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VEGETATION COMPOSITION, STRUCTURE AND PATTERNS OF DIVERSITY: A CASE STUDY FROM THE TROPICAL WET EVERGREEN FORESTS OF THE WESTERN GHATS, INDIA

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The composition, abundance, population structure and distribution patterns of the woody species having a girth at breast height of ≥ 10 cm were investigated in the tropical wet evergreen forests of the Kalakad-Mundanthurai Tiger Reserve in the southern Western Ghats, India. A 3 ha plot was established with an altitudinal range of 1170 to 1306 m. In the study plot 5624 individuals (mean density 1875 ha^{-1}) covering 68 woody species belonging to 52 genera and 27 families were enumerated. The mean basal area was 47.01 m^2 ha^{-1} and the Shannon and Simpson diversity indices were 4.89 and 0.95, respectively. Of these woody species nearly 51% are endemic to the Western Ghats. The four dominant species, *Cullenia exarillata*, *Palaquium ellipticum*, *Aglaia bourdillonii* and *Myristica dactyloides*, account for 34% of the trees and 67% of the basal area, and therefore constitute the main structure of the forest. Within this forest type, five species assemblages corresponding to altitudinal gradient were identified using correspondence analysis. Management of such mid elevation evergreen forests necessarily depends on knowledge of recognisable community types and their environmental variables. The present study provides essential background for formulating strategies for sustainable conservation of forest communities at the local level.

Keywords. Correspondence analysis, species diversity, stand structure, tropical forest, Western Ghats.

Introduction

Floristic inventory is a prerequisite for fundamental research in community ecology, such as modelling patterns of species diversity or understanding species distribution patterns. Quantitative floristic inventories have been used in recent years to characterise forest vegetation throughout the tropics (Johnston & Gillman, 1995; Condit, 1996; Pascal & Pelissier, 1996; Ayyappan & Parthasarathy, 1999; Parthasarathy, 1999, 2001; Phillips *et al.*, 2003). Under increasing anthropogenic pressure tropical forests are disappearing at alarming rates worldwide, reducing annually by

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1–4% of their current area (Laurance, 1999). The dominant species in these ecosystems are therefore also declining (Pounds *et al.*, 1999; Parmesan & Yohe, 2003; Root *et al.*, 2003; Thomas *et al.*, 2003; Ferraz *et al.*, 2004) and it has been speculated that a large proportion of these are likely to become extinct in the next few decades, leading to a large scale loss of genetic diversity (Wilson, 1992, 2000; Novacek & Cleland, 2001). However, some authors (Simon, 1986; Lugo, 1988) have contended that there is little documented evidence of species extinction and that the risks inherent in tropical deforestation have been exaggerated. Without data it is impossible to test these competing claims and it is imperative that tropical rain forests, which are rich in biological diversity, be studied intensively to investigate the complex interaction between biodiversity and ecosystem functioning.

The non-equatorial tropical forest of the Western Ghats in India is a biodiversity hotspot (Nayar, 1996; Myers *et al.*, 2000). The region shows a high degree of environmental heterogeneity. The geographic and physical complexities of the area, and the corresponding variation in macro- and microclimatic conditions, have led to complex patterns of species distribution and variation in the structure and spatial distribution of vegetation types (Pascal, 1988). The present study aims to characterise spatial and floristic structural patterns, speciation processes, and species–environment relationships in these forests in detail.

Information on floristic composition, species diversity and phytomass is essential to understand forest ecosystem dynamics (Leigh *et al.*, 1985; Gentry, 1990; Hartshorn, 1990). Recently, several patches of evergreen forest in the Kalakad-Mundanthurai Tiger Reserve (KMTR) in the Western Ghats have undergone considerable change in biological diversity (Johnsingh, 2001; Amarnath *et al.*, 2003; Ganesh & Devy, 2006). The causes may be either abiotic or biotic. The remaining large portion of undisturbed mid elevation evergreen forest possesses high species diversity and endemism (Pascal, 1988). A number of taxonomists and ecologists have studied its complex floristic composition (Ganesh *et al.*, 1996; Parthasarathy, 1999, 2001), tree size, tree form and sapling density (Ganesh *et al.*, 1996), pollinators (Devy & Davidar, 2001; Ganesh & Devy, 2006), seed dispersal (Ganesh & Davidar, 2001) and above-ground biomass (Pascal, 1988). A few studies have attempted to analyse structure and floristic composition using correspondence analysis (CA) to identify species assemblages and their relationship to environmental factors (Pascal, 1988; Ramesh & Swaminath, 1999). The present study aimed to determine the spatial pattern of vegetation (girth class distribution and population stand structure) and floristic structure (species richness, diversity, and dispersion) using CA to identify species assemblages in relation to topography and disturbance, caused largely by encroachment for crop cultivation, human population and resource extraction.

Studies in French Guiana, in which more detailed analyses linked individual trees to soil conditions and topography, demonstrated the existence of significant floristic gradients when analysed using CA and non-symmetric correspondence analysis (NSCA) (Sabatier *et al.*, 1997; Pelissier *et al.*, 2002; Couteron *et al.*, 2003). Giriraj (2006) identified different habitat complexities and the effect of extrinsic factors on tree diversity in the KMTR. In the present study we have chosen an area that has very high habitat complexity, attributed to high rainfall, varied topography and biotic disturbance factors, and high patch complexity in terms of stand structure and floristic composition. These areas are expected to suffer further human encroachment. Thus, the effect of anthropogenic factors on vegetation structure and species diversity needs to be examined for future biological conservation policy.

Study Area

The study site is located in the Kakachi forest range of the KMTR adjoining the Agasthyamalai region at the southern end of the Western Ghats. It lies between 8°32′25″N–8°32′31″N latitude and 77°22′36″E–77°22′44″E longitude (Fig. 1). The Kakachi plot site is on the western side of the KMTR at an altitude between 1170 and 1306 m. The site receives rainfall from both the southwest and northeast monsoons. Mean annual rainfall is 3000 mm with an average of 108 rainy days per year. The mean monthly temperature ranges from 13 to 23°C (Pascal, 1984). Geologically the area is granitoid gneiss of the archaean age. The soil is a sandy loam, and the pH, organic carbon and available nutrients were analysed for the present study (Table 1).

These areas predominantly constitute mid elevation evergreen forest belonging to the *Cullenia–Mesua–Palaquium* type (Pascal, 1988). Resident tribal peoples in the adjacent areas make a living from the harvesting of tea and coffee and the transportation of tea boxes. Anthropogenic activities in the study area include collection of fuel wood, honey, edible fruits (*Artocarpus heterophyllus* Lam., *Syzygium mundagam* (Bourd.) Chithra, *Baccaurea courtallensis* (Wight) Müll.Arg.) and black damar (*Canarium strictum* Roxb.).

Materials and Methods

Sampling design

A 3 ha plot was established in the wet evergreen forest and was subdivided into 10 × 10 m subplots according to the sampling design of Elouard & Krishnan (1999) (Fig. 1D). In each subplot all trees with a girth ≥ 10 cm at 1.3 m height (girth at breast height or gbh) were measured and identified. Trees with buttressed trunks or stilt roots were measured at 1.5 m from the ground. Each tree was sequentially numbered after measurement. The height of the trees was estimated visually. Nomenclature of taxa identified in the plots is based on the *Flora of Tamil Nadu* (Nair & Henry, 1983; Henry *et al.*, 1987, 1989).

Phytosociological analysis

Standard procedures were adopted to generate information on the following measures of phytosociology. Individuals having ≥ 10 cm girth were considered for

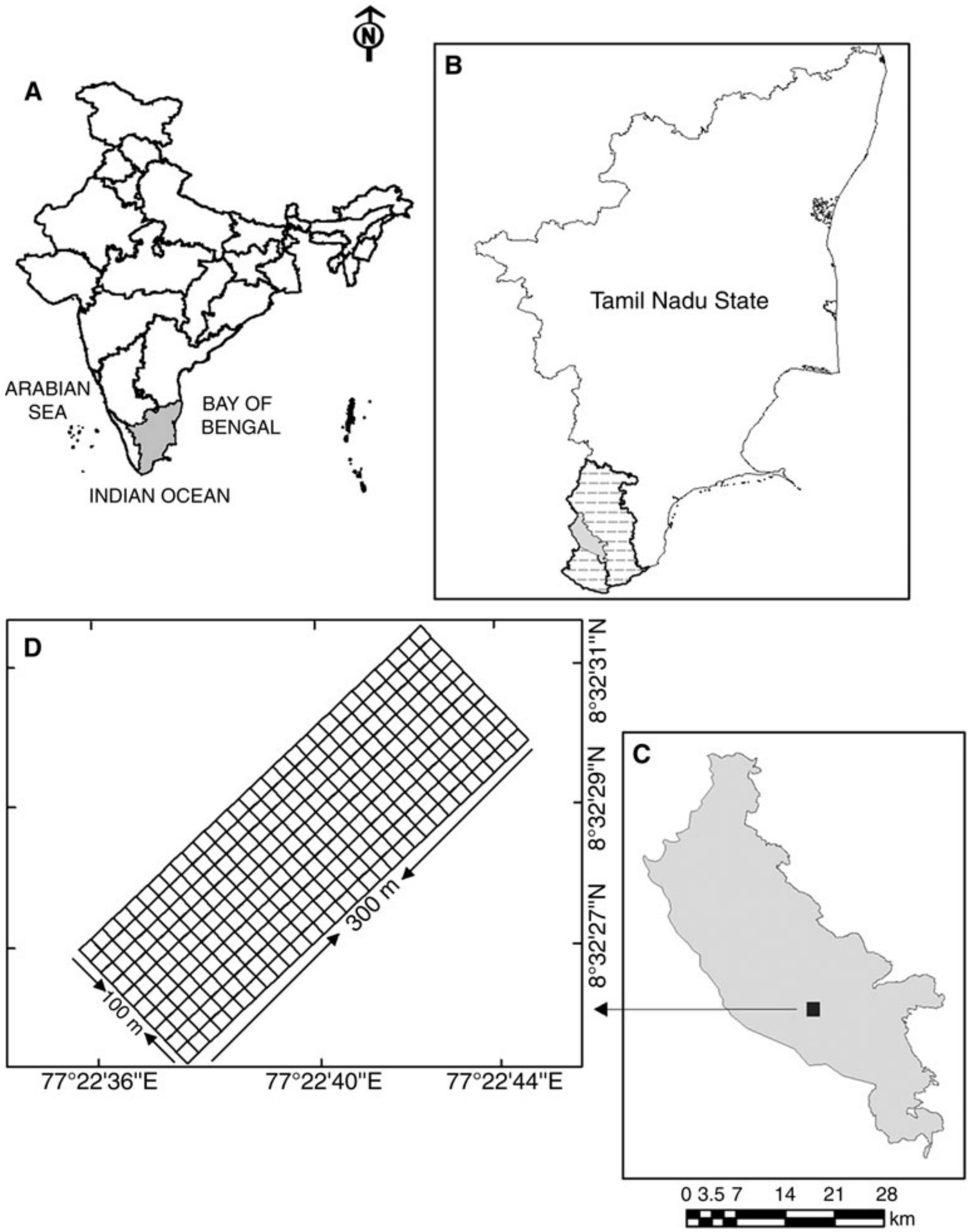

FIG. 1. Location map of the study area and its gridded sample design in the Kakachi forest range of the Kalakad-Mundanthurai Tiger Reserve (KMTR), southern Western Ghats, India. A, India – Tamil Nadu State; B, Tirunelveli and Kanyakumari districts in Tamil Nadu State; C, enlarged view of KMTR sanctuary; D, sampling design of the 3 ha plot in the Kakachi forest range.

TABLE 1. Physico-chemical parameters of the soil in the Kakachi forest range, as measured for the present study

Parameter	Value
pH	4.63
EC (dS m^{-1})	0.25
Lime status	Nil
Texture	Sandy loamy
OC (%)	1.14
Total primary nutrients (%)	
N	1.752×10^{-2}
P_2O_5	0.084×10^{-2}
K_2O	3.827×10^{-2}
Ca	3.14×10^{-2}
Mg	1.71×10^{-2}
Available nutrients (kg ha^{-1})	
N	50.43
P_2O_5	1.13
K_2O	70.82
CEC ($cmol_+$ kg^{-1})	6.76
Exchangeable bases ($cmol_+$ kg^{-1})	
Ca	8.2
Mg	6.5
Na	0.72
K	0.11

EC, electrical conductivity; OC, organic carbon; CEC, cation exchange capacity.

phytosociological analysis. Vegetation structure in terms of girth, height class distribution, forest stand density and basal area was computed for all trees with a girth ≥ 10 cm. To compute the biomass index per hectare, we used D^2H, where D is the diameter at breast height and H is the height of the tree.

Species richness

The species–area curve was plotted from randomly shuffled samples in order to remove the effect of the sample order on the species accumulation curve. The curves were drawn using the EstimateS software (Colwell, 1997).

Diversity indices

A number of diversity indices are available for measuring floristic diversity. We have calculated four of these indices for trees with girth ≥ 10 cm.

- Shannon–Weaver Index $H' = -\sum p_i \log_2 p_i$ (Shannon & Weaver, 1949), where p_i is the proportion of species i;

- Simpson Index $D = 1 - \sum_{i=1}^{S} \left({}^{n_i}/_{N}\right)^2$ (Simpson, 1949), where n_i is the number of individuals of species i, N is the total number of individuals in the plot, and S is the number of species in the plot;
- Evenness Index $E = \frac{H'}{H_{\max}}$, where $H_{\max} = \log_2 S$, where S is the total number of species (Krebs, 1978);
- Fisher's alpha $S = a^*\ln(1 + n/a)$, where S is the number of taxa, n is the number of individuals, and a is Fisher's alpha.

The floristic structure was studied using the Importance Value Index (IVI) of Curtis & McIntosh (1950). This index is generally calculated as the sum of the relative frequency (rF), relative density (rD) and relative basal area (rBA) for each species.

Delineating floristic composition using correspondence analysis

The aim of correspondence analysis is to project the species being analysed on independent axes and search for the axes which show the maximum information. Seventy-five blocks (20 × 20 m) with 52 tree species were analysed. The basis for choosing the most important numerical contributions among the taxa rests on the following two criteria: (i) the absolute contribution of an individual taxon has to be greater than twice the mean contribution of the taxa; (ii) the relative contribution of the taxa chosen using the first criterion has to be greater than 10%.

The taxa are considered as markers when they satisfy both the given criteria. The same basis is used for choosing the main numerical contributors among the plots. Thus, in this analysis the ranking for an axis depends on the blocks and species having higher absolute contribution. The ADE-4 software package, with an interface for Windows, was used for the statistical analysis (Thioulouse *et al.*, 1997).

Results

Phytosociological analysis

The forest stands were dense, with 5624 stems in the 3 ha plot (mean density 1875 stems ha^{-1}). The population structure of the forest stand was reverse J-shaped, with girth frequency and basal area distribution in various size classes (Fig. 2). The tree species richness, density, and diversity index consistently decreased with increasing stem size classes from 10 cm gbh to 210 cm gbh, except in the last class of 210 cm gbh (Table 2). The lowest size class captured 89% of species richness and 67% of forest stand density. The height distribution of all the individuals taken together is roughly bell shaped. The distribution pattern for the total number of individuals (girth ≥ 10 cm) shows a peak in the 6–7 m class, mostly due to the high frequency of saplings which contribute 45% of the total number of individuals. The basal area is 59.24 m^2 ha^{-1} and is made up mostly of trees with a girth ≥ 120 cm. The Biomass Index, based on the diameter and height relationship, is 1253 t ha^{-1}.

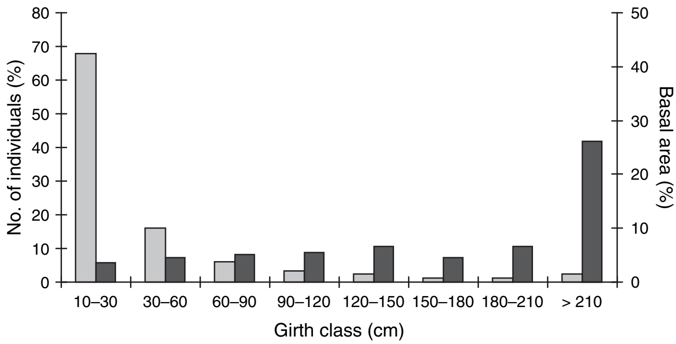

FIG. 2. Population structure of woody species based on girth frequency and basal area in the Kakachi forest range. Grey bars show number of tree individuals; black bars show basal area.

Floristic richness and diversity

In the 3 ha plot, 68 woody species of ≥ 10 cm girth, belonging to 52 genera and 27 families, as traditionally delimited, were recorded. The species–area curve is presented in Fig. 3. It can be seen that at 1.5 ha a majority of the tree species have been accounted for. The occurrence of *Nageia wallichiana*, the only conifer native to peninsular India, and the endemic palm *Bentinckia condapana* is notable. Appendix 1 lists the 81 plant species occurring in the plot, of which 68 are tree species and 13 are herbs and climbers. The diversity of tree species, as calculated by the Shannon and Simpson indices, was 4.89 and 0.95, respectively (Table 3).

Species dominance

Cullenia exarillata, known locally as 'Vedipala', was identified as the most dominant species in this locality (IVI = 37.00). This was followed by *Palaquium ellipticum* (IVI = 33.35), *Aglaia bourdillonii* (IVI = 16.00), *Myristica dactyloides* (IVI = 14.21) and *Epiprinus mallotiformis* (IVI = 13.04), as listed in Appendix 1.

TABLE 2. Species richness, stand density and diversity index for different stem size classes for the 3 ha plot in the Kakachi forest range

Girth class (cm)	Species richness	Stand density	Shannon Index
10–30	61	3817	4.816
30–60	47	900	4.431
60–90	31	339	3.629
90–120	22	182	3.407
120–150	21	130	3.346
150–180	10	63	2.484
180–210	12	62	2.445
> 210	13	131	2.005

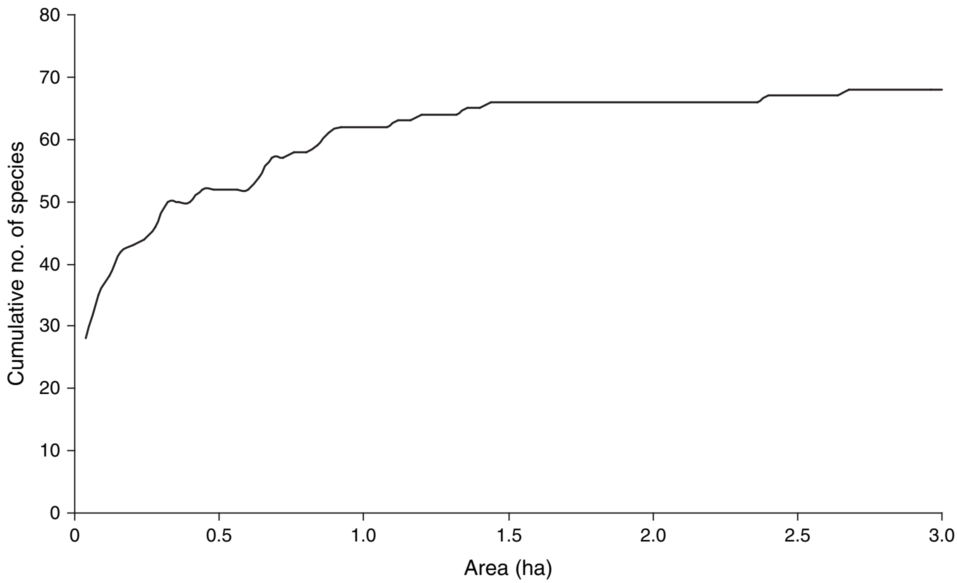

FIG. 3. Species–area curve for the study site in the Kakachi forest range.

Family dominance

The number of plant families in the study site was 27. Taxonomically well-represented families include *Lauraceae* (13 species), *Euphorbiaceae* (10), *Rubiaceae* (8), *Rutaceae* (4), *Flacourtiaceae* (3), *Sapotaceae* (3) and *Meliaceae* (3). Four families, *Myrtaceae*, *Annonaceae*, *Elaeocarpaceae* and *Myrsinaceae*, had two species each and 16 families had only a single species each in the study area. Based on density five families, *Bombacaceae* (1 species, IVI = 39.31), *Sapotaceae* (3 species, 36.42),

TABLE 3. Floristic richness, number of individuals and diversity indices for the 3 ha plot in the Kakachi forest range

Parameter	Value
Area (m^2)	30,000
No. of species (*S*)	68
No. of individuals (*N*)	5624
N/S	82.7
Simpson Index	0.956
Fisher's alpha	4.230
Shannon–Weaver Index:	
H'	4.896
H_{max}	6.196
$E = H'/H_{max}$	0.790

Lauraceae (13 species, 29.45), *Euphorbiaceae* (10 species, 29.22) and *Meliaceae* (3 species, 18.83) were abundant, contributing 58% of the total density (Table 4).

Floristic composition using correspondence analysis

Correspondence analysis (CA) was carried out using species and their individuals for the 3 ha plot. Taxa represented by only one individual were excluded, so that 52 taxa from the original set of 68 were analysed. Different combinations of the first four dominant eigenvectors were examined. The three axes together explain 25.83% of the total variance. The best dispersion is given by the first two axes, which together explain 19.81% of the total variation in the data set (Fig. 4). The dispersion of the samples in space shows three visually delineated groups. The horizontal axis of the CA includes a strong element of elevational gradient while the vertical axis includes a strong element of a gradient from the species found at the core to those at the

TABLE 4. Dominant families based on Importance Value Index (IVI) and number of species in the Kakachi forest range

Family	No. of species	IVI
Bombacaceae	1	39.31
Sapotaceae	3	36.42
Lauraceae	13	29.45
Euphorbiaceae	10	29.22
Meliaceae	3	18.83
Myristicaceae	1	16.52
Rubiaceae	8	16.24
Myrtaceae	2	14.15
Icacinaceae	1	12.98
Guttiferae	1	11.88
Rutaceae	4	10.90
Verbenaceae	1	8.88
Anacardiaceae	1	7.39
Annonaceae	2	6.37
Moraceae	1	6.35
Oleaceae	1	5.80
Theaceae	1	4.74
Flacourtiaceae	3	4.37
Elaeocarpaceae	2	4.31
Myrsinaceae	2	3.75
Podocarpaceae	1	3.68
Cornaceae	1	3.09
Aristolochiaceae	1	1.81
Erythroxylaceae	1	1.58
Stilaginaceae	1	1.21
Ebenaceae	1	0.59
Acanthaceae	1	0.20

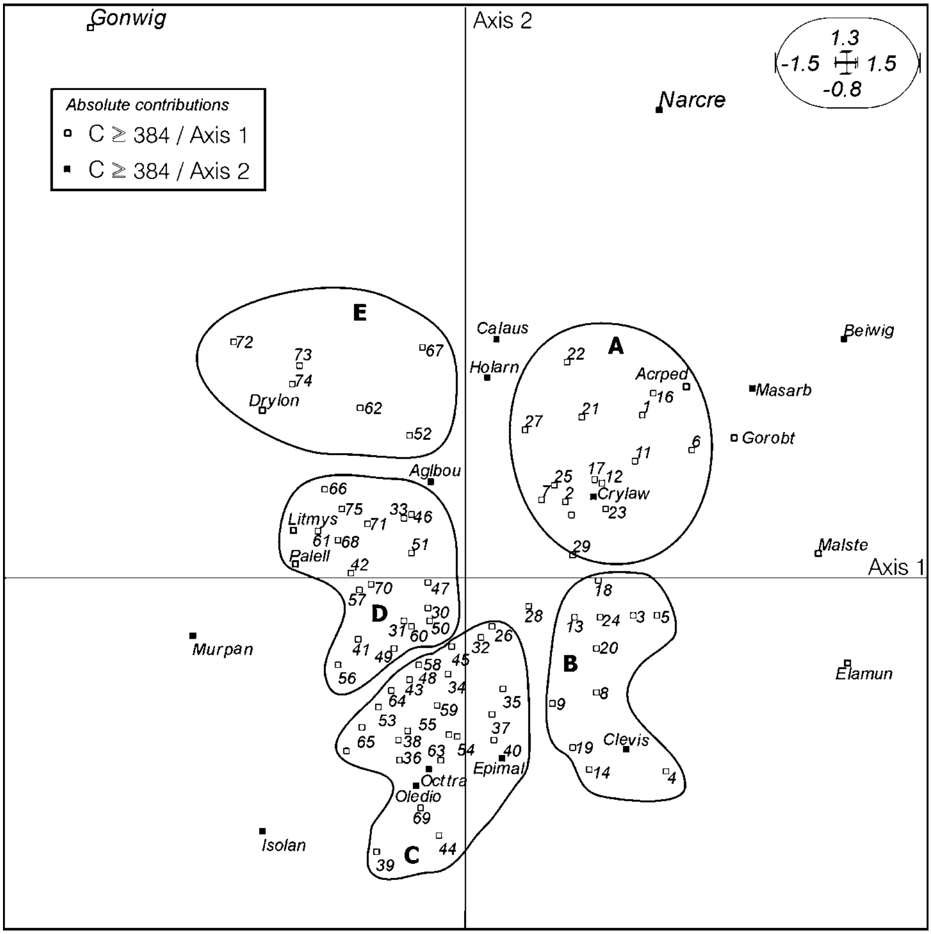

FIG. 4. Scatter diagram using correspondence analysis for the Kakachi forest range, Kalakad-Mundanthurai Tiger Reserve, southern Western Ghats, India.

margin. Group A at the top right and Group B at the bottom right are made up of samples from the low altitude evergreen species (ranges from 1171 to 1227 m). Group E at the top left and Groups C and D consist mainly of high altitude evergreen species (ranges from 1279 to 1306 m).

The taxa chosen as markers characterised by absolute and relative contribution are given in Table 5. They are represented by eight species associates drawn from axis 1 in Fig. 4. *Acronychia pedunculata*, *Gordonia obtusa*, *Mallotus stenanthus*, *Elaeocarpus munroii*, *Litsea mysorensis*, *Palaquium ellipticum*, *Drypetes longifolia* and *Goniothalamus wightii* are the absolute contributions while the associated taxa include *Cryptocarya lawsonii*, *Beilschmiedia wightii*, *Mastixia arborea*, *Isonandra lanceolata* and *Murraya paniculata*. For axis 2 the absolute contribution includes

TABLE 5. Taxon markers characterised by absolute and relative contribution identified using correspondence analysis in the Kakachi forest range

		Absolute contribution C > 384			Relative contribution > 10%	
Group	Taxon	Axis 1	Axis 2	Associated taxa	Axis 1	Axis 2
A	*Acronychia pedunculata*	1388	839	*Cryptocarya lawsonii*	1699	–
	Calophyllum austroindicum	–	654	*Beilschmiedia wightii*	1141	–
	Gordonia obtusa	410	–	*Mastixia arborea*	1706	–
	Mallotus stenanthus	446	–	*Holigarna arnottiana*	–	1968
				Naringi crenulata	–	1983
B	*Elaeocarpus munroii*	437	–			
	Clerodendrum viscosum	–	397			
	Epiprinus mallotiformis	–	1531			
C	*Epiprinus mallotiformis*	–	1531	*Isonandra lanceolata*	1629	–
	Octotropis travancorica	–	1769	*Olea dioica*	–	1937
D	*Litsea mysorensis*	1083	–	*Murraya paniculata*	1098	–
	Palaquium ellipticum	1668	–			
E	*Drypetes longifolia*	709	–	*Aglaia bourdillonii*	–	1522
	Goniothalamus wightii	766	–			
	Palaquium ellipticum	1668	–			
	Litsea mysorensis	1083	–			

Acronychia pedunculata, *Calophyllum austroindicum*, *Clerodendrum viscosum*, *Epiprinus mallotiformis* and *Octotropis travancorica* while the relative contribution includes *Holigarna arnottiana*, *Naringi crenulata*, *Olea dioica* and *Aglaia bourdillonii*.

Of the eight species associates in axis 1 of Fig. 4, *Litsea mysorensis*, *Palaquium ellipticum*, *Drypetes longifolia* and *Goniothalamus wightii*, and the associated taxa *Calophyllum austroindicum* and *Aglaia bourdillonii*, characterise the high altitude evergreen species. The corresponding markers of the low altitude evergreen species defined by axis 1 are *Mallotus stenanthus*, *Gordonia obtusa* and *Mastixia arborea*. Axis 2 separates the core and marginal species: *Palaquium ellipticum*, *Calophyllum austroindicum*, *Aglaia bourdillonii*, *Litsea mysorensis* and *Holigarna arnottiana* represent the core species, and *Epiprinus mallotiformis*, *Clerodendrum viscosum* and *Olea dioica* the marginal species.

Discussion

Forests at Kakachi are biologically rich and possess high levels of floristic species diversity and endemism. This forest is characterised by high stand density, basal area and species diversity comparable to that of other tropical forests in Asia, Africa and South America (Giriraj, 2006). Thus a systematic sampling of a 3 ha plot gives a fairly good representation of stand density, basal area and floristic composition. The present study shows less species richness (68 tree species in 3 ha with girth $\geq$ 10 cm) compared with other areas, although in some of these the study area was not in a single plot (174 species in four 1 ha plots in the Sengaltheri Hills [Parthasarathy, 2001]; 91 species in 3.21 ha in Kakachi [Ganesh *et al.*, 1996]). The present site is a single plot over a gradient from undisturbed to disturbed forest.

Other areas in Asia having higher diversity include Sabah (198 species in 1.81 ha [Nicholson, 1965]) and Pasoh, Malaysia (244 species in 2 ha [Manokaran & Kochummen, 1987]). Tropical forests in Africa have levels of diversity similar to that of our study site (50 species in 4.05 ha in Nigeria [Okali & Ola-Adams, 1987]; 120 species in 2 ha in Ghana [Swaine *et al.*, 1987]). The species diversity ($H' = 4.89$) is high and comparable to that of Amazonia (H' between 4.8 and 5.4 for trees $\geq$ 10 cm diameter at breast height (dbh); Uhl & Murphy, 1981) and Sabah ($H' = 4.78$ for trees $\geq$ 10 cm gbh; Newbery *et al.*, 1992), due to the occurrence of sporadic, rare species.

Endemism

In Kakachi endemics make up 51% of the total number of tree species (35 endemic species). In the southern Western Ghats endemism could be as high as 63% (for trees $\geq$ 10 cm dbh) (Ramesh & Pascal, 1997). The endemic tree species are important in the structure of the ecosystem of the Kakachi forest. The combined IVI of the endemic species is c.64% of the total IVI of all species. Of the endemics, *Cullenia exarillata*, *Palaquium ellipticum* and *Aglaia bourdillonii* constitute c.28% of the combined IVI of all species.

Species dominance

The dominant species in the Kakachi evergreen forest are *Cullenia exarillata*, *Palaquium ellipticum*, *Aglaia bourdillonii* and *Myristica dactyloides*. These four species account for 34% of the trees and 67% of the basal area and therefore constitute the framework of the forest. As each of them occupies a different layer they effectively determine the vertical structure of the local stand: (i) *Cullenia exarillata* and *Palaquium ellipticum* are emergents and their importance derives from the large girth established in the top canopy; (ii) *Aglaia bourdillonii* trees are well represented in all the girth classes and are found in intermediate strata; (iii) *Myristica dactyloides* fills the intermediate layer, its limited capacity to grow in height as well as diameter hindering its access to the upper canopy (Fig. 5). In spite of disturbance and other factors, the majority of individuals (82%) of the endemic species are in the girth class 10–30 cm, indicating a healthy regeneration.

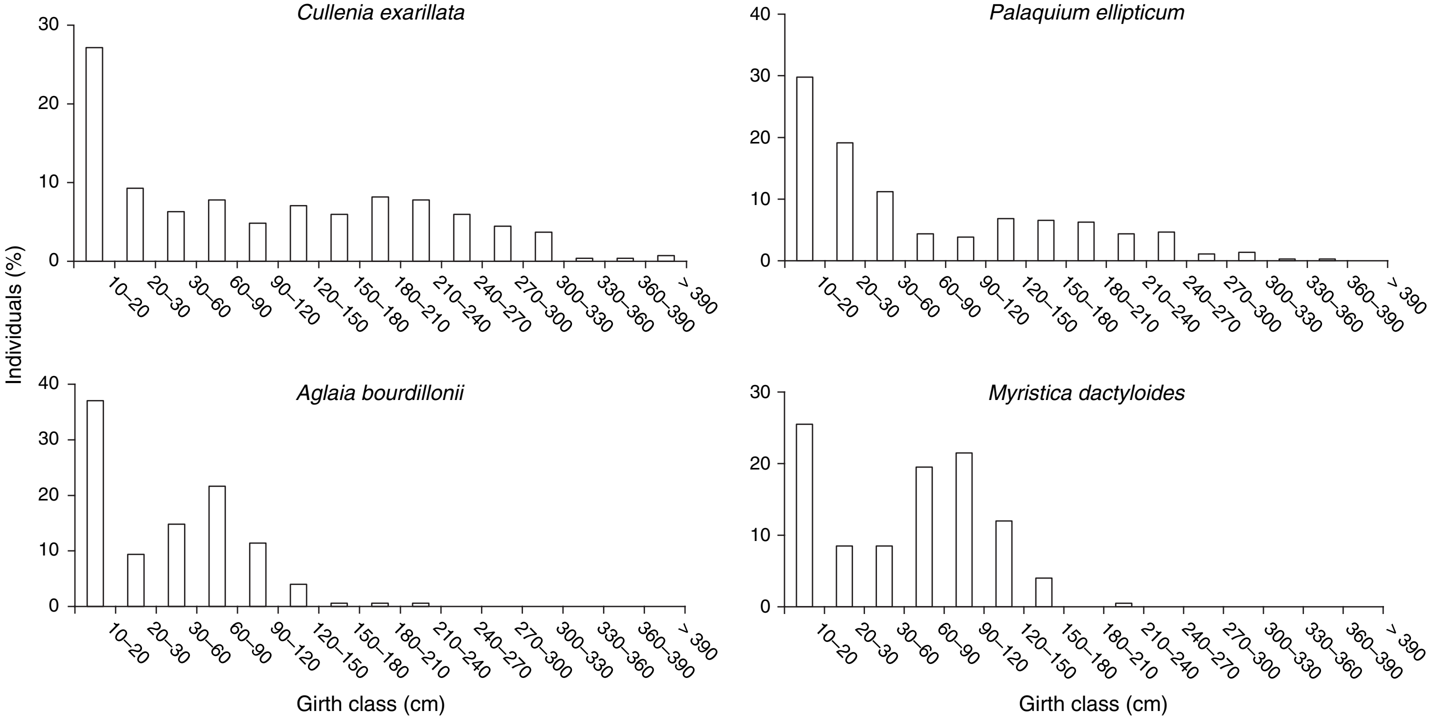

FIG. 5. Population structure for the dominant evergreen species observed in the Kakachi forest range, Kalakad-Mundanthurai Tiger Reserve, southern Western Ghats, India.

The sample forest area selected can be divided into core (primary species) and marginal (pioneer species, secondary succession species, or deciduous species in evergreen habitats) areas based on the species assemblages. Figure 6 shows the population structure of the major marginal species, based on their abundance in different girth classes. Marginal species compete with primary species during the successional stage and will gradually decline with time.

Stand density and basal area

Tree density and diversity increases from the margin towards the centre of the 300 m length of the plot. The stand density of 1875 trees ha^{-1} of all woody species of $\geq$ 10 cm gbh is higher than that of 716 ha^{-1} in the Kalakad National Park of the KMTR (Parthasarathy, 1999) and 635 ha^{-1} in Uppangala (Pascal & Pelissier, 1996). The mean basal area of 47.01 m^2 ha^{-1} is close to that of the Pantropical average of 32 m^2 (Dawkins, 1959). This is notably higher than figures reported at other sites of tropical evergreen forest in the Western Ghats: 39.7 m^2 ha^{-1} at Uppangala (Pascal & Pelissier, 1996); 42.03 m^2 ha^{-1} at Kakachi (Ganesh *et al.*, 1996); and 36.26 m^2 ha^{-1} at Anamalais (Ayyappan & Parthasarathy, 1999). It is lower than the 53.3–94.6 m^2 ha^{-1} reported in Kalakad (Parthasarathy *et al.*, 1992). The mean basal area at Kakachi is relatively high compared with other tropical forests of the world, for example in Malaysia (24.2 m^2 ha^{-1}; Poore, 1968), Puerto Rico (35.7 m^2 ha^{-1}; Crow, 1980) and French Guiana (34.8 m^2 ha^{-1}; Pelissier & Riera, 1993).

Ten species dominated the forest stand at Kakachi. Dominance increases as a function of stress (Keel & Prance, 1979) due to factors such as past damage (Jacobs, 1987) and poor drainage (Richards, 1996). In terms of top canopy density, *Palaquium ellipticum* (*Sapotaceae*) (400 individuals; 7%), *Aglaia bourdillonii* (*Meliaceae*) (353 individuals; 6%) and *Cullenia exarillata* (*Bombacaceae*) (269 individuals; 5%) contributed nearly 18% of the stand density. By family, the species of *Lauraceae* are most dense in the canopy (21% of the total), followed by the species of *Myristicaceae*, *Euphorbiaceae* and *Rubiaceae*.

The total above-ground biomass is within the range previously reported in other tropical forests (Folster *et al.*, 1976; Edwards & Grubb, 1977; Kato *et al.*, 1978; Ramesh, 1989; Yamakura *et al.*, 1990). In these studies the value of results ranged from 28.3 t ha^{-1} to 873.2 t ha^{-1} for total above-ground biomass, and 3.3 m^2 ha^{-1} to 70.0 m^2 ha^{-1} for basal area. However, the values obtained for forests within the vicinity of the Kakachi forest range were higher than those previously reported. The high above-ground biomass is comparable with that found in Soepadmo's (1987) study at Endau Rompin, Malaysia.

Floristic composition

Analysis of the floristic data from the Kakachi forest range allows the detection of five main floristic groups. Interestingly, the analysis clearly shows two different

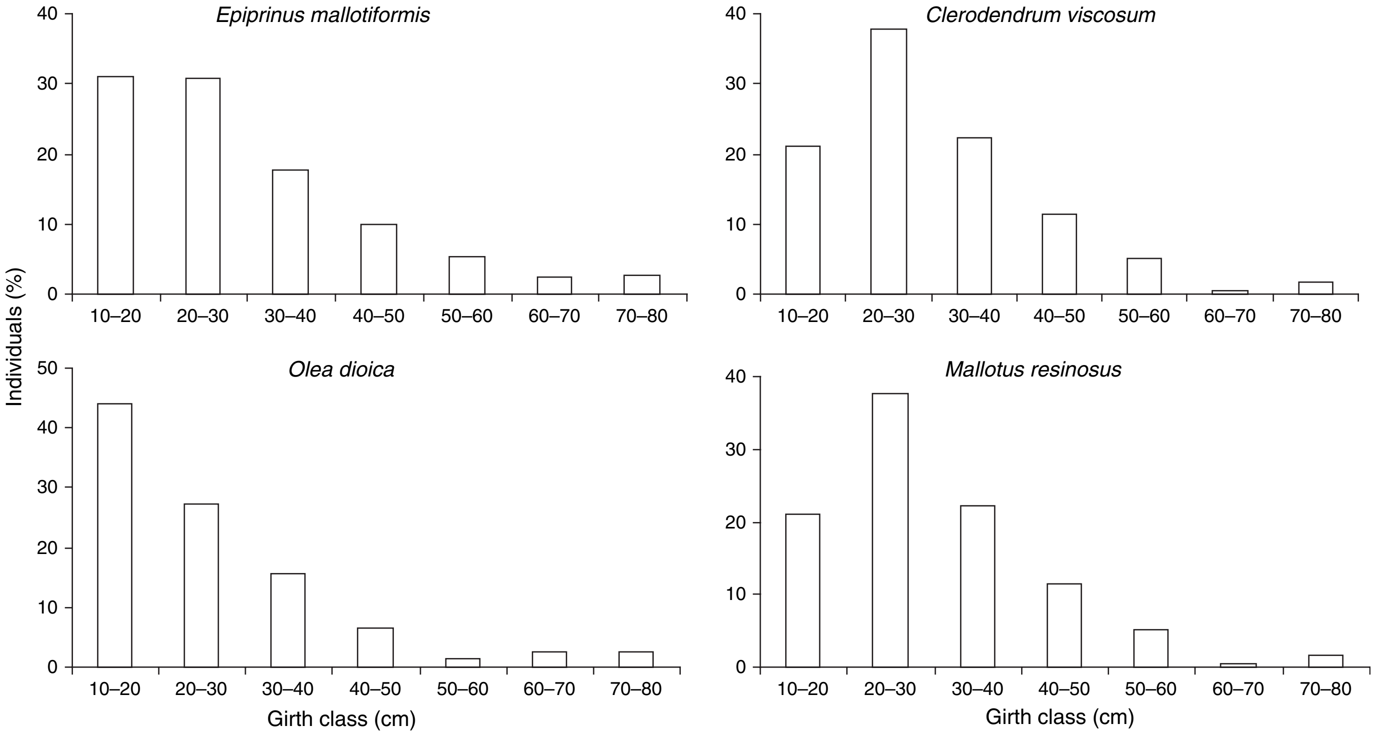

FIG. 6. Population structure for the marginal/pioneer species observed in the Kakachi forest range, Kalakad-Mundanthurai Tiger Reserve, southern Western Ghats, India.

evergreen formations: high altitude evergreen (Groups C, D and E) at elevations of 1279–1306 m, characterised by core (primary) species such as *Cullenia exarillata*, *Palaquium ellipticum*, *Aglaia bourdillonii* and *Myristica dactyloides*; and low altitude (Groups A and B) at elevations of 1171–1227 m, with marginal species such as *Macaranga peltata*, *Clerodendrum viscosum*, *Maesa indica* and *Macaranga flexuosa*. Species of *Lauraceae* predominate at higher altitudes (> 1300 m).

We have explicitly used the stand structure, described through the distribution of girth class, to explain floristic variation. The analysis showed that the stand structure and topography could be used as predictors for floristic composition. The stand structure appears to explain, at least in part, the distribution of some abundant primary species (see Fig. 6), among which are the marginal species (Group B in Fig. 4). This result is backed up by the fact that evergreen patches of such areas possess secondary succession stages, as has been documented recently by Ganesh *et al.* (1996) and Parthasarathy (1999, 2001). When the marginal habitat surrounds primary forest areas range extensions of many species become possible, enhancing structure and floristic composition. To some extent it also acts as a barrier to invasion from exotic species. Maintenance of such a linkage between marginal habitat and the primary forest allows survival of core and endemic species.

Conclusion

A quantitative floristic inventory based on a 3 ha plot showed high species richness, diversity and endemism. Correspondence analysis delineated vegetation communities that are positively related to selected environmental variables. It also demonstrated the distribution of species assemblages along an altitudinal gradient, and the occurrence of certain species unique to a particular altitude or habitat.

With an increasing resident population in the core areas of the KMTR reliant on tea, coffee and cardamom plantations, and the lack of firm conservation policies, the forest may become more and more disturbed and fragmented. The local people exploit forest resources through the extraction of plant products such as *Dioscorea* tubers, rattans, bamboo, honey, damar, and gum from *Canarium strictum* and *Kingiodendron pinnatum*. Management of mid elevation evergreen forests must necessarily depend on knowledge of the vegetation and its environmental variables.

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Appendix 1

Species recorded in the 3 ha plot, their species codes, family, habit and Importance Value Index (IVI) in the Kakachi forest range

No.	Species	Species code	Family	Habit*	IVI
1	*Acronychia pedunculata* (L.) Miq.	*Acr ped*	*Rutaceae*	T	7.08
2	*Actinodaphne bourdillonii* Gamble	*Act bou*	*Lauraceae*	T	2.25
3	*Actinodaphne campanulata* Hook.f.	*Act cam*	*Lauraceae*	T	0.12
4	*Aglaia bourdillonii* Gamble	*Agl bou*	*Meliaceae*	T	16.00
5	*Aglaia simplicifolia* (Bedd.) Harms	*Agl sim*	*Meliaceae*	T	0.12
6	*Agrostistachys borneensis* Becc.	*Agr bor*	*Euphorbiaceae*	T	9.76
7	*Agrostistachys indica* Dalzell	*Agr ind*	*Euphorbiaceae*	T	2.95
8	*Antidesma menasu* (Tul.) Müll.Arg.	*Ant men*	*Stilaginaceae*	T	0.74
9	*Apama siliquosa* Lam.	*Apa sil*	*Aristolochiaceae*	T	1.12
10	*Apollonias arnottii* Nees	*Apo arn*	*Euphorbiaceae*	T	5.05
11	*Aporosa fusiformis* Thwaites	*Apo fus*	*Euphorbiaceae*	T	0.12
12	*Artocarpus heterophyllus* Lam.	*Art het*	*Moraceae*	T	4.73
13	*Beilschmiedia wightii* (Nees) Benth. ex Hook.f.	*Bei wig*	*Lauraceae*	T	0.59
14	*Calophyllum austroindicum* Kosterm. ex P.F.Stevens	*Cal aus*	*Guttiferae*	T	9.57
15	*Canthium travancoricum* (Bedd.) Hook.f.	*Can tra*	*Rubiaceae*	T	0.39
16	*Casearia ovata* (Lam.) Willd.	*Cas ova*	*Flacourtiaceae*	T	0.31
17	*Cinnamomum filipedicellatum* Kosterm.	*Cin fil*	*Lauraceae*	T	7.07

APPENDIX 1. (*Cont'd*)

No.	Species	Species code	Family	Habit*	IVI
18	*Cinnamomum malabatrum* (Burm.f.) Blume	*Cin mal*	*Lauraceae*	T	9.11
19	*Clerodendrum viscosum* Vent.	*Cle vis*	*Verbenaceae*	T	6.72
20	*Cryptocarya lawsonii* Gamble	*Cry law*	*Lauraceae*	T	5.28
21	*Cullenia exarillata* A.Robyns	*Cul exa*	*Bombacaceae*	T	37.00
22	*Diospyros malabarica* (Desr.) Kostel.	*Dio mal*	*Ebenaceae*	T	0.36
23	*Diotacanthus grandis* Benth.	*Dio gra*	*Acanthaceae*	T	0.12
24	*Drypetes longifolia* (Blume) Pax & K.Hoffm.	*Dry lon*	*Euphorbiaceae*	T	5.24
25	*Dysoxylum malabaricum* Bedd. ex C.DC.	*Dys mal*	*Meliaceae*	T	0.60
26	*Elaeocarpus munroii* (Wight) Mast.	*Ela mun*	*Elaeocarpaceae*	T	3.01
27	*Elaeocarpus tuberculatus* Roxb.	*Ela tub*	*Elaeocarpaceae*	T	0.56
28	*Epiprinus mallotiformis* (Müll.Arg.) Croizat	*Epi mal*	*Euphorbiaceae*	T	13.04
29	*Erythroxylum obtusifolium* Hook.f.	*Ery obt*	*Erythroxylaceae*	T	0.96
30	*Gomphandra coriacea* Wight	*Gom cor*	*Icacinaceae*	T	10.68
31	*Goniothalamus wightii* Hook.f. & Thomson	*Gon wig*	*Annonaceae*	T	1.40
32	*Gordonia obtusa* Wall. ex Wight & Arn.	*Gor obt*	*Theaceae*	T	3.35
33	*Holigarna arnottiana* Hook.f.	*Hol arn*	*Anacardiaceae*	T	5.47
34	*Hydnocarpus alpina* Wight	*Hyd alp*	*Flacourtiaceae*	T	0.17
35	*Isonandra lanceolata* Wight	*Iso lan*	*Sapotaceae*	T	2.11
36	*Isonandra perrottetiana* A.DC.	*Iso per*	*Sapotaceae*	T	0.34
37	*Lasianthus acuminatus* Wight	*Las acu*	*Rubiaceae*	T	0.12
38	*Lasianthus cinereus* Gamble	*Las cin*	*Rubiaceae*	T	2.26
39	*Litsea floribunda* Gamble	*Lit flo*	*Lauraceae*	T	6.67
40	*Litsea glabrata* (Wall. ex Nees) Hook.f.	*Lit gla*	*Lauraceae*	T	0.13
41	*Litsea insignis* Gamble	*Lit ins*	*Lauraceae*	T	1.09
42	*Litsea mysorensis* Gamble	*Lit mys*	*Lauraceae*	T	7.56
43	*Litsea stocksii* Hook.f.	*Lit sto*	*Lauraceae*	T	0.12
44	*Macaranga flexuosa* Wight	*Mac fle*	*Euphorbiaceae*	T	0.12
45	*Macaranga peltata* (Roxb.) Müll.Arg.	*Mac pel*	*Euphorbiaceae*	T	0.29
46	*Maesa indica* (Roxb.) A.DC.	*Mae ind*	*Myrsinaceae*	T	0.36
47	*Mallotus resinosus* (Blanco) Merr.	*Mal res*	*Euphorbiaceae*	T	1.52
48	*Mallotus stenanthus* Müll.Arg.	*Mal ste*	*Euphorbiaceae*	T	1.29
49	*Mastixia arborea* (Wight) Bedd.	*Mas arb*	*Cornaceae*	T	2.24
50	*Miliusa wightiana* Hook.f. & Thomson	*Mil wig*	*Annonaceae*	T	3.74
51	*Murraya paniculata* (L.) Jack	*Mur pan*	*Rutaceae*	T	1.47
52	*Myristica dactyloides* Gaertn.	*Myr dac*	*Myristicaceae*	T	14.21
53	*Nageia wallichiana* Kuntze	*Nag wal*	*Podocarpaceae*	T	2.44
54	*Naringi crenulata* (Roxb.) Nicolson	*Nar cre*	*Rutaceae*	T	1.28
55	*Neolitsea scorbiculata* (Meisn.) Gamble	*Neo sco*	*Lauraceae*	T	1.23
56	*Octotropis travancorica* Bedd.	*Oct tra*	*Rubiaceae*	T	11.70
57	*Olea dioica* Roxb.	*Ole dio*	*Oleaceae*	T	4.02
58	*Palaquium ellipticum* (Dalzell) Baill.	*Pal ell*	*Sapotaceae*	T	33.35
59	*Pavetta indica* L.	*Pav ind*	*Rubiaceae*	T	2.54
60	*Persea macrantha* (Nees) Kosterm.	*Per mac*	*Lauraceae*	T	3.67
61	*Psychotria anamallayana* Bedd.	*Psy ana*	*Rubiaceae*	T	0.12
62	*Rapanea wightiana* (Wall. ex A.DC.) Mez	*Rap wig*	*Myrsinaceae*	T	2.18

APPENDIX 1. (*Cont'd*)

No.	Species	Species code	Family	Habit*	IVI
63	*Saprosma corymbosum* Bedd.	*Sap cor*	*Rubiaceae*	T	0.63
64	*Scolopia crenata* (Wight & Arn.) Clos	*Sco cre*	*Flacourtiaceae*	T	3.02
65	*Syzygium gardneri* Thwaites	*Syz gar*	*Myrtaceae*	T	10.02
66	*Syzygium mundagam* (Bourd.) Chithra	*Syz mun*	*Myrtaceae*	T	3.91
67	*Tricalysia apiocarpa* (Dalzell) Gamble	*Tri api*	*Rubiaceae*	T	1.26
68	*Vepris bilocularis* (Wight & Arn.) Engl.	*Vep bil*	*Rutaceae*	T	1.95
69	*Curculigo orchioides* Gaertn.	*Cur orc*	*Hypoxidaceae*	H	
70	*Cyathea gigantea* (Wall. ex Hook.) Holttum	*Cya gig*	Pteridophyte	H	
71	*Dorstenia indica* Wight	*Dor ind*	*Moraceae*	H	
72	*Elatostema lineolatum* Wight	*Ela lin*	*Urticaceae*	H	
73	*Elettaria cardamomum* Maton	*Ele car*	*Zingiberaceae*	H	
74	Grasses	Grass	*Poaceae*	H	
75	*Selaginella* sp.	*Sel* sp.	Pteridophyte	H	
76	*Derris benthamii* (Thwaites) Thwaites	*Der ben*	*Fabaceae*	C	
77	*Elaeagnus kologa* Schltr.	*Ela kol*	*Elaeagnaceae*	C	
78	*Jasminum azoricum* L.	*Jas azo*	*Oleaceae*	C	
79	*Piper* sp. L.	*Pip* sp.	*Piperaceae*	C	
80	*Sageretia hamosa* (Wall. ex Roxb.) Brongn.	*Seg ham*	*Rhamnaceae*	C	
81	*Toddalia asiatica* (L.) Lam.	*Tod asi*	*Rutaceae*	C	

*T, tree; H, herb; C, climber.