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Wet evergreen forest types of the southern western ghats, India

J.P. PASCAL[1], B.R. RAMESH[2] & DARIO DE FRANCESCHI[2]

[1]UMR CNRS 5558, Laboratoire de Biométrie et de Biologie Evolutive, Université de Lyon 1. 43 Bd du 11 Novembre 1918, 69622 Villeurbanne, France, [2]French Institute of Pondicherry, P.O. Box 33, Pondicherry 605 001, India

Abstract: The paper presents the classification of the wet evergreen forest types covering the southern part of the western ghats of India (south of the Palghat Gap). This classification was based on intensive field surveys and floristic analysis done on 143 sampling stations representing, with duplication, all the physiognomic and phenological types encountered within the framework of the vegetation mapping of southern India project, at the scale of 1/250,000. Only the results for wet evergreen forests are given here. Multivariate floristic analysis was done to separate the formations and to detect the characteristic species for each group. Five types have been identified in the wet evergreen forests, from the plains to the higher elevation (with 3 facies). For each type, the relationships with the environmental conditions, the main characteristics of its floristic composition and a brief account of its structure are given.

Resumen: Este trabajo presenta la clasificación de los tipos de bosques húmedos perennifolios que cubren la porción sur de los Gates Occidentales de la India (al sur de la Depresión Palghat). Esta clasificación se basó en trabajo intensivo de campo y análisis florísticos realizados en 143 estaciones de muestreo que representan, con replicación, todos los tipos fisonómicos y fenológicos encontrados en el marco del proyecto de la cartografía de la vegetación del sur de la India, a escala 1/250,000. Aquí se presentan solamente los resultados para los bosques húmedos perennifolios. Se realizaron análisis florísticos multivariados para separar las formaciones y detectar las especies características para cada grupo. Se han identificado cinco tipos en los bosques húmedos perennifolios, desde las planicies hasta las elevaciones mayores (con 3 facies). Para cada tipo se presentan las relaciones con las condiciones ambientales, las principales características de su composición florística y un breve recuento de su estructura.

Resumo: Este artigo apresenta a classificação dos tipos florestais sempreverdes cobrindo a parte sul dos Ghats Ocidentais da Índia (Sul da falha de Palghat). Esta classificação foi baseada em inventariações intensivas de campo e análise florística em 143 estações amostra representando, com duplicação, todos os tipos fisionómicos e fenológicos encontrados no contexto do projecto de mapeamento da vegetação do sul da Índia numa escala de 1/250 000. Neste artigo só se apresentam os resultados para as florestas sempreverdes. Uma análise florística multivariada foi efectuada para separar as formações e para detectar as espécies características de cada grupo. Foram identificados cinco tipos nas florestas sempreverdes húmidas desde a planície às maiores elevações (com 3 fáceis). Para cada tipo, a relação com as condições ambientais, as principais características da sua composição florística e uma breve caracterização da sua estrutura é apresentada.

Key words: Biodiversity, forest typology, India, western ghats, wet evergreen forests.

**Corresponding Author*: B.R. Ramesh

Introduction

The western ghats form a more or less continuous mountain chain over a distance of about 1600 km along the western coast of India. The western slopes and summits of these reliefs experience the full intensity of the summer monsoon, which, as a result of orographic effect, brings abundant rainfall, sometimes more than 7000 mm at few places. Such conditions have enabled the growth of dense, humid forest formations from the coast up to the summit of the Ghats. However, the climatic conditions are not uniform throughout the ghats. Since the monsoon arrives from the south and retreats in the reverse direction, the rainy season is longer in the south than in the north of the western ghats. Thus, beyond about 16°N, the dry season is too long for the growth of evergreen forests except in the moist pockets on the hills. A second aspect is that the monsoon rains diminish very rapidly once they cross the Ghats summit. From there onwards, the interior regions, which become increasingly dry eastwards, are covered only by deciduous, instead of evergreen formations. The third climatic gradient governing the distribution of formations is the fall in temperature with altitude (Pascal 1988).

This diversity in climatic conditions is expressed by a large variety of plant formations and high species richness. Nearly 4000, or 27% of the total plant species in India, have been recorded from the western ghats (Nayar 1996). The evergreen forests of the western ghats are characterised by a very high percentage of species endemic to the region. The total number of endemic plant species is estimated to be 1500 (MacKinnon & MacKinnon 1986). Among the evergreen tree species, 56% are endemic. Therefore, the western ghats are considered as one of the biodiversity hot spots of the world (Myers 1988).

Species richness and endemism are, however, not uniformly distributed along the Ghats. The southernmost regions which have the most favourable climatic conditions with high, but not excessive, rainfall and short dry season, are the ones with the highest biodiversity and contain the highest number of endemic species (Pascal 1988; Ramesh *et al.* 1991).

However, the southern most ghats, which include Agastyamalai and Periyar regions as a whole, have never been studied in detail. Most works consisted of lists of species prepared for floras, and were generally based on an administrative division, without precise references to the environmental conditions or the corresponding forest types (Beddome 1877; Bourdillon 1908; Ganesh *et al.* 1996; Govindaragjulu & Swamy 1956, 1958; Henry & Subramanyam 1981; Lawrence 1959; Mohanan 1991a, b; Nayar 1959; Rajasingh 1961; Rama Rao 1914; Sebastine & Henry 1960, 1962; Shankaranarayanan 1960; Sharma *et al.* 1973; Sundarapandian & Swamy 1997; Swamy & Govindarajulu 1956; Vajravelu *et al.* 1987; Vivekananthan 1981).

Localised botanical and ecological studies have also been carried out, especially on 1 ha plots, resulting in more accurate descriptions of the floristic structure and composition of some types of formations (Rao 1991; Krishnamoorthy 1960; Parthasarathy & Mahadevan 1987; Pascal 1988). These works, however, do not aim at proposing a regional synthesis.

A first synthesis of the vegetation of this southern area was made with the Cape Comorin sheet (Gauseen *et al.* 1961a, b) prepared within the framework of the Vegetation Map of India at 1/1,000,000 scale. Despite taking into account for its typology the environmental conditions and the dynamic relationships between formations, this work, due to its scale, is not detailed enough at the regional level.

Another synthesis, restricted to the forest types of Kerala, was proposed by Chandrasekharan (1962a,b,c,d). This work is based mainly on the working plans of the State Forest Department and does not fully tally with our field observations.

Lack of information at global level is regrettable, especially for deriving conservation plans for these unique formations of this region. In the mean time these forests are subjected to very high anthropogenic pressure, the population density of Kerala being one of the highest in the world. Evergreen forests of the plains, for example, have practically disappeared, giving place to agriculture, agroforestry and/or plantation (Prasad 1998).

It is in this general context, that the French Institute of Pondicherry and the Forest Department of Kerala, Karnataka and Tamil Nadu decided to undertake the mapping of the vegetation at a medium scale (1/250000). This maping programme also included a typology of the plant formations of the Ghats (Pascal 1982a,b,c 1984, 1986,

1988; Pascal & Raemsh 1995; Ramesh 1989; Ramesh *et al.* 1997).

The paper presents the classification established during this mapping project for wet evergreen forest types occurring in the southern part of India, and provides some information on their distribution pattern in relation to environmental conditions.

Study area

Brief description of the physical features

The study area is situated in the extreme tip of the Indian peninsula (Fig. 1), south of 10°N. It covers the entire coastal zone of Kerala and western ghats reliefs, excluding the dry regions of the Tamil Nadu plains. It represents a total are of more than 25,000 km² within which 6800 km² are under forest. The coastal zone, 30 to 50 km wide and 250 km long, constitutes the southern part of Travancore. It consists of numerous low hills (generally lower than 500 m) with rounded peaks. The Ariankavu Pass (160 m alt., towards 9°N) separates the area into two parts. A plateau, sloping towards the west constitutes the northern part: the Periyar plateau named after its main river. The eastern part of this plateau forms the Elamalai range, better known as Cardamom Hills because of its plantations, to the north. South of

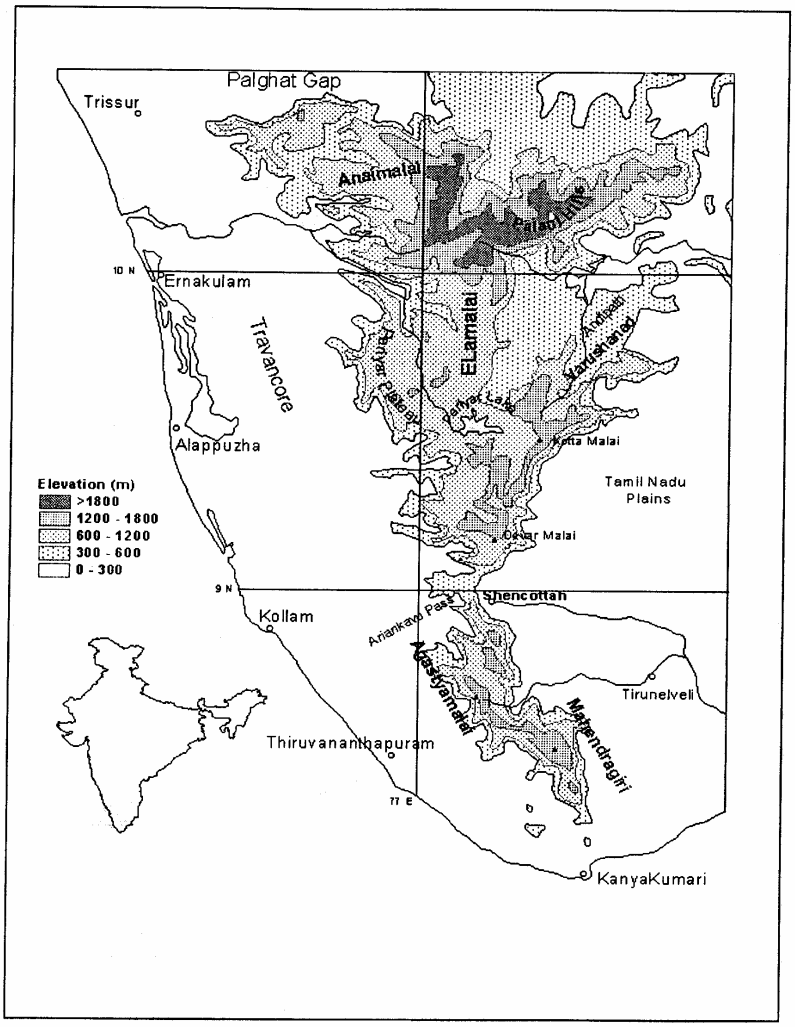

Fig. 1. Simplified physiographic map of the study area.

the Periyar lake, the edge of the plateau is still higher. It forms a ridge framed at the two extremitie by Kottai Malai (2019 m) and Devar Malai (1922 m) and dominating the dry plains of Tamil Nadu by a sheer cliff of more than 1000 m. The SW-NE oriented Varushanad massif is detached from the Kottai Malai region and is continued by the Andipathi (1301 m), which together with the Palni Hills (10°N-10°30′N) embraces the Kamban valley.

To the south of the Ariankavu Pass, the western ghats form a ridge with steep slope to the west as well as to the east. They end almost at the southern tip of India, about 20 km before Kanniyakumari. This last part, which is very rugged, culminates at 1869 m in the Agastyamalai peak. Three regions may be distinguished: Agastyamalai proper, Mahendragiri (1654 m) to the south and the Tirunelveli hills on the eastern slopes.

Geology and soil

Three main types of rock are found in this region (Naqvi & Rogers 1987). A major part of the Ghats reliefs, north of the Ariankavu Pass, is made up of a massif largely constituted by charnockites. The Ariankavu Pass constitutes a shear zone, south of which the rocks are mainly khondalites. Some areas also contain gneiss and incipient charnockite. Varushanad and Andipathi massifs are mostly made of granite. In coastal areas, except for alluvia, the sedimentary rocks are restricted to two formations: the "Quilon beds" and the "Warkali beds".

Soil maps do not show appreciable differences linked to the effect of rocks (khondalites or charnockites) from one part or the other of Ariankavu shear zone (Sehgal *et al.* 1996). The variations are due to climatic gradients. Four zones can be distinguished from west to east. (i) The foothills of the western side of the Ghats are dissected hilly hinterland and are mainly composed of highly developed humiferous soils (Haplohumults). (ii) The western and central parts of the ghats having an association of highly humiferous soils (Paleghumults) and less developed but also humiferous soils (Humitropets). (iii) The eastern zone of the ghats bears an association of poorly developed humiferous soils (Humitropepts) or not humiferous (Ustropepts). (iv) The eastern slope and Tamilnad pediment, where red soils of the semi-arid zone (haplustalfs) dominate.

Climate

Two major factors determine the climatic conditions of this region: rainfall distribution linked to exposure (west, east) and decrease in temperature with altitude.

(i) The coastal zone, western slopes, the Periyar plateau and the mountain peaks receive rainfall from the summer monsson. The rainfall is between 3000 and 3500 mm in the entire coastal zone, and then increase with the ghats relief to reach nearly 5000 mm on the crests. In contrast with the regions lying further north of the ghats, very heavy rainfall (higher than 6000 or 7000 mm) is not observed here. On the other hand, the rainy season is spread out during the year, from April to November. It thus follows that the dry season is short: 3-4 months in the coastal zone, 2-3 from the foot of the ghats up to about 1500 m, and 1-2 months above this. The central part of the Periyar plateau has a dry season of 3-4 months because of its sheltered position, and the eastern part of Elamalai receives only 2000 mm of rainfall.

Rainfall diminishes abruptly on the eastern slopes to attain 1000-1200 mm at the foot of the ghats and remains between 600 and 900 mm in the plains of Tamil Nadu. In the Varushanad and Andipathi, which are situated too much to the east to receive any rains from the summer monsoon, the rainfall ranges between 900 and 1200 mm. This decrease in rainfall is accompanied by a very rapid increase in the length of the dry season, which is 4-5 months on the eastern slopes, 5-6 at the foot of the ghats and 7-9 in the plains where too dry periods are often observed during the year. The eastern slopes of the ghats, south of the Ariankavu Pass, however, get additional humidity from the near-by sea (Pascal 1982c).

(ii) The altitudinal thermic gradient can be summarised as follows (Pascal 1988): the mean temperature of the coldest month remains higher than 20°C up to about 900 m. It falls below 15°C from 1450 m onwards. At this altitude, the mean temperature of the minima of the coldest month is around 7-8°C. In the most exposed situations, particularly on the crests, temperature is naturally lower for the same altitude: for example, a temperature of 7-8°C for the mean temperature of the minima of the coldest month is found from 1000 m instead of 1450 m.

Methods

Field survey and sampling

An intensive field survey of the study area was carried out for the mapping project (Ramesh *et al.* 1997). Most of the forest areas were visited and principal changes occurring in the stand structure and the floristic composition in relation to altitude, edaphic conditions (mainly watercourses), latitude, exposure and human interference were noted. This survey enabled us to have a general idea of the distribution of the forest types. During the survey, 143 ground-truthing stations (102 for the wet evergreen forests) were established covering all the physiognomic and phenological types with duplication. Each ground-truthing station corresponds to a circle of approximately 200 m radius in which the general structure of the stand in terms of height, density and vertical stratification was estimated. All the trees, shrubs and lianas, and some herbs, were enumerated with a coarse indication of their abundance. Species were identified using the field key prepared for evergreen arborescent species (Pascal & Ramesh 1986). Voucher herbarium specimens were also collected and deposited in the Herbarium of French Institute of Pondicherry (HIFP).

Statistical analysis

To identify and characterise floristic types, the data collected from the sampling stations were analysed through correspondence analysis (CA), using the public domain ADE.4 software package (Thioulouse *et al.* 1995).

As our major objective was to study the floristic changes, the analysis was done using species presence-absence data matrix. Species occurring in less than 5 stations and species having wider ecological amplitude (*i.e.* species widely distributed irrespective of climatic variations) were removed from the analysis.

To name the floristic types, we selected the species that were strongly linked with the CA axes, according to the following criteria: (i) their contribution to CA should be more than twice the mean contribution for all the taxa, (ii) they should be trees from the canopy or emergents, (iii) they should occur in the core of the forest and not at the margin, and should not be restricted to special edaphic or exposure conditions and (iv) they should be common, at least locally.

Some stations were characterised by very particular species assemblage, indicating generally a local variation, either due to soil conditions (swamps forests) or for other reasons. When their extension is limited, they were considered as special facies.

Results

Floristic analysis

The CA was performed with a final data matrix of 176 species and 102 stations. The first two axes explained 13% of the variation of the data set (17% with the third axis). Fig. 2 shows the distribution of the stations (indicated by their altitude) on the first two axes. A typical multivariate arch configuration was observed with low elevation stations in one extreme of the arch and high elevation in the other. Axis 2 separated the stations distributed on either sides of the Ariankavu Pass.

Eighteen species matched the conditions required for selection: *Bhesa indica, Calophyllum austro-indicum, Cinnamomum keralense, Cullenia exarillata, Diospyros atrata, D. bourdillonii, Dipterocarpus bourdilloni, D. indicus, Ficus beddomei, Gluta travancorica, Hopea parviflora, Kingiodendron pinnatum, Lophopetalum wightianum, Mangifera indica, Nageia wallichiana, Palaquium ellipticum, Strombosia ceylanica* and *Vateria indica*. Among these species, some were considered as better indicators of the ecological conditions, as their ecological amplitude is narrow: *Bhesa indica, Cullenia exarillata, Dipterocarpus bourdilloni, D. indicus, Gluta travancorica*, and *Nageia wallichiana*. Their occurrence in the stations was used to separate 3 main groups A, B and C, which correspond to low, medium and high elevation wet evergreen types respectively.

Low elevation types (0-800 m)

In the study area, the low elevation formations are characterised by the presence of *Dipterocarpus indicus* and *Strombosia ceylanica*, both species hardly occurring above 800 m (group A in Fig. 2). Like in the other low elevation evergreen forests, further north of the Ghats, *Dipterocarpus indicus* is a characteristic canopy species. However, in the study area it has been found more patchily because of over exploitation. *Strombosia ceylanica* has a wide

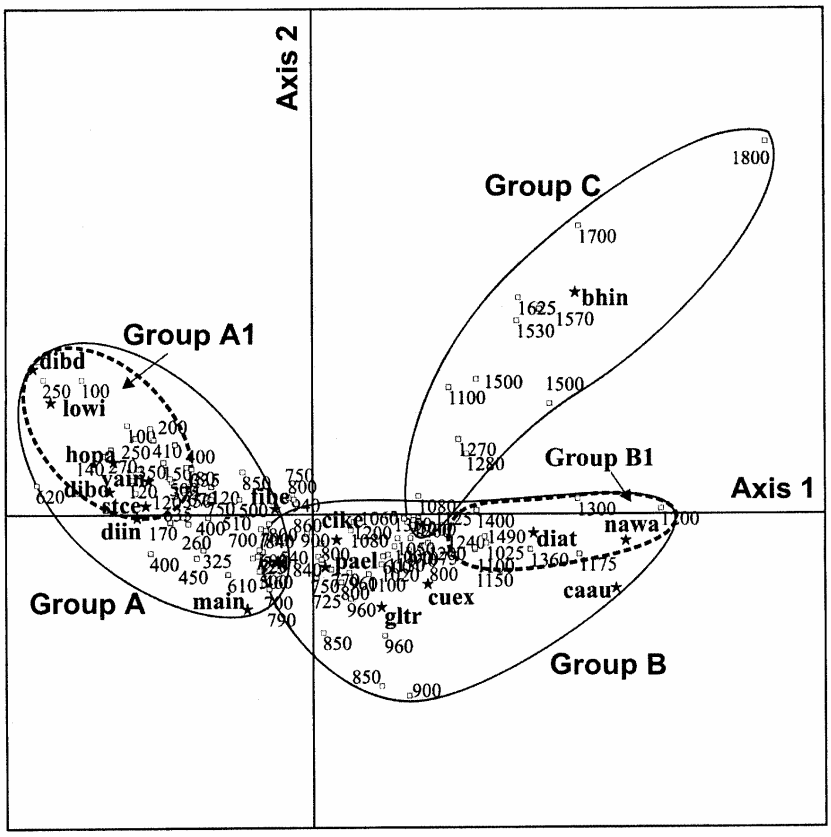

Fig. 2. Results of the correspondence analysis for the wet evergreen vegetation forests (numbers in each group correspond to the altitude of the stations) (bhin: *Bhesa indica:* caau: *Calohyllum austro-indicum;* cike: *Cinnamomum keralense;* cuex: *Cullenia exarillata;* diat: *Diospyros atrata;* dibd: *Dipterocarpus bourdilloni;* dibo: *Diospyros bourdillonii;* diin: *Dipterocarpus indicus*; fibe: *Ficus beddomei;* gltr: *Gluta travancorica;* hopa: *Hopea parviflora;* kipi: K*ingiodedron pinnatum;* lowi: *Lophopetalum wightianum;* main: *Magnifera indica;* nawa: *Nageia wallichiana;* pael: *Palaquium ellipticum;* stce: *Strombosia ceylanica;* vain: *Vateria indica)*

distribution throughout the western ghats, but is more common among the canopy trees in the low elevation types in the study area. Therefore, these two species were selected to name the low elevation types. Some other species, well contributing to the CA, are also found only at this elevation: *Diospyros bourdillonii, Dipterocarpus bourdilloni, Ficus beddomei, Hopea parviflora, Kingiodendron pinnatum* and *Lophopetalum wightianum*. Among these species, *Dipterocarpus bourdilloni* clearly separated the stations located to the north of the Ariankavu Pass (group A1) from those situated to the south which are characterised by a more prominent presence of *Kingiodendron pinnatum*. This species shows a peculiar distribution pattern in the study area. It is very rare or absent in the low elevation wet evergreen type in the north of the Ariankavu Pass, but becomes prominent again in the dry evergreen forest in the east, under entirely different climatic conditions.

Two low elevation types (DKS and DDS, see below) were then separated after these two species. These types correspond to lowland dipterocarp forests. Structurally, they are tall dense forests with four structural layers (*sensu* Oldeman 1974) with a canopy height reaching 35-45 m and an emergent layer sometimes up to 60 m.

Dipterocarpus indicus – Kingiodendron pinnatum – Strombosia ceylanica type (KDS)

DKS type is confined to south of the Ariankavu Pass (8°20′N to 9°00′N), where the length of the dry season varies from 2 to 3 months. The less disturbed parts of this type are now mainly represented by two facies, which are found above 8°40′N. Below that, the DKS type is mostly in the form of fragments or in a degraded condition where *Dipterocarpus indicus* that was over exploited becomes very rare. In the eastern side of the ghats, the DKS type is restricted to moist enclaves in Iambraparni river valley (east of Agastyamalai), at 450 to 750 m altitude. In this region, it occurs more or less as a transitional stage to medium elevation type. *Palaquium bourdilloni, Diospyros barberi* and *Memecylon subramanii*, which are the local endemics, are the characteristic species of this transitional type in the lower strata of the forest.

The two facies that have been identified under DKS type are both occurring in humid areas. One is characterised by the local abundance of an otherwise rare species (*Hopea racophloea*), and the other corresponds to a particular ecosystem adapted to water logged areas.

(1) Hopea racophloea–Humboldtia decurrens facies

This facies is characterised by *Hopea racophloea* and a third storey tree, *Humboldtia decurrens*. Other common canopy trees are *Vateria indica, Artocarpus gomezianus, Otonephelium stipulaceum, Holigarna nigra, Cynometra* sp. and *Ficus beddomei. Poeciloneuron indicum* has been found in patches. This facies is confined to humid valleys between Kallar and Shendurni rivers, west of Agastryamalai.

(2) Myristica swamps

The swamps are poorly drained flat terrains, inundated throughout the year. The soils are generally sandy loams. The special feature of this unique ecosystem is the abundance of Myristicaceae, especially two species: *Gymnacranthera canarica* and *Myristica fatua* var. *magnifica*. These species produce numerous stilt roots and sometimes pneumatophores as in mangroves. There are only few such swamps in the entire western ghats. In the study area, near Kulathupuzha, in the Travancore region, some patches of relatively well-preserved *Myristica* swamps can be seen. In these swamps, apart from the Myristicaceae members, other riparian tree species such as *Tetrameles nudiflora, Lophopetalum wightianum, Humboldita vahliana, Caralia brachiata, Elaeocarpus tuberculatus, Lagerstroemia flos-reginae, Syzygium montana* are also present.

Dipterocarpus indicus-Diptercarpus bourdilloni – Strombosia ceylanica type (DDS)

Like in the DKS type, *Dipterocarpus indicus* and *Stromosia ceylanica* are the characteristic species here also. However, *Kingiodendron pinnatum*, which is a dominant species in the earlier type, has been replaced by the gigantic dipterocarp *Dipterocarpus bourdilloni*. The distribution of both the dipterocarps are again patchy due to over-exploitation. *Dipterocarpus bourdilloni* that generally occurs at lower limits (<600 m) is the most threatened species. In the study area it is now encountered only along streams and in some inaccessible areas.

Bulk of the DDS type is in the form of disturbed forests. These forests were logged for several decades for hardwoods and softwoods. Due to this, repeated logging several species like *Vateria indica, Palaquium ellipticum, Calophyllum polyanthum, Otonephelium stipulaceum, Chrysophyllum lanceolatum, Dipterocarpus indicus, Semecarpus auriculata, Poeciloneuron indicum* have become less frequent. However, species with wider ecological amplitude viz. *Polyalthia fragrans, Pterygota alata, Artocarpus gomezianus, Antiaris toxicaria, Bombax ceiba* have taken over the canopy.

This type covers a wide area in the western ghats between 9°N and 11°N. In the study area it is found only north of the Ariankavu Pass, and is highly discontinuous. Except a big and continuous stretch of forest between 9°10′N and 9°35′N, DDS type is in the form of smaller fragments amidst secondary moist deciduous forest and as degraded stages represented by either thickets or savannas, intermixed with several deciduous species.

Medium elevation types (800 - 1450 m)

Generally comprise between 800 to 1450 m, the medium elevation forests may sometimes appear at lower elevation (650 m) according to local variations in moisture or exposure, etc. They are structurally very similar to low elevation ones with a canopy reaching 35-45 m and four structural layers, especially at their lower limits. Towards the upper limit, the forests become stunted with two to three layers (canopy <18 m). They differ floristically from the low elevation types either by the

disappearance or the variation in relative abundance of certain species, and the appearance of others. The floristic analysis showed that *Cullenia exarillata* was a good indicator for this elevation as it ranges generally from 700 to 1400 m and rarely descends to 550 m in some moist valleys (group B). Two other species, *Mesua ferrea* and *Palaquium ellipticum*, well contributing to CA, were also used to characterise this elevation range (CMP type). These two species also occur at lower elevation but with a lower frequency. In the south of the Ariankavu Pass, the CMP type is replaced by another type (CMPG), floristically very close, but highly characterised by the presence of some localised species: *Gluta travancorica* and *Calophyllum austro-indicum*. Inside this CMPG type, a particular facies has been identified with the presence of *Nageia wallichiana* and *Diospyros atrata* (group B1 in the CA).

Cullenia exarillata – Mesua ferrea – Palaquium ellipticum – Gluta travancorica type (CMPG)

This type is confined to Agastyamalai and Mahendragiri regions, south of the Ariankavu Pass, between 8° 20′N and 8° 50′N. Some species were found only in the CMPG type or rarely found in the medium elevation type of further north. They are *Calophyllum austroindicum, Garcinia rubro-echinata, Garcinia imbertii, Garcinia travancorica, Diospyros barberi, Atuna travancorica* at canopy and subcanopy level and, *Memecylon subramanii, Popowia beddomeana, Memecylon gracile, Octotropis travancorica, Diotacanthus grandis, Goniothalamus rhyncantherus* and *Vernonia travancorica* at undergrowth level.

Nageia wallichiana facies

This facies of the CMPG type is characterised by the abundance of the only indigenous Gymnosperm tree species in South India, *Nageia wallichiana*. Its distribution is confined to eastern side of the crest of the western ghats between 8° 20′N and 9° 30′N and above 1000 m. Other tree species, characteristic of this facies, are *Diospyros atrata, Elaeocarpus venustus, Eugenia floccosea, Aglaia bourdillonii, Actinodaphne campanulata* and *Syzygium microphyllum*. *Bentinckia conddapanna,* an endemic palm, is often found along the margins of the facies near the cliffs.

Cullenia exarillata – Mesua ferrea – Palaquium ellipticum type (CMP)

This type is found along the western ghats between the Ariankavu Pass and the Brahmagiri ghat, north of the Palghat Gap (Pascal 1982a). The lower limit of the type on the western side of the ghats locally varies from 550 to 700 m and, in the eastern side it is found only above 800 m. In the study area, the best part of the CMP has been found in the southern part of the Periyar plateau. In the Elamalai region, the entire CMP type has been converted into cardamom plantations. Around the Idukki dam in the northern part of the Periyar plateau, the CMP forests are highly fragmented and in the form of thickets and savannas.

In the dense forests, apart from the type species, other species that are common as canopy trees or emergents are *Diospyros sylvatica, Drypetes elata, Cinnamomum keralense, Syzygium gardneri, Dimocarpus longan, Aglain jainii, Litsea oleoides*. All these species are widely distributed. In the second and third layers also there are species with wide distribution such as *Agrostistachys meeboldii, Symphilia mallotiformis, Tricalysia apiocarpa, Myristica dactyloides, Homalium travancoricum, Diospyros paniculata*. However, some species like *Drypetes venusta, Semecarpus travancorica, Diospyros nilagirica, Litsea bourdillonii, Litsea keralana, Bhesa indica, Aglaia exstipulata,* which are common in the CMP part of the study area, show further extension up to the Palghat gap. Beyond the Palghat Gap these species either disappear or become rare. In the understorey, *Ardisia pauciflora, Goniothalamus wightiana, Tabernaemontana gamblei, Psychotria anamalayana, Lasianthus jackianus* are relatively more common in the study area than in other regions. *Nageia wallichiana*, which forms a facies in the CMPG type, is also sparsely distributed between Kottai Malai and Devar Malai.

High elevation type (1400-1800 m)

Only one type was identified at this elevation: group C in the CA.

Bhesa indica – Gomphandra coriaceae – Litsea spp. Type (BGL)

This type is characterised by the presence of *Bhesa indica,* which becomes dominant above 1350 m, especially on the exposed terrain. The lower strata species *Gomphandra coriacea*, a vicarious of *Gomphandra tetrandra* of low elevation forest, strongly contributing to the CA, was used to name the type as it is very abundant, like different species of *Litsea.*

In the study area, this type is distributed along the high eastern ridge of the ghats between Kottai Malai and Devar Malai and extends further to Varushunad hills. At this elevation range, several species of the lower elevations disappear or become very rare viz. *Cullenia exarillata, Palaquium ellipticum, Diospyros* spp. and *Agrostistachys meeboldi*. The Annonaceae family, which is dominant at lower strata in both low and medium elevations, disappears completely at high elevation. Some species like *Gomphandra coriacea, Hydnocarpus alpina*, which are less important at lower elevations become significant at higher elevation range. Several other species like *Schefflera capitata, Mastixia arborea, Archidendron clyperia, Cocculus laurifolius, Acronychia pedunculata, Isonandra* spp. *Meliosma* spp., *Symplocos* spp. are also commonly found in this type.

Structurally, the forests are stunted, with two layers, and the canopy seldom exceeds 15 m.

Relationship with climatic conditions

The Table 1 summarises the climatic conditions of the different forest types. Wet evergreen forests generally occur under high rainfall (>2000 mm) and low number of dry months (<4 months). However, in the Varushanad region, the high elevation type is found under much lower precipitation (around 1500 mm). The deficit in rainfall is probably compensated by occult precipitation. Within the wet evergreen types, the decrease in temperature with the increase in elevation differentiates the low, medium and high elevation forest types.

Discussion

Comparison with other classification

Two classifications of the vegetal formations have been established for the whole of India: Legris (1963) and Champion & Seth (1968). In consideration of the scale of the work, these classifications are inadequately detailed for our study area.

The former (Legris 1963) has been prepared together with the vegetation mapping of India (1/1,000,000 scale) of which the Cape Comorin sheet (Gauseen *et al.* 1961b) comprises the entire region of our present study. In the Cape Comorin sheet, all the evergreen formations at the altitude less than 1500 m have been regrouped in the *Mesua – Palaquium – Cullenia* series. Legris (1963) described this formation as *Mesua – Palaquium – Cullenia – Dipterocarpus* series. Actually, the two species *Cullenia exarillata* and *Dipterocarpus indicus* are found together only between 600 and 850 m, as the former generally does not descend below

Table 1. Relationships between the forest types and the climatic conditions and their correspondence with the Champion and Seth's revised classification.

FOREST MAP OF SOUTH INDIA CLASSIFICATION		Annual rainfall (mm)	Temperature (°C)			Dry season (month)	CHAMPION & SETH (1968)	
			t	m	T			
Low elevation	*Dipterocarpus indicus – Kingiodendron pinnatum – Strombosia ceylanica* (DKS)	2000-5000	>20	>15	23 - 31	2 - 3	GROUP 1A Southern tropical wet evergreen forests	1A/C4. West coast tropical evergreen forests
	Dipterocarpus indicus – Dipterocarpus bourdilloni – Strombosia ceylanica (DDS)	2000-5000	>23	>17	23 - 31	2 - 4		
Medium elevation	*Cullenia exarillata – Mesua ferrea – Palaquium ellipticum – Gluta travancorica* (CMPG)	2000-5000	16 - 23	9 - 15	19 - 25	2 - 3		1A/C3. Southern hilltop tropical evergreen forests
	Cullenia exarillata – Mesua ferrea – Palaquium ellipticum	2000-5000	16 - 23	9 - 15	19 - 25	2 - 4		
High elevation	*Bhesa indica – Gomphandra coriacea – Litsea* spp. (BGL)	3000-5000	14 - 16	7 - 9	16 - 20	2 - 3	GROUP 8 – Subtropical broad-leaved hill forests	8A. Southern subtropical broad-leaved hill forests

t = mean temperature of the coldest month; T = mean temperature of the hottest month; m = mean of the minimum of the coldest month of a year; $\overline{m}$ = mean of m.

550 m and the latter does not exceed 850 m. Formations at an altitude above 1500 m are regrouped under the term "montane forest". They are characterised by many species of *Syzygium, Elaeocarpus, Symplocos, Schefflera*, and several Lauraceae. The species *Bhesa indica* that characterises this type of formation has not been mentioned.

The revised classification of Champion & Seth (1968) concerns also the whole of India (Table 1).

(i) The Southern tropical wet evergreen forests (sub-group 1A) were subdivided into two groups according to the exposure to wind and the soil and climatic conditions: the West coast tropical evergreen forests (1A/C4) and, under poorer conditions, the Southern hilltop tropical evergreen forests (1A/C3). The group 1A/C4 extends from the extreme south of India up to Ratnagiri (in Maharastra). In our study the two plains and low elevation types (DKS and DDS) and the two medium elevation types (CMPG and CMP) will enter into this group. The forests growing under the more unfavourable correspond rather to the group 1A/C3.

(ii) The formations of higher altitude were divided into two categories around 1500 m: Montane subtropical forests (sub-group 8A Southern subtropical broad-leaved hill forests) and Montane temperate forests (sub-group 11A Southern montane wet temperate forests). In the study area, the altitude does not exceed 2000 m, the sub-group 11A is therefore so limited that it has not been individualised in our classification. Our type BGL may be included in Southern subtropical hill forests of the sub-group 8A.

Chandrasekharan (1962b,c,d) proposed a more detailed classification of the forest types of Kerala based on the working plans of the Forest Department. He segregated the Low Level Evergreen forests from the High Level forests at about 450 m. The latter extends from 450 m to 1050 m. Above 900 m the Low Tropical Ghats Evergreen forests begin to appear on the upper slopes and tops of ridges. Between 1050-1200m and 1500-1650 m appear the Montane Sub-tropical forests, and above 1500 m the Montane Temperate forests. However, he recognised that there was no marked zonal differentiation between the types, as they appeared to merge directly with one another. This altitudinal zonation tallies partly with our field observations. The limit of 450 m almost corresponds to that of our DDS type, but the DKS type reaches generally 800 m, where it is replaced by the formations of medium altitudes (CMP and CMPG), without any structural change in the stand. The main structural change appears around 1400 m, sometimes at lower altitude according to the exposure that means sensibly at an altitude where Chandrasekharan demarcated the lower limit of the Montane Temperate forests.

Characteristics of the study area

The study area is one of those in India, which shows sharpest contrasts. The combined effects of a rugged relief and a heavy monsoon rain are manifested by a marked asymmetry of environmental conditions. On the one hand, the coastal zone, the western slopes and the summits receive heavy rainfall, and, on the other hand, the leeward side and the plains of Tamil Nadu are subject to drier conditions. The altitude/temperature gradient is superimposed on this first gradient. The result is the multiplication of forest types, as well as facies within the types.

The evergreen forests of this region are the richest in tree species within the western ghats (Pascal 1988). At the regional scale, it is due to the multiplicity of the forest types that, growing under different climatic conditions, contain different kinds of species (gamma diversity). But high species richness and diversity are also observed within a forest type (alpha and beta diversities). It is also in the humid forests of this area that the highest rates of endemism for the western ghats are recorded (Ramesh & Pascal 1997).

These formations, which are among the most interesting ones in India, from the point of view of their species richness, are unfortunately exposed to a very heavy anthropogenic pressure as a result of the high population density of Kerala. The rate of deforestation in this state has become considerably more serious during the last few years (Chattopadhyay 1985; Ramesh *et al.* 1996). In the coastal zone, the forests subsist only as relict patches such as the sacred groves. The forest types of low altitude are currently very much fragmented and some of the characteristic species may be considered to be on the verge of extinction. The evergreen forests, when they have not disappeared, are often in a highly degraded state, or replaced by deciduous secondary formations. The situation is not better on the eastern slope where the dry deciduous forests are regularly run

by fire and where the dry evergreen forests are affected by the excessive fuel-wood collection restricting them mostly to the most humid parts of the talwegs.

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