Tree diversity and stand structure in inland and coastal tropical dry evergreen forests of peninsular India

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To examine tree diversity and stand structure and their relation to site disturbances, we used the tree dataset of ten 1-ha permanent plots of tropical dry evergreen forests of peninsular India, distributed five in inland and five in coastal areas. In the ten independent sites, a 100 m × 100 m permanent plot was established, and all trees ≥ 10 cm girth at breast height were enumerated, their girth measured and tagged. Tree diversity totalled 77 species in 61 genera of 30 families. Tree density varied from 596 to 2813 stems ha^{-1}, and basal area ranged between 12.4 and 36.5 $m^2 ha^{-1}$. Species richness did not show any significant variation within and between the inland and coastal areas. We examined the relationship between basal area and site disturbance scores between the five sites of inland and coastal forest areas and found a negative correlation in both the areas. The coefficient of variability in species distribution among the ten sites revealed the extent of species heterogeneity. The number of species and stems decreased from the smallest to largest girth class. The tree inventories of the studied sites when compared with those of other tropical dry evergreen forests showed great differences in density and basal area, probably due to different geographical location and varying annual rainfall patterns. Our study sites can be designated as *Memecylon umbellatum–Drypetes sepiaria–Pterospermum canescens* series, based on species importance value.

Keywords: Coastal area, day evergreen forests, inland area, stand structure, tree diversity.

PLANT diversity inventories in tropical forests have mostly been concentrated on tree species than the other life-forms, because tree species diversity is an important aspect of forest ecosystem diversity[1] and also fundamental to total tropical forest biodiversity[2]. They provide resources and habitat structure for almost all other species[3]. Studies on tropical tree diversity have accumulated over the past decades and there is a great deal of interest to decipher the pattern and process relating to tropical forest diversity and in generating comprehensive review papers[4–7].

A wide range of sampling methods have been employed in tree-diversity inventories over the years, especially the number, size and shape of the plots besides the girth threshold of trees. Quantifying species diversity on a regional scale is quite challenging because of difficulties in measuring species abundance and distribution[8], and hence floristic inventories and studies of forest dynamics usually rely on sampling plots[9]. Quantitative floristic sampling also provides necessary context for planning and interpreting long-term ecological research[6]. In particular, large-scale permanent plots provide the basis for floristic and structural studies[10], and are important for conservation and management of tropical forests[11].

Tropical dry evergreen forests are distributed on the eastern (Coromandel) coast of India and extending inland about 50 km, northern Sri Lanka[12], northeastern Thailand[13], southwest China[14], Jamaica[15] and the Bahamas[16]. The peninsular Indian dry evergreen forests presently occur as patches or forest fragments of natural climax ecosystems. These are also ‘sacred groves’ or ‘temple forests’ composed fully of native plant species and preserved as a result of the religious belief of the local people[17]. The sacred groves are the treasure sources of rare and endemic species[18]. These forests could act as a reserve of trees which can help create climax forest through succession. All sacred-grove tree species are rich sources of native medicine[19]. Hence development of temple forests would also indirectly lower the currently high cost of native medicine. At present, these sites experience disturbance due to cattle grazing, resource removal, and site encroachment or the abandonment of areas that were previously cleared for agricultural activities, and land-use systems in many sacred groves are now threatened[18]. Although knowledge of biodiversity levels is uncertain, it is well-established that biodiversity is threatened greatly by human activity[20].

In human-dominated landscapes, forest may be portrayed as completely absent, when in fact, small forest patches may exist[21]. Small forest fragments are reported to provide a safety net for a significant number of species and their genetic diversity[22]. During the past several years, large complexes of natural habitat have been converted into agricultural, industrial or urbanized landscapes, leading to severe loss of the original habitat and an increasing fragmentation of the remnant patches[23]. Increasing fragmentation will result in the loss of a valuable portion of the forest ecosystem: the rare and shade-tolerant species[24]. Rapid

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fragmentation of formerly vast and uninterrupted forests has resulted in the present-day species composition, which is not in full equilibrium[25]. Tree species with small populations will be the first to be lost in the process of forest fragmentation[26]. Small fragments are likely to differ markedly in composition from the original forest[27], and species richness following fragmentation declines over time[28]. Fragmentation changes physical conditions through edge effects[29]. Further, even small forest patches of less than 1 ha in size could play a major role in maintenance of regional biodiversity[30].

Tree diversity data have become available from high-diversity and low-diversity tropical forests over the past decades and they could be potentially used for planning and managing forest biodiversity. Research on aspects of tree diversity has been carried out in each of the five 1-ha plots of inland and coastal tropical dry evergreen forest of peninsular India. The main objectives of the present study were to compare the species diversity, density and stand structure of the ten forest sites of peninsular India, and to study inter-site variation in inland and coastal areas.

Materials and methods

Study area

The dataset on tree diversity used here is based on the inventories carried out in a total of ten 1-ha permanent plots established five each in inland[31] and coastal[32] tropical dry evergreen forests of peninsular India. The five inland sites are located in Pudukottai district (9°5′–10°45′ lat. and 78°25′–79°15′ long.), Tamil Nadu and are 40 km west of the eastern coastal area and *c*. 250 km southwest of Pondicherry town (Figure 1). They include Araiyapatti, AP; Karisakkadu, KR; Maramadakki, MM; Shanmuganathapuram, SP and Rayapatti, RP. The forest area of each study site ranges from 1.5 to 2.5 ha and inter-distance between the five sites ranges from 3 to 20 km. The mean annual temperature for a decade (1992–2002) is 29.5 ± 2.45°C and the mean annual rainfall is 1033 ± 69.79 mm. The five coastal plots are located on the Coromandel coast of Tamil Nadu, south India (Figure 1). Sites Puthupet (PP, 12°03′N and 79°52′E) and Oorani (OR, 12°11′N and 79°57′E) are located 15 and 28 km north of Pondicherry town, and three other sites Arasadikuppam (AK, 11°42′N and 79°36′E), Kuzhanthaikuppam (KK, 11°43′N and 79°38′E) and Thirumanikkuzhi (TM, 11°43′N and 79°41′E) are 6 km apart and located 39 km south of Pondicherry town. The forest area of each study site ranges from 1.2 to 4 ha. The mean annual temperature is 28.5 ± 1.92°C and the mean annual rainfall is 1378 ± 116.86 mm for a decade (1992–2002).

The ten study sites experience various levels of anthropogenic disturbance. Site PP and MM are highly disturbed due to impact of temple visitors; whereas site AP is the least disturbed and the other seven sites are moderately disturbed. Site disturbance scores obtained by qualitatively assessing various disturbances (firewood collection, temple visitors' impact, grazing by cattle and goats and other resource removal) were ranked into rare (1), occasional (2) and frequent (3) level of disturbance. The sum of all the scores that showed high ranks reveals a high level of anthropogenic disturbance and low ranks express low disturbance (Table 1).

Vegetation

The vegetation of this region is tropical dry evergreen forest, based on the classification of Indian forest types[33], and it is degraded to thorny scrub due to anthropogenic disturbance in various areas. All the ten study sites are tree-dominated (mean height 8 to 12 m), two- to three-layered forests, with sparse ground flora. When compared to tropical wet forests, they receive less rainfall (< 1200 mm), have lower basal area, buttresses are rare, cauliflory is uncommon, herbaceous vascular epiphytes are very rare and large vertebrate dispersers are absent. In tropical dry evergreen forests, the upperstorey is formed by tree species such as *Pterospermum canescens*, *Garcinia spicata*, *Lannea coromandelica*, *Strychnos nux-vomica*, *Chloroxylon swietenia* and *Pongamia pinnata*. The middle storey is occupied by *Lepisanthes tetraphylla*, *Drypetes sepiaria*, *Canthium dicoccum*, *Tricalysia sphaerocarpa*,

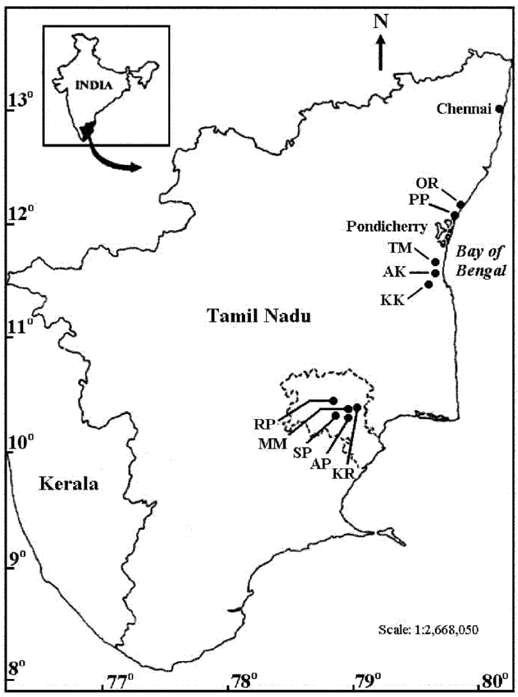

Figure 1. Map showing the location of ten tropical dry evergreen forest sites in south India (coastal sites: OR, PP, TM, AK and KK; inland sites: RP, MM, SP, AP and KR).

Table 1. Site disturbance score (1, ranked as rare; 2, occasional; 3, frequent) of five inland and five coastal tropical dry evergreen forest sites of South India

	Inland site					Coastal site				
Disturbance	AP	KR	MM	SP	RP	AK	PP	OR	KK	TM
Site encroachment (land use within the forest) for construction of temple	1	2	3	2	3	2	3	2	1	1
Bridle path used	1	2	3	3	2	2	3	2	2	2
Temple visitors' impact: area used for:										
Vehicle parking (area occupied)	1	3	3	3	2	1	3	1	1	1
Cooking inside the forest	1	3	3	2	3	1	3	1	1	1
Festive occasions	1	2	3	2	2	1	3	2	2	1
Grazing (cattle/goat)	2	2	3	2	3	2	3	2	2	2
Cultural attachment of local people	1	2	3	2	2	1	3	2	1	1
Resource removal										
Firewood	1	1	2	1	2	2	3	2	3	1
Timber	1	1	1	1	2	1	2	2	2	1
Others: medicinal plants, edible fruits and soil	1	1	2	2	2	2	1	2	3	2
Nearness of habitation and people's dependence on forest	1	2	3	3	3	2	3	2	3	3
Approach road to temple (width)	1	2	3	3	2	2	3	3	3	2
Total score	13	23	32	26	28	19	33	23	24	18

Diospyros ebenum, *Albizia amara*, etc. *Memecylon umbellatum* and *Glycosmis pentaphylla* form the understorey species. *Combretum albidum* and *S. minor* are the predominant liana species. In tropical dry evergreen forests, 69% of species are dispersed by small vertebrates such as palm civet, jackal, small Indian civet, rodents and bats. These animals depend heavily on the fleshy fruits of major fruit-rewarding species such as *M. umbellatum*, *G. pentaphylla*, *Grewia rhamnifolia*, *L. coromandelica* and *Jasminum angustifolium*[34].

Field methods

A 1-ha permanent plot (100 m × 100 m) was established in each of the ten sites and was subgridded into hundred (10 m × 10 m) quadrats for tree inventories. All trees ≥ 10 cm girth at breast height (gbh) were identified, tagged and a paint mark was made on the trunk where the gbh measurements were taken, to facilitate later re-measurement for growth. For multi-stemmed trees, bole girth was measured separately, basal area calculated and summed.

Data analysis

For species diversity, Shannon index ($H' = - p_i \ln p_i$, where p_i is the proportion of ith species, as in Magurran[35]) was calculated for all the sites. This index, formulated on theoretical basis, does not account for tree size and size-class variation, and is thus less sensitive when used in forest stands[36]. The frequency distribution of tree size (gbh) classes between the study sites was compared using Kolmogorov–Smirnov one-sample test[37]. We analysed the patterns of tree species composition in the ten sites using non-metric multidimensional scaling (NMS) ordination based on the data of importance value index (IVI)[38] of top fifteen species, using PC-ORD package. Coefficient of variation (CV; standard deviation/mean for a species) was computed to identify whether there is an oligarchy in tree species between the inland and coastal forest areas. This would provide information on site differentiation with respect to species composition, whether species with low CV regardless of absolute density are equitably distributed, or those with high CV show a large degree of variability in their distribution. This single/supportive objective method for designating dominance subdivided an obvious continuum of relative abundance for practical propose[39,40].

Results

Species richness and diversity

A total of 77 tree species (≥ 10 cm gbh) representing 61 genera and 30 families were recorded in the ten 1-ha plots, distributed five each in inland and coastal tropical dry evergreen forests (Table 2). Species richness ranged from 19 to 35 species in the ten sites. Out of 77 species, 24 (31%) were exclusive to the inland sites and 17 (22%) were confined to the coastal sites; while 36 species (47%) were common to both the areas.

The inland site AP scored a high value of Shannon index (2.44) and the coastal site AK recorded a low value (0.05), when compared to the other sites. The proportion of multi-stemmed individuals was greater in site AK (34.3%, 965 stems), which is four to five times greater than the five inland sites. The observed species richness did not vary significantly with the expected values among the five indi-

Table 2. Summary of tree diversity inventory (≥ 10 cm gbh) in ten tropical dry evergreen forest sites of South India

	Inland sites						Coastal site						
Variable	AP	KR	MM	SP	RP	Sub-total for five sites	AK	PP	OR	KK	TM	Sub-total for five sites	Grand total for ten sites
Species richness	35	30	28	26	19	60	30	30	29	28	22	54	77
No. of genera	30	27	25	24	18	49	28	27	28	25	21	46	61
No. of families	20	17	18	18	15	26	20	21	19	18	15	26	30
Stand density (stems ha^{-1})	807	596	724	1663	886	–	2813	1567	1284	1349	1077	–	–
Basal area ($m^2 ha^{-1}$)	19.1	21.6	15.5	22.1	12.4	–	17.6	36.5	27.3	16.9	29.3	–	–
Diversity indices Shannon index	2.44	2.24	2.01	1.29	1.84	–	1.82	1.64	2.33	2.02	2.06	–	–

Table 3. Density of top 15 tree species (≥ 10 cm gbh) enumerated in five individual sites of inland and coastal tropical dry evergreen forests of South India, arranged in decreasing order of their total abundance

	Inland site						Coastal site						
Species	AP	KR	MM	SP	RP	Sub total	AK	PP	OR	KK	TM	Sub total	Grand total
Memecylon umbellatum Burm. f. (Melastomataceae)	89	73	323	1148	74	1707	566	890	395	561	4	2416	4123
Tricalysia sphaerocarpa (Dalz.) Gamble (Rubiaceae)	–	–	–	–	–	–	915	–	–	252	351	1518	1518
Pterospermum canescens Roxb. (Sterculiaceae)	–	8	14	228	193	443	649	136	74	123	43	1025	1468
Drypetes sepiaria (Wight & Arn.) Pax & Hoffm. (Euphorbiaceae)	3	253	86	38	–	380	–	170	259	12	71	512	892
Lepisanthes tetraphylla (Vahl) Radlk (Sapindaceae)	121	3	4	1	–	129	193	24	37	51	273	578	707
Chloroxylon swietenia DC. (Flindersiaceae)	40	6	10	26	390	482	12	–	–	–	–	12	494
Diospyros ebenum Koen. (Ebenaceae)	11	3	–	–	–	14	281	10	57	100	26	474	488
Glycosmis pentaphylla (Retz) DC. (Rutaceae)	48	11	80	26	–	165	38	13	149	1	9	210	375
Canthium dicoccum (Gaertn.) Teijsm & Binn. (Rubiaceae)	–	11	69	–	–	80	14	123	41	23	13	214	294
Strychnos nux-vomica L. (Loganiaceae)	235	–	–	5	–	240	–	–	–	–	–	–	240
Albizia amara (Roxb.) Boivin (Mimosaceae)	61	30	25	48	58	222	2	1	7	–	–	10	232
Garcinia spicata (Wight & Arn.) J. D. Hook. (Clusiaceae)	–	–	–	–	–	–	–	97	30	59	19	205	205
Atalantia monophylla (L.) Correa (Rutaceae)	4	–	–	6	–	10	47	12	5	29	94	187	197
Mallotus rhamnifolius Muell.-Arg. (Euphorbiaceae)	–	–	–	–	–	–	14	–	–	35	76	125	125
Euphorbia antiquorum L. (Euphorbiaceae)	5	56	11	25	30	124	–	–	–	–	–	–	124
Sub-total	617	464	622	1551	745	3999	2731	1476	1054	1246	979	7486	11482
Remaining 62 species	190	132	102	112	141	677	82	91	230	103	98	604	1284
Grand total	807	596	724	1663	886	4676	2813	1567	1284	1349	1077	8090	12766

vidual sites of the inland and coastal areas ($\chi^2_{(4)} = 9.48$, $P > 0.05$). Further, singleton species were twice greater in inland sites (8 species) than coastal sites (4 species), while doubleton species were just up by one species in the inland sites (7 species) than the coastal ones (6 species).

Species dominance

The abundance of the enumerated 77 tree species varied considerably across the ten forest sites with more than 30-fold difference even among the top 15 species (Table 3). *M. umbellatum* (36.5% in inland and 29.8% in coastal areas) was the most abundant species in both the areas. The middlestorey species *S. nux-vomica* (with total abundance of 240 trees in 5 ha), *Euphorbia antiqorum* (124), *Manilkara hexandr*a (94), *P. pinnata* (72), and the lower storey species *Tarenna asiatica* (43) and *Clausena dentata* (31) were confined to the inland forest sites. Whereas *Tricalysia sphareocarpa* (1518), *Garcinia spicata* (205) and *Chionanthus zeylanica* (178) of middle storey and the lowerstorey species, *Mallotus rhamnifolius* (125) and *Eugenia bracteata* (38) were exclusive to coastal forest sites. The coefficient of variation (CV), used to predict the consistency of species occurrence within the forest type, revealed species heterogeneity among the plots. Species with both high dominance and low CV value reveal high predictability in a particular site. CV of species density varied from 10 to 2416 for the ten sites, but the dominant species exhibited different patterns. In the inland areas, the top fifteen abundant species contributed 86% of the total density and the CV of these dominant species was > 1.88, except for *L. tetraphylla*, indicating relatively consistent contribution to the proportion of stems among the five inland plots. Whereas in the coastal areas, the top fifteen abundant species contributed 92% of the density and all the species scored a CV < 1.46, except *Chloroxylon sweitenia,* thus revealing an inconsistency in the occurrence of dominant species in coastal plots.

Ordination

The NMS ordination revealed that axis 1 accounted for 39% variation and axis 2 accounted for 20%. The three sites SP, PP and OR got juxtaposed and these are characterized by a high abundance and moderate basal area of *M. umbellatum*, which links other species between the inland and coastal areas (Figure 2). The three coastal sites

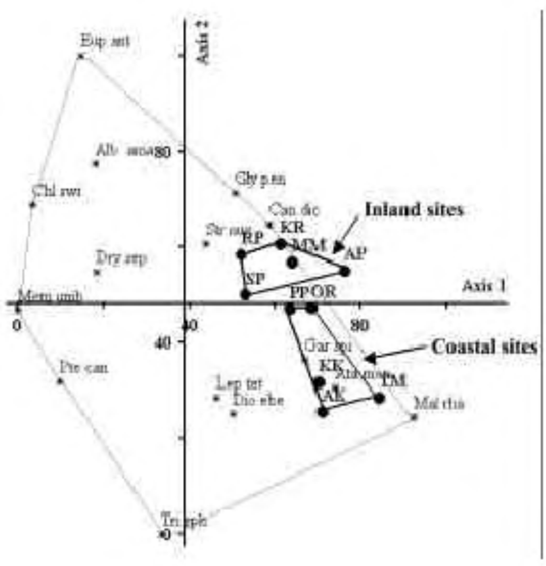

Figure 2. Scattered plot of NMS ordination using the importance value index of the top fifteen species. Species names are in six-letter codes; for their full names refer to Table 3.

KK, AK and TM figured on the right bottom of the ordination due to the exclusive occurrence of *G. spicata* and *M. rhamnifolius* in the coastal areas and also a high abundance and basal area of *L. tetraphylla*, *D. ebenum* and *Atalantia monophylla*. The inland sites were scattered on the right above the ordination, because of the three species *S. nux-vomica, C. sweitenia* and *E. antiquorum* that are exclusive to the inland area and these species also showed a positive correlation with axis 1.

Tree density and basal area

A total of 4676 trees (mean, 935 trees ha^{-1}; range, 596–1663 ha^{-1}) encountered in the five 1-ha plots of inland tropical dry evergreen forest sites, is 57.8% less than that of coastal forest sites (8090 trees; mean, 1618 trees ha^{-1}; range, 1567–2813 ha^{-1}; Table 2). The coastal site AK contained the highest stand density of 2813 trees ha^{-1}, which is 59% greater than the highest stand density of 1663 trees ha^{-1} at SP, among the five inland sites. The inland site KR contained the lowest stand density (596 stems ha^{-1}) when compared to the other sites. The basal area of individual inland forest plots was as low as 12.4 m^2 ha^{-1} in site RP to as high as 22.1 m^2 ha^{-1} in site SP; while in the coastal forest plots, the basal area ranged from a low of 16.9 m^2 ha^{-1} in site KK to a high of 36.5 m^2 ha^{-1} in site PP (Table 2).

Stand density and forest structure

Tree species richness and stem density across girth classes in both the areas decreased from the smallest to largest trees, while the occurrence rate of species (species richness/density) increased with tree size-class (Table 4). The species occurrence rate of lower (10–30 cm) and higher girth classes (> 181 cm) was greater in inland sites, whereas in 151–181 cm girth class, it was greater in the coastal areas. Tree size-class distribution of both the inland and coastal forest areas followed a reverse J-pattern (Figure 3). A comparison of size-class distribution of tree density across the ten sites did not show a significant variation, with the exception of inland site KR (Kolmogorov–Smirnov one-sample test, $P < 0.05$), which had a poor representation of trees in almost all girth classes, when compared to the other sites (Figure 3). The mean tree density in lower girth class (10–30 cm) was 50% greater in coastal sites (1236 stems ha^{-1}) than in the inland sites (615 stems ha^{-1}). The basal area distribution of various girth classes did not differ statistically across the ten sites ($\chi^2_{(11)} = 3.03$, $P > 0.05$). The mean basal area contribution in the smaller girth class (10–30 cm) was 43.6% greater in the coastal sites (3.9 m^2 ha^{-1}) than the inland sites (1.7 m^2 ha^{-1}). The middle girth-class (61–90 and 121–150 cm) was represented almost equally in both the areas; while the basal area of higher girth class (> 151 cm) was 61.3%

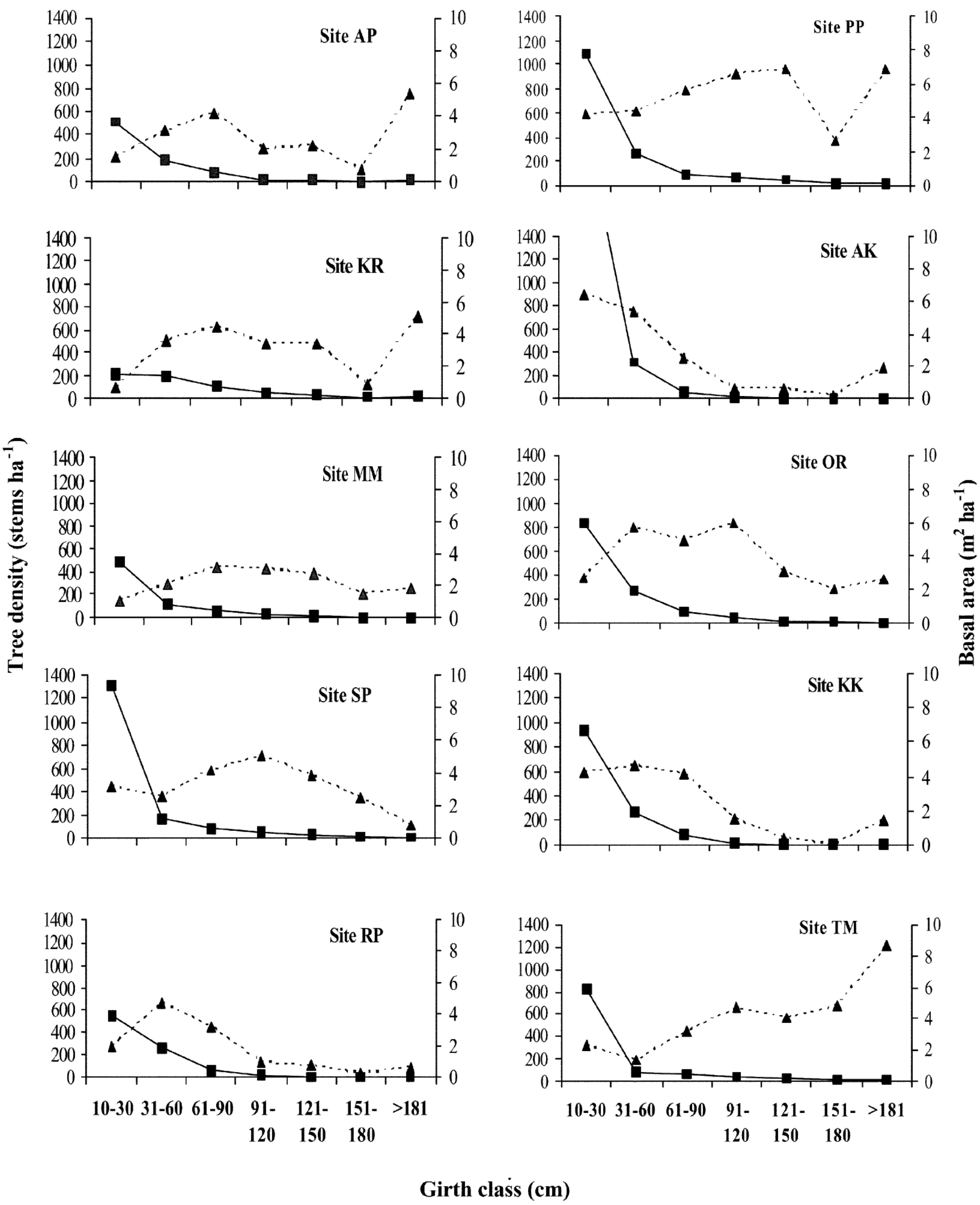

Figure 3. Stand structure based on tree density (solid line) and basal area (dotted line) in the ten forests sites.

greater in coastal sites (6.2 m^2 ha^{-1}) than the inland sites (3.8 m^2 ha^{-1}). The relationship between basal area and disturbance scores showed a negative correlation for both inland (Spearman rank correlation, $r^2_{(5)} = 5.3$, $P < 0.05$) and coastal areas ($r^2_{(5)} = 0.1763$, $P < 0.05$).

Comparison with other tropical dry evergreen forests

Variation in the methods employed in tree diversity inventories, particularly plot area, dimension and size threshold considered, renders a direct comparison of tropical dry evergreen forest across sites difficult. Yet an attempt has been made to compile available data on tree diversity inventories in the tropical dry evergreen forests (Table 5). At 1-ha scale, the mean tree density of 935 stems ha^{-1} in inland and 1618 stems ha^{-1} in coastal areas remained well within the range of 1115–1499 trees ha^{-1} in dry evergreen forest of Thailand[13] for stems ≥ 10 cm gbh. Whereas the species richness (65–111 species ha^{-1}) and basal area (28.9–29.4 m^2 ha^{-1}) were greater in Thailand than in the presently studied forests (Table 5). While at the scale for 0.1 ha area, the tree density is lower in peninsular Indian forests than in the Bahamas (1700–6500 trees ha^{-1} for upperstorey) and Jamaica (512–659 trees ha^{-1}). The basal

Table 4. Mean tree species richness and density, occurrence rate of species (species richness/stem density) averaged from the data of five sites in the inland and coastal forests under various girth classes

	Inland			Coastal		
Girth class (cm)	Mean species richness (± SD)	Mean stem density (± SD)	Species occurrence rate (species richness/stem density)	Mean species richness (± SD)	Mean stem density (± SD)	Species occurrence rate (species richness/stem density)
10–30	21.4 ± 3.21	615.6 ± 415.16	0.035	22 ± 2.65	1236.6 ± 685.1	0.018
31–60	15 ± 3.16	182.2 ± 52.51	0.082	14.8 ± 4.66	234.6 ± 89.67	0.063
61–90	11.8 ± 3.77	78 ± 16.23	0.151	10.2 ± 1.92	75.8 ± 17.63	0.134
91–120	7.4 ± 2.07	31 ± 17.46	0.238	7 ± 2.35	36.4 ± 23.09	0.192
121–150	6 ± 2.55	17.6 ± 8.68	0.340	5.8 ± 2.61	17.4 ± 14.88	0.333
151–180	3 ± 1.58	5.2 ± 3.90	0.576	3.8 ± 3.03	5.6 ± 8.26	0.678
> 181	3.6 ± 2.07	5.6 ± 4.93	0.643	4.4 ± 2.41	8.8 ± 7.53	0.500

Table 5. Comparison of species and family richness, density and basal area of trees inventoried in various other tropical dry evergreen forests at the scale of 1-ha and 0.1-ha

		Number of					
Location	gbh/dbh	Trees	Species	Families	Basal area	Predominant species	Major families
At 1-ha scale					($m^2\ ha^{-1}$)		
Peninsular India[1]							
Inland sites	≥ 10 cm gbh	596–1663	19–35	26	12.4–22.1	*Memecylon umbellatum*	Melastomataceae
(five 1-ha plots)						*Pterospermum canescens*	Sterculiaceae
Coastal sites	≥ 10 cm gbh	1077–2813	22–31	26	16.9–37.4	*M. umbellatum*	Melastomataceae
(five 1-ha plots)						*Tricalysia sphaerocarpa*	Rubiaceae
Northeastern Thailand[13]	> 4.5 cm dbh	1115–1499	65–111	–	28.9–29.4	*Hopea ferrea*	Dipterocarpaceae
(two 1-ha plots)						*Shorea henryana*	Dipterocarpaceae
At 0.1-ha scale					(m^2/0.1 ha)		
Peninsular India[1]							
Inland sites	≥ 10 cm gbh	41–197	10–13	10–12	0.93–3.23	*M. umbellatum*	Melastomataceae
(five 0.1 ha plots)						*Drypetes sepiaria*	Euphorbiaceae
Coastal sites	≥ 10 cm gbh	48–273	11–16	9-14	1.48–3.55	*M. umbellatum*	Melastomataceae
(five 0.1 ha plots)						*T. sphaerocarpa*	Rubiaceae
North Andros Island, Bahamas[16] (fifteen 0.1 ha plots)							
Overstorey species	≥ 5 cm dbh	1700–3918	17–35*	–	1.36–3.28	*Metopium toxiferum*	Anacardiaceae
						Coccoloba spp.	Polygonaceae
Understorey species	≥ 5 cm dbh	2700–6500	4–10	–		*Psychotria ligustrifolia*	Rubiaceae
						Randia aculeate	Rubiaceae
Round Hill, Jamaica[15]	≥ 5 cm dbh	512–659	42–51	–	2.8–3.2	*Metopium brownii*	Euphorbiaceae
(two 0.1 ha plots)						*Bursera simaruba*	Myrtaceae

*For 20 × 50 m plots; [1]Present study.

area values (range 0.90–3.55 m^2/0.1 ha) remained within the range of other tropical dry evergreen forests of Jamaica[15] and the Bahamas[16].

Discussion

The present study revealed the differences between inland and coastal forest areas in terms of composition of dominant species, stand structure and plant physiognomic groups (evergreen/deciduous). The difference in the number and density of trees under the two species physiognomic groups can be attributed to the variation in mean annual rainfall. The mean annual rainfall in the coastal area is 33.4% greater than the inland areas and also the mean annual temperature is greater by 1°C in the inland areas. In inland forests, the density of deciduous species is fivefold greater than the coastal forests, and these are mostly the upperstorey species. According to Beard[41], formation series, edaphic factors as well as annual rainfall are responsible for the differences in forest structure among various tropical dry evergreen forest formations. There is a much better understanding of the interactive nature of nutrient availability and seasonality in soil moisture, which led to broad patterns of forest dominance by evergreen or deciduous species[42].

Overall, the composition and abundance of species varied across the ten sites studied. *M. umbellatum* (36.5% total stem density in inland and 29.8% in coastal sites) is the only predominant understorey species that occurred in all the studied sites and is well represented in lower girth classes (10–61 cm gbh). It is a shade-tolerant species with clumped distribution and constituted 69% (1148 stems) of the forest stand density in the inland site SP, which featured this site as unique and exemplifying SP as a monodominant forest[31]. Single-dominant species share certain characteristics which are probably connected with a gregarious or strongly clumped dispersal pattern[43] and clumped distribution pattern of habitat patches may lead to higher survival rates in dynamic landscape for species with restricted distance effects of dispersal abilities[23,44,45]. The inland and coastal forest areas which are distanced by *c.* 250 km, varied in rainfall patterns and showed no consistency in the composition of dominant species. However, within each forest area there was a set of four to six important species. The dominance of some oligarchic species may also be due to disturbance[39]. For example, *M. umbellaum* in one of the inland sites (SP) and *T. sphaerocarpa* in one of the coastal sites (KK) was most abundant, probably due to past disturbance.

The IVI of three species showed a positive correlation with axes 1 and 2 (Figure 2) because of their high density and basal area. The studied peninsular Indian dry evergreen forests can be designated based on these dominants as *M. umbellatum–D. sepiaria–P. canescens* series; whereas in other tropical dry evergreen forests, an association of *Hopea ferrea–Shorea henryana* in Thailand[13], *Metopium–Coccoloba* (in coastal sites) and *Exothea–Bursera–Metopium* (interior) in the Bahamas[16] and *Metopium brownii–Bursera simaruba* in Jamaica[15] was reported. The tree inventories summarized in Table 5 compare the studied peninsular Indian tropical dry evergreen forests with other sites. Although the sites compared in Table 5 belong to the same vegetation type, viz. tropical dry evergreen forests, variation in species composition, families and stand structure can be attributed to geography, location, climatic and soil factors.

The studied peninsular Indian tropical dry evergreen forests are ‘sacred grove’ or ‘temple forests’ and they offer a unique opportunity for studying the impacts of human disturbances on biodiversity. Site encroachment and temple visitors’ impact constitute the major disturbances across the sites and each site experiences various gradients of disturbance (Table 1).

Our study demonstrated a negative correlation between the stand basal area and disturbance scores in both the inland and coastal areas. Smiet[46] correlated basal area with the rate of disturbance, and diameter distributions are commonly used to assess the disturbance effect within forests[47]. The basal area of the studied stands indicates a high level of human disturbance in lower (10–60 cm gbh) and middle girth classes (61–120 cm gbh; Figure 3) because of selective felling of understorey (*M. umbellatum*) and upperstorey trees (*Pterospermum canescens* and *Chloroxylon swietenia*) for fence-posts, house construction and other agricultural implements according to the information gathered during field work. Such selective elimination of species would affect forest species composition and stand structure, and also a more subtle impact and depends largely on accessibility, which itself is related to topography[45]. Sites MM and PP were mostly affected because of the temple constructed there, resulting in the reduction of voluminous trees (> 180 cm gbh) of species such as *Drypetes sepiaria*, *Albizia amara*, *Pterospermum canescens* and *Manilkara hexandra*. Logging may have been disproportional, such that the basal area in larger diameter classes has become reduced as also reported in western Kenya[48].

Conclusion

The quantitative inventory of tree species diversity revealed a considerable variation in the composition of dominant species and stand density in the inland and coastal forest areas. Compared to other tropical dry evergreen forests, tree diversity in the studied peninsular India is very low. Tree diversity in tropical forests varies greatly from place to place, mainly due to variation in biogeography, habitat and disturbance[49]. Human disturbance patterns also affect the structure and composition of forest sites[50].

The studied forests are represented by small patches or fragments, and are also associated with the cultural tradition of the local people as sacred groves. The role of natural forest sites, particularly sacred groves, in attracting increasing interest in international and conservation organizations such as UNESCO and WWF, has significant relevance for the implementation of Article 8j of the Conservation of Biological Diversity, which stresses more on the use of traditional wisdom and practices for conservation and sustainable use of biological diversity[18]. The extant level of plant diversity of these forests is because of their sacred grove status. These forests also contribute to the conservation of biodiversity by providing habitat for plants and food for faunal communities.

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