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FOREST ECOSYSTEM STRUCTURE AND COMPOSITION ALONG AN ALTITUDINAL GRADIENT IN THE WESTERN GHATS, SOUTH INDIA

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SUNDARAPANDIAN, SM. & SWAMY, P. S. 2000. Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. Vegetation structure and composition of deciduous and evergreen forest ecosystems were studied along an altitudinal gradient (250–1150 m) at Kodayar in the Western Ghats of South India. Plants >10 cm in DBH were enumerated to measure the diversity, dominance, similarity, evenness and species richness indices of plant communities and also to assess the regeneration status of tree species. A total of 58, 77, 125 and 105 plant species belonging to 30, 28, 52 and 45 families were recorded in moist deciduous forests (MDF, sites I & II), an evergreen forest (EF, site III) and a forest at higher elevation (HEF, site IV) respectively. Species diversity indices (Shannon index) of tree community were 2.20, 2.37, 2.65 and 2.48, ranking low compared to other studies available in the Western Ghats. *Terminalia paniculata, Pterocarpus marsupium* and *Aporosa lindleyana* were the dominant species in the moist deciduous forests, whereas *Hopea parviflora, Vateria indica* and *Xanthophyllum flavescens* dominated in the evergreen forest. The forest at higher elevation was dominated by *Agrostistachys meeboldii, Cullenia excelsa* and *Drypetes oblongifolia.* Stem density and basal area of the evergreen forest (748 trees ha^{-1}, 81.38 $m^2 ha^{-1}$) were twice those of the moist deciduous forests (352–450 trees ha^{-1}, 28.05–33.77 $m^2 ha^{-1}$), while the forest at higher elevation showed higher density and lower basal area (1173 trees ha^{-1}, 72.72 $m^2 ha^{-1}$). The "L" shaped curve of different DBH classes of trees and saplings indicated good regeneration in these forests. *Eupatorium* and *Ageratum* are two dominant exotic weeds that form part of the ecosystem in open and disturbed sites here. The changes in species composition are largely due to transition in vegetation types influenced by anthropogenic perturbations and other abiotic factors.

Keywords: Tropical moist deciduous forests - evergreen forest - Western Ghats - vegetation structure - species diversity - endemic plants - regeneration

SUNDARAPANDIAN, SM. & SWAMY, P. S. 2000. Struktur dan komposisi ekosistem hutan di sepanjang cerun altitud di Ghat Barat, India Selatan. Struktur dan komposisi tumbuhan bagi ekosistem hutan daun luruh dan hutan malar hijau dikaji di sepanjang cerun altitud (250–1150 m) di Kodayar di Ghat Barat di India Selatan. 'Tumbuhan dengan garis pusat aras dada dibanci untuk menyukat indeks kepelbagaian, kedominanan, kesamaan, kesamarataan dan kekayaan spesies komuniti tumbuhan

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dan juga untuk menilai status pemulihan spesies pokok. Sejumlah 58, 77, 125 dan 105 spesies tumbuhan yang dipunyai oleh 30, 28, 52 dan 45 famili dicatatkan masing-masing di hutan daun luruh lembap (MDF, tapak I & II), hutan malar hijau (EF, tapak III) dan sebuah hutan dengan ketinggian yang lebih tinggi (HEF, tapak IV). Indeks kepelbagaian spesies (indeks Shannon) bagi tiga komuniti pokok ialah 2.20, 2.37, 2.65 dan 2.48, didapati rendah berbanding dengan kajian lain yang boleh didapati di Ghat Barat. *Terminalia paniculata, Pterocarpus marsupium* dan *Aporosa lindleyana* ialah spesies dominan di hutan daun luruh lembap, manakala *Hopea parviflora, Vateria indica* dan *Xanthophyllum flavescens* mendominasi hutan malar hijau. Hutan di kawasan ketinggian yang lebih tinggi didominasi oleh *Agrostistachys meeboldii, Cullenia excelsa* dan *Drypetes oblongifolia.* Ketumpatan batang dan luas pangkal hutan malar hijau (748 pokok ha^{-1}, 81.38 $m^2 ha^{-1}$) ialah sekali ganda bagi hutan daun luruh lembap (352–450 pokok ha^{-1}, 28.05–33.77 $m^2 ha^{-1}$), manakala hutan di ketinggian yang lebih tinggi menunjukkan ketumpatan yang lebih tinggi dan luas pangkal yang lebih rendah (1173 pokok ha^{-1}, 72.72 $m^2 ha^{-1}$). Keluk bentuk "L" bagi kelas garis pusat aras dada yang berbeza bagi pokok dan anak pokok menunjukkan pemulihan yang baik di hutan ini. *Eupatorium* dan *Ageratum* merupakan dua rumpai eksotik dominan yang membentuk sebahagian daripada ekosistem di tapak yang terbuka dan tapak yang telah rosak di sini. Perubahan dalam komposisi spesies sebahagian besarnya ialah akibat daripada peralihan dalam jenis tumbuhan yang dipengaruhi oleh gangguan antropogenik dan faktor-faktor abiotik yang lain.

Introduction

Tropical forests are amongst the richest and complex biological communities on earth and exhibit tremendous intrinsic ability for self maintenance. However, most of these forests have lost this ability due to increasing biotic interferences such as anthropogenic perturbations and cattle grazing. The disappearance of these forests, at an estimated rate of 1–2% per year (Soule 1986), comes at a time when our knowledge of their structure and functional dynamics is woefully inadequate (Hubbell & Foster 1992).

The Western Ghats of India, because of their geographical location, stable geological history, equable climate, heavy rainfall and good soil conditions support a variety of tropical forest ecosystems. Phytogeographically these forests are not only rich with high species diversity but also contain several palaeo-endemic species which are botanically a"relict" of an ancient and unique vegetation (Champion & Seth 1968). During the last few decades these forests were subjected to various human pressures like agriculture, construction of a hydroelectric project, raising monoculture plantations (*Hevea brasiliensis, Acacia mangium, Acacia auriculiformis, Acacia dealbata, Tectona grandis,* etc.) and other developmental activities. The ever-increasing demand for forest products and forest land, together with the alarming rate of population growth has put the remaining patches of forests on the verge of extinction (Tamrat 1994). Regeneration in many Indian forests, including those forests of the Western Ghats, is inadequate to replace the adults (Sukumar *et al.* 1992). Conservation of these forests will depend on an understanding of forest ecosystem dynamics (Sussman & Rakotozafy

1994). Detailed quantitative and qualitative description and information on the regeneration status of the remaining forests are necessary as they form the basis for future plans to manage and restore these vanishing resources. This study aims at (1) assessing and describing the plant species richness of the tropical forest ecosystems at Kodayar along an altitudinal gradient, and (2) understanding the regeneration status of tree species.

Materials and methods

Study area

The study area at Kodayar, in Kanyakumari district, is located 400 km south of Madurai (77°15'–20' E, 8° 29'–33' N) at 250–1150 m elevation in the Western Ghats of Tamil Nadu, South India (Figure 1). Kodayar is part of the Agasthyamalai hill range and falls within the Veerapuli Forest Reserve in South India. This forest area has 30 Kani, local tribal settlements, which occupy an area of 6.85 km^2. The mean annual rainfalls recorded in the study sites were 2338 and 3000 mm at lower (250–500 m) and at higher elevations (1150 m) respectively, of which 81% occur from June to November. December to March represents a brief dry period. Average monthly maximum and minimum temperatures are 30 °C and 26 °C in summer, and 28 °C and 24 °C in winter respectively, at lower elevation. Temperature does not vary much over the seasons at higher elevation. Mean maximum temperature is 24 °C and the minimum is about 16 °C.

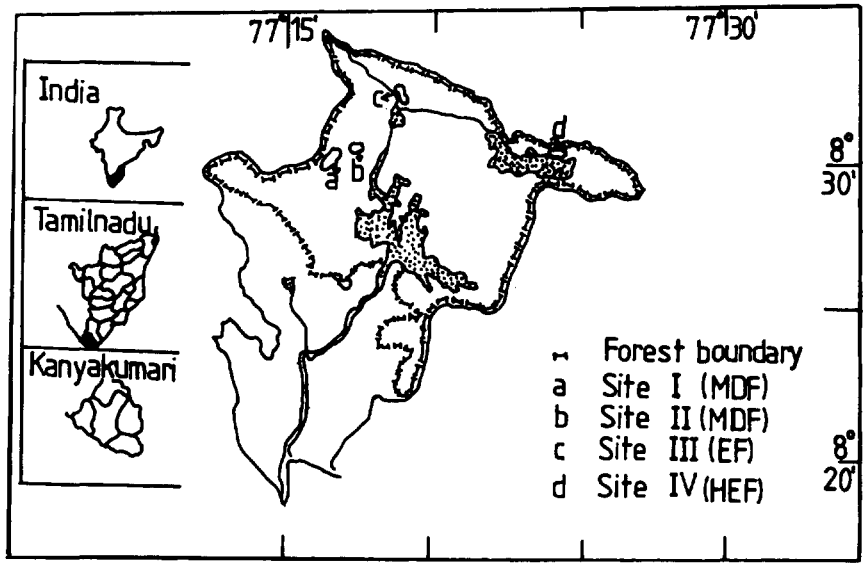

Figure 1. Map of the study area showing location of the study sites

Methods

Phytosociological studies were carried out in four selected forests, i.e. two in moist deciduous forests (sites I & II), one in an evergreen forest (EF; site III) and the other in a higher altitude forest (HEF; site IV; Table 1).The density, frequency, basal area and importance value index (IVI) were estimated at each site using 50 randomly placed quadrats (10×10 m^2) for trees [individuals with girth at breast height (GBH) more than 30 cm], saplings (>10–<30 cm GBH), and shrubs. Similar number of quadrats (1×1 m^2) were studied for herbs at each study site (Kershaw 1973, Misra 1968). Similarly, lianas (all climbers of all sizes) whose base fell inside the quadrats (10×10 m^2) were enumerated. Epiphytes were not sampled in this study due to technical problems. The plant samples were identified in the field with the help of Gamble's (1925) flora and a field key prepared by Pascal and Ramesh (1987) and later verified with the reference material (herbarium specimens) at the Botanical Survey of India, Coimbatore. A reference collection of specimens was preserved in the University herbarium. Species diversity was calculated using the equation (Margalef 1968),

$$H' = -\sum(n_i/N) \ln (n_i/N)$$

where H'= Shannon index of general diversity, n_i = importance value index of species i, and N = importance value index of the community. The index of dominance of the community was calculated by Simpson's index (Simpson 1949) as

$$C = \sum (n_i/N)^2$$

where C= index of dominance; n_i and N being the same as in the Shannon index of general diversity. The index of the species richness (d) was calculated following Menhinick (1964) as

$$d = S/\sqrt{n}$$

where S = number of species, n = number of individuals. The evenness index of the community (e) was calculated following Pielou (1966) as

$$e = H'/\log S$$

where S = number of species, H' = Shannon index. Index of similarity (s) between two samples was calculated following Odum (1971) as

$$s = 2c/(a+b)$$

where a = number of species in sample A, b = number of species in sample B, and c = number of species common to both samples. The family importance value was calculated following Ganesh *et al.* (1996):

FIV = relative density + relative diversity + relative dominance (for all numbers of a given plant family combined)

Relative density = (number of individuals of the species × 100)/total number of individuals in the sample

Relative diversity = (number of species in the family × 100)/total number of species in the sample

Relative dominance = (basal area of the family × 100)/total basal area in the sample

Results

Vegetation structure and composition

A total of 228 species of plants were recorded from the study sites at Kodayar. The number of species was greatest in the evergreen forest (EF) with 125 and lowest in the moist deciduous forests (MDF) with 58 and 77 species (Table 1). Stem density and basal area of the EF were twice greater than those of the MDF. The forest at higher elevation (HEF) showed greater density and lower basal area when compared to the EF. Diversity indices were greater in the EF when compared to the MDF. Similarly, species richness values were greater in the EF when compared to the MDF and HEF. Evenness index values were greater in the MDF when compared to the EF and HEF. Dominance indices were greater in site I compared to other study sites except for tree species. The species area curve showed that only very few species were added after the 28th quadrat (Figure 2). In the MDF, such saturation occurred around the 20th quadrat.

Combretaceae, Euphorbiaceae and Sapindaceae were the few dominant families in terms of species richness in the MDF (Table 2), whereas in the EF, Myrtaceae, Oleaceae, Dipterocarpaceae and Clusiaceae and in the HEF, Lauraceae and Euphorbiaceae were the dominant families. However, the familial importance value indices of trees showed that the Combretaceae was the most important family in the MDF, whereas in the EF and HEF, Dipterocarpaceae and Euphorbiaceae contribute most to the forest tree community structure.

Table 1. Stem density, basal area, species diversity and dominance indices of different life forms in tropical forest ecosystems at Kodayar in the Western Ghats of Tamil Nadu, South India

Criteria	MDF		EF	HEF
	Site I	Site II	Site III	Site IV
Altitude	300	250	500	1150
Number of species *	58	77	125	105
(No. 0.5 ha^{-1})	(5)	(8)	(16)	(12)
Stem density (No. ha^{-1})	450	352	748	1173
(> 30 cm GBH)	(51)	(28)	(63)	(98)
Basal area (m^2 ha^{-1})	28.05	33.77	81.38	72.72
	(2.34)	(2.94)	(10.4)	(7.92)
Species diversity index (Shannon index)				
Trees	2.196	2.370	2.648	2.484
Shrubs	1.063	1.190	1.764	1.810
Herbs	0.910	1.510	1.899	2.334
Climbers & lianas	1.224	1.510	2.505	2.184
Dominance index				
Trees	0.143	0.157	0.146	0.125
Shrubs	0.424	0.125	0.250	0.197
Herbs	0.639	0.125	0.227	0.136
Climbers & lianas	0.345	0.167	0.093	0.142
Species richness (tree)	3.87	5.80	9.14	5.51
Evenness index (tree)	1.87	1.77	1.69	1.67

Values in parentheses represent standard error n = 3;
* - includes trees, tree seedlings and saplings, shrubs, herbs, climbers and lianas.

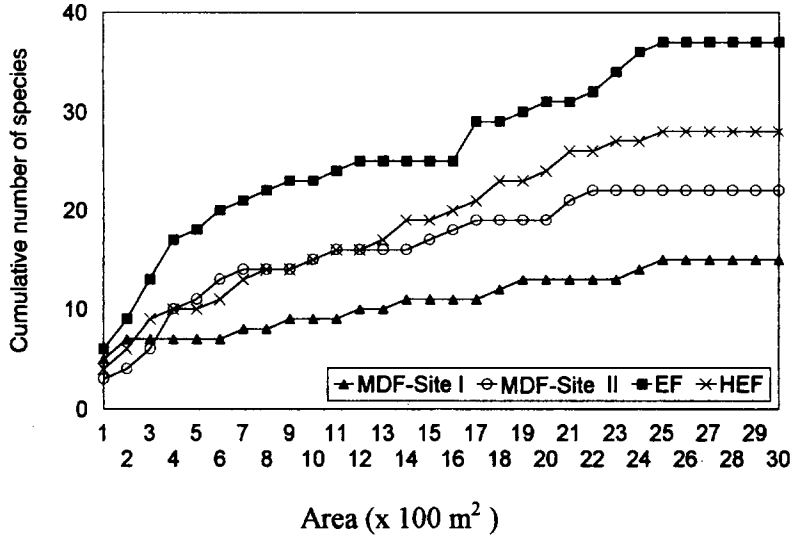

Figure 2. Species–area relationship of trees (>10 cm DBH) in the tropical forest ecosystems at Kodayar in the Western Ghats

Table 2. Family importance value indices (FIV) of tree species in the tropical forest ecosystems at Kodayar in the Western Ghats of Tamil Nadu, South India

Families	MDF		EF	HEF
	Site I	Site II	Site III	Site IV
Acanthaceae	-	-	-	3.606 (1)
Anacardiaceae	32.138 (1)	-	17.837 (2)	10.840 (2)
Anonaceae	7.202 (1)	15.180 (1)	3.282 (1)	3.530 (1)
Apocynaceae	-	28.037 (2)	3.557 (1)	-
Bignoniaceae	-	-	3.263 (1)	-
Bombacaceae	-	-	4.801 (1)	51.394 (1)
Clusiaceae	-	-	10.204 (3)	14.545 (1)
Combretaceae	121.725(5)	85.683 (1)	-	-
Cornaceae	-	-	-	7.342 (1)
Cycadaceae	7.343 (1)	-	-	-
Dilleniaceae	22.785 (1)	8.143 (1)	-	-
Dipterocarpaceae	-	-	122.068 (3)	-
Ebenaceae	-	-	9.006 (1)	5.870 (1)
Euphorbiaceae	28.873 (2)	39.531 (3)	3.287 (1)	80.562 (3)
Fabaceae	37.320 (1)	7.533 (1)	-	-
Flacourtiaceae	-	-	3.272 (1)	3.521 (1)
Icacinaceae	-	-	7.638 (1)	9.086 (1)
Lauraceae	-	-	7.591 (2)	26.241 (7)
Lecythidaceae	26.848 (1)	12.280 (1)	-	-
Meliaceae	-	-	-	27.836 (2)
Moraceae	-	12.827 (2)	3.602 (1)	-
Myristicaceae	-	-	6.595 (1)	18.241 (1)
Myrtaceae	-	-	13.991 (3)	8.915 (1)
Oleaceae	-	-	10.630 (3)	-
Rubiaceae	-	21.361 (2)	13.615 (2)	10.137 (2)
Sapindaceae	-	20.740 (3)	4.014 (1)	-
Staphyleaceae	-	-	-	3.876 (1)
Sterculiaceae	-	13.007 (1)	-	-
Ternstroemiaceae	-	-	4.530 (1)	-
Tiliaceae	-	13.956 (2)	-	-
Verbenaceae	-	-	10.520 (1)	-
Xanthophyllaceae	-	15.127 (1)	6.138 (1)	-
Others	15.753 (2)	6.583 (1)	30.568 (5)	14.488 (3)

Values in parentheses represent number of species.

Both study sites of MDF were dominated by *Terminalia paniculata,* followed by *Pterocarpus marsupium, Buchanania lanzan* and others in site I and *Aporosa lindleyana, Holarrhena pubescens* and *Ixora brachiata* in site II (Table 3). The EF was dominated by *Hopea parviflora* followed by *Vateria indica, Gluta travancorica,* etc., while the HEF was dominated by *Agrostistachys meeboldii* and *Cullenia excelsa* followed by *Drypetes oblongifolia, Aglaia barberi* and others. The relative dominance of large trees such as *T. paniculata, H. parviflora* and *C. excelsa* accounted for 41–57, 44 and 55% respectively, of the IVI values in these study sites, whereas *B. lanzan,* and *A. meeboldii,* although abundant, accounted for only 22 and 23% respectively. The DBH distribution of tree species in all the forest sites showed a typical "L" shaped curve (Figure 3). The DBH distribution of saplings (>3 cm – <10 cm DBH) in all these forest sites also showed a similar pattern except in site I (Figure 4).

Table 3. Species importance value indices of the vegetation of the tropical forest ecosystems in an altitudinal gradient at Kodayar in the Western Ghats of Tamil Nadu, South India

Species	MDF		EF	HEF
	Site I	Site II	Site III	Site IV
Trees				
Aglaia barberi	-	-	-	31.62
Agrostistachys meeboldii	-	-	-	61.54
Aporosa lindleyana	-	36.11	-	-
Bridelia crenulata	7.96	-	-	-
Buchanania lanzan	40.44	-	-	-
Calophyllum polyanthum	-	-	1.44	15.06
Careya arborea	31.56	11.14	-	-
Cullenia excelsa	-	-	2.89	62.07
Dillenia pentagyna	26.30	5.87	-	-
Diospyros bourdilloni	-	-	11.86	-
Dipterocarpus indicus	-	-	8.17	-
Drypetes oblongifolia	-	-	-	37.09
Emblica officinalis	21.35	2.88	-	-
Gluta travancorica	-	-	18.15	-
Gomphandra tetrandra	-	-	8.90	12.28
Grewia tiliaefolia	-	5.52	-	-
Holarrhena pubescens	-	28.53	-	-
Holigarna arnottiana	-	-	-	6.71
Hopea parviflora	-	-	102.83	-
Ixora brachiata	-	18.61	15.57	-
Mastixia arborea	-	-	-	7.86
Myristica dactyloides	-	-	6.27	25.17
Polyalthia wightii	1.14	14.03	-	-
Pterocarpus marsupium	40.23	-	-	-
Terminalia arjuna	19.49	-	-	-
T. chebula	14.32	-	-	-
T. crenulata	6.14	-	-	-
T. paniculata	82.64	103.87	-	-
Vateria indica	-	-	31.94	-
Vitex altissima	-	-	13.37	-
Xanthophyllum flavescens	-	17.40	15.39	-
Others	9.04	56.04	63.21	40.63
	(4)	(12)	(25)	(22)
Shrubs				
Calamus brandisii	-	-	123.58	64.56
C. travancoricus	-	-	-	72.56
Clausens heptaphylla	-	16.91	-	-
Desmodium velutinum	-	21.88	-	-
Diotacanthus albiflorus	-	-	13.72	-
D. grandis	-	-	-	12.39
Eupatorium odoratum	135.75	201.69	-	-
Helicteres isora	89.03	-	-	-
Ixora lanceolaria	-	-	19.06	-
Leea indica	-	-	12.05	-
Microtropis stocksii	-	-	19.60	-
Nilgirianthus foliosus	-	-	-	76.65
Ochlandra travancorica	-	-	76.39	-
Psychotria connata	-	-	-	14.59
P. nudiflora	-	-	11.71	-

(continued).

(Table 3 - continued)

Saprosma corymbosum	-	-	2.49	45.83
Thespesia lampas	8.96	26.96	-	-
Trema orientalis	-	6.30	-	-
Zizypus oenoplia	53.77	20.66	-	-
Others	12.49	5.64	21.40	13.42
	(2)	(2)	(4)	(6)
Herbs				
Ageratum conyzoides	-	20.39	-	-
Curculigo orchioides	21.13	17.22	2.95	28.63
C. trichocarpa	-	-	51.85	8.26
Digitaria ciliaris	13.20	33.24	23.35	-
Globba orixensis	7.14	137.72	-	-
Hemidesmus indicus	5.43	-	-	-
Kalanchoe sp.	-	-	-	16.83
Memecylon sp.	-	-	-	8.13
Ophiorrhiza mungos	-	-	1.48	41.42
Panicum sp.	3.19	17.03	29.35	-
Pteris argyraea	-	-	-	25.49
P. confusa	-	-	6.41	-
Rungia wightiana	-	-	-	85.23
Selaginella sp.	-	-	-	24.91
Themeda cymbaria	238.2	71.13	-	-
Zingiber roseum	-	-	5.87	8.37
Others	11.70	3.27	178.77	50.04
	(6)	(2)	(6)	(7)
Climbers & Lianas				
Ancistrocladus heyneanus	-	-	49.75	-
Asparagus sp.	33.21	-	-	-
Butea parviflora	-	48.14	-	-
Calycopteris floribunda	127.41	125.77	-	-
Canthium angustifolium	-	-	6.49	13.15
Connarus wightii	-	-	29.08	81.63
Coscinium fenestratum	-	-	15.38	-
Derris benthamii	-	19.97	-	-
Elaeagnus hologa	-	-	-	22.72
Hiptage benghalensis	-	-	11.59	-
Jasminum azoricum	-	-	25.19	2.83
Luvunga sarmentosa	-	-	22.00	26.69
Piper sp.	6.66	-	5.49	38.03
Pothos scandens	-	-	35.20	-
Sageretia hamosa	-	-	-	5.63
Smilax zeylanica	-	-	28.69	18.88
Strychnos wallichiana	-	-	28.86	40.76
Toddalia asiatica	-	-	-	33.86
Zizyphus rugosa	115.42	29.42	4.72	-
Others	17.30	77.15	59.61	4.67
	(1)	(2)	(3)	(3)

Values in parentheses represent number of species which have less than 5 IVI values and unidentified species.

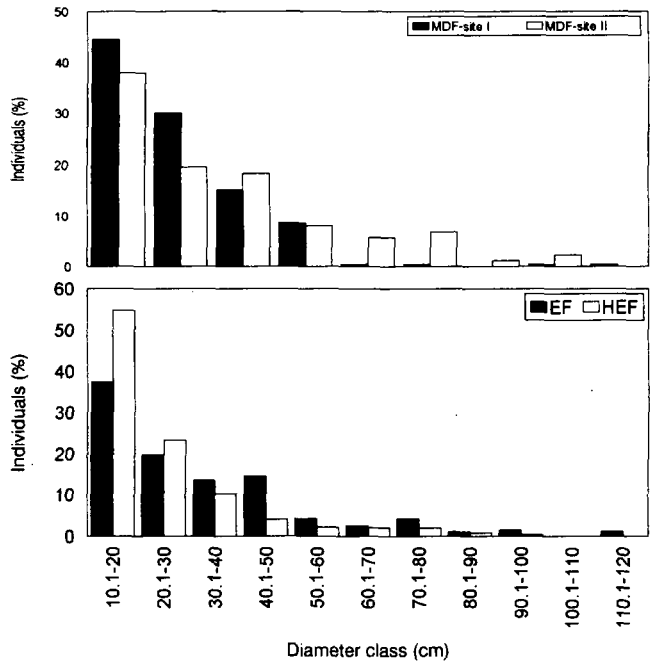

Figure 3. Size class distribution of all individuals of trees (>10 cm DBH) in the tropical forests at Kodayar in the Western Ghats

The MDF (sites I and II) were poorly (3 and 6 species only) represented by lianas. A total of 15 species of lianas were recorded in the EF, while the HEF site was represented by 13 species. Lianas of DBH >10 cm occurred in low densities in these forests. *Calycopteris floribunda* was the dominant species in the MDF sites, while *Ancistrocladus heyneanus, Pothos scandens, Connarus wightii* and *Strychnos wallichiana* were dominant species in the EF. The HEF was dominated by *C. wightii* and *S. wallichiana.*

The shrub community of the MDF sites (I and II) was dominated by *Helicteres isora* and *Eupatorium odoratum* followed by *Zizypus* sp. and *Thespesia lampas.* The shrub community in the EF was dominated by *Calamus* followed by *Ochlandra travancorica,* and in the HEF by *Nilgirianthus foliosus, Calamus travancoricus* and *C. brandisii* (Table 3). Rubiaceae is the dominant family in terms of species richness (number of species) for shrub community in the EF and HEF sites. The herbaceous community was dominated by Graminae (Poaceae) in the MDF sites. *Themeda cymbaria* was the dominant species in site I, whereas site II was dominated by *Globba orixensis* and *Digitaria ciliaris.* Rubiaceae, Graminae and Hypoxidaceae were the few families dominant in terms of species richness (number of species) in the EF. *Curculigo* and grasses were dominant in herbaceous community in EF. Pteridophytes and Hypoxidaceae were dominant families in the forest floor at higher elevation. The species such as *Rungia wightiana, Ophiorrhiza* and *Curculigo orchioides* were dominant in the herbaceous community in HEF.

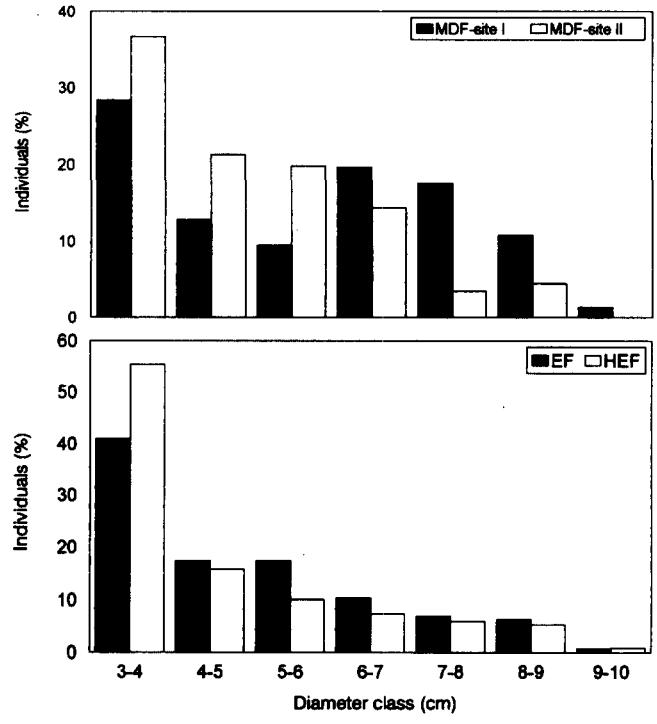

Figure 4. Size class distribution of all individuals of tree saplings (>3 – <10 cm DBH) in the tropical forest ecosystems at Kodayar in the Western Ghats

Similarity indices of tree species are presented in Figure 5. Twenty-seven percent similarity occurred between site I and site II. No similarity was found between site I and other study sites, except site II. Low similarity was observed among the EF and HEF sites.

Regeneration potential

Tree saplings: (>3 cm – <10 cm DBH)

Most of the dominant tree species had good representation in the saplings except *T. paniculata* in site II (Table 4). In MDF sites, dominant saplings were *B. lanzan, Emblica officinalis* and *H. isora,* whereas the EF was dominated by *I. brachiata, Xanthophyllum flavescens* and others. HEF was dominated by *Octotropis travancorica* followed by *A. meeboldii, D. oblongifolia* and *Isonandra lanceolata.* Eighteen, 17, 45 and 39 species of saplings were recorded from MDF site I, MDF site II, EF and HEF respectively.

Table 4. Tree seedlings and saplings recorded (No. ha^{-1}) in the tropical forests at Kodayar in the Western Ghats of Tamil Nadu, South India

Species	MDF		EF	HEF
	Site I	Site II	Site III	Site IV
Acrocarpus fraxinifolius	-	-	12	-
Actinodaphne campanulata	-	-	-	(3)
Aglaia barberi	-	-	-	558 (56)
Agrostistachys indica	-	-	328 (4)	1032 (58)
A. meeboldii	-	-	-	765 (216)
Albizia sp.	4	-	-	-
Allophylus sp.	-	4	-	-
Alstonia scholaris	2	80	(8)	-
Antiaris toxicaria	-	8	-	-
Antidesma menasu	-	-	84	6 (35)
A. zeylanicum	-	-	300	-
Apodytes beddomei	-	-	-	65
A. benthamiana	-	-	-	13
Aporosa lindleyana	-	688 (20)	-	-
A. fusiformis	34	-	-	-
Ardisia pauciflora	-	-	36	-
Arenga wightii	-	8	44	-
Artocarpus heterophyllus	-	-	56	13 (13)
A. hirsutus	2	84	-	-
Baccaurea courtallensis	-	-	12 (4)	-
Bassia sp.	-	24	-	-
Beilschmiedia gemmiflora	-	-	24 (4)	68 (10)
Berrya cordifolia	-	60	-	-
Bridelia crenulata	52 (8)	4	-	-
Buchanania lanzan	636 (82)	12	-	-
Calophyllum polyanthum	-	4	-	165 (29)
Canarium strictum	-	-	16	-
Carallia brachiata	-	-	(4)	-
Careya arborea	534 (26)	40	-	-
Caryota urens	-	4	84	-
Casearia bourdillonii	-	-	-	55
Cassia fistula	12 (18)	4	-	-
Chionanthus leprocarpa	-	-	(8)	-
Cinnamomum malabathrum	-	4	-	277 (45)
C. verum	-	-	-	1284 (65)
Clerodendrum infortunatum	-	4	-	13
Cryptocarya bourdillonii	-	-	4	68 (7)
Cullenia excelsa	-	-	308 (4)	477 (29)
Cycas sp.	22	-	-	-
Dalbergia latifolia	40	156 (4)	-	-
Dillenia pentagyna	20 (16)	8	-	-
Dimocarpus longan	-	128 (4)	56 (16)	-
Diospyros bourdilloni	-	16	-	-
D. pruriens	-	-	136	-
Diospyros sp.	-	-	(16)	145 (15)
Diotacanthus sp.	-	-	-	100
Dipterocarpus indicus	-	-	8	-
Drypetes oblongifolia	-	-	-	1387 (142)
Elaeocarpus munronii	-	-	-	(13)
Emblica officinalis	196 (102)	4	-	-
Epiprinus mallotiformis	-	-	-	6 (36)

(continued)

(Table 4 - continued)

Erythroxylum obtusifolium	-	-	(4)	3
E. Moonii	-	(4)	-	-
Eugenia thwaitesii	-	-	4	1190
Euonymus sp.	-	-	(4)	(3)
Excoecaria crenulata	-	-	-	6
Ficus sp.	-	12 (8)	12 (4)	-
Garcinia travancorica	-	-	44 (4)	-
Glochidion ellipticum	-	12	8 (12)	-
Gluta travancorica	-	-	848 (56)	-
Gomphandra tetrandra	-	48	20 (24)	52 (45)
Grewia tiliaefolia	14	64 (4)	-	-
Helicteres isora	-	6644 (248)	-	-
Holarrhena pubescens	-	204	-	-
Holigarna arnottiana	-	-	-	3 (12)
Hopea parviflora	-	-	500 (44)	-
Hunteria corymbosa	-	-	8	-
Hydnocarpus alpina	-	-	124 (4)	-
Hymenodictyon orixense	-	8	-	-
Isonandra lanceolata	-	-	116 (4)	848 (113)
Ixora brachiata	8	2588 (8)	1492 (68)	-
I. lawsonii	-	-	64	-
I. notoniana	-	-	8	90 (3)
Ixora sp.	-	8	464 (12)	-
Kingiodendron pinnatum	-	-	188 (20)	-
Lepisanthes decipiens	-	-	-	174
Litsea laevigata	-	132 (4)	-	4
L. mysorensis	-	-	-	397 (77)
Macaranga peltata	6	76	16	-
Mallotus beddomei	-	-	-	28 (36)
M. muricatus	-	-	-	(6)
M. philippensis	-	386 (4)	104 (4)	-
M. stenanthus	-	-	-	316 (3)
Mangifera indica	-	4	(8)	-
Mastixia arborea	-	-	-	10 (3)
Memecylon malabaricum	-	-	-	10
Memecylon sp.	-	-	-	3
Mesua ferrea	-	-	248 (12)	-
Microtropis wallichiana	-	-	-	13
Miliusa wightiana	-	-	-	74
Murraya paniculata	-	20	-	26 (3)
Myristica dactyloides	-	16	104 (8)	203 (39)
Nageia wallichiana	-	-	-	19
Neolitsea zeylanica	-	-	16	894 (3
Nothopegia travancorica	-	-	276 (20)	-
N. racemosa	-	-	-	587 (71)
Octotropis travancorica	-	-	-	661 (345)
Odina wodier	4	4	-	-
Olea dioica	192 (8)	164	4	-
Orophea erythrocarpa	-	-	32 (12)	-
O. ramarowii	-	-	32	500 (74)
Persea macrantha	-	-	(4)	171 (6)
Phaeanthus malabaricus	-	12	(12)	-
Phoenix loureirii	4 (2)	-	-	-
Pinanga dicksonii	-	-	92(8)	-
Polyalthia coffeoides	-	76 (4)	-	-
P. wightii	72 (12)	-	-	-

(continued)

(Table 4 - continued)

Prunus ceylanica	(4)	-	36	13
Psychotria anamallayana	-	-	-	1603 (52)
P. nigra	-	-	684	1439 (23)
Psychotria sp.	-	-	864	-
Pterocarpus marsupium	470 (2)	12	-	-
Pterospermum diversifolium	-	276	8	-
P. rubiginosum	2	8	8	-
Sapindus emarginatus	-	308	-	-
Schefflera racemosa	-	-	-	6
Schleichera oleosa	-	76	-	-
Scolopia crenata	-	-	28 (4)	19
Stereospermum personatum	-	12	12 (4)	-
Syzygium laetum	-	-	24 (4)	-
S. gardneri	-	-	38	135 (16)
S. mundagam	-	-	52 (8)	210 (19)
Tabernaemontana heyneana	-	40	-	-
Terminalia arjuna	-	(2)	-	-
T. bellirica	6 (4)	-	-	-
T. chebula	190 (2)	-	-	-
T. paniculata	1026 (46)	140	-	-
T. tomentosa	92	-	-	-
Tricalysia apiocarpa	-	-	-	87
Turpinia malabarica	-	-	-	6
Vateria indica	-	-	724 (24)	-
Vitex altissima	8	8	(4)	-
Walsura trifolia	-	-	4	-
Xanthophyllum flavescens	2	768 (8)	136 (60)	-
Others	10	268	358	35
	2*	2*	7*	3*
	(10)	(12)	(24)	(36)
	4*	3*	6*	2*

Values in parentheses represent number of saplings; * refers to the number of unidentified species in the study sites.

Tree seedlings: (<3 cm DBH)

Most of the dominant species had good representation in seedlings (Table 4). In the study site I, dominant species of seedlings were *T. paniculata, B. lanzan, C. arborea,* etc., while study site II was dominated by *H. isora* followed by *I. brachiata, A. lindleyana, X. flavescens,* etc. EF was dominated by *I. brachiata* followed by *Psychotria* sp., *Gluta travancorica, V. indica, Psychotria nigra* and *H. parviflora.* However, HEF was dominated by *P. anamallayana* and others. Twenty-nine, 52, 61 and 55 species of tree seedlings were recorded in MDF site I, MDF site II, EF and HEF respectively.

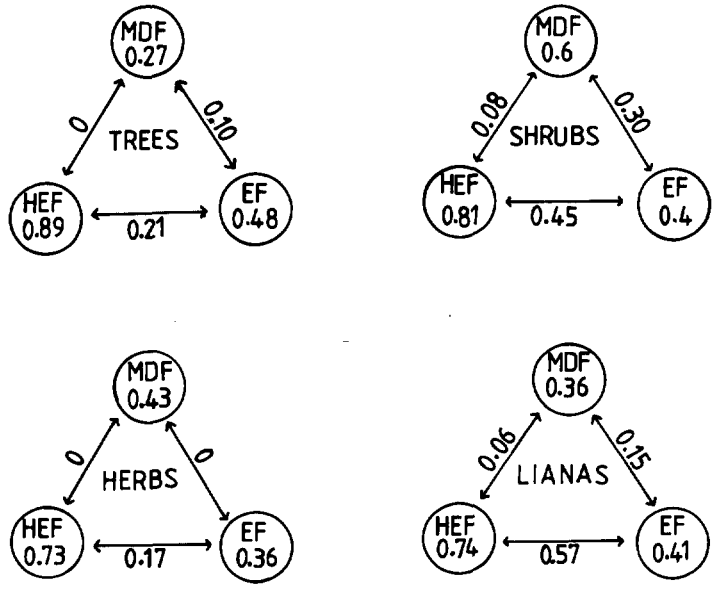

Figure 5. Similarity indices of different life forms (values in circle represent within the sites; values on the arrows represent between the sites) in tropical forests [moist deciduous MDF (sites I & II); evergreen EF (site III); forest at higher elevation HEF (site IV)] at Kodayar in the Western Ghats

Discussion

High species richness is one of the characteristic features of humid tropical forest ecosystem (Parsons & Cameron 1974). The Western Ghats harbour over 4000 species of flowering plants out of 17 000 species described in India (Meher-Homji & Pascal 1996). The Agasthyamalai Range (2000 km^2) in the southern Western Ghats includes more than 2000 (50%) of the 4000 species (Ganesh *et al.* 1996). Of these, 228 (11.4%) plant species occur in the study sites at Kodayar.

The species-area relationship for random quadrats showed that by 2000 and 2800 m^2 the species accumulation curve saturated in the moist deciduous and the other forest sites respectively. The shape of the species area curve obtained at Kodayar was similar to those for other forests (Singh *et al.* 1981, Ganesh *et al.* 1996). Ganesh *et al.* (1996) suggested that 500 x 10 m^2 linear plot is sufficient to estimate the diversity of tree species for mid-elevation forest of the Western Ghats. The present study showed that only very few species could be encountered with additional samplings.

Whitmore (1975) recorded about 140 tree (> 30 cm GBH) species ha^{-1} in the Malaysian forest. The number of tree species estimated in the Western Ghats varied; that in Silent Valley was 84 ha^{-1} (Singh *et al.* 1981), in Nelliampathy 30 ha^{-1} (Chandrashekara & Ramakrishnan 1994), and in Kakachi it was 45 ha^{-1}

(Ganesh *et al.* 1996). According to Proctor *et al.* (1983) and Whitmore (1975), in tropical rain forests, the range of tree species count ha^{-1} is about 20 to a maximum of 223. The number of tree species >30 cm GBH in Kodayar forest sites ranged from 15 to 37 per 0.5 ha and this number is at the lower side of the range given in wet evergreen forests. In his study on tree species richness of the upper Amazonian forests, Gentry (1988) stated that pronounced dry season and relatively low annual precipitation (2000 mm) factors may correlate with low species richness. The lower tree species diversity (number of species) in the present study could also be partly attributed to (a) smaller sampling areas or inadequate sample size (Sukumar *et al.* 1992), and (b) enumerations restricted to only adult tree species (> 10 cm DBH). In the process juveniles (especially pioneer species) which come up in the canopy gaps were ignored.

The range of tree (>10 cm DBH) density recorded in the present study is higher (352–1173 trees ha^{-1}) than that reported by Campell *et al.* (1986) and Gentry (1988) for Amazonian forests (range 205–858 trees ha^{-1}). The tree density values obtained in the present study were comparable with others reported in the southern Western Ghats (Chandrashekara & Ramakrishnan 1994, Ganesh *et al.* 1996). However, the values were lower than those reported by Pascal (1988) and Jose *et al.* (1994) in the Western Ghats at Karnataka and Eravikulam (Kerala) respectively. Burgess (1961) recorded a basal area of 73.6 m^2 ha^{-1} for trees (>30 cm GBH) over a small area (0.08 ha) at Gum Gum, Sabah. The basal areas of trees in the Kodayar forests (28.05–81.38 m^2 ha^{-1}) were within the range recorded by others. However, the values were lower than those (102.7 m^2 ha^{-1}) reported by Singh *et al.* (1981). The differences in basal area may be attributed to altitude, species composition, age of the trees, degree of disturbances and successional stage of the stand. The greater basal area recorded in the present study could also be attributed to smaller sample size. The edge to area ratio in small samples would be disproportionate.

The tree (>10 cm DBH) diversity index (Shannon index) in the study at Kodayar was in the range of 2.2–2.65, which was lower than the indices recorded in tropical rain forests of Barro Colarado Island (4.8; Knight 1975), Silent Valley (4.89; Singh *et al.*1981), Nelliampathy (2.95; Chandrashekara & Ramakrishnan 1994) and Kakachi (3.37, Ganesh *et al.* 1996). Because of the differences in the areas sampled, lack of uniform plot dimensions and standard girth or diameter classes makes the comparison difficult. On the other hand, the value obtained for the concentration of dominance for the tree layer (0.125–0.157) in the present study was greater than those recorded in Nelliampathy (0.085; Chandrashekara & Ramakrishnan 1994) and Silent Valley (0.06–0.14; Singh *et al.* 1981). The higher dominance value in the present study indicates single species dominance (around 30% of IVI value; cf. Table 1) by *T. paniculata* and *H. parviflora* in both the moist deciduous and evergreen forest sites respectively. However, the low value observed in the forest sites at higher elevation might be due to lack of absolute dominance by any single species.

The flora of the study sites at Kodayar consists of 48.4% of tree species (>10 cm DBH), 20.9% of shrubs, 17.3% of herbs and 13.3% of lianas. Daniel *et al.* (1995) showed that the flora of the Western Ghats in general comprises 20% of trees, 16% shrubs and 52% herbs. In the study sites at Kodayar, a total of 228 species were recorded and 38 (16.67%) of them (33 trees and 5 shrubs) are endemic to the Western Ghats. Of these, 6 (2.63%) species (4 trees and 2 shrubs) are localised endemics. No endemics were found in the herbaceous community in this study.

The present study showed that the number of species decreased with an increase in altitude (500–1150 m). The diversity index of tree species also showed a similar pattern. The altitudinal variation might be due to variation in temperature, relative humidity, evapotranspiration rates, radiation values and wind movements (Hollermann 1981, Leuschnar & Schulte 1991, Nakashizuka *et al.* 1992). The changes in species composition with altitude are very difficult to explain (Proctor *et al.* 1988). The present study found that the dipterocarpaceous members such as *Dipterocarpus indicus, Hopea parviflora* and *Vateria indica* did not occur in higher altitude (1150 m). Similarly, Proctor *et al.* (1988) reported that Dipterocarpaceae could not be found at sites above 770 m elevation, even though the slopes were favourable for growth. Burgess (1961) also found that the steepness of slopes increased with elevation and dipterocarps did not occur where these exceeded 65°. However, these factors could not explain the limits of the distribution of Dipterocarpaceae on Gunung Silam. One drawback in the present study is the lack of data from mid-altitude (700–1000 m). Ganesh *et al.* (1996) reported that *Xanthophyllum flavescens* was common only above 1400 m in the Western Ghats. In contrast, the present study showed that the *X. flavescens* is also common at lower elevation at Kodayar.

In the present study MDF sites have been disturbed repeatedly by biotic interference. Such an anthropogenic perturbation may alter the structure and composition of the forest ecosystem at Kodayar forests (Chandrasekaran & Swamy 1995, Sundarapandian & Swamy 1996, 1997). Studies are available on the impact of perturbations on nutrient cycling and the relative fragility of forests (Toky & Ramakrishnan 1983, Uhl & Jordan 1984, Proctor 1989, Turner *et al.*1994). Fire affects plant regeneration both directly through burning of seeds, seedlings and saplings and indirectly through its action on the soil. Annual fires remove the ground vegetal cover and litter fall and increase evaporation, which results in loss of soil moisture (Christenson & Muller 1975), loss of clay content (Dawkins 1939) and soil nutrients (Kauffman *et al.* 1993). Site I was subjected to annual fires. This may be the reason for the *Themeda* dominated grassland with few trees such as *T. paniculata* and *P. marsupium* in the present study. The present study suggests that repeated burning and other associated factors alter the course of succession by giving an advantage to certain species over others such as *T. paniculata* and *T. cymbaria.* It may also lead to the formation of scrubs with scattered medium sized trees over a large area. Recurrence of annual fires also leads to decline of biodiversity. However, site II was relatively less disturbed, and the forest has not been subjected to wild fire in the recent past. Therefore, the forest floor is rich with humus and has been conducive to natural regeneration

of both evergreen and deciduous species such as *Alstonia scholaris, Aporosa lindleyana, Artocarpus hirsutus, Dimocarpus longan, Diospyros bourdilloni* and *Helicteres isora.* Forest gaps (treefall) are occupied by pioneer trees such as *Macaranga peltata.* The present study agrees with that of Anderson *et al.* (1992) who found that the nearby valley in the montane rain forest was relatively pristine, whereas the upper and lower regions were heavily infested by alien species. In the present study, the spatial pattern of invasion by alien species such as *E. odoratum* and *Ageratum. conyzoides* in site II reflects past disturbance events. *Ageratum conyzoides,* in particular, indicates that this site still has been under the influence of anthropogenic perturbation, since the species is an early successional ruderal weed which comes up in disturbed and recently opened-up areas (Chandrasekaran & Swamy 1995).

Though many forests in the Western Ghats are reported to have poor regeneration (Sukumar *et al.* 1992), the dominant species at Kodayar forest sites showed adequate regeneration. The lower representation of juveniles of certain tree species observed in the present study is in agreement with the observation of Swaine and Hall (1988) in Kada, Ghana.

It is concluded that the forest ecosystems at Kodayar have high plant species diversity (but relatively lower range of tree species) and floristic composition. The 'L' shaped (diameter) distribution of trees exhibited adequate regeneration status. Recurrence of annual fires and anthropogenic perturbation have led to the formation of monotypic tree dominated grasslands and alien plant invasion. Therefore, the forest ecosystems at Kodayar should be given due attention for the conservation of its rich biodiversity.

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