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Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India

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Abstract. The composition, abundance, population structure and distribution patterns of all woody species ($\geq$ 30 cm gbh) were investigated in an undisturbed and two adjacent human-impacted sites of a tropical wet evergreen forest in Kalakad National Park, Western Ghats, south India. Three 1-ha plots were established, one each in (i) an undisturbed site (named site UD), (ii) in a site selectively felled 35 years ago (site SF – small stems felled leaving the large trees (as shade) for developing it into a cardamom estate, on the failure of which the site was abandoned) and (iii) a frequently disturbed site (site FD – round woods logged for use in ovens for curing cardamom). These sites are 1 to 3 km apart in the same wet evergreen forest. In the three study plots a total of 2150 stems (mean density 716 ha^{-1}) covering 122 species in 89 genera and 41 families were enumerated. Species richness was greatest (85 species ha^{-1}) in the undisturbed site UD, intermediate (83) in SF and lowest (80) in FD. Tree density was greatest (855 stems ha^{-1}) in site SF, intermediate (720) in UD and lowest (575) in FD. The forest stand was exceptionally voluminous in site UD (basal area 94.64 m^2 ha^{-1}), intermediate (66.9 m^2) in SF and least (61.7 m^2) in FD, due to tree removal for fuel in the latter sites. Species composition and abundance patterns markedly varied between the three sites. In UD and SF, primary forest species (*Cryptocarya bourdillonii* , *Cullenia exarillata Myristica dactyloides* etc.) occurred in greater density. In FD heliophilic secondary forest species (*Elaeocarpus venustus*, *Litsea wightiana*, *Viburnum punctatum* and *Vitex altissima*) were abundant, while these were absent in UD and SF. The species–area curve did not reach an asymptote in any of the sites on the 1-ha scale. The stand population structure was clearly reverse 'J' shaped in UD and SF, while small stems were 2- to 3-fold fewer in FD. Most trees exhibited clumped distribution of individuals on the 1-ha scale. Variation in the kind and richness of species and their abundance is related to human interference and the need for forest conservation is emphasized.

Key words: biodiversity, conservation, human interference, species abundance, tropical forest, Western Ghats

Introduction

Primary forests of Asia, particularly those of the Western and Eastern Ghats of peninsular India are disappearing at an alarming rate, due to anthropogenic pressure and they are either being replaced by forests containing inferior species, or the land use pattern is changed. The disappearance of tropical forests comes at a time when our knowledge of their structure and dynamics is still inadequate (Hubbell and Foster

1992). Human impacts on forests date back to antiquity and even to pre-history. However, documenting such impacts on the genetic diversity of forest trees is difficult and few quantitative data exist (Ledig 1992).

An understanding of forest processes is fundamental to the management of natural and disturbed vegetation. Such an understanding is necessary for assessment of potential impacts, the amelioration of effects of disturbance, optimization of productivity and rehabilitation of degraded ecosystems (Congdon and Herbohn 1993).

The Agasthyamalai range (2000 km^2) located at the southern end of Western Ghats in south India is known for high species diversity, harbouring 2000 flowering plant species with 7.5% endemism (Henry et al. 1984). Kalakad National Park, which is one of the 10 forests constituting the Agasthyamalai range, harbours 550 vascular plant species with 3.3% endemism (Parthasarathy 1988). Some studies have been carried out on the plant biodiversity in the evergreen forests of Western Ghats (Ganesh et al. 1996; Pascal and Pelissier 1996; Parthasarathy and Karthikeyan 1997a). The site histories of these areas are quite different. The primary aim of this research was to evaluate qualitative and quantitative changes in tree diversity in undisturbed and human-impacted sites of tropical wet evergreen forests in southern Western Ghats. These data are expected to be useful in conservation planning.

Materials and methods

Study area

Research was carried out in Kalakad National Park (KNP) (8°25′ N and 8°35′ N latitude and 77°25′ E and 77°35′ E longitude) located in the Agasthyamalai range of southern Western Ghats (Figure 1), in the Tirunelveli district of Tamil Nadu, south India. The altitude of KNP ranges from 100 to 1775 m. The park covers an area of 220 km^2 (Parthasarathy 1988). KNP is a part of a continuous forest extending over 887 km^2 of Kalakad–Mundanthurai Tiger Reserve (KMTR). The rocks are granitoid gneiss. The terrain is undulating. Major perennial rivers in the area include Pachayar, Manimuthar, Kusanguliar and Kakkachiar. Mean annual ambient temperature in the evergreen forest is 22.5 °C (range 15–30 °C) and soil temperature 21.9 °C (range 14–25 °C). Mean annual rainfall is about 3000 mm from the southwest (May–August) and northeast monsoons (October–December). Strong winds are common during the southwest monsoon.

The type of vegetation varies along the elevation gradient. The foothills harbour scrub vegetation up to an altitude of 200 m. Dry teak forest, composed of stunted, thin-poled teak (*Tectona grandis*), occurs between 200 and 300 m, mixed deciduous forest up to 750 m, semi-evergreen forest up to 850 m and wet evergreen forest from 920 to 1500 m, beyond which high altitude grasslands occupy the hill top. There are savanna woodlands adjacent to mixed deciduous and semi-evergreen forest tracts

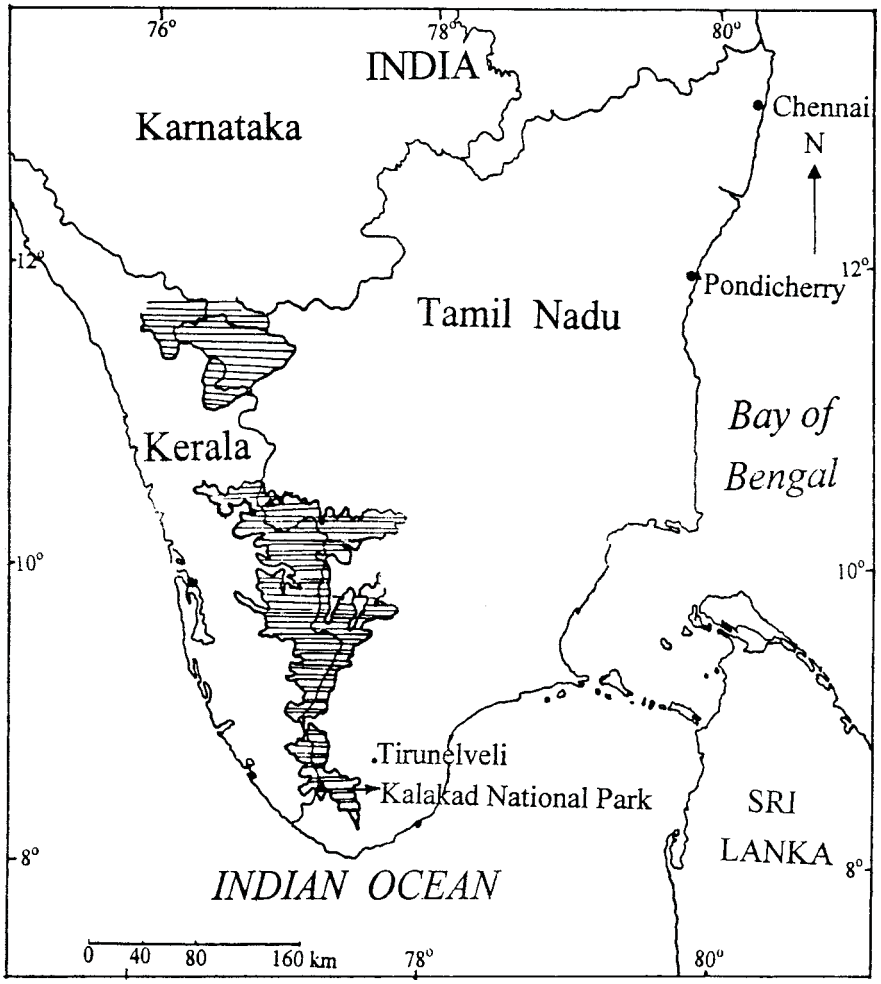

Figure 1. Map showing the location of Kalakad National Park, Western Ghats, near Tirunelveli town in Tamil Nadu State, south India.

from 400 to 920 m, in some places up to 1400 m. Ground fire occurs in savanna woodlands during the dry months of April–May. A detailed floristic account of the forest types of KNP already exists (Parthasarathy 1986; Parthasarathy and Mahadevan 1987). The study sites, located in Sengaltheri and adjacent areas of KNP (altitude 920 to 1200 m) are in tropical wet evergreen forest. These forests are classified as Tirunelveli hill top forests (Champion and Seth 1968) and as *Cullenia–Mesua–Palaquium* series by Pascal (1988). Nearly a century ago about three patches of evergreen forest measuring about 5 ha each were converted to cardamom plantations, and cultivation continued until 1993. A few patches, initially developed for cardamom plantation, were later abandoned because of poor crop yield. This study

was conducted from February to May 1991. There are no tribal people resident there, but a small population of 30 families of cardamom estate workers inhabited the forest until 1993; it is now uninhabitated. Their habitation was located 1 to 2 km from the three study plots.

The forest is rich in wildlife, particularly mammals, reptiles, avifauna and insects. Major vertebrates include mammals such as tiger (27 individuals in KMTR as per 1998 census), panther, hyena, elephants, sloth bear, Nilgiri langur, lion-tailed macaque, malabar giant squirrel, slender loris, bats etc. (the latter 7 species are involved in seed dispersal); and birds such as hill myna, velvet-fronted nuthatch, minivets, large green barbet, flycatchers, warblers, sunbirds, horn bills (great pied and malabar grey), Nilgiri wood pigeon, maroon-backed imperial pigeon, wood pecker, fairy blue bird etc. Many of these are involved in seed dispersal.

Three 1-ha plots were established covering one undisturbed and two human-impacted sites of the wet evergreen forest in Sengaltheri and adjoining areas. Plot 1 in the undisturbed site (named UD) at 1170 m elevation, is located in a pristine forest area (as evidenced by the tall, voluminous and large- and long-buttressed trees, with no signs of felling). Plot 2 in a selectively felled area (SF) at 1160 m, is located at a site that was disturbed 35 years ago. There are no records of the intensity or extent of disturbance. According to the local, elderly estate workers small stems were removed, leaving the large ones as shade, to develop it into a cardamom estate. As cardamom yield was low the site was abandoned without further interference. Since then, the site has been regenerating. Plot 3, a frequently disturbed area (FD), located in Sengaltheri–Kakkachi route, has been subjected to (i) logging of round woods (mostly *Eleaocarpus serratus* and *E. munronii*) for cardamom curing and (ii) gathering dead (!) wood to meet the fuel wood requirement of about 30 families employed on the cardamom estate. These estates were leased forest lands (leased for 99 years) and once the lease had expired (in 1993–94), they were handed over to the state forest department. Presently the site is being left to regenerate naturally, but during the early 90's, when this study was conducted, cardamom cultivation was still in progress.

Methods

Each of the three 1-ha square plots was systematically surveyed by subgridding them temporarily into 10 $\times$ 10 m quadrats, as workable units. All living trees and lianas $\geq$30 cm girth at breast height (gbh) were identified and their girth measured at 1.3 m from ground level. For buttressed trees, measurements were made above the buttress as far as possible. For multi-stemmed trees, bole girths were measured separately, basal area calculated and summed. Voucher specimens were collected for species confirmation and deposited in the herbarium of School of Ecology, Pondicherry University.

For species diversity, Shannon index (H′) (Magurran 1988) was calculated. Species–area curves were constructed by sequential summing of 100 $\times$ 10 m (0.1 ha)

sub-plots. Distribution patterns of species were determined based on the quadrat count method using Morisita's index as per Krebs (1989).

Results

Species diversity

The 3-ha tropical wet evergreen forest inventory yielded a total of 122 woody species $\geq$30 cm gbh that belonged to 89 genera and 41 plant families. Two species remained unidentified. Species diversity was greatest (85) in the undisturbed site (UD), intermediate (83) in the selective-filled site (SF) and least (80) in the frequently disturbed site (FD). Generic level diversity also followed a similar trend (Table 1). Shannon diversity index did not vary much in the three plots. Genera with a large number of species include *Syzygium* (8 species, excluding 2 species of *Eugenia*), *Ficus* (6), *Litsea* (5), *Elaeocarpus* (4) and *Diospyros* (3).

Of the 122 species, 8 were lianas and the remaining 114 were trees. Forty-seven species (39%) were common to all the three plots. Sites UD and SF shared 57 species, SF and FD 54 species and UD and FD 55 species. With the exception of three deciduous species, *Bischofia javanica*, *Melia dubia* and *Vitex altissima*, all were evergreens. Buttressed trees were greater in site UD followed by FD. Liana diversity and density were greater in site FD.

Variation in species composition

A clear difference in species composition and their population density can be discerned between the undisturbed and human-impacted sites (Table 2). Site UD was

Table 1. Details of woody species inventory in undisturbed site (UD), site selectively felled 35 years ago (SF) and frequently disturbed (FD) site of the tropical wet evergreen forest in Kalakad National Park, Western Ghats, south India.

	Site			
Variable	Undisturbed (UD)	Select-felled (SF)	Frequently disturbed(FD)	In all 3-ha
Species richness	85	83	80	122
No. of genera	72	70	66	89
No. of families	35	33	35	41
Shannon index	3.66	3.70	3.67	
Stand density (stems ha^{-1})	720	855	575	2150
Stand basal area (m^2 ha^{-1})	94.64	66.87	61.70	
Liana species richness	6	5	8	8
(and density)	14	14	18	46
No. of buttressed trees	484	370	328	

Table 2. Population density (site-wise and total) of woody species, in order of total abundance in undisturbed (UD), selectively-felled (SF) and frequently disturbed (FD) tropical wet evergreen forest sites in Kalakad National Park, Western Ghats, India.

Species	Family	Number of individuals in Site UD	Site SF	Site FD	All 3-ha
1. *Cryptocarya bourdillonii* Gamble	Lauraceae	62	77	8	147
2. *Myristica dactyloides* Gaertn.	Myristicaceae	72	64	6	142
3. *Harpullia arborea* (Blanco) Radlk.	Sapindaceae	23	74	12	109
4. *Mangifera indica* L.	Anacardiaceae	41	55	8	104
5. *Cullenia exarillata* Robyns	Bombacaceae	47	40	1	88
6. *Litsea wightiana* (Nees) Hook.f.	Lauraceae	0	0	80	80
7. *Symplocos macrocarpa* Wt. ex Cl. ssp. *macrocarpa*	Symplocaceae	29	22	14	65
8. *Cinnamomum keralaense* Kosterm.	Lauraceae	14	10	37	61
9. *Holigarna arnottiana* Hook.f.	Anacardiaceae	22	27	6	55
10. *Heritiera papilio* Bedd.	Sterculiaceae	7	45	1	53
11. *Diospyros sylvatica* Roxb.	Ebenaceae	16	23	12	51
12. *Antidesma menasu* (Tul.) Miq. Ex M. Arg.	Stilaginaceae	36	8	7	51
13. *Syzygium mundagam* (Bourd). Chitra	Myrtaceae	23	12	9	44
14. *Filicium decipiens* (Wt. & Arn.) Thw.	Sapindaceae	3	1	39	43
15. *Syzygium lanceolatum* (Lam.) Wt. & Arn.	Myrtaceae	3	36	2	41
16. *Bischofia javanica* Bl.	Bischofiaceae	4	1	35	40
17. *Xanthophyllum flavescens* Roxb.	Xanthophyllaceae	24	1	15	40
18. *Palaquium ellipticum* (Dalz.) Baillon	Sapotaceae	37	2	0	39
19. *Olea dioica* Roxb.	Oleaceae	14	24	0	38
20. *Vitex altissima* L.f.	Verbenaceae	0	0	35	35
21. *Casearia rubescens* Dalz.	Flacourtiaceae	3	25	3	31
22. *Hydnocarpus alpina* Wt.	Flacourtiaceae	13	18	0	31
23. *Diospyros ferrea* (Willd.) Bakh. var. *neilgherrensis* (Wt.) Bakh.	Ebenaceae	3	21	5	29
24. *Syzygium cumini* (L.) Skeels	Myrtaceae	5	7	15	27
25. *Aglaia jainii* Viswa. & Ramachan.	Meliaceae	16	7	2	25
26. *Canarium strictum* Roxb.	Burseraceae	15	4	5	24
27. *Listsea stocksii* (Meisner) Hook.f. var. *glabrescens* (Meisner) Hook.f.	Lauraceae	3	21	0	24
28. *Gordonia obtusa* Wall. ex Wt. & Arn.	Theaceae	3	8	11	22
29. *Eugenia thwaitesii* Duthie	Myrtaceae	5	9	7	21
30. *Syzygium caryophyllatum* (L.) Alston	Myrtaceae	4	15	2	21
31. *Scolopia crenata* (Wt. & Arn.) Clos.	Flacourtiaceae	8	11	1	20
32. *Beilschmedia gemmiflora* (Bl.) Kosterm.	Lauraceae	3	6	11	20
33. *Excoecaria robusta* Hook.f.	Euphorbiaceae	1	8	10	19
34. *Macaranga peltata* (Roxb.) M.Arg.	Euphorbiaceae	6	0	13	19
35. *Memecylon talbotianum* Brandis	Melastomataceae	5	11	3	19
36. *Mesua ferrea* L.	Clusiaceae	6	10	2	18
37. *Oreocnide integrifolia* (Gaud.) Miq.	Urticaceae	17	0	1	18
38. *Litsea laevigata* (Nees) Gamble	Lauraceae	9	3	5	17
39. *Pleurostylia opposita* (Wall.) Alston	Celastraceae	0	1	15	16
40. *Epiprinus mallotiformis* (M. Arg.) Croizat	Euphorbiaceae	1	15	0	16
41. *Viburnum punctatum* Buch.-Ham. ex D. Don	Caprifoliaceae	0	0	14	14
42. *Elaeocarpus venustus* Bedd.	Elaeocarpaceae	0	0	14	14
43. *Ardisia rhomboidea* Wt.	Myrsinaceae	6	8	0	14

Table 2. Continued.

Species	Family	Number of individuals in Site UD	Site SF	Site FD	All 3-ha
44. *Acronychia pedunculata* (L.) Miq.	Rutaceae	7	2	5	14
45. *Nothopegia beddomei* Gamble	Anacardiaceae	1	9	3	13
46. *Cinnamomum malabatrum* (Burm.f.) Bl.	Lauraceae	2	4	7	13
47. *Ficus nervosa* Heyne ex Roth	Moraceae	2	2	8	12
48. *Canthium dicoccum* (Gaertn.) Teijsm & Binn.	Rubiaceae	0	8	4	12
49. *Ventilago madraspatana* Gaertn.	Rhamnaceae	6	4	1	11
50. *Clausena indica* (Dalz.) Oliver	Rutaceae	2	6	3	11
51. *Cassine glauca* (Rottb.) Kuntze	Celastraceae	1	7	2	10
52. *Agrostistachys borneensis* Becc.	Euphorbiaceae	10	0	0	10
53. *Pseudaidia rugulosa*	Rubiaceae	1	5	4	10
54. *Artocarpus heterophyllus* Lam.	Moraceae	2	2	5	9
55. *Tarenna asiatica* Hook.f.	Rubiaceae	0	5	4	9
56. *Isonandra lanceolata* Wt.	Sapotaceae	1	4	4	9
57. *Casearia ovata* (Lam.) Wild.	Flacourtiaceae	0	2	6	8
58. *Gnetum ula* Brongn.	Gnetaceae	0	1	7	8
59. *Eugenia floccosa* Bedd.	Myrtaceae	2	6	0	8
60. *Goniothalamus* sp.	Annonaceae	7	0	0	7
61. *Litsea glabrata* (Wall. ex Nees) Hook.f.	Lauraceae	7	0	0	7
62. *Persea macrantha* (Nees) Kosterm.	Lauraceae	2	3	2	7
63. *Garcinia gummi-gutta* (L.) Robson	Clusiaceae	4	1	1	6
64. *Rourea minor* (Gaertn.) Alston	Connaraceae	3	3	0	6
65. *Mallotus phillippensis* (Lam.) Muell.-Arg.	Euphorbiaceae	4	0	2	6
66. *Litsea insignis* Gamble	Lauraceae	6	0	0	6
67. *Syzygium zeylanicum* (L.) DC. var. *zeylanicum*	Myrtaceae	1	2	3	6
68. *Xylopia parviflora* (Wt.) Hook.f. & Thoms.	Annonaceae	3	2	0	5
69. *Elaeocarpus munronii* (Wt.) Masters	Elaeocarpaceae	1	2	2	5
70. *Ormosia travancorica* Bedd.	Papilionaceae	0	5	0	5
71. *Chukrasia tabularis* A. Juss.	Meliaceae	5	0	0	5
72. *Melia dubia* Cav.	Meliaceae	1	1	3	5
73. *Drypetes wightii* (Hook.f.) Pax & Hoffm.	Euphorbiaceae	0	2	2	4
74. *Neolitsea scrobiculata* (Meisner) Gamble	Lauraceae	2	1	1	4
75. *Aphanamixis polystachya* (Wall). Parker	Meliaceae	4	0	0	4
76. *Ligustrum travancoricum* Gamble	Oleaceae	0	4	0	4
77. *Unidentified-2*	Rubiaceae	0	2	2	4
78. *Murraya koenigii* (L.) Spr.	Rutaceae	2	2	0	4
79. *Microtropis microcarpa* Wt.	Celastraceae	1	2	0	3
80. *Elaeocarpus serratus* L.	Elaeocarpaceae	0	2	1	3
81. *Alseodaphne semicarpifolia* Nees	Lauraceae	0	3	0	3
82. *Strychnos vanprukii* Craib	Loganiaceae	1	1	1	3
83. *Memecylon umbellatum* N. Burman	Melastomataceae	0	0	3	3
84. *Aglaia* sp.	Meliaceae	0	3	0	3
85. *Dysoxylum malabaricum* Bedd. ex Hiern	Meliaceae	1	2	0	3
86. *Lepisanthes decipiens* Radlk.	Sapindaceae	0	2	1	3
87. *Pterospermum reticulatum* Wt. & Arn.	Sterculiaceae	0	0	3	3
88. *Beaumontia jerdoniana* Wt.	Apocynaceae	2	0	0	2
89. *Calophyllum austroindicum* Kosterm. ex Stevens	Clusiaceae	0	2	0	2
90. *Breynia vitis-idaea* (Burm.f.) Fischer	Euphorbiaceae	2	0	0	2

Table 2. Continued.

Species	Family	Number of individuals in Site UD	Site SF	Site FD	All 3-ha
91. *Glochidion malabaricum* Bedd.	Euphorbiaceae	0	0	2	2
92. *Derris benthamii* (Thw.) Thw.	Papilionaceae	0	0	2	2
93. *Ficus amplissima* J.E. Smith	Moraceae	1	1	0	2
94. *Ficus hispida* L.f.	Moraceae	1	0	1	2
95. *Ficus tsjahela* N. Burman	Moraceae	0	1	1	2
96. *Ficus* sp.	Moraceae	0	0	2	2
97. *Syzygium gardneri* Thw.	Myrtaceae	0	0	2	2
98. *Syzygium hemisphericum* (Wt.) Alston	Myrtaceae	1	0	1	2
99. *Syzygium zeylanicum* (L.) DC. var. *lineare* (Duthie) Alston	Myrtaceae	0	1	1	2
100. *Canthium angustifolium* Roxb.	Rubiaceae	1	0	1	2
101. *Vepris bilocularis* (Wt. & Arn.) Engl.	Rutaceae	1	0	1	2
102. *Callicarpa tomentosa* (L.) Murray	Verbenaceae	1	0	1	2
103. Unidentified sp. 1		0	2	0	2
104. *Miliusa wightiana* Hook.f. & Thoms.	Annonaceae	0	1	0	1
105. *Schefflera wallichiana* (W. & A.) Arn.	Araliaceae	0	0	1	1
106. *Bentinckia condapanna* Berry ex Roxb.	Arecaceae	0	0	1	1
107. *Diospyros assimillis* Bedd.	Ebenaceae	0	1	0	1
108. *Elaeagnus conferta* Roxb.	Elaeagnaceae	0	0	1	1
109. *Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae	1	0	0	1
110. *Drypetes longifolia* (Bl.) Pax & Hoffm.	Euporbiaceae	0	1	0	1
111. *Mallotus stenanthus* M. Arg.	Euphorbiaceae	0	1	0	1
112. *Taraktogenos macrocarpa* (Bedd.) Balak.	Flacourtiaceae	1	0	0	1
113. *Actinodaphne malabarica* Balak.	Lauraceae	1	0	0	1
114. *Phoeba lanceolata* Nees	Lauraceae	1	0	0	1
115. *Ficus microcarpa* L.f.	Moraceae	1	0	0	1
116. *Gomphia serrata* (Gaertn.) Kanis	Ochnaceae	1	0	0	1
117. *Chionanthus mala-elengi* (Dennst.) P.S. Green	Oleaceae	1	0	0	1
118. *Psychotria connata* Wall.	Rubiaceae	0	1	0	1
119. *Chrysophyllum roxburghii* G. Don	Sapotaceae	0	1	0	1
120. *Madhuca bourdillonii* (Gamble) Lam.	Sapotaceae	0	0	1	1
121. *Unidentified* sp. 4		1	0	0	1
122. *Unidentified* sp. 2		1	0	0	1
Total		720	855	575	2150

largely composed of primary forest species with fewer (species-wise 3% and density-wise 1.8%) secondary forest species. Compared to UD, site FD contained 3-fold more secondary forest species (9% species-wise and 5-fold more (40%) density-wise). Site SF contained 2.4% (species-wise) secondary forest species (0.2% density-wise). In SF, evergreen species such as *Heritiera papilio*, *Syzygium lanceolatum*, *Casearia rubescens*, *Diospyros ferrea* var. *neilgherrensis*, *Litsea stocksii* and *Epiprinus mallotiformis* were abundant, while these were poorly represented in sites UD and FD. All these are small trees. Thus, site SF which was selectively felled 35 years ago is probably now in the late succession stage, containing (density-wise) 19% of

late succession species, in contrast to 2.8% and 0.2% in UD and FD, respectively. *Cryptocarya bourdillonii*, *Myristica dactyloides*, *Cullenia exarillata*, *Olea dioica* and *Hydnocarpus alpina* were abundant in both UD (29%) and SF (26%) while these were poorly represented (2.6%) in FD. *Palaquium ellipticum* was abundant in UD, but meager (2 trees ha^{-1}) in SF and absent in FD.

Species–area curve

Species–area curves for sites UD and FD increased gradually, while that of SF increased in a step-wise manner (Figure 2). In none of the plots did the curve reach an asymptote, indicating that one hectare is not a sufficient size to sample all the species in these sites.

Tree density and basal area

Total stand density was 2150 stems in the 3-ha area (mean 716 stems ha^{-1}). Stand density was greatest (855 ha^{-1}) in site SF, intermediate (720) in UD and lowest (575) in FD. The stand density was slightly lower in UD, but it is compensated by voluminous trees that scored the greatest basal area of 94.64 m^2 ha^{-1}. Sites SF and FD scored 66.9 and 61.7 m^2 ha^{-1} respectively.

Species density, dominance and rarity

As is typical of many tropical forests, a small number of species at each site had a disproportionately greater density. The number of very rare, rare, common, dominant and predominant species was nearly equal in all the three sites (Tables 2 and 3), although species varied. Site UD was dominated by six species (*Cryptocarya bourdillonii*, *Myristica dactyloides*, *Harpullia arborea*, *Mangifera indica*, *Cullenia exarillata* and *Palaquium ellipticum*) which contributed 39% (282 stems ha^{-1}) of stand density and 44% (41.2 m^2) of basal area. In SF in addition to the first 5 species listed above, *Heritiera papilio* and *Syzygium lanceolatum* contributed 46% (391 stems) of stand density and 52% (35 m^2 ha^{-1}) of basal area. Site FD was dominated by 5 totally different species, namely *Litsea wightiana*, *Cinnamomum keralaense*, *Filicium decipiens*, *Bischofia javanica* and *Vitex altissima* which contributed 39% (226 stems) of stand density and 40% (25 m^2) of stand basal area.

Family composition

The total number of plant families from the three study sites was 41. The Lauraceae with 14 species (11%), constitute an important family of canopy trees dominating the forest locally. Euphorbiaceae (10 species, 8%) and Myrtaceae (10 species, 8%) were the families represented next best, followed by Moraceae (7 species, 6%),

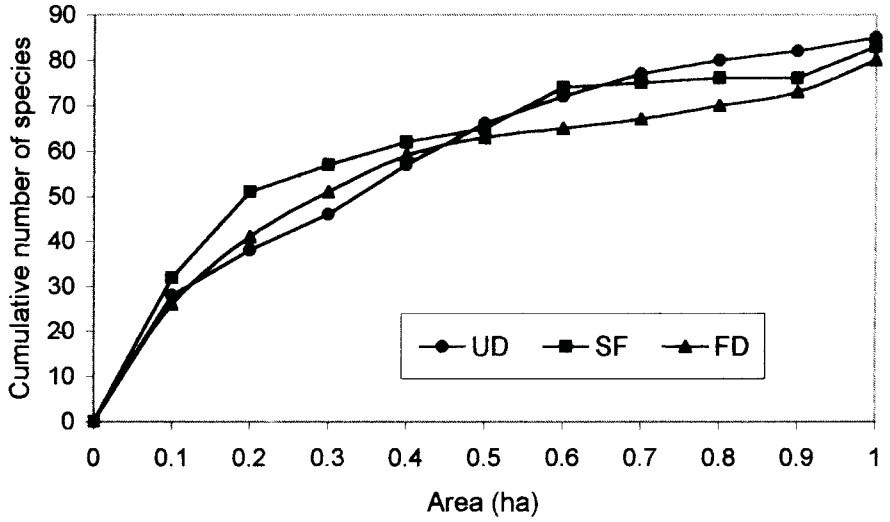

Figure 2. Species–area curves for study plots UD, SF and FD in the tropical wet evergreen forest of Kalakad National Park, Western Ghats.

Meliaceae (6, 5%), Rubiaceae (6, 5%), Flacourtiaceae (5, 4%), Sapotaceae (5, 4%), Elaeocarpaceae and Rutaceae (4 species each, 4%) (Figure 3). Seven families were represented by three species; four families by 2 species, while the remaining 20 families by a single species. Density-wise, 5 families, Lauraceae (371 individuals, 17%), Myrtaceae (174, 8%), Anacardiaceae (172, 8%), Sapindaceae (155, 7%) and Myristicaceae (142, 6%) represented only by *Myristica dactyloides*, dominated the stand, contributing 47% of the total stand density (Figure 3).

Population structure of forest stand

The overall forest stand exhibited an expanding population structure, but the small size class (30–60 cm) was nearly two-and-a-half times lower in site FD as compared to UD and SF, respectively (Figure 4). There was an equal representation in other tree

Table 3. Number (and percentage) of species in very rare (frequency (f) < 2), rare ($f > 2$–9), common ($f > 9$–25), dominant ($f > 25$–50) and predominant ($f < 50$) categories in the three study sites.

	No. of species in site			
No. of individuals	UD	SF	FD	Total
$f < 2$	36 (42.9)	33 (40.2)	35 (43.8)	36 (29.5)
$f > 2$–9	29 (34.5)	26 (31.7)	28 (35)	31 (25.4)
$f > 9$–25	11 (13.1)	14 (17.1)	12 (15)	29 (23.8)
$f > 25$–50	5 (5.9)	4 (5)	4 (5)	11 (9)
$f < 50$	2 (2.4)	5 (6.1)	1 (1.3)	13 (10.7)

Table 4. Morisita's index value and dispersion patterns of dominant species in undisturbed (UD), selectively-felled (SF) and frequently disturbed (FD) forest sites in Kalakad National Park, Western Ghats.

	Morisita index value & dispersion		
Species*	Site UD	Site SF	Site FD
Antidesma menasu	0.95 r	1.66 c	*
Bischofia javanica	*	*	1.01 c
Casearia rubescens	*	1.66 c	*
Cinnamomum keralaense	*	*	1.35 c
Cryptocarya bourdillonii	1.28 c	1.23 c	*
Cullenia exarillata	1.11 c	1.67 c	*
Filicium decipiens	*	*	1.48 c
Harpullia arborea	*	1.00 c	*
Heritiera papilio	*	1.31 c	*
Holigarna arnottiana	*	1.85 c	*
Litsea wightiana	x	x	1.42 c
Mangifera indica	1.83 c	1.95 c	*
Myristica dactyloides	1.17 c	1.54 c	*
Palaquium ellipticum	1.20 c	1.23 c	x
Symplocos macrocarpa	2.22 c	*	*
Syzygium lanceolatum	*	0.90 r	*
Vitex altissima	x	x	1.18 c

∗ Those species with density >25 individuals in the 3 ha area were not considered for dispersion analysis;
x – not represented at these sites,
c – clumped distribution,
r – random distribution.

size classes in all the three sites. The trends in basal area distribution differed. Basal area contribution of the largest (>210 cm) size class in UD was almost three times that of SF and FD, indicating that UD harbours an undisturbed, mature forest stand.

Patterns of tree dispersion and fruit types

Of the 17 tree species (represented by more than 25 individuals in the three sites) analysed for spatial patterns on the 1-ha scale, most were clumped, particularly the dominants. *Antidesma menasu* and *Syzygium lanceolatum* were randomly dispersed. Of the 118 woody species (excluding the 4 unidentified ones) in the 3-ha study plots, 76% bear fleshy fruits (48% berries and 28% drupes); 24% dry fruits, which includes 5% of species with arillate seeds and the remaining without any rewards (legumes, nuts, follicles and capsules). Many of these are vertebrate-dispersed.

Discussion

Quantitative tree diversity inventories of comparable girth threshold (≥30 cm gbh) in various wet evergreen forests of the Western Ghats reveal that the species richness of

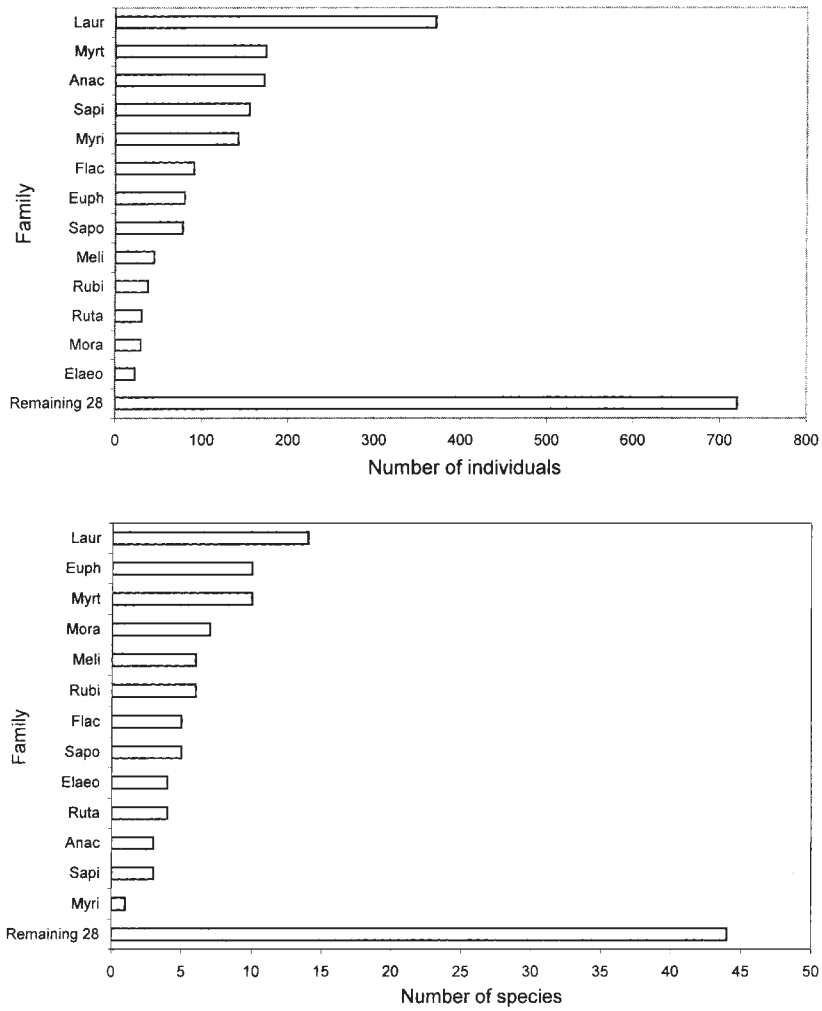

Figure 3. Contribution of major plant families to species richness and stand density in the tropical wet evergreen forest of Kalakad National Park, Western Ghats.

122 species (114 trees and 8 lianas) enumerated on a 3-ha scale in Kalakad National Park, is greater than that of 90 tree species recorded (Ganesh et al. 1996) in 3.82 ha of Kakkachi area, located about 50 km northeast of the present study site, within the Kalakad–Mundandurai Tiger reserve, and that of 91 species, recorded in 3.12 ha (Pascal and Pelissier 1996) in the wet evergreen forest Uppangala, central Western Ghats.

On a hectare basis the range of species richness obtained in the present study (80 to 85 species ha^{-1}) is also greater than other wet evergreen forests of the Western Ghats, namely Nelliampathy (30 species ha^{-1}, Chandrashekara and Ramakrishnan 1994), and Mylodai, Courtallum reserve forest (57 species ha^{-1}, Parthasarathy and Karthikeyan 1997a). Admittedly, compared to other sites of central and southern

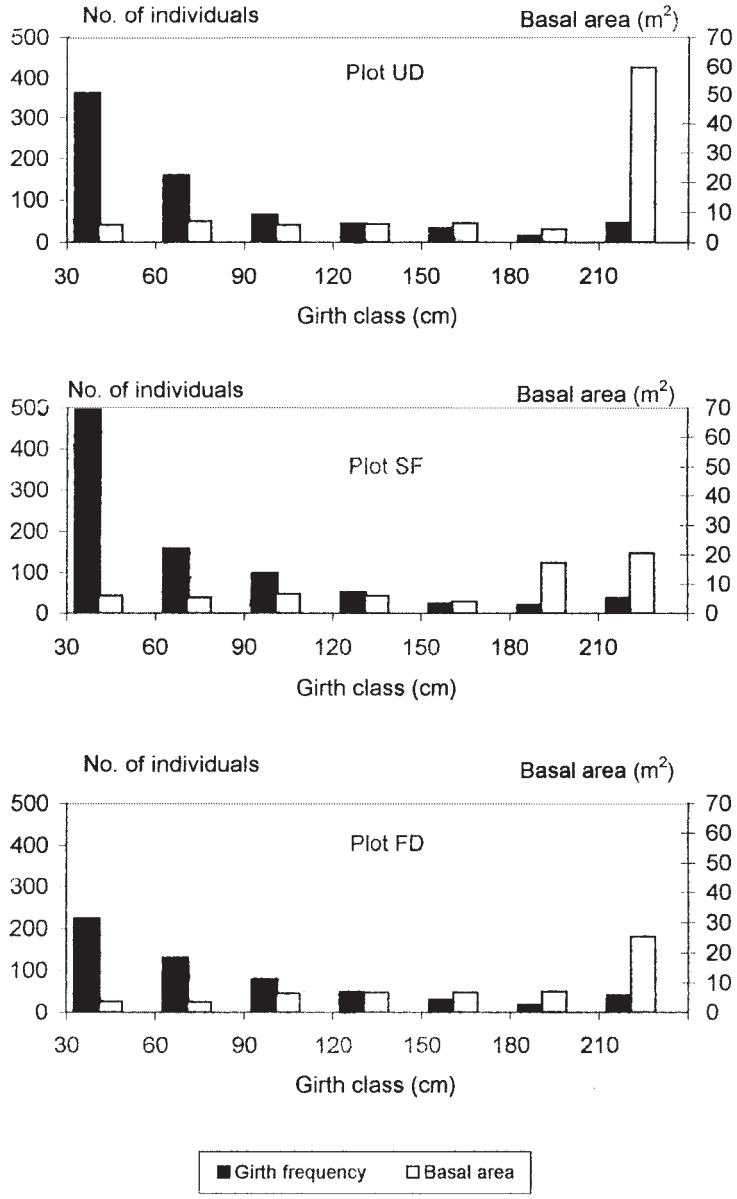

Figure 4. Population structure of woody species in sites UD, SF and FD based on girth-frequency and basal area.

Western Ghats, the Sengaltheri wet evergreen forest of Kalakad, is species-rich. This could be due to the relatively 'undisturbed' condition of the forest, as compared to other sites, poor accessibility of the area, lack of transport facility, and the entry restricted to the National Park, as a protected area, allowing only researchers and

forest staff to enter. However, the former cardamom plantation activity has locally affected species richness in some portions of the forest due to plantation and related activities. Floristically the entire Agasthyamalai hill complex (composed of 10 forest reserves, including Kalakad) is a botanically important area with its floristic affinity, with the flora of Sri Lanka and Malaysia (Parthasarathy 1988).

Tree diversity recorded in various wet evergreen forests across the tropics showed a wide variation, ranging from 20 species ha^{-1} in the Varzea forest of Rio Xingu, Brazil (Campbell et al. 1992) to 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994), both from the neotropics.

Variation in stand density between the three study sites UD, SF and FD could be related to the extent of human interference in the past and present. The undisturbed site UD contained moderate stem density (720 ha^{-1}), but this was compensated by greater basal area. In SF, because of selective felling of small poles 35 years ago, leaving the canopy trees as shade for developing it into a cardamom estate and the site abandoned due to poor yield, the seedling and seed banks of primary forest species under the shade of canopy trees would have grown up in the 35-year period contributing to overall greater stem density and in particular to the lowest size class (Figure 4). This is also evidenced from the kinds of species composing the stand, containing a mixture of primary forest species and late succession species, but not secondary forest species. Tree density was considerably lower in FD because of tree removal for cardamom curing and fire wood requirement of the estate dwellers. The primary forest species are fewer in FD because of the openness created by tree removal and their replacement by heliophilic, light demanding species that presently dominate the stand.

The range (575–875 ha^{-1}) and mean (716 ha^{-1} tree density of the present study sites are greater than that of 419 trees ha^{-1} reported (Ghate et al. 1998) as mean tree density for Western Ghats closed canopy evergreen forest, and that of the nearby Mylodai site in Courtallum reserve forest (482 stems ha^{-1}, Parthasarathy and Karthikeyan 1997a) and comparable to that of the nearby Kakkachi site (583 stems ha^{-1}, Ganesh et al. 1996), Uppangala forest of central Western Ghats (635 ha^{-1}, Pascal and Pelissier, 1996) and most other tropical forests, for trees ≥ 30 cm gbh as compared in Appendix 2 of Parthasarathy and Karthikeyan (1997a).

The stand basal area of Kalakad wet evergreen forest (61.7 to 94.64 m^2 ha^{-1}) is nearly 2- to 3-fold greater than the pantropical average of 32 m^2 ha^{-1} (Dawkins 1959). The strikingly high basal area of 94.64 m^2 ha^{-1} obtained in the undisturbed site UD reflects the girth potential of the native, primary forest species, when left undisturbed. Several trees in site UD were lofty and were climax forest species with girths measuring 5 and 9.54 m, which contributed to greater basal area. Site SF and FD scored 30% lesser basal area because of selective felling 35 years ago in SF and continuous tree removal in FD. The nearby Nelliampathy wet evergreen forest of Western Ghats scored 61.9 m^2 ha^{-1} (Chandrashekara and Ramakrishnan 1994). In the tropical wet evergreen forests of the tropics stand basal area ranged from

25.5 m^2 ha^{-1} in Rio Xingu, Brazil (Campbell et al. 1992) to 82.67 m^2 ha^{-1} in the tropical rainforest of Reunion islands (Strasberg 1996).

The most obvious variation in tree composition and the proportion of dominant species in the three sites, can directly be attributed to human impact particularly in site FD. Dominance increases as a function of stress (Keel and Prance 1979) or due to past damage (Jacobs 1987). Based on the dominant species, medium-elevation evergreen forest of Kalakad National Park can be classified as *Cryptocarya–Myristica–Harpullia* association with *Mangifera* and *Cullenia* as codominants within the broader *Cullenia–Mesua–Palaquium* series designated by Pascal (1988) for a large area comprising southern Western Ghats in Tamil Nadu and Kerala states. The *Litsea–Cinnamonum–Filicium* association would characterize the disturbed sites.

According to Ho et al. (1987) in the Jenkga forest reserve, Euphorbiaceae with a species density of 24.6% was the most important individual family in Malaysia. Hara et al. (1997) reported Lauraceae (9 species) and Rubiaceae (7) as dominant families in broad-leaved forest in Taiwan, while the present study site was dominated by Lauraceae, Euphorbiaceae and Myrtaceae.

The expanding tree population structure exhibited by trees in the present study sites is in conformity with many other tropical forest stands in the Western Ghats such as Uppangala (Pascal and Pelisseir 1996) Mylodai, Courtallum (Parthasarathy and Karthikeyan 1997a) and also that of Malaysia (Poore 1968; Manokaran and La-Fankie 1990; Ho et al. 1987) Amazonian Ecuador (Balslev et al. 1987), Costa Rica (Lieberman et al. 1985; Nadkarni et al. 1995) Brazilian Amazon (Swaine et al. 1987; Campbell et al. 1986) and Uganda (Taylor et al. 1996).

The predominantly clumped dispersion of trees obtained in all the three sites is consistent with the results of various other tropical forest studies (Ashton 1969; Whitmore 1975; Hubbell 1979; Thorington et al. 1982; Parthasarathy and Karthikeyan 1997a,b). Most trees in this forest bear small of bulky fleshy fruits (drupes or berries) and are dispersed by vertebrates, chiefly birds (pigeons, hornbills etc.) and mammals (lion-tailed macaque, bears, bats, etc.).

Conclusion

In the wet evergreen forest of Kalakad National Park, in a relatively small area, there are both virgin forest and various stages of (secondary) disturbed forests, because of human impacts. Natural undisturbed forests are self-maintaining in accordance with the local processes of mortality, growth, regeneration and lost trees are replaced by new recruits; vegetation thus continues in a dynamic equilibrium (Swaine et al. 1987). Disturbance and predation are considered to be the main mechanisms underlying the maintenance of species diversity in the face of strong competitive interaction (Hay 1986).

The disturbance in the research area is directly related to cardamom plantation activities. Tree removal results in gap creation, allows increased light penetration to

the forest floor and large inputs of green litter and woods. The intensity of these disturbances depends on the number and the kind of trees felled, their spatial location and periodicity of removal. The main changes in floristic composition and the abundance of inferior species in site FD, and the occurrence of late succession species in SF, accentuate the fact that primary forests once disturbed would require a longer period for ecosystem recovery. The handing over of the estate in 1993 to the forest department after the completion of the 99-year lease, the evacuation of the estate dwellers and the winding up of plantation activities, have currently changed the situation for the better. Hence, the forest should recover its original condition in the course of time. Since these disturbed areas are surrounded by intact, relatively undisturbed forests, the system recovery should proceed well. It is imperative that this forest with its rich biodiversity be conserved as a genetic reservoir of wild species.

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