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TREE DIVERSITY AND FOREST STAND STRUCTURE ALONG DISTURBANCE GRADIENTS IN INDIAN TROPICAL DRY EVERGREEN FOREST

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Abstract. We investigated tree diversity and forest stand structure in understudied Indian tropical dry evergreen forest experiencing different degrees of human disturbance. We hypothesized that tree species richness and forest stand structure differ with differing levels of human disturbance. All trees ≥ 10 cm girth at breast height were assigned to four forest disturbance categories: relatively undisturbed (RD), moderately disturbed (MD), much disturbed (MU), and heavily disturbed (HD). A total of 5167 trees representing 106 species in 86 genera and 36 families were enumerated. Analysis of variance showed no significant difference between tree diversity across the disturbance categories ($P>0.05$). With increasing forest disturbance, tree species richness, abundance, and basal area scores decreased. The highest tree species richness was recorded in RD sites and the lowest in HD sites. A Bray-Curtis cluster analysis produced three groups, in which MU sites formed a distinct group. Zoochorous dispersal was prevalent in terms of species richness and abundance as well. The low species richness and tree abundance in the disturbed sites indicate the degraded status of these forests, showing the urgent need for ecological restoration of the heavily disturbed sites and conservation of MD and MU sites. The predominantly zoochorous mode of propagation also indicates the trees dependence on the local fauna, underlining the need for a holistic approach in biodiversity conservation of tropical dry evergreen forests.

Keywords: Dispersal mode, ecological guild, forest disturbance, tree size class.

INTRODUCTION

Tropical forests are rich in biodiversity and are important for conservation and timber production (Htun *et al.* 2010). Historical and contemporary losses in forest cover associated with human activities occur in many regions of the world, particularly in tropical regions. Due to rapid human population growth, pressure on natural ecosystems has increased dramatically during the last 50 years (Potts 2007), and half of the remaining tropical forests are already degraded, both old-growth and secondary forests. In general, natural as well as human disturbances often lead to altered environmental conditions, which influence the processes that can both augment and erode species diversity in a forest community (Kennard *et al.* 2002, Sagar *et al.* 2003). These disturbances determine forest dynamics and tree diversity at both the local and regional scale (Hubbell *et al.* 1999, Sheil 1999, Ramirez Marcial *et al.* 2001, Kennard *et al.* 2002, Sapkota *et al.* 2010).

Human disturbance may have various impacts on forest ecosystems. The impact of human disturbance on forest characteristics may be site-specific and the intensity and frequency of disturbance may also vary between sites (Htun *et al.* 2011). Even the same level of human disturbance may have different impacts on forests as the nature of forests and their responses to disturbances may not be the same. The general agreements on the role of disturbance of suitable intensity in maintaining species diversity (Connell 1978, Vetaas 1997, Sheil & Burslam 2003), the detailed process that structure the diversity following disturbance remain unclear yet (Van Gemerden *et al.* 2003). The intermediate disturbance hypothesis is still relevant in explaining greater species richness as too much disturbance leads to the loss of late-successional species and too little disturbance leads to exclusion of species added to colonizing the younger sites (Sapkota *et al.* 2010). The knowledge of forest structure, composition and diversity at different levels of human disturbance would facilitate the caution and implementation of more effective conservation measures (Htun *et al.* 2011). Understanding the response

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of forest vegetation to different intensities of human disturbance would identify where conservation efforts should be given priority, and thereby enable the efficient use of limited conservation funds (James *et al.* 2001, Bhuyan *et al.* 2003).

In India, forests have been used by the local communities over millennia for a variety of uses and practices (Lele & Hegde 1997, Shankar *et al.* 1998, Mehta *et al.* 2008). Of these, livestock grazing, fuel wood and fodder extraction, cutting of trees, soil removal and land encroachment are common and these activities represent substantial pressure on the forest resource base (Banerjee1995, Bhat *et al.* 2001, Saha 2002). The anthropogenic pressures from local communities residing within and on the fringes of these reserves continue to be enormous (Mehta *et al.* 2008). Consequently, livestock grazing, fuel wood, fodder extractions are recognized as a "chronic disturbance" that can have substantial impacts on the entire forest ecosystem and their resource base.

Tropical dry evergreen forests are distributed along the eastern coast of India (Parthasarathy & Sethi 1997), in northern Sri Lanka (Blasco & Legris 1973), northeastern Thailand (Bunyavejchewin 1999), Jamaica (Kelly *et al.* 1988), in Africa in Tanzania and northeastern Zambia (Lawton 1978, Kielland-Lund 1982, Woldu 1999). The tropical dry evergreen forests on the Coromandel coast, composed of indigenous species, are mostly sacred groves preserved as a result of the religious belief of the local people (Parthasarathy *et al.* 2008). The existence of sacred groves has been reported in India as well as in parts of Africa (Stuart & Ujiyediin 1997), Europe (Hartland 1893), America (Frazer 1923) and Nepal (Ingles 1990). Various anthropogenic pressures due to developmental activities, urbanization, exploitation of resources and increase in human population have threatened many sacred groves of the country (Chandrasekara & Sankar 1998, Khan *et al.* 2008). Small forest fragments are reported to provide a safety net for a significant number of species and their genetic diversity (Turner el al. 1994) as are the sacred groves on the Coromandel coast of India.

The tropical dry evergreen forest (TDEF) on the Coromandel coast of India which occurs as patches, are short-statured, largely three-layered, tree dominated evergreen forests with a sparse and patchy ground flora (Parthasarathy *et al.* 2008) and dense in lianas. Only about 4 to 5 % of the original TDEF patches exist today. Although over two decades many studies have been conducted on the biodiversity and ecology of tropical dry evergreen forests in selected sites (Venkateswaran & Parthasarathy 2003, Reddy & Parthasarathy 2003, Mani & Parthasarathy 2006, Selwyn & Parthasarathy 2006, 2007; Parthasarathy *et al.* 2008), detailed investigation on the tree diversity and abundance in relation to different categories of forest disturbance is lacking and hence the present study was undertaken with the objective of determining the patterns of tree diversity, stand structure, basal area, stem size-class distribution and ecology of tropical dry evergreen forests experiencing different degrees of human disturbance. We hypothesized that species richness and forest stand structure differ with different levels of human disturbance. We tested our hypothesis with data generated on forest stand variables and disturbance score from 40 sites of tropical dry evergreen forests on the Coromandel coast of India.

METHODS

Study area. The present study was conducted in a total of 40 tropical dry evergreen forest sites, which are classed into four categories based on the forest disturbance scores. They are located around the towns of Puducherry (11°56'N, 79°53'E), Villupuram (11°93'N, 79°48'E), Cuddalore (11°43'N, 79°49'E), and Pudukottai (10°23'N, 78°52'E) on the Coromandel coast of peninsular India. The total of 40 sites selected were distributed as ten in each of four categories of forest disturbance (relatively undisturbed - RD, moderately disturbed - MD, much disturbed - MU, and heavily disturbed - HD) to serve as replicates, chiefly based on the extent of human disturbance but also to discern variation within and across the four disturbance categories. The distance between the study sites ranged from 10 km to 20 km. The size of the forests ranged from 0.8 ha to more than 20 ha. The site disturbance level was not related to the size of the forest, and hence we have not considered size as a criterion in assessing the disturbance scores, but have included various anthropogenic activities. The distance between study sites and closest human settlement ranged from 10 m to 1 km. Agricultural fields of paddy, sugarcane, groundnut, and cashew plantations surround the study sites. Soils are basically red lateritic and sandy to sandy loam in texture in all the study sites. The climate is tropical dissymmetric type with most rainfall received during the northeast monsoon (October-December) and very little and inconsistent rainfall in the southwest monsoon (June to September). The mean annual rainfall is 1282, 1079, and 1033 mm in Puducherry, Cuddalore, and Pudukottai respectively. The mean annual maximum and minimum temperatures are 32.9ºC and 24.5ºC in Puducherry, 33.6ºC and 22.8ºC in Cuddalore, and 33.4ºC and 25.4ºC in Pudukottai. The vegetation of this region is described as tropical dry evergreen forests, Type 7/CI of Champion & Seth (1968); see also Venkateswaran and Parthasarathy (2003) and Parthasarathy *et al.* (2008). *Memecylon umbellatum* Burm. f., *Tricalysia sphaerocarpa* (Dalz.) Gamble, and *Pterospermum canescens* Roxb. are the predominant trees, and *Combretum albidum* G. Don. and Strychnos minor Dennst. The predominant liana species in the tropical dry evergreen forests. *Ecbolium viride* (Forsskal) Alston, *Amorphophallus sylvaticus* Kunth., and *Sansevieria roxburghiana* Schultes & Schultes f. are the three native perennial herbs present in the study sites.

Data collection. The fieldwork was carried out between March and December 2010. Ten sample plots of 10 × 20 m were established in each site and these totaled 100 plots for each of the four forest disturbance categories. All trees of ≥ 10 cm girth at breast height (gbh) were enumerated, measured at 1.3 m from the ground. The ecological guild, plant physiognomic type, fruit type and dispersal mode were noted from field observations and also verified with regional floras (Gamble & Fischer 1915-1935, Matthew 1991). The abundance of trees was the number of individuals in the sampling plots. For multi-stemmed trees, bole girths were measured separately, basal area calculated and summed.

The study sites are classified into four categories based on their disturbance scores. Site disturbance scores were determined based on the extent of various anthropogenic activities such as temple visitors' impact, grazing by cattle and goats, illegal timber felling, fuelwood collection, fodder leaf collection, soil removal for house and road construction, the number and width of trails made inside the forest, road construction, litter clearance, edible fruit collection, medicinal plant removal, human occupation, extent of bioinvasion, and cultural attachment of the local people. The qualitative assessment of various types of disturbance was ranked as rare (1), occasional (2), or frequent (3). The sum of all the scores that had high ranks (31-40) was designated as heavily disturbed sites, 21 to 30 as much disturbed sites, 11 to 20 as moderately disturbed sites, and 1 to 10 as relatively undisturbed sites. The ten RD sites are invariably dense, tall-statured, old-growth forests; they harbor comparatively small temple structures with infrequent visitors and these characteristic features place them in the RD category. Among the MD sites, Kothattai is a large site but the vegetation is patchy with more sandy slopes between them. The Vada Agaram site, although large, remains as a stunted forest because of resource extraction and adjacent large-scale Eucalyptus plantation, while part of the forest has been cleared for Tectona plantation. MU sites suffer from forest clearance largely due to temple expansion. The HD sites cause serious concern having already lost about 50% of their area and are still under pressure due to heavy forest dependence of the local people.

Data analysis. Diversity indices such as Shannon (H'), Simpson (D), and Fisher's alpha were computed following Magurran (2004). The species-accumulation curve was created using the program EstimateS, based on mean species accumulation after 50 times randomization of the sample order. We used one-way analysis of variance (ANOVA) to check for significance of difference in tree variables across the four forest categories. A modified family importance value (FIV) was calculated by summing the relative diversity (number of species in the family/total number of species × 100) and relative density of individuals and relative basal area (Mori *et al.* 1983). Relative density, relative dominance, relative frequency, and importance value index (IVI), a measure of relative prominence of various species in the forest, were calculated following Cottom & Curtis (1956). Bray-Curtis analysis was conducted using Biodiversity Pro, version 2, for which we used data of tree species richness and abundance of each forest disturbance category as input variables.

RESULTS

Tree diversity. We recorded a total of 5167 of trees ≥ 10 cm gbh in the total 400 sample plots of tropical dry evergreen forests (100 in each of the four categories of forest disturbance) on the Coromandel coast of India, representing 106 species in 86 genera and 36 families (Table 1). Tree species richness did not differ significantly across the four forest categories ($P > 0.05$). The maximum tree species richness was recorded in the relatively undisturbed sites (RD) with 69 species, followed by the moderately disturbed MD site with 57, MU with 54, and HD with 46 species. The diversity index values decreased with increasing forest disturbance. The Shannon index was higher in

TABLE 1. Summary of tree inventory in four categories of tropical dry evergreen forests on the Coromandel coast of India (data pooled for100 plots in 10 sites in each of the four category of forests: RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD-heavily disturbed).

	Number of plots				
Variable	RD	MD	MU	HD	Total
Species richness	69	57	54	46	
(range)	15 -27	15 -21	10 - 23	7 - 19	106
Abundance	1983	1517	1138	529	
(range)	193 - 274	124 - 297	90 - 208	62 - 109	5167
No. of families	32	25	28	27	36
Basal area (m^2) range	2.82 - 7.62	1.73 - 9.76	1.75 - 5.42	0.55 - 3.98	
Diversity indices					
Shannon	3.13	2.8	2.99	2.24	2.67
Simpson	15.04	7.89	9.71	17.38	11.43
Fisher's Alpha	14.14	11.96	12.62	12.46	12.32

RD and MU sites than in MD and HD sites, while the Simpson index was higher in HD than the other three forest categories. Tree abundance did not differ significantly across the four disturbance categories (F = 0.337, P = 0.752) and was greater in RD (1938 individuals) and MD (1517) than in MU (1138) and HD (529) sites.

Notably, with increasing forest disturbance, the basal area scores decreased across the four forest categories. The RD sites scored greatest basal area (2.82 - 7.62 m^2), least values in HD (0.55 - 3.98 m^2) and intermediate in MD and MU. There was a strong negative relationship between tree abundance and disturbance scores (Fig. 1).

Species composition. Of the total 106 tree species enumerated, 19 species were common to all four forest categories (Table 2). The most abundant tree species was *Memecylon umbellatum* in MD and MU, *Tricalysia sphaerocarpa* in RD, and *Lepisanthes tetraphylla* in HD sites. Fifteen tree species were confined only to MU sites, 10 species to HD, and 9 species occurred only in RD sites. The most abundant understory tree species *Memecylon umbellatum* was totally absent in the HD sites. Species such as *Lepisanthes tetraphylla*, *Drypetes sepiaria*, *Glycosmis mauritiana*, *Garcinia spicata*, and *Atalantia monophylla* were common and figured within the top ten abundant tree species of the four forest categories.

Importance value index (*IVI*). The top 10 species and their IVI scores varied across the four forest disturbance categories (Fig. 2). In RD sites the top 10 species formed 72% of the total IVI, in MD 77%, in MU 72%, and in HD sites 69% . Among the top 10 species, *Drypetes sepiaria* in RD sites, *Memecylon umbellatum* in MD and MU, *Azadirachta indica* in HD sites scored the highest IVI. In the four forest disturbance categories *Pterospermum canescens* in RD and MD sites and *Borassus flabellifer* in MU and HD sites scored the highest relative basal area.

Species-area curve. Species number tended to increase with increasing sample area in all the four forest categories (Fig. 3). Species-area curves for all the four forest categories did not reach an asymptote in the sampled plots. The trend of increasing species number with area stopped once the sample area reached 9 of the total 10 sites inventoried in MD, while the species number gradually increased with increasing sample area in RD, MU, and HD sites.

Bray-Curtis cluster analysis. The Bray-Curtis cluster analysis, with species richness and abundance of trees as input variables, produced three distinct groups, in which the HD sites were quite distantly placed, RD and MD sites formed one group, and the MU sites formed another distinct group (Fig. 4).

Floristic similarity index (JCS). The species similarity coefficient, Jaccard's index, ranged from 0.43 to 0.556 and the number of species shared between the studied sites ranged from 25 to 45 (Table 4). The greatest similarity was found between RD and MD sites, while HD sites exhibited very low species similarity.

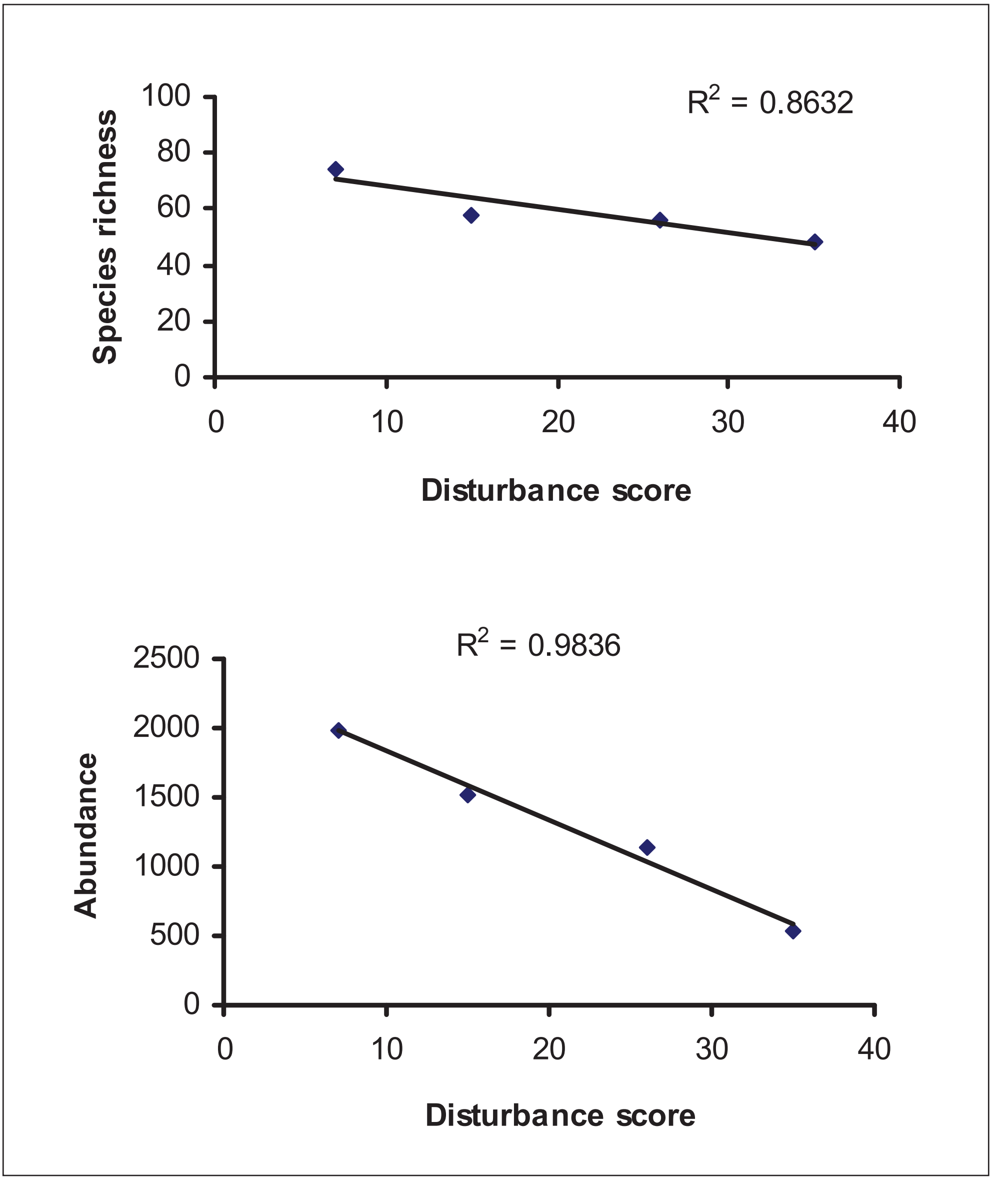

FIG. 1. Relationship between tree species richness and abundance with disturbance scores.

Family diversity. In the present study, the contribution of 36 plant families towards tree taxa diversity (genera and species) and stand density varied across the four forest categories (Table 3). The most speciose family in our sites was Rubiaceae with 10 species and 8 genera, followed by Euphorbiaceae (9 species and 8 genera), Caesalpiniaceae (8 species and 5 genera), Mimosaceae and Moraceae (7 species each), and Rutaceae (5 species and 5 genera). Rubiaceae was the predominant family in terms of species richness and its abundance was greatest in RD sites (343 individuals) followed by MD (179), MU (121), and HD (69 individuals) sites. In terms of tree abundance, Melastomataceae was represented by just one species,

TABLE 2. Tree species abundance and species traits in four categories of tropical dry evergreen forests on the Coromandel coast of India (data pooled for 10 sites in each of the four category of forests: RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD-heavily disturbed).

Sl. No.	Species	Family	EG	PT	DM	RD	MD	MU	HD	Total density
1	*Memecylon umbellatum* Burm.f.	Melastomataceae	L	E	Z	220	474	311		1005
2	*Tricalysia sphaerocarpa* (Dalz.) Gamble	Rubiaceae	M	E	Z	299	122	63		484
3	*Lepisanthes tetraphylla* (Vahl.) Radlk.	Sapindaceae	M	E	Z	90	92	55	57	294
4	*Drypetes sepiaria* (Wight & Arn.) Pax. & Hof.	Euphorbiaceae	M	E	Z	203	63	26	7	299
5	*Glycosmis mauritiana* (Lam.) Yuich. Tanaka	Rutaceae	L	E	Z	85	74	92	41	292
6	*Pterospermum canescens* Roxb.	Sterculiaceae	U	E	A	120	106	24		250
7	*Garcinia spicata* (Wight & Arn.) J.D. Hook.	Clusiaceae	M	E	Z	72	124	20	2	218
8	*Atalantia monophylla* (L.) Correa	Rutaceae	M	E	Z	80	51	46	15	192
9	*Albizia amara* (Roxb.) Boivin	Mimosaceae	U	D	Au	106	15	17	16	154
10	*Pleiospermium alatum* (Wall. ex Wight. & Arn.) Swingle	Rutaceae	M	E	Z	78	61		10	149
11	*Azadirachta indica* A. Juss.	Meliaceae	M	BD	Z	6	18	34	75	133
12	*Diospyros ebenum* Koen.	Ebenaceae	M	E	Z	77	36	12		125
13	*Dimorphocalyx glabellus* Thw.	Euphorbiaceae	L	E	Z			111		111
14	*Borassus flabellifer* L.	Arecaceae	U	E	Z	11	15	34	41	101
15	*Wrightia tinctoria* (Roxb.) R.Br.	Apocyanaceae	L	D	A	89	2			91
16	*Canthium dicoccum* (Gaertn.) Teijsm. & Binn.	Rubiaceae	M	E	Z	19	22	32		73
17	*Manilkara hexandra* (Roxb.) Dubard	Sapotaceae	M	E	Z	62	9			71
18	*Chloroxylon swietenia* DC.	Flindersiaceae	M	D	Au	48	10	9		67
19	*Syzygium cumini* (L.) Skeels	Myrtaceae	U	E	Z	15	11	17	12	55
20	*Strychnos nux-vomica* L.	Loganiaceae	M	D	Z	48	1		4	53
21	*Aglaia elaeagnoidea* (Juss.) Benth.	Meliaceae	M	E	Z	4		7	35	46
22	*Pongamia pinnata* (L.) Pierre	Papilionaceae	M	D	Au	35		7		42
23	*Benkara malabarica* (Lam.) Tirven.	Rubiaceae	L	D	Z	11	9	5	14	39
24	*Cassia fistula* L.	Caesalpiniaceae	M	D	Au	9	10	8	10	37
25	*Pterospermum xylocarpum* (Gaertn.) Sant. & Wagh.	Sterculiaceae	U	E	A	17	20			37
26	*Calophyllum inophyllum* L.	Clusiaceae	M	E	Z		2	33		35
27	*Ficus hispida* L.f.	Moraceae	L	BD	Z			11	21	32
28	*Euphorbia antiquorum* L.	Euphorbiaceae	L	D	Z	20	11			31
29	*Acacia auriculiformis* A. Cunn. ex Benth.	Mimosaceae	U	BD	Z		27	1		28
30	*Catunaregam spinosa* (Thunb.) Tirvengadum	Rubiaceae	L	D	Z		6		22	28
31	*Morinda coreia* Buch.-Ham	Rubiaceae	M	BD	Z	3	2	11	12	28
32	*Pamburus missionis* (Wight) Swingle	Rutaceae	M	E	Z	5	4	14	3	26
33	*Prosopis juliflora* (Sw.) DC.	Mimosaceae	L	E	Z	1	2	23		26
34	*Tarenna asiatica* (L.) Kuntez ex Schumann	Rubiaceae	L	E	Z	4	13	3	6	26
35	*Ficus benghalensis* L.	Moraceae	U	BD	Z	7	13	2	3	25
36	*Alangium salvifolium* (L.f.) Wangerin	Alangiaceae	L	D	Z			11	13	24
37	*Gmelina asiatica* L.	Verbenaceae	L	E	Z	4	2	3	14	23
38	*Chionanthus zeylanica* L.	Oleaceae	L	E	Z	2	10	10		22
39	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	U	D	Z	16	2	2	1	21
40	*Flacourtia indica* (Burm.f.) Merr.	Flacourtiaceae	L	E	Z	1		7	12	20
41	*Ixora pavetta* Andrews	Rubiaceae	L	E	Z	2	4	5	8	19
42	*Diospyros ferrea* (Willd.) Bakh.	Ebenaceae	L	E	Z	7		6	3	16
43	*Eugenia bracteata* (Willd.) Roxb. ex DC.	Myrtaceae	L	E	Z	2	6	8		16
44	*Vitex altíssima* L. f.	Verbenaceae	M	E	Z	3	12			15
45	*Mallotus rhamnifolius* Muell.-Arg.	Euphorbiaceae	L	D	Au	1	13			14

Sl. No.	Species	Family	EG	PT	DM	RD	MD	MU	HD	Total density
46	*Maytenus emarginata* (Willd.) Ding Hou	Celastraceae	L	E	Au	6		3	4	13
47	*Albizia lebbeck* (L.) Benth.	Mimosaceae	U	D	Au	3	1	6	2	12
48	*Cadaba trifoliata* (Roxb.) Wight & Arn.	Capparaceae	L	E	Z	8	4			12
49	*Commiphora caudata* (Wight & Arn.) Engle.	Burseraceae	L	D	Z	12				12
50	*Cordia obliqua* Willd.	Cordiaceae	M	E	Z	2		10		12
51	*Delonix regia* (Hook.) Raf.	Caesalpiniaceae	L	D	Au		1	11		12
52	*Polyalthia korintii* (Dunal) Thw.	Annonaceae	L	E	Z	6	6			12
53	*Miliusa montana*	Annonaceae	L	E	Z		11			11
54	*Canthium coromandelicum* (Burm.f.) Alston	Rubiaceae	L	D	Z			2	7	9
55	*Premna latifolia* Roxb.	Verbenaceae	M	BD	Z	5	2		2	9
56	*Streblus asper* Lour.	Moraceae	M	E	Z	7	1	1		9
57	*Thevetia peruviana* (Pers.) Merr.	Apocyanaceae	L	E	Z				8	8
58	*Carmona retusa* (Vahl) Masm	Cordiaceae	L	E	Z	4			8	12
59	*Cassia roxburghii* DC.	Caesalpiniaceae	L	D	Au	6	1			7
60	*Diospyros montana* Roxb.	Ebenaceae	M	BD	Z	1	2	4		7
61	*Ochna obtusata* DC.	Ochnaceae	L	E	Z	5			2	7
62	*Sapindus emarginatus* Vahl	Sapindaceae	M	D	Z	7				7
63	*Ehretia pubescens* Benth.	Boraginaceae	M	E	Z				6	6
64	*Madhuca longofolia* (L.) Macbr.	Sapotaceae	U	D	Z		1		5	6
65	*Polyalthia longifolia* (Sonn.) Thw.	Annonaceae	U	E	Z			6		6
66	*Bombax ceiba* L.	Bombacaceae	U	D	A				5	5
67	*Breynia vitis-idaea* (Burm. f.) Fischer	Euphorbiaceae	L	E	Z				5	5
68	*Tamarindus indica* L.	Caesalpiniaceae	U	BD	Z				5	5
69	*Clausena dentata* (Willd.) Roemer	Rutaceae	L	E	Z	1	2		1	4
70	*Dichrostachys cinerea* (L.) Wight & Arn.	Mimosaceae	L	BD	Au				4	4
71	*Gardenia resinifera* Roth	Rubiaceae	M	D	Z	4				4
72	*Sapium insigne* (Royle) Trimen	Euphorbiaceae	M	D	Z	4				4
73	*Allophylus serratus* (Roxb.) Kurz	Sapindaceae	M	E	Z	3				3
74	*Bauhinia racemosa* Lam.	Caesalpiniaceae	M	D	Au			3		3
75	*Barringtonia acutangula* (L.) Gaertner	Barringtoniaceae	M	E	H	1		1	1	3
76	*Dalbergia paniculata* Roxb.	Papilionaceae	U	D	Au	3				3
77	*Mallotus philippensis* (Lam.) Muell.-Arg.	Euphorbiaceae	L	D	Au		3			3
78	*Acacia leucophloea* (Roxb.) Willd.	Mimosaceae	M	BD	Au	1	1			2
79	*Anacardium occidentale* L.	Anacardiaceae	M	BD	Z		2			2
80	*Cassia auriculata* L.	Caesalpiniaceae	L	D	Au			2		2
81	*Crateva magna* (Lour.) DC.	Capparaceae	L	D	Z	2				2
82	*Crateva adansonii* DC. ssp. odora (Buch.-Ham.) M. Jacobs	Capparaceae	L	D	Z				2	2
83	*Dodonaea angustifolia* L.f.	Sapindaceae	L	BD	A			2		2
84	*Morinda pubescens*	Rubiaceae	M	BD	Z	1	1			2
85	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	M	E	Z				2	2
86	*Phyllanthus polyphyllus* Willd.	Euphorbiaceae	L	D	Z	2				2
87	*Walsura trifolia* (A. Juss.) Harms	Meliaceae	M	E	Z			2		2
88	*Albizia odoratissima* (L.f.) Benth.	Mimosaceae	L	D	Au	1				1
89	*Annona squamosa* L.	Annonaceae	L	E	Z				1	1
90	*Artocarpus heterophyllus* Lam.	Moraceae	M	E	Z			1		1
91	*Butea monosperma* (Lam.) Taubert	Papilionaceae	M	BD	Au		1			1
92	*Casuarina equisetifolia* Forster &Forster f.	Casuarinaceae	U	E	A			1		1
93	*Commiphora berryi* (Arn.) Engle.	Burseraceae	L	D	Z	1				1
94	*Cordia monoica* Roxb.	Cordiaceae	M	E	Z			1		1

Sl. No.	Species	Family	EG	PT	DM	RD	MD	MU	HD	Total density
95	*Delonix elata* (L.) Gamble	Caesalpiniaceae	L	D	Au				1	1
96	*Ficus amplissima* J.E. Smith	Moraceae	U	BD	Z			1		1
97	*Ficus microcarpa* L.f.	Moraceae	M	BD	Z		1			1
98	*Ficus racemosa* L.	Moraceae	U	BD	Z			1		1
99	*Hardwickia binata* Roxb.	Caesalpiniaceae	M	D	Au	1				1
100	*Millingtonia hortensis* L.f.	Bignoniaceae	U	E	Au				1	1
101	*Premna serratifolia* L.	Verbenaceae	M	BD	Z		1			1
102	*Semecarpus anacardium* L. f.	Anacardiaceae	M	BD	Z	1				1
103	*Sryrchnos potatorum* L. f.	Loganiaceae	M	D	Z	1				1
104	*Suregada angustifolia* (Baill. ex. Muell-Arg.) Airy Shaw	Euphorbiaceae	L	E	Z	1				1
105	*Terminalia arjuna* (DC.) Wight & Arn.	Combretaceae	U	BD	Z		1			1
106	*Terminalia bellirica* (Gaertner) Roxb.	Combretaceae	U	D	Z	1				1
	Total					1983	1517	1138	529	5167

Ecological guild (EG): U-upper story, M-middle story, L-lower story; Plant type (PT): E-evergreen, BD-brevideciduous, D-deciduous; Dispersal mode (DM): AU-autochory, A-anemochory, Z- zoochory, H-hydrochory.

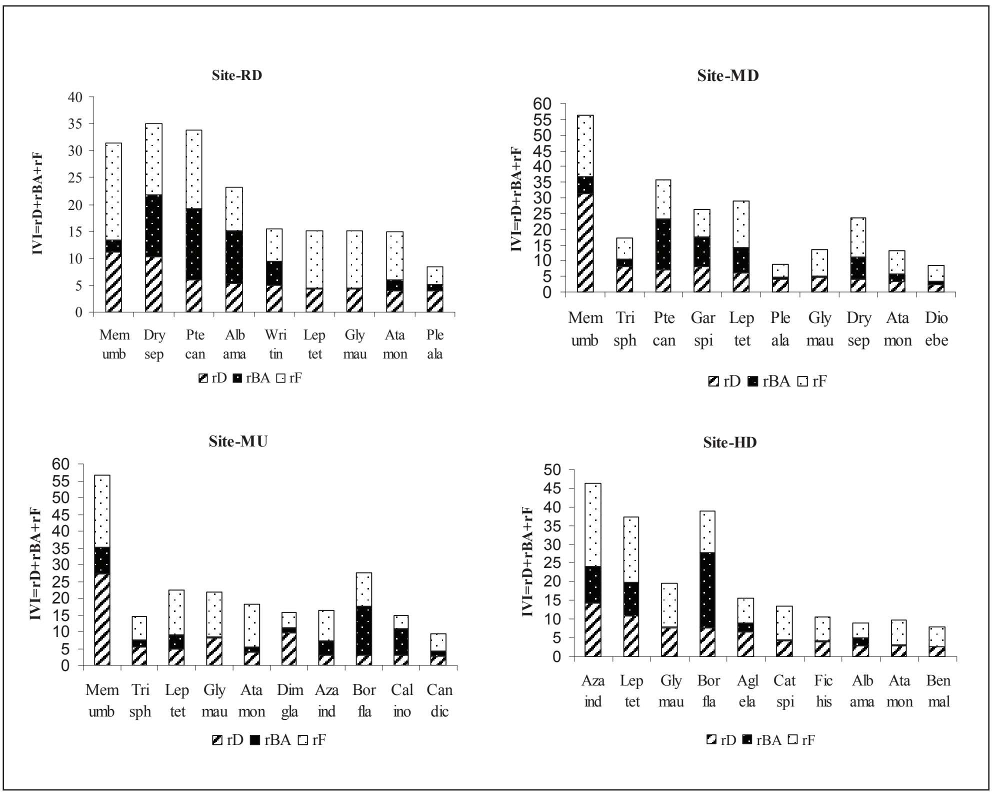

FIG. 2. Importance value indices (IVI) of top 10 tree species in forest disturbance categories RD, MD, MU and HD sites; rD-relative Density, rBA-relative Basal Area, rF-relative Frequency.

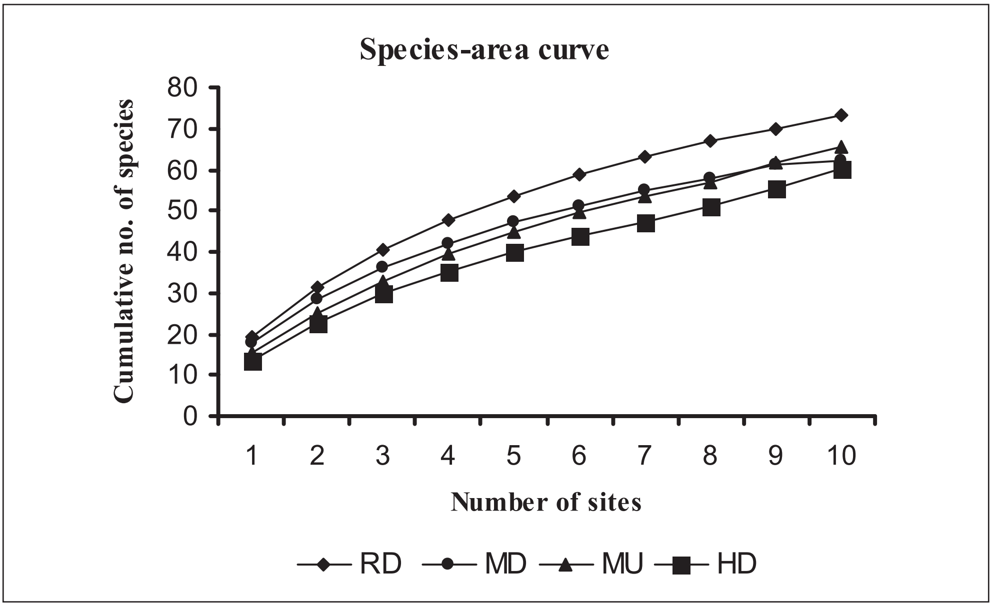

FIG. 3. Species-area curve for trees in four forest categories of tropical dry evergreen forest sites (created after 50 times randomization of 40 sample plots of 0.2 ha, distributed by ten in each category of forest disturbance).

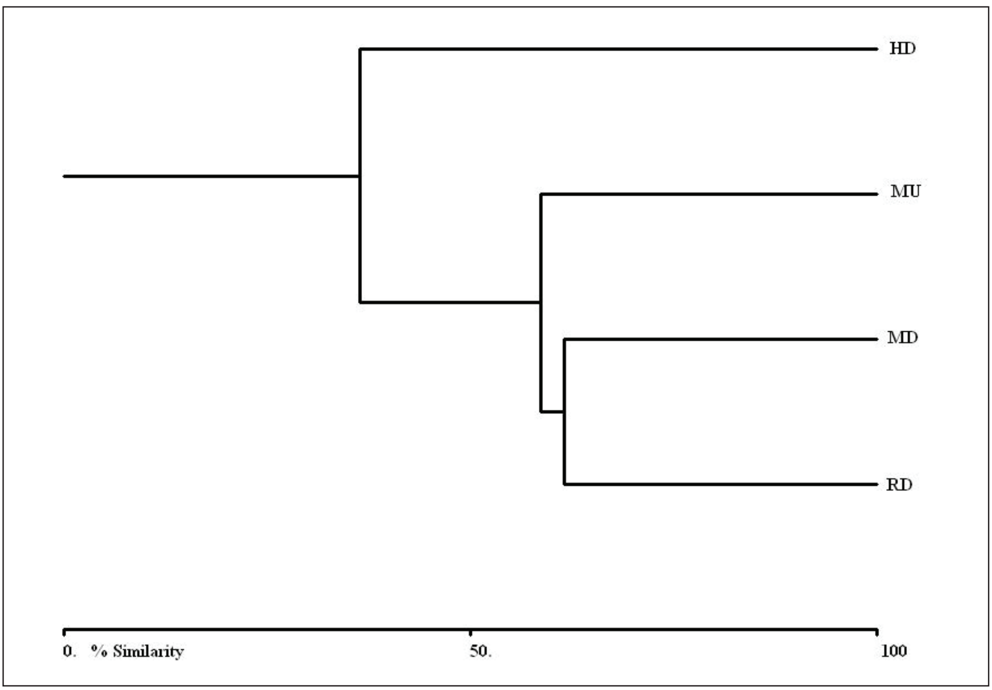

FIG. 4. Cluster analysis for species similarity and abundance of trees in four categories of tropical dry evergreen forest sites (RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD-heavily disturbed).

TABLE 3. Contribution of families of tree genera, richness and abundance, and family importance value (FIV), arranged in decreasing order of FIV combined for four forest disturbance categories.

Family	Genera	Species	Density	FIV
Rubiaceae	8	10	712	23.21
Melastomataceae	1	1	1005	20.39
Euphorbiaceae	8	9	470	17.58
Rutaceae	5	5	663	17.54
Mimosaceae	4	7	227	10.99
Sapindaceae	4	4	306	9.69
Caesalpiniaceae	5	8	68	8.86
Moraceae	3	7	70	7.95
Sterculiaceae	1	2	287	7.44
Clusiaceae	2	2	253	6.78
Meliaceae	3	3	181	6.33
Ebenaceae	1	3	148	5.69
Verbenaceae	3	4	48	4.7
Annonaceae	3	4	30	4.35
Arecaceae	2	2	103	3.88
Apocyanaceae	2	2	99	3.8
Papilionaceae	3	3	46	3.72
Sapotaceae	2	2	77	3.37
Cordiaceae	2	3	25	3.31
Anacardiaceae	3	3	24	3.29
Myrtaceae	2	2	71	3.26
Capparaceae	2	3	16	3.13
Loganiaceae	1	2	54	2.93
Flindersiaceae	1	1	67	2.24
Burseraceae	1	2	13	2.13
Combretaceae	1	2	2	1.92
Alangiaceae	1	1	24	1.4
Oleaceae	1	1	22	1.36
Flacourtiaceae	1	1	20	1.33
Celastraceae	1	1	13	1.19
Ochnaceae	1	1	7	1.07
Boraginaceae	1	1	6	1.05
Bombacaceae	1	1	5	1.04
Barringtoniaceae	1	1	3	1
Bignoniaceae	1	1	1	0.96
Casuarinaceae	1	1	1	0.96

TABLE 4. Floristic similarity index (JCS) and number of shared species between the four forest categories of tropical dry evergreen forest sites.

Forest category	RD	MD	MU	HD
	Number of shared species			
RD	–	45	37	30
MD	0.556	–	33	25
MU	0.43	0.423	–	27
HD	0.353	0.321	0.37	–

Memecylon umbellatum in three forest categories with a total of 1005 individuals, followed by Rubiaceae (712 individuals) and Rutaceae with 663 individuals. The tree abundance of Melastomataceae was greater in MD sites followed by MU and RD sites, while it was totally absent in HD sites. Twelve families were represented by single species with an abundance of 1174 individuals. The top ten families had an abundance of 4061 individuals (78.6% of the total abundance) and contributed 130.4 of total family importance value. Based on family importance value (FIV), the top-ranked families include Rubiaceae (23.2%), Melastomataceae (20.4%), Euphorbiaceae (17.6%), Rutaceae (17.5%), and Mimosaceae (10.9%).

Diversity and stand structure by size class. In all four forest categories, species richness, abundance, and basal area of stems decreased with increasing forest disturbance. The lowest size class of 10-30 cm gbh was most abundant and formed 67% of the total abundance in MU, 64% in MD, 59% in RD, and 56% in HD sites (Fig. 5). Species richness and abundance was greater in RD and MD sites than in MU and HD sites in all stem size classes. In the 90-120 cm gbh class, the stem abundance was similar in MD and MU (52 stems in each category), high in RD (54 stems) sites, and low in HD (35 stems). The species richness of very large trees (≥210 cm gbh class) was similar in RD and MD sites (5 species each), whereas their abundance was greater in MD sites than in the other three categories. A high standard error value in the tree abundance of large size classes is notable.

Phenological types. The species richness of evergreen trees and their abundance was greater (80.9% of total abundance) than that of deciduous species (13.6%; Table 2) in all four categories. The abundance of brevideciduous species was greater in HD sites, while their species richness was high in MD sites. In RD sites species richness and abundance of deciduous species was greater than in the other three disturbance categories.

Structural guilds. The species richness and abundance of different ecological guilds (lower story, middle story, and upper story species) did not differ significantly across the four forest categories ($P > 0.05$). Tree species richness and abundance of middle-story species was greater in all four disturbance categories, followed by lower-story species (Table 2). In RD sites lower-story species richness was greater, whereas the abundance of lower-story species was higher in MD (654 individuals) and MU (626) sites than in RD and HD sites. The number of upper-story tree species was greater in MU (12 species) than in the other three forest categories.

Dispersal mode of trees. These trees of tropical dry evergreen forest displayed four dispersal modes: anemochory, autochory, hydrochory, and zoochory. The species richness ($F=0.38$, $P=0.76$) and abundance ($F=0.09$, $P=0.95$) of trees in the four dispersal modes did not differ significantly across the four forest categories. Zoochorous dispersal was prevalent in all four categories in terms of species richness and abundance, followed by anemochory in terms of abundance (Table 2). Species richness and abundance in the zoochorous mode was in the order RD>MD>MU>HD. The abundance of autochorous species was higher in RD (220) and MU (66) than in MD (56) and HD (38) sites. Hydrochory was represented by a single species (*Barringtonia acutangula*) and one individual each in three forest categories except in MD (Table 2).

DISCUSSION

The fact that tree species richness, abundance and basal area were greater in the relatively undisturbed (RD) sites than the disturbed sites is consistent with the results of many other studies (Bhuyan *et al.* 2003, Mishra *et al.* 2004, Nath *et al.* 2005, Banda *et al.* 2006, Muhanguzi *et al.* 2007, Anitha *et al.* 2009). While other studies have found that intermediate disturbance can maintain or increase species diversity (Banda *et al.* 2006, Sahu *et al.* 2008, Budke *et al.* 2010). The low disturbance provides greater opportunity for species turnover, colonization, and persistence of greater species richness (Sapkota *et al.* 2010). Low density and species richness in our HD sites may possibly be due to greater resource extraction such as collection of fuel wood and fodder and grazing pressure. Such disturbances lead to thinning of the woody layer and change the forest microclimate, which in turn might have impaired the regeneration process of tree species resulting in low abundance.

The predominant tree species in the present study sites was *Memecylon umbellatum* in MD and RD sites, *Glycosmis mauritiana* in MU, and *Lepisanthes tetraphylla* in HD sites, but the most abundant *Memecylon umbellatum* was totally absent in the HD sites (Table 2) because the understory and ground flora were cleared by the local people and grazing by cattle. In contrast, the presence of invasive species such as *Acacia auriculiformis*, *Prosopis juliflora*, and *Delonix regia* in MU and HD sites indicates human

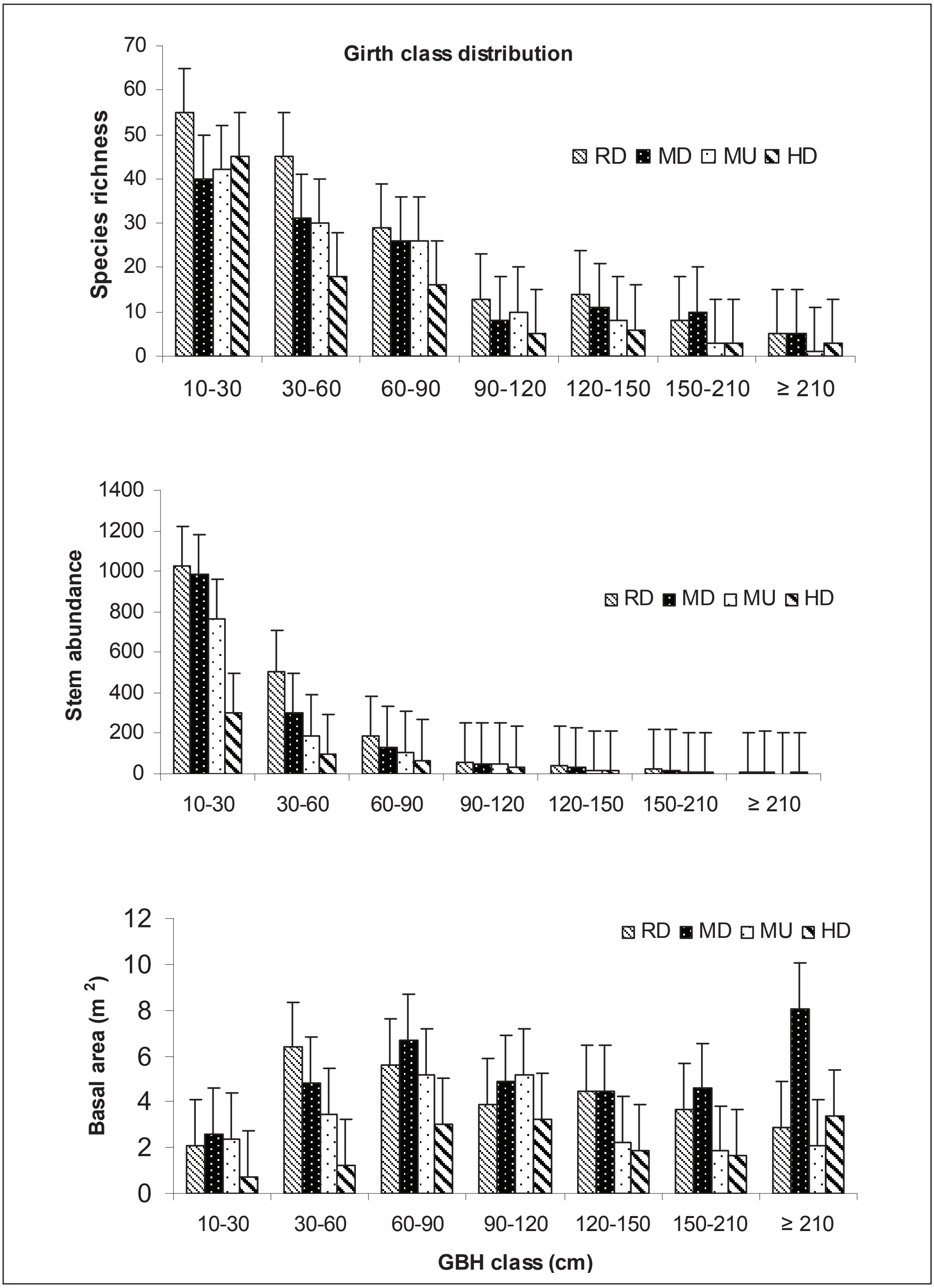

FIG. 5. Girth class distribution of tree species richness (SR), stem abundance (SA), and basal area (BA, m^2) in four forest categories (RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD- heavily disturbed) of tropical dry evergreen forests on the Coromandel coast of India.

disturbance in forests. Burke & Grime (1996) reported that plant communities are generally more susceptible to invasion when they are subjected to some form of disturbance. Invasion by non-native species is also a problem faced by most of the communities of this region. Canopy openings, resulting from local human disturbance, create patches of greater light availability and such openings can act as "windows" for many invasive species (Johnstone 1986).

Stem diameter class distribution is commonly used to assess disturbance effects within forests (Hett & Loucks 1976, Denslow 1995) and to detect trends in tree regeneration patterns. Basal area and stem density decreased with increasing forest disturbance in all the four forest categories. The low basal area value of HD sites reveals the extent of forest disturbance with poor representation of trees in higher girth classes. Forest stand density distribution across different classes indicates how well the growing forest utilizes available resources, particularly in RD sites, followed by MD sites. Distribution curves that drop exponentially with increasing gbh (reverse J-shaped) are characteristic for species with continuous regeneration (Khamyong *et al.* 2004). Few small to medium-sized trees may imply that land is not being fully utilized by the tree crop (Hitimana *et al.* 2004) as is the case with our MU and HD sites.

Rubiaceae (represented by 10 species), Euphorbiaceae (9), Caesalpiniaceae (8), Mimosaceae and Moraceae (7 species each) constituted the most diverse families in the studied tropical dry evergreen forest sites. However, Euphorbiaceae, Rubiaceae, and Dipterocarpaceae were the most dominant families in other tropical dry evergreen forests in northeastern Thailand (Bunyavejchewin 1999), northeastern Sri Lanka (Blasco & Legris 1973), and Jamaica (Kelly *et al.* 1988), and Pragasan & Parthasarathy (2010) reported Euphorbiaceae (25 species), Rubiaceae and Moraceae (17 species each) as the dominant families in the southern Eastern Ghats, India. Euphorbiaceae and Lauraceae were dominant families in Anamalais, in the Western Ghats (Ayyappan & Parthasarathy 1999), while Euphorbiaceae, Moraceae, and Rubiaceae formed the most dominant families in the tropical lowland forests of Little Andaman Island, India (Rasingam & Parthasarathy 2009). Lauraceae, Mimosaceae, and Moraceae dominated the tropical wet forests at La Selva, Costa Rica (Lieberman & Lieberman 1987).

We found that the species richness and abundance of understory trees drastically decreased with increasing forest disturbance in all the four disturbance categories and these results are corroborative with other tropical forests (Gonzalez-Espinosa *et al.* 1995, Ramirez-Marcial *et al.* 2001). The occurrence of human disturbance as well as natural disturbances creates conditions for recruitment of new individuals or the growth of pre-existing ones in the understory species (Young & Hubbell 1991, Ramirez-Marcial *et al.* 2001). However, anthropogenic disturbance, even without removing the forest canopy, may also modify recruitment patterns of the understory species. Grazing and understory species cleared in disturbed forests can cause seedling mortality, in addition to increasing solar radiation and decreasing soil moisture availability at the forest floor level (Reimoser *et al.* 1999).

Zoochory was the principal mode of dispersal in all four forest disturbance categories in terms of species richness and abundance. Our results are similar to studies conducted in other tropical forests around the world (Griz & Machado 2001, Arbelaez & Parrado-Rosselli 2005). Anemochorous dispersal mode was the second commonest dispersal type in our study, as also reported in other tropical forests (Frankie *et al.* 1974, Griz & Machado 2001, Arbelaez & Parrado-Rosselli 2005). In the present study sites anemochoruos fruits were produced exclusively in the dry season (Selwyn & Parthasarathy 2007). Dispersal by wind is efficient during the dry season, because dry conditions are more suitable for the liberation of the seeds, allowing their wings and plumes to fully expand (Du *et al.* 2009). The prevalence of succulent diaspores (berries and drupes) and their availability round the year (Selwyn & Parthasarathy 2007) in tropical dry evergreen forests indicate the possible faunal dependence of many tree species on frugivores, particularly birds.

The quantitative inventory of tree species diversity revealed a considerable variation in the composition of tree species and forest stand density in various tropical dry evergreen forest sites along disturbance gradients, and also in other tropical forests of the world, mainly due to variation in biogeography and habitat disturbance (Mani & Parthasarathy 2006). Even though the tropical dry evergreen forest sites are smaller in size, ranging from 0.5 to 20 ha or so, they hold moderate diversity and represent a unique, little-known and understudied forest type, protected on religious grounds as temple forests, thus gaining significance from ecological and societal perspectives. The small forest patches (less than 1 ha in size) could play a role in the maintenance of regional diversity by augmenting regional population and providing food for plant and animal species (Pither & Kellman 2002). The local people have unlimited and unspecified rights of firewood collection, herding, cattle grazing and browsing etc. As human activities keep escalating with an ever-increasing population, ecosystems near human settlements can become fragile (Nepstad *et al.* 1999, Pragasan & Parthasarathy 2010). The sustainable utilization of forest resources will require as a first step knowledge about their biodiversity, including their ecology, and an understanding of the people's attitudes towards conservation.

We tested the relationship between tree variables and human disturbance using the four forest disturbance categories and found strong support for the hypothesis that tree species richness and forest stand structure differed with differing levels of human disturbance. The tropical dry evergreen forests of peninsular India, with their restricted geographical distribution, are threatened by disturbance for multiple reasons, and many sites have been continuously shrinking in areal extent because of land use changes such as expanding agriculture, plantations, and village temple structures. The predominance of zoochorous dispersal indicates the faunal dependence of trees, and such natural dependence underlines the need for a holistic approach in biodiversity conservation of this and similar tropical forests. Our survey indicates that local people may underestimate the ecological impacts of their resource extraction, and this may prevent them from changing their behavior to benefit conservation. We suggest a strengthening of conservation activities through ecological restoration of degraded portions of sacred groves with native species, involving the local people, in order to save these forests and their biodiversity from further degradation. Augmenting fuelwood and fodder availability from areas outside these relict forests would help meet the survival needs of rural populations.

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APPENDIX 1

Details of forty study sites (and their disturbance scores), distributed by ten in each of the four categories of tropical dry evergreen forests on the Coromandel coast of India (RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD-heavily disturbed).

Site no.	Site	Lat. (N)	Long. (E)	Disturbance score	Size (ha)	Category
1	Sendhirakillai	11°50'30"	79°69'74"	3	3.5	RD
2	Suran viduthi	10°34'15"	79°00'41"	3	13.5	RD
3	Chinnakumatti	11°50'71"	79°70'67"	4	2	RD
4	Sunayakkadu	10°27'23"	78°97'60"	4	7.5	RD
5	Managanampatti	10°38'80"	78°89'31"	5	8.5	RD
6	Araiyapatti	10°30'28"	78°97'01"	8	1.5	RD
7	Karisakkadu	10°27'18"	79°00'29"	8	2	RD
8	Oorani	12°16'66"	79°92'49"	8	1.5	RD
9	Arasadikuppam	11°69'43"	79°67'19"	9	5.8	RD
10	S. Pudhoor	11°66'91"	79°69'56"	9	8.6	RD
11	Shanmuganathapuram	10°31'27"	78°90'48"	11	1.8	MD
12	Kuzhandhaikuppam	11°72'36"	79°64'93"	12	1.8	MD
13	Thirumanikkuzhi	11°72'46"	79°68'46"	12	1.2	MD
14	Kothattai	11°51'03"	79°70'87"	15	17.32	MD
15	Palvathunnan	11°53'34"	79°69'72"	15	1.8	MD
16	Maramadakki	10°29'39"	79°00'58"	16	3	MD
17	T.Pudhupalayam	11°73'85"	79°69'45"	16	1	MD
18	Vada agaram	12°17'94"	79°92'23"	17	5.37	MD
19	Panaiyur	12°31'37"	80°02'73"	19	1.5	MD
20	Ramapuram	11°68'64"	79°69'50"	20	4	MD
21	Chinna thanangkuppam	11°63'82"	79°67'46"	23	2.5	MU
22	Puthupet	12°05'79"	79°87'18"	23	17	MU
23	Kiliyalamman temple	11°49'07"	79°71'69"	26	1.5	MU
24	Konjikuppam	11°67'89"	79°54'83"	26	2.5	MU
25	Rayapatti	10°40'41"	78°90'49"	26	1.5	MU
26	Surianpet	11°73'40"	79°63'89"	27	2.5	MU
27	Omiper	12°50'63"	79°63'54"	28	1.2	MU
28	Thondamanatham	11°65'78"	79°71'19"	28	1	MU
29	Kadapakkam	12°26'38"	80°00'30"	29	1	MU
30	Keezhbhuvanagiri	11°44'41"	79°66'10"	29	1	MU
31	Periya pattu	11°55'83"	79°70'69"	31	1.5	HD
32	Narthamalai	10°49'96"	78°75'53"	32	1.2	HD
33	Poornankuppam	11°87'29"	79°80'60"	33	1.5	HD
34	Kottakarai	11°63'25"	79°80'00"	34	0.8	HD
35	Mangalam	11°86'28"	79°82'62"	35	1.5	HD
36	Keezhakurichi	10°27'31"	78°13'27"	36	1	HD
37	Vengadampettai	11°62'66"	79°60'40"	36	2.5	HD
38	Periya mudhaliarchavady	11°98'29"	79°84'44"	38	1	HD
39	Irimbai tank	11°86'33"	79°85'33"	39	1	HD
40	Krishnavaram	11°83'80"	79°68'46"	39	1.5	HD

APPENDIX 2

Site disturbance kind and scores of forty study sites distributed by ten in each of the four forest categories of tropical dry evergreen forest sites on the Coromandel coast of India. (RD-relatively undisturbed, MD-moderately disturbed, MU-much disturbed, HD-heavily disturbed).

	RD sites										MD sites										MU sites										HD sites									
Disturbance	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Illegal timber felling								1					1	1	1		2	1	1	1	2	2	2	2	2	3	3	3	3	4	4	3	4	4	4	4	4	4	4	4
Fuelwood collection					1	1	1	1	1	1	1	1	1	2	1	1	2	1	1	1	2	1	2	2	2	2	2	3	3	2	3	3	3	3	4	4	4	4	3	3
Number of cut stems/trees found in the forest								1		1	1	1	1	1	1	1	2	1	1	1	2	3	3	3	2	3	3	3	3	3	2	3	3	4	4	4	4	4	3	3
Fodder leaf collection										1		1	1							1	1				1	1		1			2	1	2	2	3	3	3	3	2	2
Grazing			1		1	2	2		1		2	1		2	2	2	1	2	2	2	2	2	2	2	3	3	2	3	3	2	3	3	3	3	3	3	3	4	4	4
Presence of exotic invasives										1			1					1		2	1	2	2		2	2	2	2			2	2	2	2		3	3	3	3	3
Soil removal		1		1						2	1				1	1		2			2			3	2		3	2		3		1		2						
Trails number and width	1	1	1		1		1	1	1	1		1		1	2	2	1	1	1	2	2	3	2	3	2	2	2	2	2	3	2	2	2		2	2	2	3	2	2
Road construction						1							1					2		2	1		1	1					2		2	1	3	2						
Temple structure (Large/Small)	1			1	1	1	1	1	1		2	1	1	2	2	2	2		2	1	2	3	2		3	2	2	2	3	2	2	2		2	3	1	1	3	4	4
Visitor impact						1					1	2	2	2	1	2	2	2	2	2	2	3	2	2	2	2	2	2	2	1	3	2	3	2	2	2	2	2	3	3
Litter clearance																				1						1			1				1							
Edible fruit collection				1			1	1						1	1		1	1	1		1		1	1						1	1	1	1							
Cultural attachments		1		1	1	1	2	1	2	1	2	2	1	2	1	2	1	2	2	1	1	2	2	3	2	2	2	2	3	2	2	3	2	3	3	3	3	3	3	3
Medicinal plant removal	1		1					1	1				1		1	1	1	1	1					2		1								1	1	1	1		2	2
Human occupation of site			1			1			2	1	1	2	1	1	1	2	1	2	2	1	2	2	3		2	3	3	3	2	3	3	3	3	3	4	4	4	4	4	4
Extent of bioinvasion																				2			2	2	1		2	1	2	3		2	1	1	2	2	2	2	2	2