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Biodiversity inventory of trees in a large-scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India

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Abstract. A permanent plot of 30 ha (600 × 500 m^2) was established for long-term ecological research on biodiversity and forest functioning in a tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats. This paper gives the results of the first census of trees in the 30 ha plot. All trees ≥30 cm gbh were permanently tagged with sequentially numbered aluminium tags and their girth measured. 148 tree species (in 120 genera and 49 families) were enumerated in a total sample of 13,393 individuals. Species diversity, density and dispersion patterns were determined. The mean species richness, density and basal area per hectare were 65 species, 446 stems and 36.26 m^2 respectively. The Sorensen similarity index for thirty 1-ha subplots varied from 0.7 to 0.9, indicating the homogeneity in species composition of the stand. The pronounced species hierarchy has resulted in the dominance of four species that occupy four different forest storeys: *Drypetes longifolia* (lower storey) *Reinwardtiodendron anamallayanum* (middle storey), *Poeciloneuron indicum* (upper storey) and *Dipterocarpus indicus* (emergent). The forest was dominated by Euphorbiaceae in terms of richness (18 species) and abundance of species (3788 stems), and Dipterocarpaceae based on the contribution to basal area (18.4%). Species richness and density decreased with increasing girth-class. Girth class frequency of the stand exhibited an expanding population of trees. Twenty-nine tree species, analysed for spatial dispersion at 1-ha scale, exhibited both clumped and uniform patterns, except *Vateria indica* which was randomly distributed in one hectare. Repeat census scheduled for subsequent years, will elucidate the behaviour of the individual species and the population dynamics of the tree flora and will be useful for forest conservation and management. It will also help to monitor human activity within this forest.

Key words: permanent plot, species hierarchy, stand structure, tree diversity, tropical forest, Western Ghats

Introduction

Studies on large-scale permanent plots in tropical forests have attracted much attention of ecologists over the last two decades and since then eleven large-scale (≥16 ha) permanent inventory plots have been established in each of the major tropical forest formations of the world (Condit 1995). The broad objectives of long-term research are to investigate forest composition, structure and dynamics in space and time and to serve as a research base for diverse aspects of tropical ecology. Repeat surveys of

permanent plots can provide information that is crucial for conservation and management of tropical forests (Field and Vazquezyanes 1993). Results of a few large-scale permanent plots have been published: of Barro Colorado Island, Panama (Hubbell and Foster 1983, 1990; Condit et al. 1992), Pasoh Forest Reserve in Malaysia (Manokaran and LaFrankie 1990; Manokaran et al. 1990; Kochummen et al. 1990) and Mudumalai Game Reserve, south India (Sukumar et al. 1992, 1997) and those of the others (Luquillo Experimental Forest, Puerto Rico; Huai Kha Khaeng, Wildlife Sanctuary, Thailand; Sinharaja World Heritage site, Sri Lanka; Sarawak, Malaysia; Palanan Wilderness Area, Philippines; Ituri Forest, Zaire; Korup National Park, Cameroon; Yasuni National Park, Ecuador) are in various stages of censusing.

The principal aims in setting up a large-scale permanent plot in the tropical evergreen forest at Varagalaiar, in Western Ghats, are: (i) to make biodiversity inventory of trees, lianas and ground flora in the evergreen forest, (ii) to provide a permanent basis for long-term study on forest dynamics – spatial and temporal variation of species diversity, density and distribution, and (iii) to determine tree growth, recruitment and mortality patterns. This would be in line with other large-scale inventories in various tropical forests, with a goal of providing a scientific basis for tropical evergreen forest conservation and management.

This paper presents the results of the first census on the diversity, density and distribution of trees in a large-scale permanent plot of a tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, south India.

Study area

The study was conducted in the tropical evergreen forest at Varagalaiar, located at 10°25′ N latitude and 76°52′ E longitude within the Indira Gandhi Wildlife sanctuary and National Park in the Anamalais, Western Ghats, India (Figure 1). The study site is situated about 100 km south of Coimbatore town in Tamil Nadu state. The elevation ranges from 600 to 660 m above msl. The site receives rains from the southwest (June–September) and the northeast (October–December) monsoons. Mean annual rainfall (recorded at Topslip located at 27 km west of Varagalaiar) during the 6-year period (1991–1996) was 1600 mm and the mean number of rainy days for the same period was 102.

The study site is situated between two perennial rivers, Kurampalliyar and Varagalaiar running adjacently from north to south on either side of the site. The former runs almost parallel to the study site and the latter deviates much from the site. In addition, there are many rivulets traversing the study site, later joining the two main rivers.

The vegetation is of tropical evergreen forest type. Champion and Seth (1968) classified this under west coast tropical evergreen forest and floristically it is an intermediate type between *Cullenia-Mesua-Palaquium* and *Dipterocarpus-Mesua-*

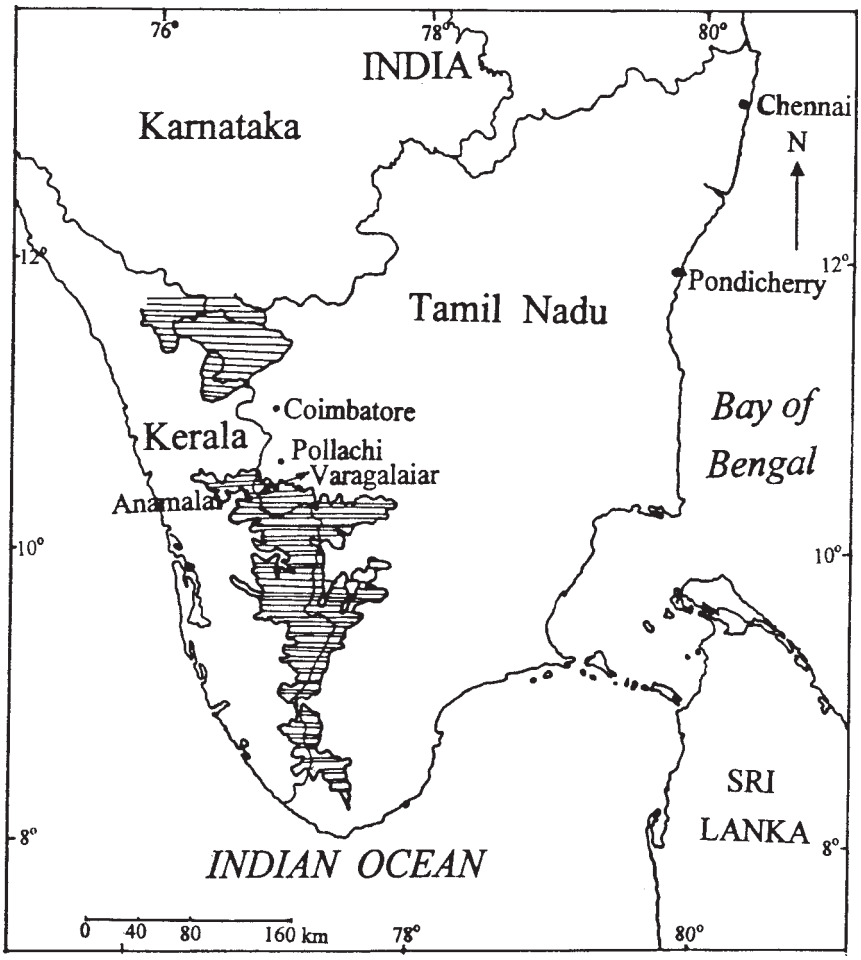

Figure 1. Location of Varagalaiar study site in the Anamalais, Western Ghats, south India.

Palaquium types recognized by Meher-Homji (1984). The upper storey is dominated by evergreen species such as *Calophyllum polyanthum*, *Dipterocarpus indicus*, *Diospyros buxifolia*, *D. sylvatica*, *Hopea parviflora*, *Palaquium ellipticum*, *Poeciloneuron indicum* and *Vateria indica* and deciduous species such as *Bombax ceiba*, *Bischofia javanica*, *Terminalia bellirica*, *Tetrameles nudiflora* and *Syzygium densiflorum*. The middle storey is dominated by *Aglaia elaeagnoidea*, *Dimocarpus longan*, *Flacourtia montana*, *Knema attenuata*, *Margaritaria indica*, *Myristica dactyloides* and *Reinwardtiodendron anamallayanum* and the lower storey by *Baccaurea courtallensis*, *Croton malabaricus*, *Drypetes longifolia*, *Prismatomeris albidiflora* and *Orophea erythrocarpa*.

There are two tribal settlements in the forest, one belonging to the native tribals (about 5 km away from the study site) and the other situated 500 m from the study

site. The resident tribals of the latter location are engaged in elephant training. The tamed elephants are used for transporting logs from the nearby teak plantations. In the past, the study site was used as thoroughfare to take the tamed elephants and leave them in the forest at nights and bring them back to the training camp the next morning. This has formed a bridle path (4 to 10 m wide) well within the study site.

Anthropogenic activities in the study area include collection of fuel wood, honey, edible fruits (*Artocarpus heterophyllus*, *Flacourtia montana*, *Mangifera indica*, *Baccaurea courtallensis* and *Garcinia gummi-gutta*) and dammer from *Canarium strictum* and *Vateria indica*.

Methods

Tree inventories

A permanent plot of 30 ha (600×500 m^2) was established in the tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats. The fieldwork was conducted from September to October 1997 and between December 1997 to May 1998, in the course of the first census. Each hectare (100×100 m^2 subplots) was subgridded into 10×10 m^2 quadrats as workable units.

All trees of $\geq$30 cm girth at breast height (gbh) in the 30 ha plot, were tagged with sequentially numbered aluminium tags. The tags were prepared using 3-mm thick aluminium sheets cut to 2.5×5 cm. Code T was prefixed for tree tags and sequential numbering (T0 00 001 onward) was embossed on the tree tags, using a BRADMA (British address machine, model 1620). Tree girths were measured at 1.3 m from the ground, unless there was abnormality on the trunk, in which case the measurement was taken at the nearest lower point where the stem was cylindrical or above the buttresses. This was facilitated by using a single-legged pipe ladder. Trees with multiple stems and connected near the ground were counted as single individual. Vouchers were collected for all tree species, processed methodically and deposited in the herbarium of School of Ecology, Pondicherry University. They were identified using various regional floras (Hooker 1872–1897; Gamble and Fischer 1915–1935; Pascal and Ramesh 1987). Each and every voucher of tree was identified to species level, except one species, which remains unidentified (named unidentified 1). Vouchers of ten individuals were either missed or spoiled during specimen processing and these were assumed to be one among the identified species and were therefore not considered in species richness counts (named indeterminate). Specimen identifications were confirmed in the herbarium of Botanical Survey of India, Coimbatore (MH), School of Ecology, Pondicherry University and French Institute, Pondicherry. Nomenclature of species follows Flora of Tamil Nadu (Nair and Henry 1983; Henry et al. 1987).

Data analysis

Diversity indices such as Shannon and Simpson's (as in Magurran 1988) were calculated. Similarity of species between subplots was obtained using Sorensen's index (Greig-Smith 1983). For trees with multiple stems, basal area was calculated separately and summed. Five species of strangler figs (*Ficus beddomei*, *F. callosa*, *F. nervosa*, *F. talbotii*, *and F. tsjahela*) were excluded from the analyses involving girth measurements, because their girths were not measured due to their abnormal shape and girdling on the host trees. The floristic structure was examined by importance value index (IVI) derived from Curtis and McIntosh (1950) excluding the indeterminates. A six-letter code was assigned to all the species (for floristic structure) with the first 3 letters denoting the generic epithet and the next 3 letters, the specific epithet. For taxa with variety or subspecies names, an additional 3-letter code was given. Species–area curve was plotted for all species, excluding very rare (species with frequency $(f) < 3$) and rare species ($f < 30$), as the sequence of enumeration proceeded i.e., by sequential arrangement of thirty 1 ha subplots. Family-area curve was also plotted similarly. Family importance value (FIV) was calculated for all families according to the formula of Mori et al. (1983). The family Moraceae, an unidentified species and an 'indeterminate' were excluded in FIV calculation. Dispersion patterns of trees were determined based on quadrat count method using standardised Morista's index (Krebs 1989).

Results

Species richness and diversity

We distinguished 148 species of trees ≥30 cm gbh, representing 120 genera and 49 families in the 30 ha plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats (Tables 1 and 2). Species richness varied in each hectare, ranging from 51 species (in the 5th hectare) to 78 species (11th hectare), with a mean value of 65 species ha^{-1}. The Shannon and Simpson diversity indices were 3.93 and 0.0345 respectively for the 30 ha area studied (Table 1). The Simpson's index indicates that 97 pairs out of 100 taken at random are composed of different species.

Species density, composition and occurrence

The population density of the 148 species enumerated in the 30 ha plot, showed a wide variation (Table 2), ranging from 1 (for 13 species) to 1404 stems for *Drypetes longifolia*. Based on their density, species were grouped into 5 categories, viz.:

(1) predominant species (those with density $(f) \geq 1000$ individuals in the 30 ha plot); 2 species (1%) in the forest stand, *Drypetes longifolia* and

Table 1. Summary of tree inventories (≥30 cm gbh) in the 30 ha permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, south India.

Variable	Whole 30 ha plot	Mean ha^{-1}	Range ha^{-1}
Species richness	148	65	51–78
Diversity indices			
Shannon	3.926		
Simpson	0.0345		
Stem density	13,393	446	270–673
Stand basal area (m^2)	1086.06	36.26	25.91–47.75
Number of			
Multi-stemmed individuals	581	19	7–39
Evergreen trees (species)	11,925 (114)	397 (55)	127–621 (30–68)
Deciduous trees (species)	1468 (35)	49 (10)	15–148 (4–21)
Trees supporting lianas	1712	57	
Trees laden with herbaceous epiphytes	162	5.4	

Reinwardtiodendron anamallayanum belonged to this category and contributed 18.4% of the stand density (Table 2),

(2) dominant species (f = 200 to 1000) accounted for 10% of species and 45% of the stand density. Notable among them are *Poeciloneuron indicum*, *Fahrenheitia zeylanica* and *Dipterocarpus indicus*,

(3) common species (f = 30 to 200) accounted for 37% of species richness and 31% of stand density. *Dimorphocalyx beddomei*, *Flacourtia montana*, *Vitex altissima* and *Calophyllum polyanthum* belong to this category,

(4) rare species (f = 3 to 29) accounted for 38% of species richness and formed 5.4% of stand density. This category comprised of *Artocarpus gomezianus* subsp. *zeylanicus*, *Ficus nervosa*, *Garcinia talbotii*, *Macaranga peltata*, *Artocarpus heterophyllus*, *Terminalia paniculata* among others, and

(5) very rare species ($f < 3$) accounted for 14% of the species richness and 0.2% of stand density. They include *Acronychia pedunculata*, *Antidesma alexiteria*, *Cinnamomum macrocarpum* etc.

In the 30 ha plot, 22% of the species were deciduous and accounted for 11% of stand density. On a per hectare basis, 7 to 41% of species were deciduous, which formed 3 to 54% of the forest tree density. Of the 30 ha, the 5th hectare harboured a greater number and density of deciduous tree species. Of the 34 total deciduous species, density-wise, 22 fall under rare and very rare categories; 10 species were common and 2 species were dominants (Table 2).

The Sorensen similarity index of species composition between the 30 subplots (1.0 indicates total similarity), varied from 0.7 (23 pairs; all in the 5th hectare pairs) to 0.9 (20 pairs). The remaining 392 pairs scored 0.8, indicating a greater homogeneity in the species composition of the stand.

Table 2. List of all tree species (and family), in decreasing order of abundance and the number of hectares of occurrence in the 30 ha permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats (Species marked with * are deciduous; others are evergreen).

Sl. no.	Species	Family	Density	No. of ha's of occurrence
1	*Drypetes longifolia* (Blume) Pax & Hoffm.	Euphorbiaceae	1404	28
2	*Reinwardtiodendron anamallayanum* (Bedd.) Saldanha	Meliaceae	1058	29
3	*Poeciloneuron indicum* Bedd.	Clusiaceae	699	29
4	*Fahrenheitia zeylanica* (Thw.) Airy Shaw	Euphorbiaceae	627	29
5	*Dipterocarpus indicus* Bedd.	Dipterocarpaceae	539	27
6	*Dimocarpus longan* Lour.	Sapindaceae	437	30
7	*Knema attenuata* (Wall. ex Hook.f. & Thoms.) Warb.	Myristicaceae	402	29
8	*Palaquium ellipticum* (Dalz.) Baillon	Sapotaceae	393	30
9	*Myristica dactyloides* Gaertn.	Myristicaceae	373	29
10	*Baccaurea courtallensis* (Wight) Muell.-Arg.	Euphorbiaceae	367	29
11	*Cleidion spiciflorum* (Burm.f.) Merr.	Euphorbiaceae	365	26
12	*Aglaia elaeagnoidea* (A.Juss.) Benth.	Meliaceae	349	29
13	*Orophea erythrocarpa* Bedd.	Annonaceae	326	21
14	*Polyalthia fragrans* (Dalz.) Bedd.	Annonaceae	315	29
15	*Vateria indica* L.	Dipterocarpaceae	305	29
16	*Croton malabaricus* Bedd.*	Euphorbiaceae	288	30
17	*Syzygium densiflorum* Wall. ex Wight & Arn.*	Myrtaceae	286	30
18	*Dimorphocalyx beddomei* (Benth.) Airy Shaw	Euphorbiaceae	191	28
19	*Flacourtia montana* Graham	Flacourtiaceae	181	25
20	*Vitex altissma* L.f.*	Verbenaceae	181	24
21	*Calophyllum polyanthum* Wall.	Clusiaceae	144	29
22	*Diospyros sylvatica* Roxb.	Ebenaceae	138	27
23	?*Cyclostemon subsessilis* Kurz	Euphorbiaceae	132	28
24	*Aglaia jainii* Viswa. & Ramachan.	Meliaceae	129	28
25	*Bischofia javanica* Blume*	Bischofiaceae	126	25
26	*Aphanamixis polystachya* (Wall.) Parker	Meliaceae	122	25
27	*Aporusa lindleyana* (Wight) Baill.	Euphorbiaceae	122	10
28	*Hydnocarpus pentandra* (Buch.-Ham.) Oken	Flacourtiaceae	121	27
29	*Vepris bilocularis* (Wight & Arn.) Engler	Rutaceae	120	29
30	*Margaritaria indica* (Dalz.) Airy Shaw*	Euphorbiaceae	103	16
31	*Chionanthus mala-elengi* (Dennst.) P.S. Green	Oleaceae	102	14
32	*Holigarna beddomei* Hook.f.	Anacardiaceae	96	24
33	*Phoebe lanceolata* Nees	Lauraceae	93	24
34	*Diospyros buxifolia* (Blume) Hiern	Ebenaceae	92	27
35	*Casearia esculenta* Roxb.	Flacourtiaceae	90	24
36	*Sageraea dalzellii* Bedd.	Annonaceae	88	25
37	*Chrysophyllum roxburghii* G.Don	Sapotaceae	87	22
38	*Glochidion ellipticum* Wight var. *ellipticum* Hook.f.*	Euphorbiaceae	84	17
39	*Hopea parviflora* Bedd.	Dipterocarpaceae	84	27
40	*Nothopegia racemosa* (Dalz.) Ramam.	Anacardiaceae	78	17
41	*Syzygium hemisphericum* (Wight) Alston	Myrtaceae	74	21
42	*Garcinia morella* (Gaertn.) Desr.	Clusiaceae	73	21
43	?*Prismatomeris albidiflora* Thw.	Rubiaceae	73	25
44	*Cinnamomum malabatrum* (Burm.f.) Blume	Lauraceae	72	17
45	*Mesua ferrea* L.	Clusiaceae	59	14
46	*Terminalia bellirica* (Gaertn.) Roxb.*	Combretaceae	59	23

Table 2. Continued.

Sl. no.	Species	Family	Density	No. of ha's of occurrence
47	*Schleichera oleosa* (Lour.) Oken*	Sapindaceae	57	10
48	*Cyathocalyx zeylanicus* Champ. ex Hook.f.& Thoms.	Annonaceae	55	23
49	*Dysoxylum malabaricum* Bedd. ex Hiern*	Meliaceae	53	22
50	*Persea macrantha* (Nees) Kosterm.	Lauraceae	53	26
51	*Canthium dicoccum* (Gaertn.) Teijsm & Binn. var. *umbellata* (Wight) Sant. & Merch.	Rubiaceae	51	22
52	*Harpullia arborea* (Blanco) Radlk.	Sapindaceae	51	19
53	*Canarium strictum* Roxb.	Burseraceae	48	23
54	*Mangifera indica* L.	Anacardiaceae	48	21
55	*Artocarpus hirsutus* Lam.	Moraceae	44	23
56	*Filicium decipiens* (Wight & Arn.) Thw.	Sapindaceae	43	15
57	*Mastixia arborea* (Wight) Bedd.	Cornaceae	38	11
58	*Elaeocarpus serratus* L.	Elaeocarpaceae	37	14
59	*Olea dioica* Roxb.	Oleaceae	37	7
60	*Prunus ceylanica* (Wight) Miq.	Rosaceae	36	20
61	*Antidesma menasu* (Tul.) Miq. ex Muell.-Arg.	Stilaginaceae	35	16
62	*Dillenia pentagyna* Roxb.*	Dilleniaceae	34	4
63	*Mallotus philippensis* (Lam.) Muell.-Arg.	Euphorbiaceae	34	16
64	*Turpinia malabarica* Gamble	Staphylaceae	33	17
35	*Zanthoxylum rhetsa* (Roxb.) DC.*	Rutaceae	33	19
66	*Memecylon malabaricum* (Clarke) Cogn.	Melastomataceae	32	14
67	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	31	13
68	*Cryptocarya bourdillonii* Gamble	Lauraceae	31	17
69	Unidentified 1		31	17
70	*Litsea floribunda* (Blume) Gamble	Lauraceae	30	14
71	*Terminalia crenulata* Roth*	Combretaceae	30	2
72	*Artocarpus gomezianus* Wall. ex Trec subsp. *zeylanicus* J.Jarrett	Moraceae	29	19
73	*Ficus nervosa* Heyne ex Roth	Moraceae	29	15
74	*Garcinia talbotii* Raiz. ex Sant.	Clusiaceae	29	12
75	*Macaranga peltata* (Roxb.) Muell.-Arg.	Euphorbiaceae	29	13
76	*Artocarpus heterophyllus* Lam.	Moraceae	28	17
77	*Terminalia paniculata* Roth*	Combretaceae	27	5
78	*Actinodaphne tadulingamii* Gamble	Lauraceae	25	17
79	*Isonandra perrottetiana* A.DC.	Sapotaceae	25	13
80	*Cordia obliqua* Willd. var. *tomentosa* (Wall.) Kazmi	Boraginaceae	22	6
81	*Stereospermum colais* (Buch.-Ham. ex Dillw.) Mabberley*	Bignoniaceae	22	8
82	*Garcinia gummi-gutta* (L.) Robs.	Clusiaceae	21	14
83	*Diospyros bourdillonii* Brandis	Ebenaceae	20	9
84	*Lagerstroemia microcarpa* Wight*	Lythraceae	20	9
85	*Litsea coriacea* (Heyne ex Meisner) Hook.f.	Lauraceae	20	7
86	*Bombax ceiba* L.*	Bombacaceae	19	16
87	*Cassia fistula* L.*	Caesalpiniaceae	19	9
88	*Excoecaria robusta* Hook.f.	Euphorbiaceae	19	5
89	*Chukrasia tabularis* A.Juss.*	Meliaceae	17	12
90	*Firmiana colorata* (Roxb.) R.Br.*	Sterculiaceae	17	4
91	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	16	11
92	*Cullenia exarillata* A. Robyns	Bombacaceae	15	2

Table 2. Continued.

Sl. no.	Species	Family	Density	No. of ha's of occurrence
93	*Pterospermum reticulatum* Wight & Arn.*	Sterculiaceae	14	10
94	*Antiaris toxicaria* (Pers.) Lesch.	Moraceae	12	10
95	*Homalium zeylanicum* (Gard.) Benth.	Flacourtiaceae	12	8
96	*Ormosia travancorica* Bedd.	Papilionaceae	12	12
97	*Symplocos cochinchinensis* (Lour.) Moore supsp. *laurina* (Retz.) Nooteb.	Symplocaceae	11	8
98	*Celtis philippensis* Blanco*	Ulmaceae	10	5
99	*Phyllanthus emblica* L.*	Euphorbiaceae	10	2
100	*Spondias pinnata* (L.f.) Kurz*	Anacardiaceae	10	7
101	*Tabernaemontana heyneana* Wall.*	Apocynaceae	10	10
102	*Tectona grandis* L.f.*	Verbenaceae	10	2
103	*Ficus callosa* Willd.	Moraceae	9	8
104	*Cassine glauca* (Rottb.) Kuntze	Celastraceae	8	7
105	*Toona ciliata* M.Roem*	Meliaceae	8	5
106	*Trichilia connaroides* (Wight & Arn.) Bentvelzen	Meliaceae	8	6
107	*Beilschmiedia wightii* (Nees) Benth. ex Hook.f.	Lauraceae	7	8
108	*Glochidion ellipticum* Wight var. *ralphii* (Hook.f.) Gamble	Euphorbiaceae	7	5
109	*Mitragyna parvifolia* (Roxb.) Korth*	Rubiaceae	7	7
110	*Diospyros montana* Roxb.	Ebenaceae	6	5
111	*Oreocnide integriofolia* (Gaudich.) Miq.	Urticaceae	6	5
112	*Dysoxylum ficiforme* (Wight) Gamble	Meliaceae	5	5
113	*Ficus tsjahela* Burm.f.	Moraceae	5	4
114	*Miliusa wightiana* Hook.f. & Thoms.	Annonaceae	5	2
115	*Xanthophyllum flavescens* Roxb.	Xanthophyllaceae	5	4
116	*Tetrameles nudiflora* R.Br.*	Datiscaceae	4	4
117	*Aphananthe cuspidata* (Blume) Planch.	Ulmaceae	3	2
118	*Apodytes dimidiata* E. Meyer ex Arn.	Icacinaceae	3	3
119	*Canthium rheedii* DC.*	Rubiaceae	3	2
120	*Clausena indica* (Dalz.) Oliver	Rutaceae	3	2
121	*Drypetes wightii* (Hook.f.) Pax & Hoffm.	Euphorbiaceae	3	2
122	*Euodia lunu-ankenda* (Gaertn.) Merr.	Rutaceae	3	2
123	*Ficus beddomei* King	Moraceae	3	3
124	*Ficus talbotii* King	Moraceae	3	3
125	*Litsea oleoides* (Meisner) Hook.f.	Lauraceae	3	3
126	*Pithecellobium gracile* Bedd.	Mimosaceae	3	3
127	*Xylosma latifolium* Hook.f. & Thoms.	Flacourtiaceae	3	3
128	*Acronuchia pedunculata* (L.) Miq.	Rutaceae	2	2
129	*Antidesma alexiteria* L.	Stilaginaceae	2	2
130	*Cinnamomum macrocarpum* Hook.f.	Lauraceae	2	2
131	*Dalbergia latifolia* Roxb.*	Papilionaceae	2	2
132	*Holigarna nigra* Bourd.	Anacardiaceae	2	2
133	*Mallotus beddomei* Hook.f.	Euphorbiaceae	2	2
134	*Mimusops elengi* L.	Sapotaceae	2	2
135	*Symplocos macrophylla* Wall. ex A.DC. supsp. *rosea* (Bedd.) Nooteb.	Symplocaceae	2	3
136	*Agrostistachys borneensis* Becc.	Euphorbiaceae	1	1
137	*Ardisia pauciflora* Heyne ex Roxb.	Myrsinaceae	1	1
138	*Casearia graveolens* Dalz.	Flacourtiaceae	1	1

Table 2. Continued.

Sl. no.	Species	Family	Density	No. of ha's of occurrence
139	*Grewia tiliaefolia* Vahl*	Tiliaceae	1	1
140	*Meliosma pinnata* (Roxb.) Walp. subsp. *arnottiana* (Walp.) Beus.	Sabiaceae	1	1
141	*Meliosma simplicifolia* (Roxb.) Walp. subsp. *simplicifolia*	Sabiaceae	1	1
142	*Neolitsea scrobiculata* (Meisner) Gamble	Lauraceae	1	1
143	*Otonephelium stipulaceum* (Bedd.) Radlk.	Sapindaceae	1	1
144	*Pajanelia longifolia* (Willd.) Schum.*	Bignoniaceae	1	1
145	*Pavetta indica* L.	Rubiaceae	1	1
146	*Pittosporum tetraspermum* Wight & Arn.	Pittosporaceae	1	1
147	*Pterygota alata* (Roxb.) R.Br.	Sterculiaceae	1	1
148	*Sterculia guttata* Roxb. ex. DC.*	Sterculiaceae	1	1
	Indeterminate	–	10	–

Among the species enumerated, 47% occurred in 10 ha or less, which constituted 5% of the stand density; the remaining 53% of species occurred in more than 10 ha, which formed 95% of the stand density. Among these, the two overstorey species, *Palaquium ellipticum* and *Syzygium densiflorum*, one middle storey species, *Dimocarpus longan* and one lower storey species, *Croton malabaricus* occurred in all the hectares and constituted 10% of the forest stand density (Table 2).

Floristic structure

This floristic structure of the study site depicted a reverse J shaped curve (Figure 2). The importance value index declined initially in steps (up to 6 species) and later it declined sequentially. Species such as *Drypetes longifolia* (lower storey), *Dipterocarpus indicus* (an emergent), *Poeciloneuron indicum* (upper storey) and *Reinwardtiodendron anamallayanum* (middle storey) ranked highest in the hierarchy of the stand and contributed together an IVI of 75. Just 20 species contributed 63% of the total IVI (300) of the stand.

Species–area curve

The species–area curve for all trees (included all species – (a)) and with two levels of exclusion of less common species ((b) species with density <3 individuals in the 30 ha plot and (c) species with <30 individuals), were plotted (Figure 3). The rate of climb of curves 'a' and 'b' is nearly equal. The curve 'b' reached an asymptote in the 24th hectare, while the curve 'a' in the 26th hectare. The curve 'c' reached an asymptote in the 7th hectare.

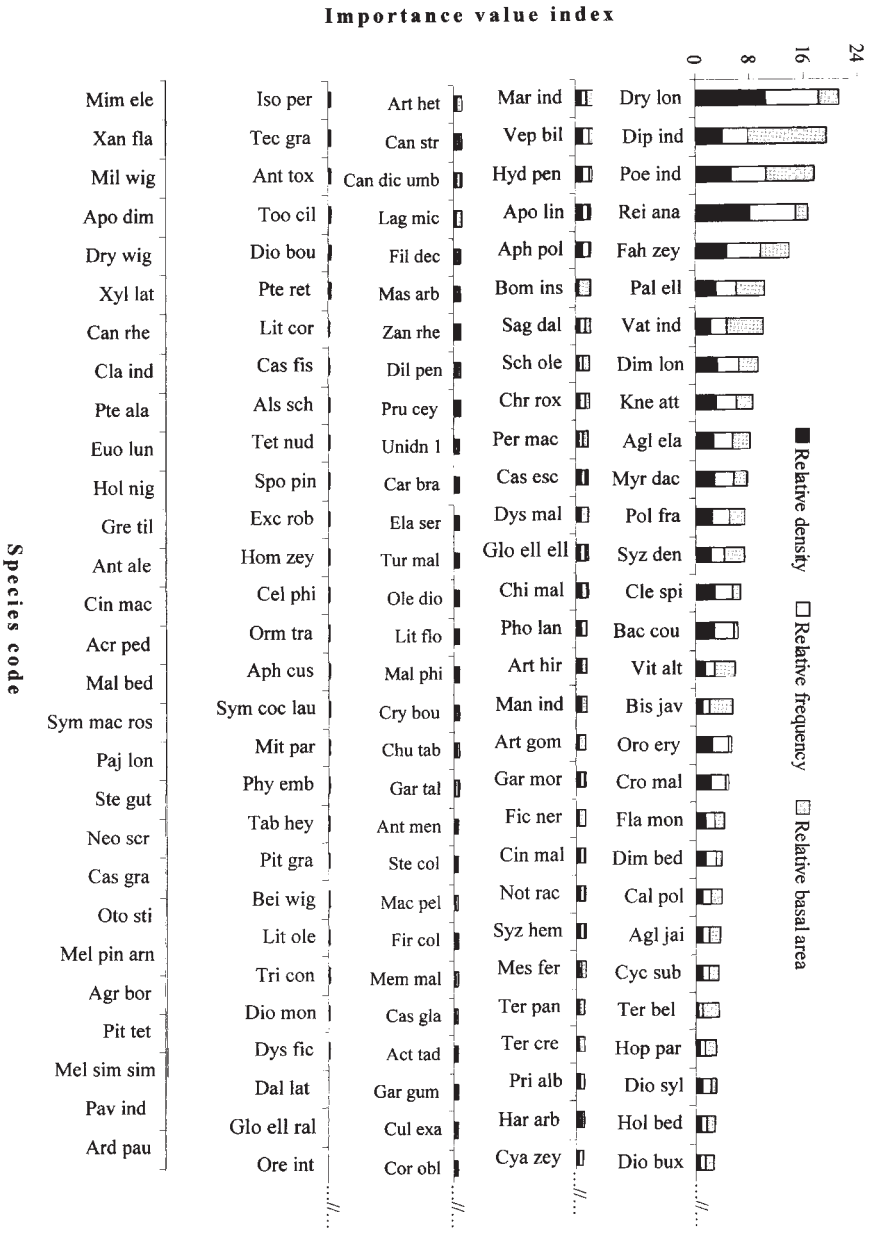

Figure 2. Species importance value index based on their relative contribution to density, basal area and frequency in the 30 ha plot of tropical evergreen forest at Varagalaiar, Western Ghats.

Family composition

The family–area curve (Figure 4) reveals that, of the total 49 families represented in the 30 ha, 51% of them figured in the first hectare and the remaining 49% entered

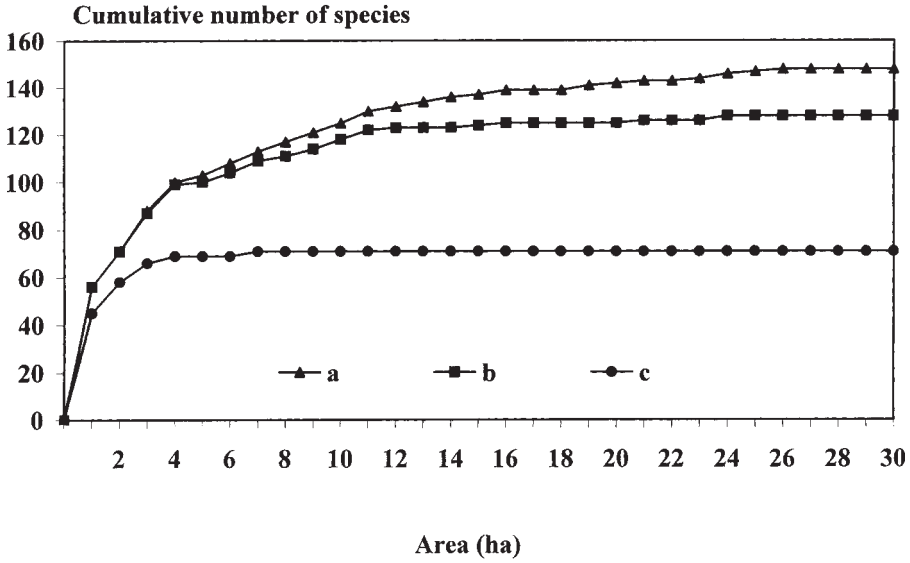

Figure 3. Species–area curves of tree species plotted for all species (a: triangles) and exclusion of very rare species (b: squares) and rare species (c: circles) in the 30 ha plot of tropical evergreen forest at Varagalaiar, Western Ghats.

from the 2nd to the 23rd hectare, above which no further families were added. The increase from 2nd to 6th ha was steep, then it was gradual from the 6th to the 23rd ha.

Of the total 49 plant families, Euphorbiaceae was the dominant family based on taxonomic diversity (represented by 18 species) and abundance (3788 stems). In

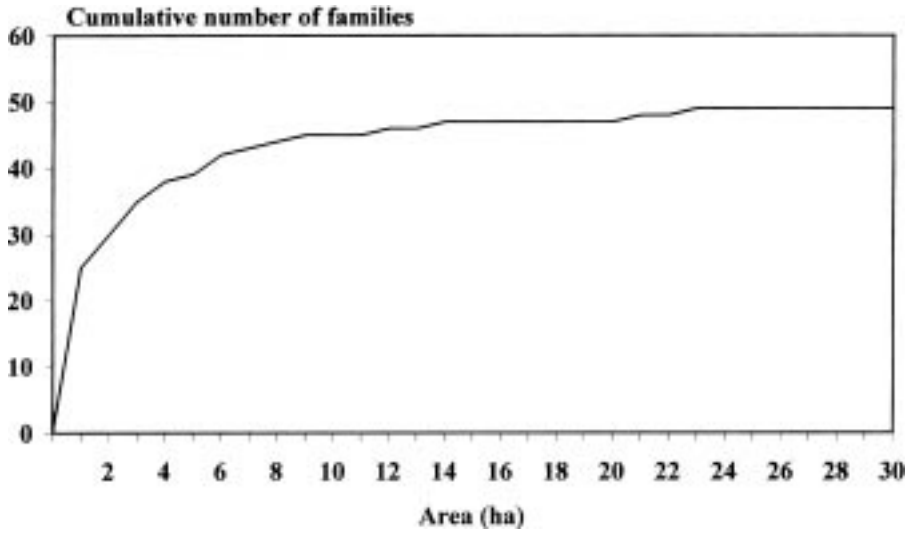

Figure 4. Family–area curve of trees in the 30 ha plot of tropical evergreen forest at Varagalaiar, Western Ghats.

terms of basal area, Dipterocarpaceae dominated the stand, accounting for 18.4% of the stand basal area (Table 3). Four families, Euphorbiaceae (FIV 55), Dipterocarpaceae and Meliaceae (28 each) and Clusiaceae (22) scored greater family importance value (Table 3) and 21 families, each represented by single species had low FIVs.

Stand density and basal area

A total of 13,393 trees of $\geq$30 cm gbh was enumerated in the 30 ha area (Table 1). The stand density of each hectare varied considerably. In a total of 14 ha tree density was greater than the mean stand density of 446 stems ha^{-1} (Figure 5). These hectares were on the northeastern corner of the study plot extending towards the centre of the plot.

The mean stand basal area was 36.26 m^2 ha^{-1}. In the 30 ha plot, 13 ha have a basal area greater than the mean stand basal area (Figure 5). Of these, 10 ha occurred on the northeastern corner of the high-density subplots and in the remaining 3 ha (1st, 2nd and the 30th ha) tree density was less than the stand mean value (i.e., $<$375 trees ha^{-1}).

Based on their contribution to the basal area of the stand, *Dipterocarpus indicus* ranked first with 124.64 m^2 (in 30 ha), followed by *Poeciloneuron indicum* (79.27 m^2), and *Vateria indica* (57.58 m^2). A total of 10 species in the study area contributed 48% of the stand basal area.

Stand structure

The girth class-frequency distribution of trees (Figure 6a) reveals that 52% of the forest stand was formed by the lower girth class (30–60 cm gbh) and with increasing girth class the number of individuals decreased exponentially.

Trends in basal area contribution of girth classes reveal (Figure 6b) a step-wise increase in basal area with increasing girth class that peaked at 150 cm gbh and thereafter decreased.

Tree girth class-wise species richness, abundance and dominance

Tree species richness and their abundance decreased with increasing girth class (Table 4). The lowest girth class (30–60 cm gbh) contributed 89% of species richness and decreased gradually with increasing tree size class. The lower storey tree *Drypetes longifolia* dominated the 30–60 cm girth class and 90 cm gbh class, followed by *Fahrenheitia zeylanica* (in 120 cm gbh class), *Poeciloneuron indicum* (150–180 and 210 cm gbh), *Dipterocarpus indicus* (240–480 cm and 600 cm gbh) and *Bombax ceiba* (510 and 570 cm gbh class) (Table 4).

Table 3. The contribution of plant families to species richness, stand density, basal area and family importance value (FIV), arranged in decreasing FIV in the 30 ha permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats.

Sl. no.	Family	Species richness	Density	Basal area(m^2)	FIV
1	Euphorbiaceae	18	3788	149.91	56
2	Dipterocarpaceae	3	928	200.08	28
3	Meliaceae	9	1749	84.87	28
4	Clusiaceae	6	1025	104.68	22
5	Annonaceae	5	789	37.80	13
6	Sapindaceae	5	589	47.81	13
7	Lauraceae	11	337	18.98	12
8	Myristicaceae	2	775	45.68	12
9	Sapotaceae	4	507	51.18	12
10	Flacourtiaceae	6	408	24.19	10
11	Anacardiaceae	5	234	24.73	8
12	Myrtaceae	2	360	32.38	7
13	Combretaceae	3	116	42.93	7
14	Ebenaceae	4	256	23.11	7
15	Verbenaceae	2	191	34.93	6
16	Rutaceae	5	161	8.75	6
17	Bischofiaceae	1	126	37.69	5
18	Rubiaceae	5	135	3.98	5
19	Bombacaceae	2	34	22.69	4
20	Sterculiaceae	4	33	4.82	4
21	Oleaceae	2	139	1.95	3
22	Bignoniaceae	2	23	3.00	2
23	Stilaginaceae	2	37	0.75	2
24	Ulmaceae	2	13	2.68	2
25	Apocynaceae	2	26	1.17	2
26	Papilionaceae	2	14	1.18	2
27	Symplocaceae	2	13	0.29	2
28	Lythraceae	1	20	7.06	2
29	Sabiaceae	2	2	0.02	1
30	Burseraceae	1	48	2.64	1
31	Dilleniaceae	1	34	3.03	1
32	Cornaceae	1	38	2.33	1
33	Rosaceae	1	36	2.30	1
34	Rhizophoraceae	1	31	2.67	1
35	Celastraceae	1	8	4.44	1
36	Staphylaceae	1	33	2.26	1
37	Elaeocarpaceae	1	37	1.56	1
38	Boraginaceae	1	22	1.56	1
39	Datiscaceae	1	4	2.76	1
40	Melastomataceae	1	32	0.34	1
41	Caesalpiniaceae	1	19	0.53	1
42	Mimosaceae	1	3	1.12	1
43	Urticaceae	1	6	0.14	1
44	Xanthophyllaceae	1	5	0.06	1
45	Icacinaceae	1	3	0.07	1
46	Tiliaceae	1	1	0.21	1
47	Pittosporaceae	1	1	0.01	1
48	Myrsinaceae	1	1	0.01	1
49	Moraceae	9	162	–	–

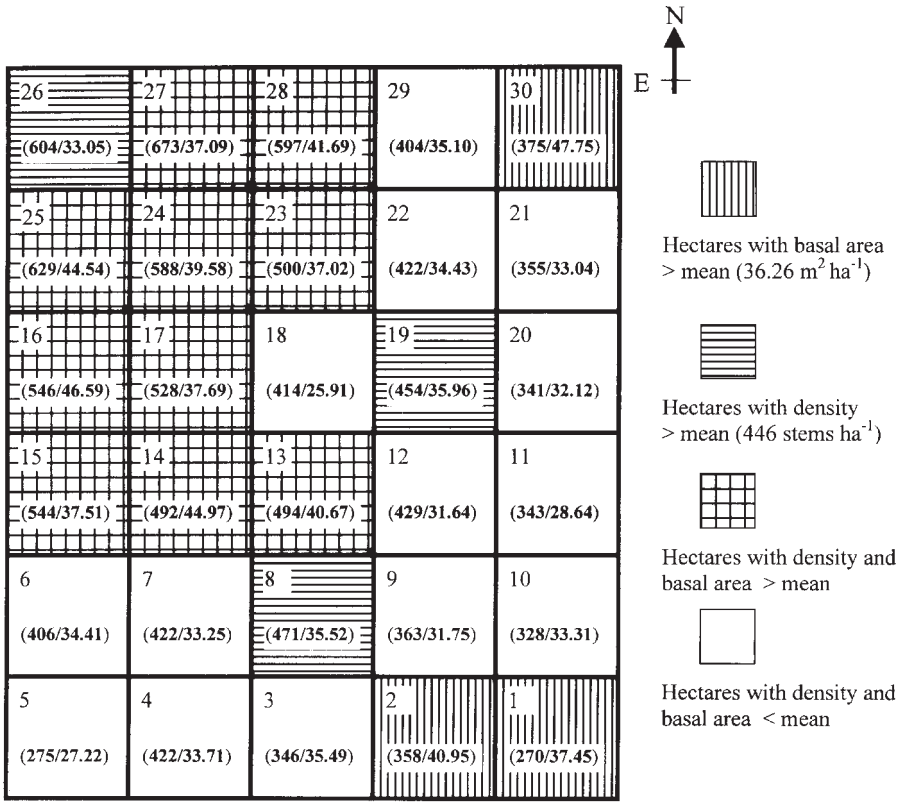

Figure 5. The 30-ha plot design along with values of stand density and basal area of each hectare in the tropical evergreen forest at Varagalaiar, Western Ghats. The hectares stand density and basal area greater/less than the mean stand values are also indicated in various shades.

Spatial patterns

The distributional patterns of species were examined at 1-ha scale, for 29 tree species with density $\geq$120 individuals in the 30 ha area (Table 5). All the species exhibited mostly clumped and uniform patterns of dispersion, except *Vateria indica*, which was randomly dispersed in the 15th ha. Totally 11 species were clumped in a greater number of hectares than those in which they had a uniform distribution. Seventeen species were uniformly dispersed in more hectares. Only *Knema attenuata* exhibited clumped as well as uniform patterns of dispersion in an equal number of hectares (Table 5).

Discussion

One of the characteristic features of the humid tropical forest is its high species richness. The species richness of the present study site (148 tree species in 30 ha, for

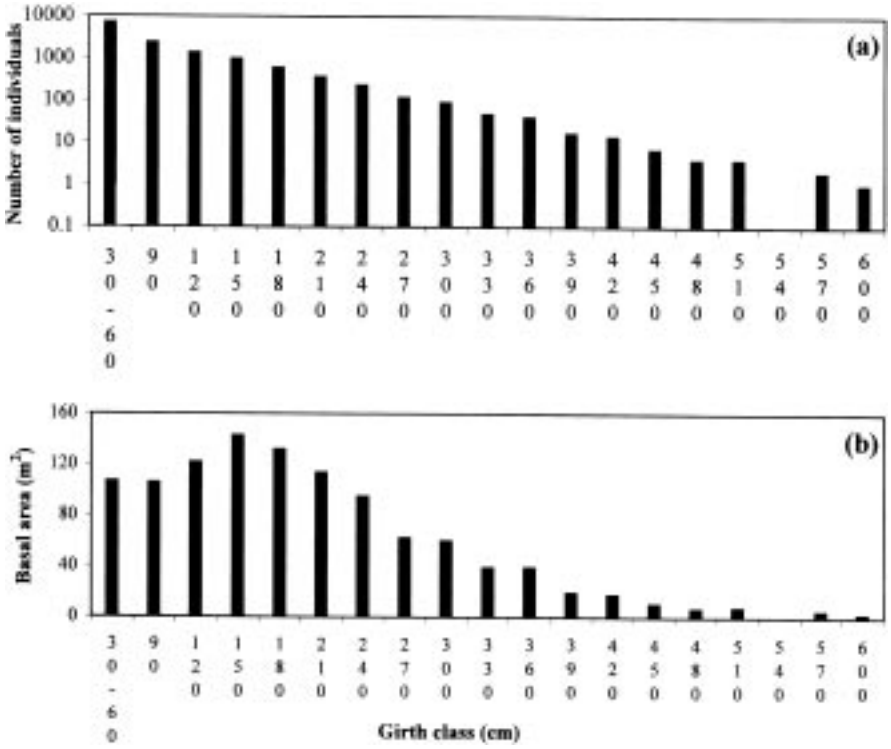

Figure 6. Population structure of trees: (a) Girth class frequency distribution (number of individuals in log scale) and (b) their basal area contribution in the 30 ha plot of tropical evergreen forest at Varagalaiar, Western Ghats.

trees ≥30 cm gbh) is low when compared to other large-scale (50 ha) permanent plot inventories for trees ≥30 cm gbh: 683 species in Pasoh Forest Reserve in Malaysia (PFR), Malaysia; 229 species in Barro Colorado Island (BCI), Panama (Condit et al. 1996); 561 species encountered along an elevational gradient (in 23.4 ha) of Costa Rica (Lieberman et al. 1996); but greater than the 103 species encountered in 28 ha of Uppangala, central Western Ghats, India (Pascal and Pelissier 1996) and 63 species in the deciduous forest (50 ha) of Mudumalai, south India (Condit et al. 1996).

The species richness in each hectare of Varagalaiar site (ranged from 51 to 78 species ha^{-1}; mean 65 species) is moderate when compared with other tropical evergreen forest inventories, which ranged from 20 species ha^{-1} in Varzea forest RioXingu, Brazil (Campbell et al. 1992) to 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994), but considerably higher when compared to other sites in southern and central Western Ghats viz., 30 species ha^{-1} in Nelliampathy (Chandrasehkara and Ramakrishnan 1994); 47 to 61 species ha^{-1} in Agumbe (Srinivas and Parthasarathy ms) and 57 species ha^{-1} in Mylodai forest of Courtallum (Parthasarathy and Karthikeyan 1997).

Table 4. Girth class tree species richness, density and dominant species (with their per cent contribution to density) in the tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats.

Tree girth class (cm)	Species richness	Density	Dominant species with their % contribution to density
30–60	132	7075	*Drypetes longifolia* (15) & *Reinwardtiodendron anamallayanum* (12)
90	108	2398	*Drypetes longifolia* (14) & *Reinwardtiodendron anamallayanum* (4)
120	93	1371	*Fahrenheitia zeylanica* (14) & *Poeciloneuron indicum* (7)
150	83	970	*Poeciloneuron indicum* (13) & *Fahrenheitia zeylanica* (5)
180	73	602	*Poeciloneuron indicum* (36) & *Dipterocarpus indicus* (23)
210	53	372	*Poeciloneuron indicum* (12) & *Palaquium ellipticum* (7)
240	44	234	*Dipterocarpus indicus* (18) & *Poeciloneuron indicum* (6)
270	30	119	*Dipterocarpus indicus* (17) & *Vateria indica* (14)
300	26	93	*Dipterocarpus indicus* (23) & *Vateria indica* (11)
330	18	49	*Dipterocarpus indicus* (31) & *Vateria indica* (6)
360	19	41	*Dipterocarpus indicus* (15) & *Vateria indica* (6)
390	10	17	*Dipterocarpus indicus* (24) & *Vateria indica* (2)
420	6	14	*Dipterocarpus indicus* (50) & *Terminalia bellirica* (14)
450	4	7	*Dipterocarpus indicus* (43) & *Bischofia javanica* (14)
480	2	4	*Dipterocarpus indicus* (75) & *Syzygium densiflorum* (25)
510	2	4	*Bombax ceiba* (75) & *Terminalia bellirica* (25)
540	0	0	
570	1	2	*Bombax ceiba* (100)
600	1	1	*Dipterocarpus indicus* (100)

The diversity of deciduous species in the stand is quite high (23%), but their contribution to stand density is lower (11%) as compared to BCI, Panama, where 18% of the canopy trees were deciduous (Condit et al. 1996). The greater number and abundance of deciduous species in the 5th hectare of our site, can be attribute to the exposed, corner location of this subplot on an elevated well drained site.

The pronounced species hierarchy is one of the most striking characteristics of the evergreen forests throughout the Western Ghats (Pascal 1988). In our 30 ha plot, 20 species dominated the stand contributing 67.5% of the stand density and 63% basal area, which utilize the majority of space and resources. The dominance of 4 species *Drypetes longifolia*, *Reinwardtiodendron anamallayanum* (due to greater stem density), *Dipterocarpus indicus*, *Poeciloneuron indicum* (due to basal area), that contributed 29% of tree density and 26% of the stand basal area, is comparable with that of 4-species dominance (48% of the trees and 55% of basal area) of central Western Ghats (Pascal and Pelissier 1996). Interestingly, the four-species dominance, that occupy four different stories at Varagalaiar, is coincident with the four-species dominance (of *Humboldtia brunonis* (lower storey), *Myristica dactyloides* (intermediate), *Vateria indica* (upper storey) and *Dipterocarpus indicus* (emergent)) in each storey of the tropical evergreen forest stand of Uppangala, central Western Ghats (Pascal and Pelissier 1996).

The asymptote approached by species–area curve (Figure 3) justifies that a 30 ha plot was a sufficient sample to determine the tree diversity of the forest. Exclusion

Table 5. Spatial patterns of tree species (those with ≥120 individuals) in the 30 ha plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats.

Sl. no.	Species	Number of hectares in which		
		Clumped	Uniform	Random
1	*Drypetes longifolia* (Blume) Pax & Hoffm.	22	6	–
2	*Reinwardtiodendron anamallayanum* (Bedd.) Saldanha	15	14	–
3	*Poeciloneuron indicum* Bedd.	20	9	–
4	*Fahrenheitia zeylanica* (Thw.) Airy Shaw	17	12	–
5	*Dipterocarpus indicus* Bedd.	19	7	–
6	*Dimocarpus longan* Lour.	15	12	–
7	*Knema attenuata* (Wall. ex Hook.f. & Thoms.) Warb.	14	14	–
8	*Palaquium ellipticum* (Dalz.) Baillon	6	23	–
9	*Myristica dactyloides* Gaertn.	11	18	–
10	*Baccaurea courtallensis* (Wight) Muell.-Arg.	9	18	–
11	*Cleidion spiciflorum* (Burm.f.) Merr.	14	10	–
12	*Aglaia elaeagnoidea* (A.Juss.) Benth.	12	17	–
13	*Orophea erythrocarpa* Bedd.	11	6	–
14	*Polyalthia fragrans* (Dalz.) Bedd.	8	21	–
15	*Vateria indica* L.	17	10	1
16	*Croton malabaricus* Bedd.	15	14	–
17	*Syzygium densiflorum* Wall. ex Wight & Arn.	10	17	–
18	*Dimorphocalyx beddomei* (Benth.) Airy Shaw	10	13	–
19	*Flacourtia montana* Graham	9	14	–
20	*Vitex altissma* L.f.	4	14	–
21	*Calophyllum polyanthum* Wall.	4	22	–
22	*Diospyros sylvatica* Roxb.	4	16	–
23	? *Cyclostemon subsessilis* Kurz.	7	18	–
24	*Aglaia jainii* Viswa. & Ramachan.	2	22	–
25	*Bischofia javanica* Blume	7	13	–
26	*Aphanamixis polystachya* (Wall.) Parker	5	14	–
27	*Aporusa lindleyana* (Wight) Baill.	5	2	–
28	*Hydnocarpus pentandra* (Buch.-Ham.) Oken	3	16	–
29	*Vepris bilocularis* (Wight & Arn.) Engler	3	23	–

of less-common species (curves ‘b’ and ‘c’) suggests that the contribution of very rare and rare species (13% and 52% respectively) to species richness of the stand is significant. Thus, the minimal area to capture the common species in our site is therefore 7 ha and this is comparable to that of the dipterocarp forest of Danum valley, Malaysia, wherein the minimal area for common species is about 2 ha (Newbery et al. 1992).

The cumulative family–area curve (Figure 4) indicates the adequacy of sample size to determine the family composition of the stand. The family dominance of Euphorbiaceae (accounted 12% of species richness and 28% of stand density for trees ≥30 cm gbh) in this study, is comparable to the dominance of Euphorbiaceae (10.6% of species and 13.81% of tree density) in the 50 ha plot of PFR, Malaysia for trees ≥1 cm dbh (Manokaran et al. 1991). Basal area-wise, Dipterocarpaceae was

dominant, both in Varagalaiar site (contributing 18.4% of stand basal area for trees ≥30 cm gbh) and in the 50 ha plot of PFR (24.38% of the stand basal area for trees ≥1 cm dbh) (Manokaran et al. 1991).

The forest stand of Varagalaiar is moderately dense (446 tree ha^{-1}), as compared to other large scale tree inventories: 537.6 trees ha^{-1} in Costa Rica (Lieberman et al. 1996), 530 trees ha^{-1} in PFR, Malaysia (Manokaran and LaFrankie 1990), 424.8 trees ha^{-1} in BCI, Panama and 300 stems ha^{-1} in Mudumalai, India (Condit et al. 1996); and also other large scale studies in the Western Ghats – 635 trees ha^{-1} (Pascal and Pelissier 1996) and 419 trees ha^{-1} (Ghate et al. 1998). The lower density at Varagalaiar (when compared to PFR, Malaysia) is compensated by the greater stand basal area. The mean stand basal area at Varagalaiar is 31% greater than PFR, Malaysia.

The girth frequency distribution of trees reveals the mature stage of the stand and good regeneration. This is consistent with the results of Malaysian forest (Poore 1968; Ho et al. 1987; Manokaran and Lafrankie 1990) and several peninsular Indian forest stands (Parthasarathy and Karthikeyan 1997; Parthasarathy 1999; Pascal and Pelissier 1996; Sukumar et al. 1992) and also that of French Guiana (Riera 1995), Costa Rica (Lieberman et al. 1983; Nadkarni et al. 1995) and Brazilian Amazon (Campbell et al. 1986; Swaine et al. 1987).

The 29 tree species analysed for dispersion at 1 ha scale, exhibited both clumped and uniform patterns. Clumping of individuals of the same species may be due to inefficient mode of seed dispersal (Richards 1996) or opportunity or chance as when numerous saplings are able to grow up where a large tree has died or in a large gap due to wind fall (Armesto et al. 1986; Richards 1996). Uniform dispersion patterns of species in tropical forests largely enable the maintenance of high levels of diversity (Connell 1971) and this pattern may be the consequence of direct competition for water or allelopathy (MacMohan and Schimpf 1981). Random pattern is very rare in our site. According to Armesto et al. (1986), random patterns are exhibited by species that are subjected to frequent large-scale disturbance.

Conclusion

The size, design and implementation of a large permanent plot provide useful information about the diversity and density of trees in a tropical evergreen forest in India. Permanently tagged individuals of trees provide a unique opportunity to investigate the dynamics of individual species and total forest tree flora in space and time. Our study site at Varagalaiar in the Western Ghats harbours a greater species richness (148 species) and moderate stand basal area (36.26 $m^2\,ha^{-1}$) when compared to other large-scale permanent plots. The importance value index of species obtained, has the advantage of using more than one measure of influence (density, frequency and basal area) in a plant community and can be used to form an association of dominant

species. Based on this large-scale quantitative inventory, an association of *Drypetes longifolia*, *Dipterocarpus indicus* and *Poeciloneuron indicum* can be designated for Varagalaiar site of the Anamalais in Western Ghats. The study site is a protected national park, yet the tribals depend on forests for some of their needs such as fuel wood (fallen branches), edible fruits and collection of white and black dammer from the mature trees of *Vateria indica* and *Canarium strictum*. Dammer collection wounds these trees resulting in pest attack and tree mortality. Growing some fast-growing native trees in the vicinity of the settlement, would be helpful for tribals, and would reduce their dependence on forest resources. The subsequent monitoring of the permanent plot by recensusing the tagged trees should provide additional data, useful for forest management and conservation, and it will indicate the influence of the local population on this forest.

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