**, Armed scrambler - Stem of *Capparis zeylanica* with recurved thorn from bullate base; **D**, Tendril climber - Spirally coiled tendrils of *Cissus quadrangularis*; **E**, Unarmed scrambler - multiple stems of *Grewia rhamnifolia*.

**Table 4.** Basal area (BA), aboveground biomass (AGB), belowground biomass (BGB), total biomass (TB) and carbon stock (CS) of trees and lianas in two tropical dry evergreen forest sites on the Coromandel Coast of India.

Variable	Study site	
	Sendhirakillai	Palvathunnan
<i>Basal area (m<sup>2</sup> ha<sup>-1</sup>)</i>		
Trees	33.33	27.62
Lianas	1.007	0.506
<i>AGB (Mg ha<sup>-1</sup>)</i>		
Trees	386.33	358.66
Lianas	9.26	5.14
<i>BGB (Mg ha<sup>-1</sup>)</i>		
Trees	100.52	93.25
Lianas	2.41	1.33
<i>Biomass (Mg ha<sup>-1</sup>)</i>		
Trees	487.15	451.91
Lianas	11.67	6.47
<i>Carbon Stock (Mg ha<sup>-1</sup>)</i>		
Trees	243.57	225.95
Lianas	5.84	3.24

### Liana share to woody-plant community

Lianas contributed 36.4% (SK) and 48.8% (PT) to the overall woody species richness (trees + lianas) and 37% (SK) and 38.3% (PT) to the overall woody species density (Table 4). Whereas lianas added just 2.93 % (SK) and 1.8% (PT) to the total woody-plant basal area. Site SK registered highest liana contribution to total woody-plant aboveground biomass and carbon stock (2.36%), while site PT registered the lowest (1.41%) (Table 4).

### Above ground biomass (AGB) and carbon stock (CS)

The mean AGB and CS of lianas were 7.2 Mg ha<sup>-1</sup> and 4.5 Mg ha<sup>-1</sup>, accounting for 1.94% of total woody species biomass (trees + lianas). The AGB and CS were greater in undisturbed site SK compared to disturbed site PT (Table 4). In site SK the highest contributing species to carbon stock include *Combretum albidum* (1.88 Mg), *Reissantia indica* (1.40 Mg) and *Strychnos lenticellata* (1.19 Mg). Whereas at PT *Grewia rhamnifolia* (1.13 Mg), *Derris scandens* (Roxb.) Benth. (0.90 Mg) and *Cissus vitiginea* L. (0.44 Mg) were the highest contributors. Lianas  $\geq$  10cm diameter represented by 13 individuals accounted for 24.6 % of total AGB in SK and in PT there were 8 stems contributing to 45.8 % of total liana AGB. Notably, in disturbed site PT *Derris scandens* (4 stems) alone contributed approximately 28% to total liana biomass.

## DISCUSSION

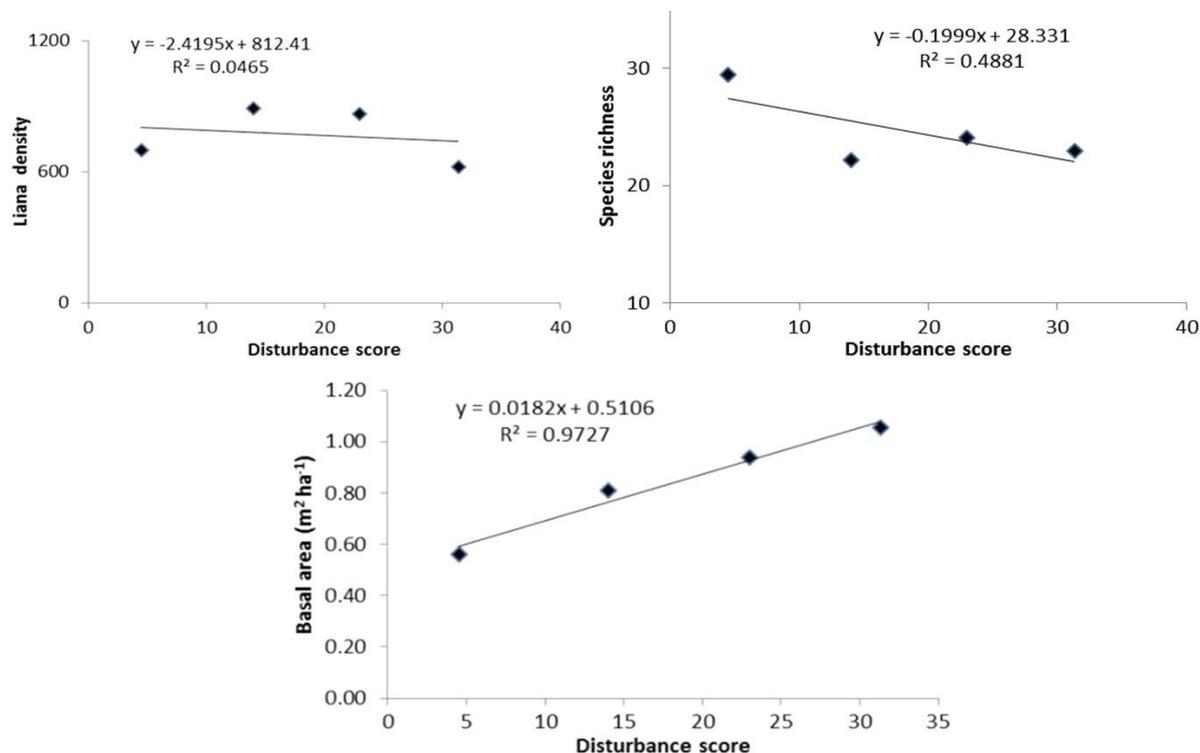
Lianas are considered to be an important life-form in tropical dry evergreen forest sites due to their moderate species richness (11–31 species ha<sup>-1</sup>) and high density (408–1658 stems ha<sup>-1</sup>) (Reddy & Parthasarathy 2003, 2006, Vivek & Parthasarathy 2015a). Besides richness, the density, basal area, carbon stock values were higher in site SK and this difference can be attributed to the uniqueness of the site in terms of forest stature, disturbance level and human pressure (Table 1) and the presence of larger trees which supported large lianas ( $\geq$  6cm) and thus greater diameter and basal area (Reddy & Parthasarathy 2006).

Comparative analysis of lianas at 1-ha scale for stems  $\geq$  1 cm diameter inventoried in a total of 20 TDEF sites revealed that species richness, density, basal area, carbon stock and set of dominant species varied across the sites (Table 6), indicating that, no two sites can be considered as replicas. However, *Strychnos lenticellata* was an exception, maintaining its dominance in the maximum number of sites. Across the 20 sites, species richness, density, basal area and carbon stock ranged 11–29 species ha<sup>-1</sup>, 408–1658 stems ha<sup>-1</sup>, 0.20–1.76 m<sup>2</sup> ha<sup>-1</sup> and 1.42–33.88 Mg ha<sup>-1</sup>, respectively, and showed averages of 24 species ha<sup>-1</sup>, 820 stems ha<sup>-1</sup>, 0.87 m<sup>2</sup> ha<sup>-1</sup>, and 5.29 Mg ha<sup>-1</sup> respectively. The density and carbon stock contribution by lianas grossly varied as relatively undisturbed sites scored higher species density and carbon stock compared to disturbed sites. However, a high variability is evident within a category, with 408 to 1455 lianas ha<sup>-1</sup>, 1.42 to 24.14 Mg ha<sup>-1</sup> in undisturbed and relatively undisturbed categories and 438 to 835 lianas ha<sup>-1</sup>, 3.24 to 18.46 Mg ha<sup>-1</sup> in heavily disturbed sites. The set of dominant and rare species varied across the 20 sites (Table 6, See Reddy & Parthasarathy 2003, 2006, Vivek & Parthasarathy 2015a). A species rare in one site may be dominant in another site. Why does dominance vary? Innate site variation with a pool of species which occur in a given category of site disturbance, forest structure, and variation in the local ecological setting, edapho-microclimatic conditions and the edge effect could contribute to the prevailing species composition of a site. Sites that are more exposed may harbor a higher proportion of thorny stragglers as is evident at the disturbed PT and other TDEF sites.

Although all the 20 sites fall under the same forest type- TDEF, the stature, set of dominant tree species, tree density variation, soil sub-type and the extent of human disturbance including edge effect could have contributed to varying liana species composition. Species richness of 20 sites showed a weak negative correlation with disturbance score (Fig. 5). Liana basal area of 20 sites showed a significant positive relationship with disturbance but, density did not show any relation (Fig. 5). This could be ascribed to the presence of large lianas in disturbed forests and removal of small size lianas by the local people as they are easy to cut. Therefore medium and large lianas attain higher stem diameter and contribute to the high basal area. Pandian & Parthasarathy (2016) also found that increasing AGB with an increase in disturbance in four inland tropical dry evergreen forest sites.

Comparison of species richness and density across the tropics is difficult due to the variation in methods used, area sampled and diameter limit considered. At the scale of 0.80 to 1.25 hectare area and for stems  $\geq$  1cm diameter, our results are comparable with the other studies across the tropics (Table 5). An average richness 18 species  $\geq$  1cm diameter ha<sup>-1</sup> in our study sites coincides with the other studies reported from Indian tropics: Western Ghats- 17–23 species 1.08 ha<sup>-1</sup> in two montane evergreen forests (Mohandass *et al.* 2015), 19–22 species ha<sup>-1</sup> in two tropical forests of northeastern India (Barik *et al.* 2015). However, the average liana richness

of this study is much lower than the results obtained from other parts of Asia: India (Muthuramkumar & Parthasarathy 2000, Padaki & Parthasarathy 2000, Muthumperumal & Parthasarathy 2010), South China (Ding & Zang 2009), Africa: Ethiopia (Senbeta *et al.* 2005), Neotropics (Ibarra-Manriquez & Martinez-Ramos 2002, Burnham 2004), Panama (Putz 1984), Australia (Chalmers & Turner 1994) and New Caledonia (Bruy *et al.* 2018). This could be attributed to variation in total forest area (TDEFs occurs as patches), forest type and dynamics, stature, macro and micro-climatic condition, and disturbances by various means (overexploitation of resources, illegal cutting of host plants and lianas and grazing by animals, etc.).



**Figure 5.** The correlation between disturbance score and liana species richness, density and basal area pooled for twenty tropical dry evergreen forest sites on the Coromandel Coast of India.

**Table 5.** Compilation of liana diversity inventories carried out in various selected tropical forests of the world at the unified scale for stems  $\geq 1$  cm dbh.

Forest type	Site location	Area Inventoried	Total number of		Reference
			Individuals	Species	
Dry, mesic and rain forests	New Caledonia	1.08 ha	992	71	Bruy <i>et al.</i> (2018)
Tropical dry evergreen Forest	Cuddalore, Nagapattinam, Pudukottai dist. of Tamil Nadu	10 ha	9237	52	Vivek <i>et al.</i> (2015)
Tropical montane forest	Nilgiri biosphere reserve, India	13.58 ha	1658	33	Mohandoss <i>et al.</i> (2015)
Tropical rain forest	Atewa range Tropical rain forest Reserve	2.5 ha	429	40	Addo-Fordjour <i>et al.</i> (2012)
Tropical lowland forest	Pasoh forest reserve, Malaysia	2.5 ha	1623	167	Nurfazliza <i>et al.</i> (2012)
Lowland tropical forest	Barro Colorado Island, Panama	50 ha	47183	162	Schnitzer <i>et al.</i> (2012)
Tropical lowland forest	Hainan Island	3 ha	1594	70	Ding & Zang (2009)
Tropical evergreen forest	Varagalaia, W.Ghats, India	30 ha	11200	75	Muthuramkumar & Parthasarathy (2000)
Tropical, sub tropical & temperate forests	Eastern himalayayas & N.E. India	94 ha	3586	196	Barik <i>et al.</i> (2015)
Evergreen, semi-evergreen deciduous and thorny type	Six hills, Eastern Ghats	55 ha	32033	143	Muthumperumal & Parthasarathy (2010)

Subtropical wet forest	Puerto Rico	0.8 ha	419	6	Rice <i>et al.</i> (2004)
Tropical rain forest	Yasuni national park, Ecuador	2.4 ha	4348	311	Burnham (2004)
Tropical rain forest	Lacandon, Mexico	1.2 ha	2510	90	Ibarra-Manriquez & Martinez-Ramos (2002)
Tropical rain forest	Albertine rift, Uganda	6 ha	2783	35-62	Eilu (2000)
Rain forest	Lower Hunter valley, Australia	1 ha	520	27	Chalmers & Turner (1994)
Semi-deciduous forest	Barro Colorado Island, Panama	1 ha	3165	65	Putz (1984)

The average density of lianas (591 stems ha<sup>-1</sup>) found in this study is higher than the values obtained from other Indian tropics (Muthuramkumar & Parthasarathy, 2000, Muthuramkumar *et al.* 2006, Mohandas *et al.* 2015, Barik *et al.* 2015.), Asian tropics (Ding & Zang 2009), Neotropics (Burnham 2004) and Australia (Chalmers & Turner 1994). Whereas liana density is slightly lower than some other peninsular Indian sites (Padaki & Parthasarathy 2000, Muthumperumal & Parthasarathy 2010) and two to four-fold lower than the than the results from New Caledonia (Bruy *et al.* 2018), Neotropics (Putz 1984, Ibarra-Manriquez & Martinez-Ramos 2002), Africa (Senbeta *et al.* 2005).

**Table 6.** Comparison of liana species richness, density, basal area and carbon stock (CS) at the unified scale of 1-ha for stems  $\geq$  1cm dbh, and list of top 3 dominant species along with site disturbance scores and categories (UN- undisturbed RUN- relatively undisturbed; MOD- moderately disturbed; HD- heavily disturbed) of various tropical dry evergreen forest sites. (SK- Sendhirakillai; PT- Palvathunna; OR-Oorani; AK- Arasadikuppam; KK- Kuzhanthaikuppam; PP- Puthupet; AP- Araiypatti; KR- Karisakkadu; SP- Shanmuganathapuram; MM- Maramadakki; KA- Karukkai; KT- Kothattai; MK- Manadikuppam; PC1- Point Calimere 1; PC2- Point Calimere 2; PR- Purangani; SL- Silattur, SN- Sunayakadu; SV- Suran Viduthi; VV- Vanniyan Viduthi)

Site code	Species richness	Density no. ha <sup>-1</sup>	Basal are m <sup>2</sup> ha <sup>-1</sup>	CS Mg ha <sup>-1</sup>	Disturbance		Top 3 dominant species	Ref.
					score	category		
SK	16	744	1	5.84	13	RUN	<i>Strychnos lenticellata</i> <i>Reissantia indica</i> <i>Tinospora cordifolia</i>	A
PT	20	438	0.5	3.24	29	HD	<i>Coccinia grandis</i> <i>Tinospora cordifolia</i> <i>Grewia rhamnifolia</i>	A
AK	29	1163	0.58	11.01	19	MOD	<i>Strychnos lenticellata</i> <i>Derris ovalifolia</i> <i>Secamone emetica</i>	B
OR	24	812	1.85	12.96	23	MOD	<i>Strychnos lenticellata</i> <i>Reissantia indica</i> <i>Combretum albidum</i>	B
KK	28	497	1.37	41.85	24	MOD	<i>Combretum albidum</i> <i>Derris scandens</i> <i>Reissantia indica</i>	B
PP	28	835	0.99	3.63	33	HD	<i>Strychnos lenticellata</i> <i>Jasminum angustifolium</i> <i>Gymnema sylvestre</i>	B
AP	26	792	1.09	9.15	13	RUN	<i>Combretum albidum</i> <i>Derris scandens</i> <i>Cissus quadrangularis</i>	C
KR	23	515	0.67	33.88	23	MOD	<i>Combretum albidum</i> <i>Reissantia indica</i> <i>Coccinia grandis</i>	C
SP	27	775	0.44	30.44	26	MOD	<i>Combretum albidum</i> <i>Strychnos lenticellata</i> <i>Jasminum angustifolium</i>	C
MM	21	596	1.68	18.46	32	HD	<i>Combretum albidum</i> <i>Derris scandens</i> <i>Strychnos lenticellata</i>	C
PC1	28	672	0.68	6.56	4	UN	<i>Jasminum angustifolium</i> <i>Carissa spinarum</i> <i>Strychnos lenticellata</i>	D

PC2	31	720	0.44	5.21	5	UN	<i>Carissa spinarum</i> <i>Jasminum angustifolium</i> <i>Zizyphus oenoplia</i>	D
PR	22	919	0.65	6.29	13	RUN	<i>Strychnos lenticellata</i> <i>Hugonia mystax</i> <i>Secamone emitica</i>	D
SN	28	701	0.95	24.14	13	RUN	<i>Combretum albidum</i> <i>Acacia caesia</i> <i>Carissa spinarum</i>	D
MK	11	408	0.20	1.42	15	RUN	<i>Reissantia indica</i> <i>Strychnos lenticellata</i> <i>Combretum albidum</i>	D
SL	25	1213	0.77	8.43	15	RUN	<i>Strychnos lenticellata</i> <i>Combretum albidum</i> <i>Carissa spinarum</i>	D
SV	27	1455	1.06	10.31	16	RUN	<i>Strychnos lenticellata</i> <i>Derris ovalifolia</i> <i>Hugonia mystax</i>	D
VV	20	1658	1.76	26.55	19	MOD	<i>Strychnos lenticellata</i> <i>Reissantia indica</i> <i>Grewia rhamnifolia</i>	D
KA	22	941	0.61	5.77	23	MOD	<i>Strychnos lenticellata</i> <i>Combretum albidum</i> <i>Grewia rhamnifolia</i>	D
KT	20	552	0.23	2.21	27	MOD	<i>Ichnocarpus frutescens</i> <i>Pyrenacantha volubilis</i> <i>Jasminum angustifolium</i>	D

**Note:** Ref.- Reference; A- Present study; B- Reddy & Parthasarathy (2003); C- Reddy & Parthasarathy (2006); D- Vivek & Parthasarathy (2015).

Many studies have confirmed that liana diversity and density have been shown to be higher in disturbed forests than the undisturbed forests (Schnitzer & Carson 2010, Anbarashan & Parthasarathy 2013, Roels 2016) as disturbed forests have the ability to promote liana success by providing more favorable conditions than the less disturbed forests (DeWalt *et al.* 2000, Lawrance *et al.* 2001, Ibarra-Manriquez & Martinez-Ramos 2002). However, in the current study species richness was greater in the disturbed forest supporting the view of the above studies. But, density has shown a reverse trend with high density in undisturbed forest and this is supported by few other studies conducted in tropics (Chittibabu & Parthasarathy 2001, Addo-Fordjour *et al.* 2009a, 2012, Rahman *et al.* 2010).

The diversity indices were higher in disturbed site PT than the undisturbed site SK which is in conformity with the other findings from Indian tropical dry evergreen forests (Anbarashan & Parthasarathy 2013) and Panamanian lowland forests (DeWalt *et al.* 2000). The species composition varied between the two sites indicating that the forest stature and the level of disturbance coupled with micro-environmental conditions within the sites play an important role (Parthasarathy *et al.* 2015). *Tinospora cordifolia* was the only dominant species common to both the sites and that shows its ability to tolerate disturbance. Interestingly the density of top five lianas of both the sites differed with contrasting density values. Though disturbance might be the reason for this variation as it may respond differently to depending on the intensities, there may be different ecological demands and possible habitat associations among the liana species attributed to this change (Yuan *et al.* 2009, Addo-Fordjour *et al.* 2012). The presence of higher tendril climbers and four times higher density of *Coccinia grandis* in disturbed forest attests that site PT is highly disturbed. This is in agreement with the results of Vivek & Parthasarathy 2015a who reported greater abundance of tendril climber in disturbed forests which can also be related to the low canopy height of trees and the extent of forest disturbance (Ding 2006, Parthasarathy *et al.* 2015).

Two species *Strychnos lenticellata* and *Combretum albidum* have ability to exploit site resources and survive in different environmental conditions including disturbed forests (Vivek & Parthasarathy 2015a) but they were not represented in the disturbed site in our study area. One possible reason could be that undisturbed site SK is tall statured with a dense tree canopy which favored the shade tolerant species *Strychnos lenticellata*. This finding is similar to the study conducted in few other tropical dry evergreen forest sites (Anbarashan & Parthasarathy 2013). Another reason could be the vigorous vegetative sprouting capacity and dispersal strategy (Ewango 2010). Even though the distance between the two sites is hardly six km and faunal diversity

particularly of avifauna is high similar species composition could have been expected but what prevents diaspore dispersal/species establishment remains unclear thus ultimately making each TDEF site unique like this. The Menispermaceae was abundant in undisturbed as well as in disturbed sites supporting previous study pointing out that Menispermaceae was one of the dominant families represented in all four disturbance categories (Anbarashan & Parthasarathy 2013).

The diameter class distribution of lianas followed a typical reverse J-shaped curve in both the sites. The small stem lianas were relatively lesser in undisturbed site. Anbarashan & Parthasarathy (2013) also found that undisturbed forests had less small stems than the heavily disturbed forest. The greater number of lianas in small diameter class may be assigned to their extremely slow stem diameter increments by an inverse allocation of resources as compared with trees within the same forest (Muthumperumal & Parthasarathy 2010). But also disturbance contributes to this, by creating gaps where lianas can recruit and proliferate best and therefore lead to a higher abundance of small lianas (Roels 2016).

Stem twining formed the predominant climbing mechanism in terms of richness and density in both the sites, as reported from other tropical forests (Muthuramkumar & Parthasarathy 2000, DeWalt *et al.* 2000, Cai *et al.* 2009, Anbarashan & Parthasarathy 2013, Mastan *et al.* 2015, Vivek & Parthasarathy 2015a, Srinivas & Sundarapandian 2017, Bruy *et al.* 2018). Zoochory formed the most common dispersal mode in both the sites revealing the importance of lianas in providing resources and shelter which can also increase animal population densities. This result coincides with many other studies from Indian tropics (Muthuramkumar & Parthasarathy 2000, Reddy & Parthasarathy 2003, 2006, Anbarashan & Parthasarathy 2013, Vivek & Parthasarathy 2015a) and Asian tropics (Yuan *et al.* 2009). On a comparative basis greater number of liana species are wind dispersed in Neotropics as Bignoniaceae is one of the dominant families whose winged seeds in follicles are wind dispersed which increasing the possibility of circulating to more areas, which might offer the reproductive advantage over other dispersal modes for liana species.

In tropical forests, lianas commonly compose 8–45% of the woody stems (Schnitzer & Bongers 2002, Parthasarathy *et al.* 2004, Schnitzer *et al.* 2006, 2012, DeWalt *et al.* 2015, Addo-Fordjour *et al.* 2016) and 20% of woody stems in dry forests of Central America (Gillespie *et al.* 2000). Lianas in the present study contributed 42.6% to the total woody species density and this is in agreement with other studies (Vivek & Parthasarathy 2015a, Naveenkumar *et al.* 2017). Perez-Salicrup (2001), Parthasarathy *et al.* (2004, 2015) and DeWalt *et al.* (2015) found that lianas comprise up to 35% of woody species richness in tropical forests. An important finding is that across the sites the liana share to the total woody species (trees + lianas) richness, density and carbon stock ranged 36.4–53.8 %, 24.5–62 %, 1–21.4 % respectively (Table 7). Parthasarathy *et al.* (2004) and Vivek & Parthasarathy (2015a) reported that lianas contributed respectively 55.2% and 52% of total woody species richness and density in different tropical dry evergreen forest sites. Overall, considering 20 sites together lianas contributed 47%, 42% and 6.3% to the total woody species richness, density and carbon stock (Table 7).

**Table 7.** Species richness, stem density and carbon stock of lianas and trees by sites and percentage (%) contribution of lianas to these three variables in 1-ha plots of 20 different tropical dry evergreen forest sites. (For site codes see Table 6)

Site code	Species richness		Liana share (%)	Density		Liana share (%)	Carbon Stock		Liana share (%)
	Lianas	Trees		Lianas	Trees		Lianas	Trees	
SK	16	28	36.4	744	1264	37.0	5.84	243.57	2.4
PT	20	21	48.7	438	707	38.3	3.24	225.95	1.4
AK	29	31	48.3	1163	2815	29.2	11.01	213.25	4.9
OR	24	30	44.4	812	1619	33.4	12.96	322.7	3.8
KK	28	26	51.8	497	1459	25.4	41.85	153.15	21.4
PP	28	24	53.8	835	1567	34.8	3.63	370.70	1.0
AP	26	35	42.6	792	807	49.5	9.15	204.50	4.2
KR	23	30	43.4	515	596	46.4	33.88	189.20	15.2
SP	27	26	51.0	766	1663	31.5	30.44	196.20	13.4
MM	21	28	42.8	596	724	45.2	18.46	160.20	10.3
PC 1	28	37	43.0	672	790	45.9	6.56	358.84	1.8
PC 2	31	27	53.4	720	803	47.2	5.21	193.66	2.6
PR	22	20	52.3	919	948	49.2	6.29	80.73	7.2
SN	28	27	50.9	701	841	45.4	24.14	222.50	9.8
MK	11	18	37.9	408	786	34.1	1.42	60.80	2.3
SL	25	22	53.1	1213	1211	50.0	8.43	161.80	4.9
SV	27	37	42.1	1455	888	62.0	10.31	235.50	4.2
VV	20	30	40.0	1658	1693	49.4	26.55	215.20	10.9

KA	22	20	52.3	941	845	52.6	5.76	165.20	3.3
KT	20	25	44.4	552	661	45.5	2.21	187.00	1.1
Average	24	27	47.0	820	1134	42.0	13.4	207.70	6.3

The effect of disturbance is clearly reflected in the present study on basal area and aboveground biomass (AGB) and carbon stock (CS), with higher values in the undisturbed site than the disturbed site. These results are in conformity with the other studies which demonstrated a decrease in the basal area of lianas with an increase in disturbance (van der Heijden & Phillips 2008, Addo-Fordjour *et al.* 2012, Anbarashan & Parthasarathy 2013, Mohandass *et al.* 2015). In contrast, Addo-Fordjour *et al.* (2009b) found a contrary result that is increasing basal area with increasing disturbance. Overall, decrease in basal area, AGB and CS of lianas in site PT can be explained by the fact that, frequent removal of lianas and available host trees by the local communities thereby affecting their diversity, composition, basal area, AGB and CS potential which is also noticed in other studies (Chittibabu & Parthasarathy 2001, Addo-Fordjour *et al.* 2012). It was also found that, a 10-year change in tree diversity in disturbed site PT resulted in loss of 44% of total tree stems (Babu & Parthasarathy, unpublished) which underline fact that in long run lianas always require supportive host trees for their very survival, and a substantial reduction in tree density as in the case of site PT is deleterious to liana community.

The average above ground biomass of lianas in the present study is 7.2 Mg ha<sup>-1</sup>. This value is comparable with other studies 3.7 to 12.3 Mg ha<sup>-1</sup> (Laurance *et al.* 2001), 3.39 Mg ha<sup>-1</sup> (Lu *et al.* 2009), 43 Mg ha<sup>-1</sup> (Gerwing & Farias 2000), 3.6–9.33 Mg ha<sup>-1</sup> (Naveenkumar *et al.* 2017), 2.24–42.13 Mg ha<sup>-1</sup> (Vivek & Parthasarathy 2015b), 15.05–49.08 Mg ha<sup>-1</sup> (Pandian & Parthasarathy 2016). This indicates that lianas contribute less biomass as compared to trees yet, they may play important role in reducing the total forest carbon stock and carbon sequestration potential by competing with their hosts for above and belowground resources (Schnitzer & Bongers 2011). The contribution of lianas to the total biomass rarely surpasses 5% in undisturbed forests (Hegarty & Caballé 1991), but in case of Roels (2016) and our study, the lianas share was less than 5% in both undisturbed and disturbed sites.

## CONCLUSION

We conclude that human-induced disturbances would have resulted in varied species diversity, biomass and carbon stock of liana species in the studied sites. TDEF sites are subjected to various anthropogenic disturbances and loss of belief system over two decades resulted in rapid decline of trees and increase in liana community (Pandian & Parthasarathy 2016). The data obtained and discussed from 20 sites provide valuable information to researchers in understanding the importance of lianas in maintaining the present level of diversity, carbon stocks and dynamics in this unique forest type. The extent of variation in species diversity and carbon stock between these sites, call for the concerted effort by the management of TDEFs to control human disturbance in the forest and embark on artificial regeneration of lianas. Data on carbon stocks and flux in tropical forests are urgently required to understand how lianas would respond to climate change and anthropogenic disturbances.

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