Tropical Plant Research
An International Journal
© Society for Tropical Plant Research

ISSN (E): 2349 – 1183
ISSN (P): 2349 – 9265
2(3): 230–239, 2015

Research article

Diversity and carbon stock assessment of trees and lianas in tropical dry evergreen forest on the Coromandel Coast of India

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Abstract: The diversity and carbon stock of all woody plants were investigated in ten tropical dry evergreen forest (TDEF) sites on the Coromandel Coast of India. All trees ≥ 10 cm girth at breast height and all lianas ≥ 1 cm diameter, measured at 1.3 m from the rooting point were enumerated. A total of 81 tree species (26.3±6.7 species ha^{-1}) and 52 liana species (23.4±5.7 species ha^{-1}) that belonged respectively to 34 and 28 families were inventoried from the ten study sites. The abundance of woody plants in the ten study sites totaled 18705 individuals (9466 trees and 9239 lianas) and the average tree density was 946.6±298.9 stems ha^{-1} and liana density was 923.9±403.3 stems ha^{-1}. Trees contributed 61 % and 51 % respectively to the total woody species richness and abundance. The basal area of trees in the ten study sites ranged from 8.23 m^2 ha^{-1} to 29.48 m^2 ha^{-1} and that of lianas ranged from 0.2 m^2 ha^{-1} to 1.76 m^2 ha^{-1}. The aboveground biomass (AGB) of trees totaled 3025.8 Mg and ranged from 96.9 Mg ha^{-1} to 576.4 Mg ha^{-1} across the ten sites. The liana aboveground biomass ranged from 2.24 Mg ha^{-1} to 42.13 Mg ha^{-1} and totaled 153.76 Mg in the ten sites. The woody plants in the present study sites stocked 1978.24 Mg Carbon and it ranged from 62.2 Mg C ha^{-1} to 365.4 Mg C ha^{-1}. Trees accounted for a maximum share of 95 % and lianas contributed just 5 % to the total woody-plant carbon stock in the study sites. The extent of woody species diversity and estimated carbon stock of the TDEF sites, underlines the need for biological conservation of this unique forest type which are fast vanishing due to anthropogenic pressure.

Keywords: Biomass - Allometric equation - Anthropogenic pressure - Wood specific density - Carbon flux.

[**Cite as:** Vivek P & Parthasarathy N (2015) Diversity and carbon stock assessment of trees and lianas in tropical dry evergreen forest on the Coromandel Coast of India. *Tropical Plant Research* 2(3): 230–239]

INTRODUCTION

Forests are one of the major pools of carbon, where plants fix atmospheric carbon into the biological system. Indeed it is the tropical forest ecosystems that have the potential to hold and sequester large amounts of carbon than the other forest biomes (Metz *et al.* 2001). Tropical forests comprise about 40 % of the total terrestrial carbon stock (Dixon *et al.* 1994), but uncertainty prevails in their quantitative contribution to the global carbon cycle (Chave *et al.* 2005). This uncertainty is largely due to the lack of standard methods for converting field measurements into biomass estimates (Hall 2012, Liu *et al.* 2014). The woody biomass of trees and lianas, their standing crop of litter including the soil organic matter together comprise the key carbon pools in tropical forest ecosystems (Gibbs *et al.* 2007). The carbon stocked as aboveground and belowground biomass in woody plants is impacted directly by human-mediated disturbances. Deforestation currently accounts for about 18 % of the global carbon emissions (IPCC 2007). Several other factors including selective logging, forest fragmentation and shifting cultivation are expected to play a major role in altering forest biomass (Houghton 2005). Under the present scenario of global climate change and increasing deforestation rates, it has become crucial to quantify the carbon stocks and fluxes particularly in the tropics. Currently, data presented on forest biomass is available from wide array of sources (*e.g.* quantitative inventories, output of ecological models and through satellite products). However, it is the direct assessment of biomass through destructive sampling is likely to give better estimates on forest carbon stocks. It could also be approached by applying generalized allometric equations (Brown 1997, Chave *et al.* 2005) using variables such as diameter, height and wood specific density. Allometric

Received: 29 July 2015

equations applied for forest inventory data, relate these inventory data to measurements made from destructive sampling by statistical means, and available for most forest types (Brown 1997, Chave *et al.* 2005).

Tropical dry evergreen forest (TDEF) is a unique and geographically restricted forest type distributed as numerous patches along the Coromandel Coast of peninsular India. All the TDEF sites are protected as sacred forests owing to the religious and traditional believes of the local people. However, the recent developments and erosion in the belief system, questioned the concept of sacred forests and as a result, some TDEF sites are now subjected to unprecedented levels of anthropogenic pressure. Meher-Homji (1974) estimated that just 4–5 % of the original TDEFs remain. Hence, it is of prime importance to estimate the diversity and carbon stocking potential of TDEF ecosystem for conservation with the aid of scientific data. Although, there have been many studies that reported the estimation of carbon stocks of trees in tropical forests, only few studies have included the liana life-form. Hence, the present study is aimed to investigate woody species (trees and lianas) diversity and their carbon stocks in TDEF ecosystem.

MATERIALS AND METHODS

Study area

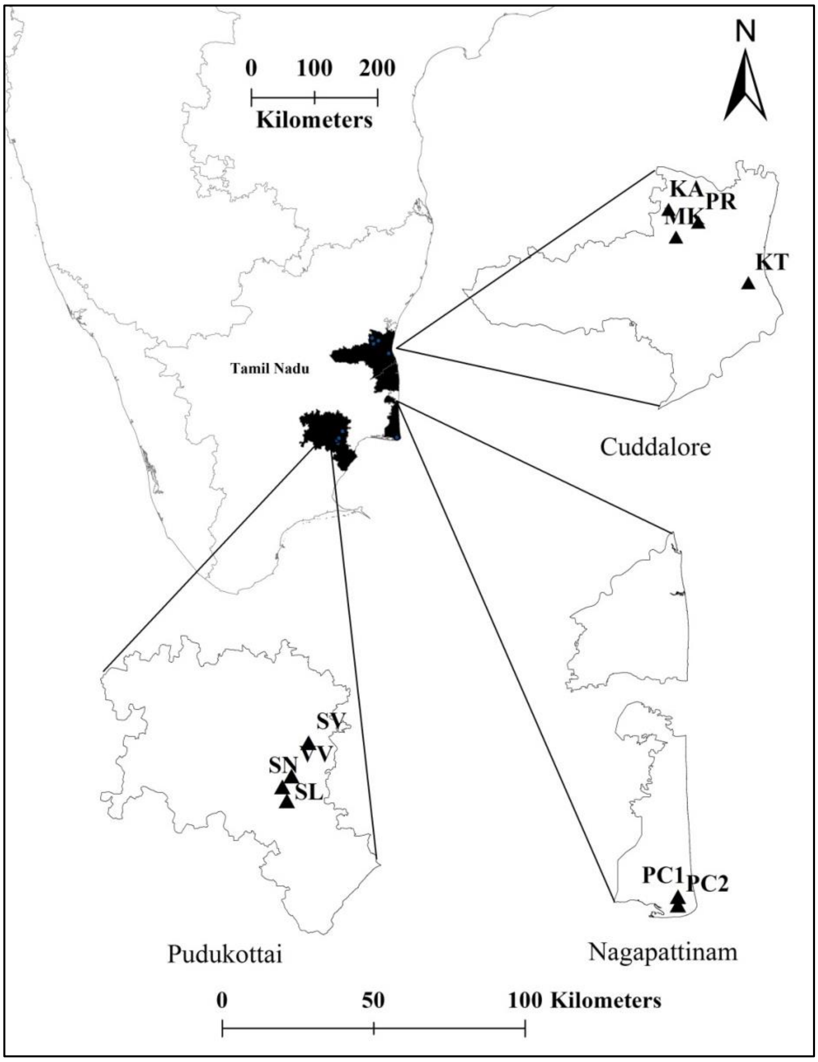

Figure 1. Map showing ten tropical dry evergreen forest sites distributed in Cuddalore, Pudukottai and Nagapattinam districts on the Coromandel Coast of India.

The present study was conducted in ten tropical dry evergreen forest (TDEF) sites located in Cuddalore (11° 44' 57.88'' N latitude and 79° 44' 50.99'' E longitude), Nagapattinam (10° 45' 56.28'' N latitude and 79° 50' 31.68'' E longitude) and Pudukottai (10° 22' 46.63'' N latitude and 78° 49' 18.35'' E longitude) districts of Tamil Nadu, India (Fig. 1). The tropical dry evergreen forest that occurs as patches along the Coromandel Coast of peninsular India is characterized by two to three-layered, tree-dominated forests with short stature and sparse ground flora (Parthasarathy *et al*. 2008, Vivek & Parthasarathy 2015). The rainfall here is tropical dissymmetric type with most rains received during the north-east monsoon and a little, inconsistent rainfall during the south-west monsoon. The mean annual rainfall is 1184 mm, 1346 mm and 919 mm in Cuddalore, Nagapattinam and Pudukottai respectively. The length of dry season is 6–8 months annually. The mean annual maximum and minimum temperature are 36.9°C and 20.8°C in Cuddalore, 34.9°C and 22.3°C in Nagapattinam and 36.1°C and 21.6°C in Pudukottai. Soil type varies from hard lateritic, red ferralitic and alluvium to coastal sandy. All the study sites are community-managed, except the sites Point Calimere 1 and 2, which are a part of Point Calimere Wildlife Sanctuary (RAMSAR site) and is probably the largest existing TDEF site in India. The community-managed sites are protected by the local people as sacred groves (sacred forests) dedicated to Gods, based on the traditional belief system. However, the concentration of human settlements near these study sites makes them more vulnerable to anthropogenic pressure.

Field inventory

Field work was carried out between April 2013–May 2014 in ten 1-ha study plots. Each one-hectare study plot was further divided into one-hundred 10 × 10 m sub-grids to facilitate the inventory. During inventory, all trees $\geq$ 10 cm girth at breast height (gbh) were measured at 1.3 m from the ground level and all lianas $\geq$ 1 cm diameter were measured at 1.3 m from the rooting point. All the inventoried tree and liana species were recognized to species-level using regional floras (Gamble & Fischer 1915–1935, Matthew 1991) and confirmed with the specimens lodged in the herbarium of Department of Ecology and Environmental Sciences, Pondicherry University. Diversity indices such as Shannon, Fisher’s alpha and Simpson index were computed following Magurran (2004).

Allometric equation and biomass estimation

We used the forest inventory data (dbh values) to estimate the aboveground (AGB) and belowground biomass (BGB). The aboveground biomass of trees was estimated following the allometric equation of Chave *et al.* (2005) using two variables, the diameter and wood specific density (WSD):

$$\mathrm{AGB}_{\mathrm{est}} = \rho \times \exp\left(-1.499 + 2.148 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3\right)$$

where D is the diameter and ρ is the wood specific density of tree species.

The wood specific density of each tree species was taken from available literature (Mani & Parthasarathy 2007) and also from global wood density database. We used the generalized allometric equation (Pearson 2005) for few species for which WSD value was not available, using diameter as the only variable.

For lianas, the allometric equation of Schnitzer *et al.* (2006) was used:

$$\mathrm{AGB} = \exp\left[-1.484 + 2.657 \ln(D)\right]$$

where D is the diameter.

The belowground biomass of trees and lianas was calculated by multiplying the aboveground biomass value with 0.26 (Cairns *et al.* 1997, IPCC 2003). The carbon stock was estimated to be 50 % of the total biomass (AGB + BGB) (IPCC 2005).

RESULTS AND DISCUSSION

Woody species diversity

Woody species inventory yielded a total of 133 species including 81 tree species and 52 liana species from ten study sites (Table 1) and it ranged from a minimum of 29 species ha^{-1} at site MK to the maximum of 64 species ha^{-1} at site PC 1. Trees in the study sites comprised 60 % of the total woody species richness and lianas the rest. A total of 18705 woody individuals were enumerated from the study sites, of which trees and lianas shared 51 % and 49 % of the total abundance respectively. Site VV harbored maximum density of trees and lianas (3351 individuals ha^{-1}) and it was minimum at site MK (1194 individuals ha^{-1}). Site PC 1 with greater species richness had the highest Fisher’s α value and site MK, the lowest (Table 1). Shannon and Simpson index values were higher for sites PR and SN respectively. *Memecylon umbellatum* (2318 individuals), *Glycosmis mauritiana* (740 individuals) and *Albizia amara* (700 individuals) were the top three abundant tree species forming 42 % of the total tree species abundance. Among lianas, *Strychnos lenticellata* (1920 individuals), *Combretum albidum* (987 individuals) and *Reissantia indica* (747 individuals) were the predominant species which together accounted for 40 % of the total liana abundance.

Table 1. Consolidated details of woody plant (trees and lianas) diversity in ten tropical dry evergreen forest (TDEF) sites distributed 1-ha each at: Karukkai (KA), Kothattai (KT), Maanadikuppam (MK), Point Calimere 1(PC1), Point Calimere 2 (PC2), Purangani (PR), Silattur (SL), Sunayakkadu (SN), Suran Viduthi (SV) and Vanniyan Viduthi (VV) on the Coromandel Coast of India.

Variable	**Study site**										**Total**
	KA	**KT**	**MK**	**PC1**	**PC2**	**PR**	**SL**	**SN**	**SV**	**VV**	**for 10 ha**
TWSR (number of spp.)	42	45	29	65	58	42	47	55	64	50	133
Trees	20	25	18	37	27	20	22	27	37	30	81
Lianas	22	20	11	28	31	22	25	28	27	20	52
TWSD (individuals ha^{-1})	1786	1213	1194	1462	1523	1867	2424	1542	2343	3351	18705
Trees	845	661	786	790	803	948	1211	841	888	1693	9466
Lianas	941	552	408	672	720	919	1213	701	1455	1658	9239

Note: TWSR- Total woody species richness; TWSD- Total woody species density.

Forest biomass

The total woody species basal area in the ten study sites was 176.75 m^2 and it varied from a maximum of 30.16 m^2 ha^{-1} at site PC 1 to a minimum of 8.43 m^2 ha^{-1} at site MK (Table 2). Trees in the study sites comprised 96 % of the total woody species basal area. The total biomass of the woody species recorded in study sites was 3956.4 Mg with the maximum contribution from trees (95 %). The mean woody species carbon stock in the ten study sites was 197.8±81.8. Whereas, Tiwari & Singh (1987) estimated 68.5–122.5 Mg ha^{-1} biomass carbon in Himalayan region of Uttar Pradesh. Ravindranath *et al.* (1997) reported the average of 63 % Mg C ha^{-1} from the values for few forest types studied using harvest method. Thus, the estimated carbon on per hectare basis in the present study is much higher than the values reported in the previous studies in India. The increased interests in estimating the biomass and carbon stocks resulted in the evolution of new methods that confounded comparisons across the different studies. For example, Mani & Parthasarathy (2007) obtained two contradictory results on aboveground biomass using two different allometric equations for the same dataset. It is of paramount importance to obtain more accurate estimates on carbon stocks for tropical forests to understand the role of tropical ecosystems in the global carbon cycle (Brown *et al.* 1989, Kale *et al.* 2004, Kuller *et al.* 2001). The

Table 2. Basal area (BA), aboveground biomass (AGB), belowground biomass (BGB), total biomass (TB) and carbon stock (CS) of all woody plants followed by trees and lianas in ten TDEF sites on the Coromandel Coast of India: Karukkai (KA), Kothattai (KT), Maanadikuppam (MK), Point Calimere 1(PC1), Point Calimere 2 (PC2), Purangani (PR), Silattur (SL), Sunayakkadu (SN), Suran Viduthi (SV) and Vanniyan Viduthi (VV).

Variable	**Study site**										**Total**
	KA	**KT**	**MK**	**PC1**	**PC2**	**PR**	**SL**	**SN**	**SV**	**VV**	**for 10 ha**
BA (m^2 ha^{-1})	13.99	16.15	8.43	30.16	20.97	11.29	15.13	19.02	20.25	21.35	176.74
Trees	13.38	15.92	8.23	29.48	20.53	10.64	14.36	18.07	19.19	19.59	169.39
Lianas	0.61	0.23	0.2	0.68	0.44	0.65	0.77	0.95	1.06	1.76	7.35
AGB (Mg ha^{-1})	271.35	300.31	98.84	580.02	315.67	138.07	270.26	391.5	390.26	383.83	3140.11
Trees	262.2	296.8	96.6	569.6	307.4	128.1	256.9	353.2	373.9	341.7	2986.4
Lianas	9.15	3.51	2.24	10.42	8.27	9.97	13.36	38.30	16.36	42.13	153.71
BGB (Mg ha^{-1})	70.551	78.080	25.698	150.80	82.074	35.898	70.267	101.79	101.46	99.795	816.41
Trees	68.172	77.168	25.116	148.09	79.924	33.306	66.794	91.832	97.214	88.84	776.45
Lianas	2.379	0.9126	0.5824	2.7092	2.1502	2.5922	3.4736	9.958	4.2536	10.95	39.96
TB (Mg ha^{-1})	341.90	378.390	124.53	730.82	397.74	173.96	340.52	493.29	491.72	483.62	3956.49
Trees	330.37	373.96	121.71	717.69	387.32	161.40	323.69	445.03	471.11	430.54	3762.82
Lianas	11.529	4.4226	2.8224	13.129	10.420	12.562	16.833	48.258	20.613	53.083	193.67
CS (Mg ha^{-1})	170.95	189.19	62.2692	365.41	198.87	86.984	170.26	246.64	245.86	241.81	1978.24
Trees	165.18	186.98	60.858	358.84	193.66	80.703	161.84	222.51	235.55	215.27	1881.39
Lianas	5.7645	2.2113	1.4112	6.5646	5.2101	6.2811	8.4168	24.129	10.306	26.541	96.8356

choice of equation is therefore much important when comparing the biomass estimates in regional scale. Among all the study sites, the relatively undisturbed site PC 1 stocked maximum carbon (365.41 Mg C ha^{-1}). Tree species such as *Manilkara hexandra* with 481 individuals stocked maximum carbon (399.4 Mg C), followed by *Drypetes sepiaria* (192.20 Mg C) and *Albizia amara* (165.29 Mg C) (Table 3). The predominant tree species *Memecylon umbellatum* and *Glycosmis mauritiana* contributed at least four-fold lower value (92.12 Mg C and 58.64 Mg C respectively) than that of *Manilkara hexandra*, possibly due to their major representation in smaller girth classes. *Ventilago madraspatana*, an unarmed scrambler was the highest contributor of carbon stock among the 52 liana species, followed by *Acacia caesia* (16.72 Mg C) and *Derris scandens* (11.95 Mg C) (Table 3). Although lianas continue to increase in biomass in tropical forests (Schnitzer & Bongers 2011), they have not been figured in most forest biomass assessment studies. It is estimated that lianas can add up to 30% of the total aboveground biomass in tropical forests with dense liana population (Schnitzer & Bongers 2011). However, in the present study sites, lianas with almost equal abundance as that of the trees, comprised just 5 % of the total forest biomass. Yet, they may play a major role in reducing the whole forest carbon stock and sequestration potential by competing aggressively with trees for aboveground and belowground resource (Schnitzer & Bongers 2011). Lianas usually capitalize and grow well on the disturbed environments and reduces tree growth and increases the tree mortality rates. This may not be a good sign as lianas do not compensate for the tree biomass that they displace (van der Heijden & Phillips 2009, Schnitzer & Bongers 2011).

Table 3. Species abundance (Ab), aboveground biomass (AGB), belowground biomass (BGB), total biomass (TB) and total carbon stock (TCS) of all the 81 tree species and 52 liana species enumerated from 10-ha area distributed 1-ha in each of ten tropical dry evergreen forest sites

S.No.	Woody species	Ab (10-ha)	AGB (kg)	BGB (kg)	TB (kg)	TSC (kg)
Tree species						
1	*Acacia leucophloea* (Roxb.) Willd.	4	228.6	59.4	288.0	144.0
2	*Alangium salvifolium* (L.f.) Wangerin	6	1416.6	368.3	1784.9	892.5
3	*Albizia amara* (Roxb.) Boivin	700	262366.6	68215.3	330581.9	165290.9
4	*Allophyllus serratus* (Roxb.) Kurz	7	65.4	17.0	82.3	41.2
5	*Anacardium occidantale* L.	9	35973.4	9353.1	45326.4	22663.2
6	*Atalantia monopylla* (L.) Correa	363	44060.3	11455.7	55516.0	27758.0
7	*Azadirachta indica* A. Juss.	87	73078.3	19000.4	92078.6	46039.3
8	*Bauhinia racemosa* Lam.	1	213.5	55.5	269.0	134.5
9	*Benkara malabarica* (Lam.) Tirven.	14	339.6	88.3	427.9	213.9
10	*Borassus flabellifer* L.	51	64176.7	16685.9	80862.6	40431.3
11	*Breynia vitis-idaea* (Burm. f.) Fischer	3	7.9	2.1	9.9	5.0
12	*Cadaba trifoliata* (Roxb.) Wight & Arn.	143	2439.5	634.3	3073.8	1536.9
13	*Canthium coromandelicum* (Burm.f.) Alston	18	17.1	4.4	21.5	10.8
14	*Canthium dicoccum* (Gaertn.) Teijsm.& Binn	230	28752.3	7475.6	36227.9	18114.0
15	*Carmona retusa* (Vahl) Masm	6	22.8	5.9	28.7	14.3
16	*Cassia auriculata* L.	1	3.8	1.0	4.7	2.4
17	*Cassia fistula* L.	146	26408.0	6866.1	33274.1	16637.1
18	*Cassia roxburghi* DC.	8	2631.8	684.3	3316.1	1658.1
19	*Cassine glauca* (Rottb.) Kuntze	17	710.2	184.7	894.9	447.5
20	*Catunaregam spinosa* (Thunb.) Tirven	13	43.8	11.4	55.2	27.6
21	*Chionanthus zeylanica* L.	48	9929.4	2581.6	12511.0	6255.5
22	*Chloroxylon sweitenia* DC.	398	61783.0	16063.6	77846.6	38923.3
23	*Clausena dendata* (Willd.) Roemer	248	1627.7	423.2	2050.8	1025.4
24	*Commiphora berryi* (Arn) Engler	2	329.0	85.5	414.6	207.3
25	*Commiphora caudata* (Wight & Arn.) Engl.	26	7268.7	1889.9	9158.6	4579.3
26	*Cordia obliqua* Willd.	7	666.1	173.2	839.2	419.6
27	*Dalbergia coromandeliana* Prain	2	234.9	61.1	296.0	148.0

28	*Dalbergia paniculata* Roxb.	46	81653.5	21229.9	102883.5	51441.7
29	*Dichrostachys cinerea* (L.) Wight & Arn.	4	54.5	14.2	68.7	34.3
30	*Diospyros ebenum* J. Koenig ex Retz.	149	28684.8	7458.0	36142.8	18071.4
31	*Diospyros ferrea* (Willd.) Bakh. var. buxifolia (Rottb.) Bakh.	103	22402.1	5824.6	28226.7	14113.4
32	*Diospyros montana* Roxb.	85	6368.3	1655.8	8024.1	4012.0
33	*Dodonea angustifolia* L. f.	47	1837.2	477.7	2314.8	1157.4
34	*Drypetes sepiaria* (Wight & Arn.) Pax & Hoffm.	390	305091.4	79323.8	384415.2	192207.6
35	*Ehretia pubescens* Benth.	2	5.0	1.3	6.3	3.1
36	*Ehretia wightiana* Wall. ex G.Don	2	973.4	253.1	1226.5	613.3
37	*Eugenia bracteata* (Willd.) Roxb. ex DC.	4	41.5	10.8	52.3	26.2
38	*Euphorbia antiquorum* L.	176	-	-	-	-
39	*Ficus amplissima* Sm.	1	4238.4	1102.0	5340.4	2670.2
40	*Ficus benghalensis* L.	17	172077.9	44740.3	216818.1	108409.1
41	*Ficus microcarpa* L.f.	7	8950.6	2327.1	11277.7	5638.8
42	*Ficus religiosa* L.	1	84.4	21.9	106.3	53.1
43	*Garcinia spicata* (Wight & Arn.) J. D. Hook.	161	88635.4	23045.2	111680.5	55840.3
44	*Gardenia resinifera* Roth	17	3441.7	894.8	4336.5	2168.2
45	*Glycosmis mauritiana* (Lam.) Yuich. Tanaka	940	9308.1	2420.1	11728.2	5864.1
46	*Gmelina asiatica* L.	33	2951.0	767.3	3718.2	1859.1
47	*Ixora pavetta* T.Anderson	36	10299.4	2677.8	12977.2	6488.6
48	*Jatropha gossipyfolia* L.	1	1.8	0.5	2.3	1.2
49	*Lannea coromandelica* (Houtt.) Merr.	32	3094.8	804.6	3899.4	1949.7
50	*Lepisanthes tetraphlla* (Vahl.) Radlk.	313	153606.5	39937.7	193544.2	96772.1
51	*Mallotus phillipensis* (Lam.) Muell.-Arg.	20	2693.5	700.3	3393.8	1696.9
52	*Manilkara hexandra* (Roxb.) Dubard	481	634041.8	164850.9	798892.7	399446.3
53	*Maytenus emarginata*	43	599.5	155.9	755.3	377.7
54	*Memecylon umbellatum* Burm.f.	2318	146235.1	38021.1	184256.2	92128.1
55	*Morinda coreia* Buch.-Ham.	14	1162.7	302.3	1465.1	732.5
56	*Muntingia calabura* L.	4	417.0	108.4	525.4	262.7
57	*Ochna obtusata* DC.	33	4957.3	1288.9	6246.2	3123.1
58	*Pamburus missionis* (Wight) Swingle	4	13.8	3.6	17.4	8.7
59	*Phyllanthus polyphyllus* Willd.	2	87.9	22.9	110.8	55.4
60	*Pleiospermium alatum* (Wall. ex Wight. & Arn.) Swingle	48	12944.2	3365.5	16309.7	8154.8
61	*Polyalthia korintii* (Dunal) Thw.	10	904.4	235.1	1139.6	569.8
62	*Polyalthia longifolia* (Sonn.) Thw.	4	137.8	35.8	173.7	86.8
63	*Pongamia pinnata* (L.) Pierre	65	86160.0	22401.6	108561.6	54280.8
64	*Premna serratifolia* L.	14	7548.2	1962.5	9510.7	4755.4
65	*Prosopis juliflora* (Sw.) DC.	131	119681.9	31117.3	150799.1	75399.6
66	*Pterospermum canescens* Roxb.	86	105674.5	27475.4	133149.9	66575.0
67	*Pterospermum xylocarpum* (Gaertn.) Sant. & Wagh.	8	13920.2	3619.2	17539.4	8769.7
68	*Salvadora persica* L. var. *wightiana* (Thwaites) Verdc	15	6820.1	1773.2	8593.4	4296.7
69	*Sapindus emarginatus* Vahl	3	21.0	5.5	26.5	13.2
70	*Sapium insigne* (Royle) Trimen	16	140.1	36.4	176.5	88.2
71	*Securenega leucopyrus* (Willd.) Muell.-Arg.	3	12.5	3.2	15.7	7.9
72	*Strebulus asper* Lour.	5	60.7	15.8	76.5	38.2

73	*Strychnos nux-vomica* L.	2	126.0	32.8	158.8	79.4
74	*Syzygium cumini* (L.) Skeels	51	211847.6	55080.4	266928.0	133464.0
75	*Tamarindus indica* L.	4	62402.1	16224.5	78626.6	39313.3
76	*Tarenna asiatica* (L) kuntz ex Schumann.	510	4990.5	1297.5	6288.1	3144.0
77	*Tricalysia sphaerocarpa* (Dalz.) Gamble	372	81809.3	21270.4	103079.7	51539.8
78	*Vitex altíssima* L.f.	10	7734.7	2011.0	9745.8	4872.9
79	*Walsura trifolia* (A. Juss.) Harms	6	683.1	177.6	860.7	430.4
80	*Wrightia tinctoria* (Roxb.) R. Br.	4	75.5	19.6	95.2	47.6
81	*Zizyphus mauritiana* Lam.	13	603.0	156.8	759.8	379.9
Liana species						
82	*Abrus precatorius* L.	9	4.4	1.1	5.6	2.8
83	*Acacia caesia* (L.) Willd.	196	16722.9	4348.0	21070.9	10535.5
84	*Adenia wightiana* (Wall.exWight & Arn.) Eng.	1	0.3	0.1	0.4	0.2
85	*Aristolochia indica* L.	5	1.7	0.4	2.1	1.1
86	*Asparagus racemosus* Willd.	82	70.2	18.3	88.5	44.2
87	*Azima tetracantha* Lam.	25	357.6	93.0	450.6	225.3
88	*Canavalia virosa* (Roxb.) Wight & Arn.	7	4.7	1.2	6.0	3.0
89	*Cansjera rheedii* Gmel.	74	1150.1	299.0	1449.2	724.6
90	*Capparis brevispina* DC.	141	1971.9	512.7	2484.5	1242.3
91	*Capparis divaricata* Lam.	1	0.3	0.1	0.4	0.2
92	*Capparis rotundifolia* Rottl.	28	104.4	27.1	131.5	65.7
93	*Capparis sepiaria* L.	4	26.8	7.0	33.7	16.9
94	*Capparis zeylanica* L.	58	1463.9	380.6	1844.5	922.3
95	*Carissa spinarum* L.	575	2224.3	578.3	2802.6	1401.3
96	*Cissus quadrangularis* L.	254	409.3	106.4	515.7	257.8
97	*Cissus vitiginea* L.	293	4972.1	1292.7	6264.8	3132.4
98	*Clerodendrum inerme* (L.) Gaertn.	13	60.7	15.8	76.4	38.2
99	*Coccinia grandis* (L.) Voigt	182	960.0	249.6	1209.6	604.8
100	*Combretum albidum* G.Don	987	10042.2	2611.0	12653.1	6326.6
101	*Derris ovalifolia* (Wight & Arn.) Benth.	192	9014.1	2343.7	11357.8	5678.9
102	*Derris scandens* (Roxb.) Benth.	343	11951.2	3107.3	15058.5	7529.3
103	*Dioscorea oppositifolia* L.	1	0.2	0.1	0.3	0.1
104	*Gloriosa superba* L.	4	3.0	0.8	3.7	1.9
105	*Grewia rhamnifolia* Heyne ex Roth	445	11772.3	3060.8	14833.1	7416.6
106	*Gymnema sylvestre* (Retz.) R.Br. ex Schultes	180	4053.4	1053.9	5107.3	2553.7
107	*Hugonia mystax* L.	488	6329.6	1645.7	7975.3	3987.6
108	*Ichnocarpus frutescens* (L.) R.Br.	162	158.9	41.3	200.2	100.1
109	*Ipomoea staphylina* Roemer & Schultes	5	36.4	9.5	45.9	23.0
110	*Jasminum angustifolium* (L.) Willd.	309	1123.2	292.0	1415.2	707.6
111	*Jasminum sessiliflorum* Vahl	61	34.8	9.1	43.9	21.9
112	*Olax scandens* Roxb.	18	138.4	36.0	174.4	87.2
113	*Pachygone ovata* (Poir) Miers ex Hook.	56	391.1	101.7	492.7	246.4
114	*Plecospermum spinosum* Trecul.	30	1061.2	275.9	1337.1	668.6
115	*Premna corymbosa* (Burm.f.) Rottl. & Willd.	137	459.5	119.5	578.9	289.5
116	*Pterolobium hexapetalum* (Roth.) Sant.&Wag.	74	208.3	54.2	262.5	131.2
117	*Pyrenacantha volubilis* Wight	191	209.5	54.5	264.0	132.0
118	*Reissantia indica* (Willd.) Halle	747	10709.3	2784.4	13493.7	6746.8
119	*Rivea hypocrateriformis* (Desr.) Choisy.	39	922.1	239.7	1161.8	580.9

120	*Salachia chinensis* L.	8	66.0	17.1	83.1	41.6
121	*Sarcostemma acidum* (Roxb.) Voigt	57	103.0	26.8	129.8	64.9
122	*Scutia myrtina* (Burm. f.) Kurz	110	2892.3	752.0	3644.3	1822.1
123	*Secamone emetica* (Retz.) R. Br.	186	505.1	131.3	636.4	318.2
124	*Strychnos lenticellata* (Dennst.) Hill	1920	7554.2	1964.1	9518.2	4759.1
125	*Symphorema involucratum* Roxb.	62	6260.5	1627.7	7888.2	3944.1
126	*Tiliacora acuminata* (Lam.) Hook.f. & Thoms.	16	23.2	6.0	29.2	14.6
127	*Tinospora cordifolia* (Willd.) Hook.f.&Thoms.	87	87.0	22.6	109.6	54.8
128	*Toddalia asiatica* (L.) Lam.	40	301.9	78.5	380.4	190.2
129	*Trichosanthes tricuspidata* Lour.	2	5.5	1.4	6.9	3.5
130	*Tylophora indica* (Burm. f.) Merr.	7	4.4	1.1	5.5	2.8
131	*Ventilago madraspatana* Gaertn.	87	26031.1	6768.1	32799.2	16399.6
132	*Wattakaka volubilis* (L.f) T. Cooke	102	1048.4	272.6	1321.0	660.5
133	*Zizyphus oenoplia* (L.) Mill.	136	9759.3	2537.4	12296.7	6148.4

Size-class distribution and carbon stock

Overall, in the ten study sites, 62 % of trees and 70 % of lianas fell within the lowest dbh class (Fig. 2 & 3) and this observed pattern could have resulted from the greater recruitment and mortality rates in the lowest dbh class (Vivek & Parthasarathy 2015). The highest dbh class comprised just 7 % of the total tree abundance, yet, managed to represent 75 % of the total tree carbon stock, suggesting the role of large trees in maintaining the carbon pools in TDEF ecosystem. Similarly in lianas, the highest dbh class represented by 3 % of the total liana abundance across the study sites, accounted for 67 % of the total carbon stocked by lianas in the study sites. In general, the carbon stock of the trees and lianas increased with increasing size-class irrespective of the number of individuals.

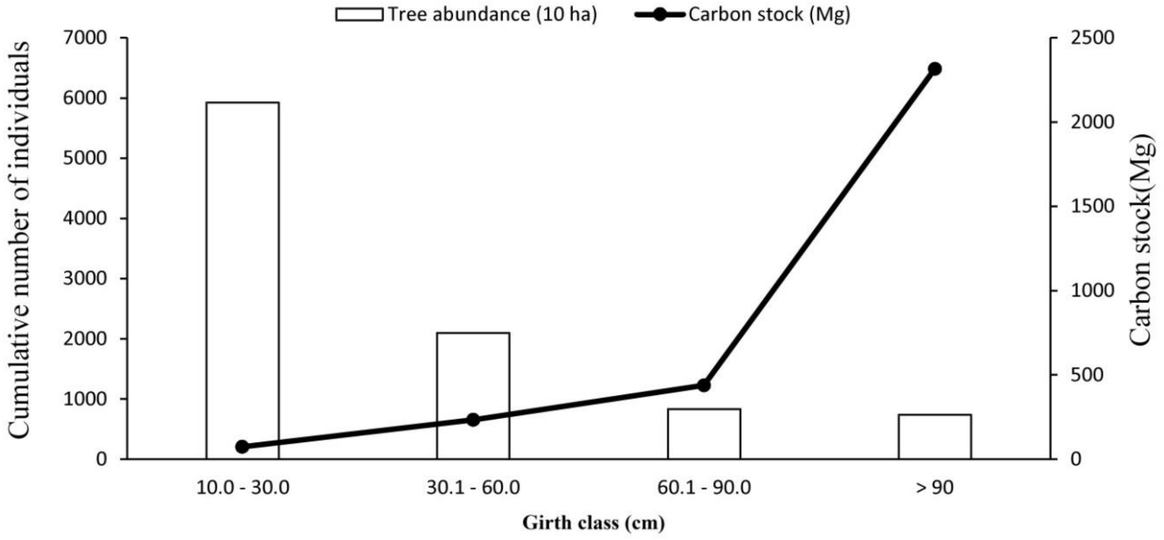

Figure 2. Girth-class wise distribution of tree abundance and their corresponding carbon stocks in tropical dry evergreen forests on the Coromandel Coast of India.

CONCLUSION

This study provides valuable data on biomass carbon of woody plants, thereby emphasizes the role of TDEF ecosystem in maintaining carbon pool of the local forest environment and will be helpful in framing conservation strategies and action plans. The present study also indicates the role of trees, particularly the large trees in maintaining the carbon stock, but in recent years, the TDEFs on the Coromandel Coast are experiencing immense pressure that result in reduced tree counts (Baithalu *et al*. 2012), but the lianas on the other hand increased drastically (Khadanga 2015). Therefore, we recommend long-term monitoring studies to estimate carbon stocks and dynamics in TDEF ecosystem under the current scenario of climate change and anthropogenic disturbance.

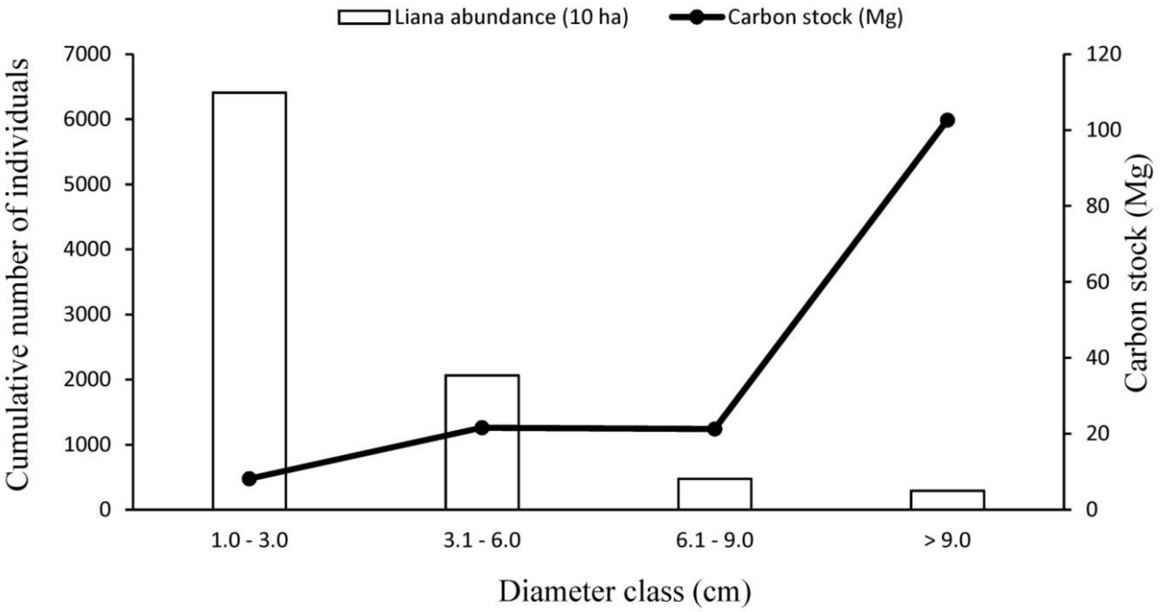

Figure 3. Diameter-class wise distribution of liana abundance and their corresponding carbon stocks in tropical dry evergreen forests on the Coromandel Coast of India.

ACKNOWLEDGEMENTS

We thank the Ministry of Environment and Forests for funding this study through a project (No.22/16/2011-(SG)-RE).

REFERENCES

Baithalu S, Anbarashan M & Parthasarathy N (2012) Changes in tree diversity and stand structure of two tropical dry evergreen forest on the Coromandel Coast of peninsular India over a decade. *International Journal of Ecology and Environmental Sciences* 38: 87–96.

Brown S (1997) Estimating biomass and biomass change of tropical forests: a primer FAO Forestry Paper no. 134 Rome.

Brown S, Gillespie A & Lugo AE (1989) Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* 223: 1290–1293.

Cairns MA, Brown S, Helmer EH & Baumgardner GA (1997) Root biomass allocation in the world's upland forests. *Oecologia* 111: 1–11.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D & Yamakura T (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87–99.

Dixon RK, Solomon AM, Brown S, Houghton RA, Trexier MC & Wisniewski J (1994) Carbon pools and flux of global forest ecosystems. *Science* 263: 185–190.

Gamble JS & Fischer CEC (1915–1935) *Flora of the Presidency of Madras*, Volumes I–III. London: Adlard and Son.

Gibbs HK, Brown S, Niles JO & Foley JA (2007) Monitoring and estimating tropical forest carbon stocks: making REDD a reality. *Environmental Research Letters* 2: 1–13.

Hall A (2012) Forests and climate change. The social dimensions of REDD in Latin America. Edward Elgar Publishing, pp. 213.

Houghton RA (2005) *Tropical deforestation as a source of greenhouse gas emissions Tropical Deforestation and Climate Change* (ed) Mutinho and Schwartzman (Belem: IPAM).

IPCC (2007) Climate change 2007: Synthesis report: Contribution of working groups I, II and III to the fourth assessment report (Intergovernmental Panel on Climate Change).

IPCC (2003) Mitigation of Climate Change. Prepared by working group III of the Intergovernmental Panel on Climate Change.

IPCC (2005) Special report on carbon dioxide capture and storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change.

Kale M, Singh S, Roy PS, Deosthali V & Ghole VS (2004) Biomass equation of dominant species of dry deciduous forest in Shivpuri district, Madhya Pradesh. *Current Science* 87: 683–687.

Khadanga SS, Muthumperumal C & Parthasarathy N (2015) Liana diversity changes over a decade in two Indian tropical dry evergreen forests. In: Tripathi SK (ed) *Biodiversity of Indian tropical forest ecosystems* (in press). Today and Tomorrow Printers and Publishers, New Delhi. pp. 61–79.

Kuller M, Palace M & Hurtt G (2001) Biomass estimation in the Tapajos National Forest, Brazil: examination of sampling and allometric uncertainties. *Forest Ecology and Management* 154: 371–382.

Liu X, Ekoungoulou R, Loumeto JJ, Ifo SA, Bocko YE & Koula FE (2014) Evaluation of carbon stock in above- and belowground biomass in Central Africa: Case study of Lesio-Louna tropical rain forests of Congo. *Biogeosciences Discuss* 11: 10703–10735.

Magurran A (2004) *Measuring Biological Diversity*. Oxford: Blackwell.

Mani S & Parthasarathy N (2007) Above-ground biomass estimation in ten tropical dry evergreen forest sites of peninsular India. *Biomass and Bioenergy* 31: 284–290.

Matthew KM (1991) *An Excursion Flora of Central Tamil Nadu, India*. Oxford and IBH, New Delhi, India

Meher-Homji VM (1974) On the origin of tropical dry evergreen forest of south India. *International Journal of Ecology and Environmental Sciences* 1: 19–39.

Metz BD, Swart R & Pan J (2001) Climate change 2001. Mitigation. Contribution of working group III to the third assessment report of the IPCC. Cambridge University Press, UK, 700 p.

Parthasarathy N, Selwyn MA & Udayakumar M (2008) Tropical dry evergreen forests of peninsular India: ecology and conservation significance. *Tropical Conservation Science* 1: 89–110.

Pearson T, Walker S & Brown S (2005) Source Book for LULUCF Projects, Winrock International, Arlington, VA, USA.

Ravindranath NH, Somasekhar BS & Gadgil M (1997) Carbon flows in Indian forest. *Climatic Change* 35: 297–320.

Schnitzer SA & Bongers F (2011) Increasing liana abundance and biomass in tropical forests: emerging patterns and putative mechanisms. *Ecology Letters* 14: 397–406.

Schnitzer SA, DeWalt SJ & Chave J (2006) Censusing and measuring lianas: a quantitative comparison of the common methods. *Biotropica* 38: 581–591.

Tiwari AK & Singh JS (1987) Analysis of forest land-use and vegetation in a part of Central Himalaya, using aerial photographs. *Environmental Conservation* 14: 233–244.

Van der Heijden GMF & Phillips OL (2009) Environmental effects on Neotropical liana species richness. *Journal of Biogeography* 36: 1561–1572.

Venkateswaran R & Parthasarathy N (2005) Tree population changes in a tropical dry evergreen forest of south India over a decade (1992-2002). *Biodiversity and Conservation* 14: 1335–1344.

Vivek P & Parthasarathy N (2015) Liana community and functional trait analysis in tropical dry evergreen forest of India. *Journal of Plant Ecology* 8: 501–512.