Floristic composition and distribution of evergreen forests in the Western Ghats, India

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After an analysis of the three main climatic gradients governing the Western Ghats region, relationships are established between the climate and the distribution of the evergreen forest types. Some cases of distribution linked to soil are also discussed. The second part deals with the distribution of species in the different evergreen forest types with particular reference to their relative importance and the relative importance of the families. Figures of species richness are compared with results obtained in other tropical rain forests, and areas with high percentage of endemism are considered. The distribution of the species within the forest ecosystem is then studied: distribution in the structural ensembles, relative density and species diversity.

Key-words—Evergreen forests, Floristic composition, Endemism, Western Ghats (India).

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सारांश

भारत में पश्चिमी घाट में सदाहरित वनों की वनस्पतिक संरचना तथा इनका वितरण

जे० पी० पास्कल

पश्चिमी घाटों की जलवायु नियंत्रित करने वाले तीन मुख्य जलवायवी कारकों के विश्लेषण से सदाहरित वनों के वितरण एवं जलवायु में पारस्परिक सम्बन्ध स्थापित किये गये हैं। इसके साथ-साथ मिट्टी के आधार पर पौधों के वितरण पर भी विवेचना की गई है। इस शोध-पत्र के दूसरे भाग में विभिन्न सदाहरित वनों में जातियों के वितरण पर विशेष सन्दर्भ सहित इनके पारस्परिक महत्व एवं कुलों के आपेक्षिक महत्व पर प्रकाश डाला गया है। उपलब्ध जातियों की प्रचुरता के आँकड़ों की तुलना अन्य उष्णकटिबन्धीय वर्षा वाले वनों तथा देशजता की उच्च प्रतिशतता से प्राप्त आँकड़ों से की गई है। वन के पारिस्थितिक तन्त्र में विद्यमान जातियों के वितरण का विस्तृत अध्ययन किया गया है।

THE Western Ghats of India provide one of the best examples in the world (together with Madagascar, and to a lesser degree, Queensland in Australia) of a belt of tropical evergreen forests spread over more than 10° in latitude, not centered over the equatorial zone.

Although they have been subjected to intense exploitation and a large part of the climax evergreen forests have already disappeared, they still form a very suitable zone for studying the limits and the conditions necessary for the development of dense wet evergreen forests, as well as the variations in their structure and floristic composition in relation to the gradual changes in the climate.

As this text is addressed mostly to palaeobotanists and palynologists, it seems appropriate to describe the major trends in the present distribution of species in the Western Ghats and within the evergreen ecosystem. Knowledge of this distribution can, in fact, provide considerable information for the reconstruction of plant formations and climates of the recent past, specially from fossil pollen.

We will limit our study to the region south of 16°N (more or less the latitude of Goa), true evergreen forests being rare and most often highly degraded to the north of this latitude. We will also restrict ourselves to arborescent species, leaving out epiphytes and herbaceous species although some of them are undoubtedly "ecological markers".

The results presented here are mostly based on the studies carried out at the French Institute, Pondicherry, most often in close collaboration with the forest departments. For more detailed information, references are given in the following paragraph.

DISTRIBUTION OF THE NATURAL EVERGREEN FORMATIONS OF THE WESTERN GHATS

The different formations of the Western Ghats have been mapped under the programme "Forest map of south India", at a scale of 1 : 250,000 (Pascal, 1982a, b, 1984, 1986). This work followed the publication of a map of Peninsular India on a smaller scale 1 : 1,000,000 (Gaussen *et al.*, 1961, 1965a, b). For these projects, studies were carried out on the bioclimates of the Western Ghats (Pascal, 1982c) and on the structure, floristic composition and dynamism of the evergreen forests of the Ghats (Pascal, 1988). These publication give an idea of the relationships existing between the different evergreen forest types and the natural environmental conditions.

The distribution of forests is essentially dependent on three climatic parameters: total amount of annual rainfall, length of the dry season and minimum temperature. Locally, however, edaphic conditions become the determining factors.

Relationships between climate and plant formations

These relationships are mainly along three gradients: west-east, south-north and altitudinal gradients.

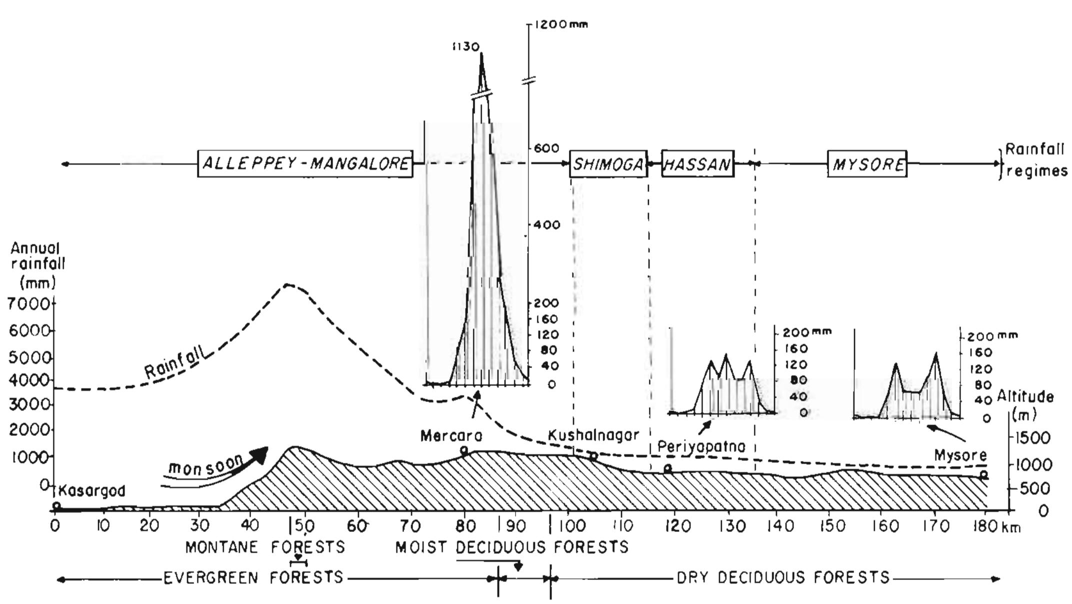
West-east rainfall gradient

The rains accompanying the monsoon are, however, very unevenly distributed from the coast to the interior of the plateau. Text-figure 1 illustrates this phenomenon at the latitude of Mercara: high rainfall in the coastal region (3500-4000 mm); effect of the Western Ghats barrier on precipitation which exceeds 7000 mm at the edge of the Ghats; rapid diminution in the amount of rainfall on the leeward side of the Ghats (from 7000 to 2000 mm over just 35 km). The rainfall is not more than 1186 mm in Kushalnagar (105 km from the coast) and is only 767 mm in Mysore (180 km). From Peryapatna onwards (120 km from the coast), the main source of rainfall is no more the S.W. monsoon, but convectional air currents, as can be clearly seen in the rainfall diagram of Mysore (Text-fig. 1).

The rapid decrease in the monsoon rainfall towards the interior is observed throughout the Ghats. It determines the eastern limit of the expanse of dense wet evergreen forests which is generally situated near the 2000 mm isohyete. The regime is always characterised by a preponderance of the S.W. monsoon rains. Moist deciduous forests dominate between 2000 mm and 1500 mm followed eastwards by several dry deciduous forest types with less than 1500 mm. Regions with low rainfall support only more or less high and dense thickets.

South-north gradient : lengthening of the dry season

The south-west monsoon arrives at the southern tip of India by the end of May and usually has



Text-figure 1—Relationships between rainfall distribution and climax plant formations.

already passed Bombay by 10th June. The withdrawal is more gradual, taking about 21/2 months. These phenomena result in a decrease in the duration of the rainy period from south to north and naturally a concomittant lengthening of the dry period. It is this gradient which, within the total rainfall limits necessary for evergreen forests, is responsible for the variations in the floristic composition of the forest continuum with latitude. When the dry period exceeds 7 months, whatever the rainfall regime, the wet evergreen forest disappears.

Altitudinal gradient

The elevation of the Ghats is variable. A large part of the crest north of 13°30'N does not exceed 650 m. The reliefs are more pronounced in the south, attaining a height of 2695 m in the Anaimudi peak. The effect of the temperature gradient, which is linked to altitude, is therefore not uniform in all the places. Differences in exposure (leeward, windward and phenomena linked to crest) should also be taken into account.

Generally, the mean temperature of the coldest month ranges from 25°C at sea level to 11°C at 2400 m. The gradient is steeper for the mean minimum temperature of the coldest month: 23°-6°C.

As the evergreen forests are found almost up to the summit of the Ghats, the decrease in temperature determines two kinds of changes:

— structural changes from high forests (canopy higher than 30 m) to low forests (canopy lower than 20 m or sometimes 15 m);
— changes in the floristic composition: low and medium elevation types in high forests and Lauraceae formations and "montane sholas" in low forests.

Distribution linked to soil

A comparative study of the distribution of evergreen forests and the bioclimate of the Western Ghats has brought to light some anomalies in the distribution of forests with regard to the climate.

— Some evergreen, or semi-deciduous forests are, in fact, found in regions where rainfall is usually suited to moist deciduous forests (between 1850 & 1750 mm). The reasons for these anomalies are varied, but generally the deficit in rain water is compensated in some way or the other. In Karian Shola in the Anaimalai, the evergreen formation is found at the foot of a mountainous peak which constitutes a kind of water tower benefiting the forest by lateral supply.

The case of the evergreen and semi-deciduous islets surrounded by moist deciduous forests in Sorab region (Karnataka), locally called Kan forests, is still different (location in Text-fig. 2). The forests grow on gravelly ferrallitic soils which have a fairly good water holding capacity and release water gradually during the dry season. Hence they can withstand dry seasons of 5-7 months with rainfall of about 1800 mm (Bourgeon & Pascal, 1986; Pascal *et al.*, 1988).

— The opposite is also common: certain regions where the climate and topography would ideally favour an evergreen forest, support only low formations: like tree or grass savannas or low thickets. This is generally due to certain soil characteristics which hinder the development of a dense forest: very shallow soils or hardening of the soils or yet gradual exposure of the hardened layer.

Such examples are observed on the hills between the Ghats and the coast (particularly in South Kanara), on the Western side of the plateau (Agumbe, Kodachadri, hills near the latitude of Goa, etc.) and even to the west of Sorab. They form gaps in the forest continuum which are very often enlarged by human action.

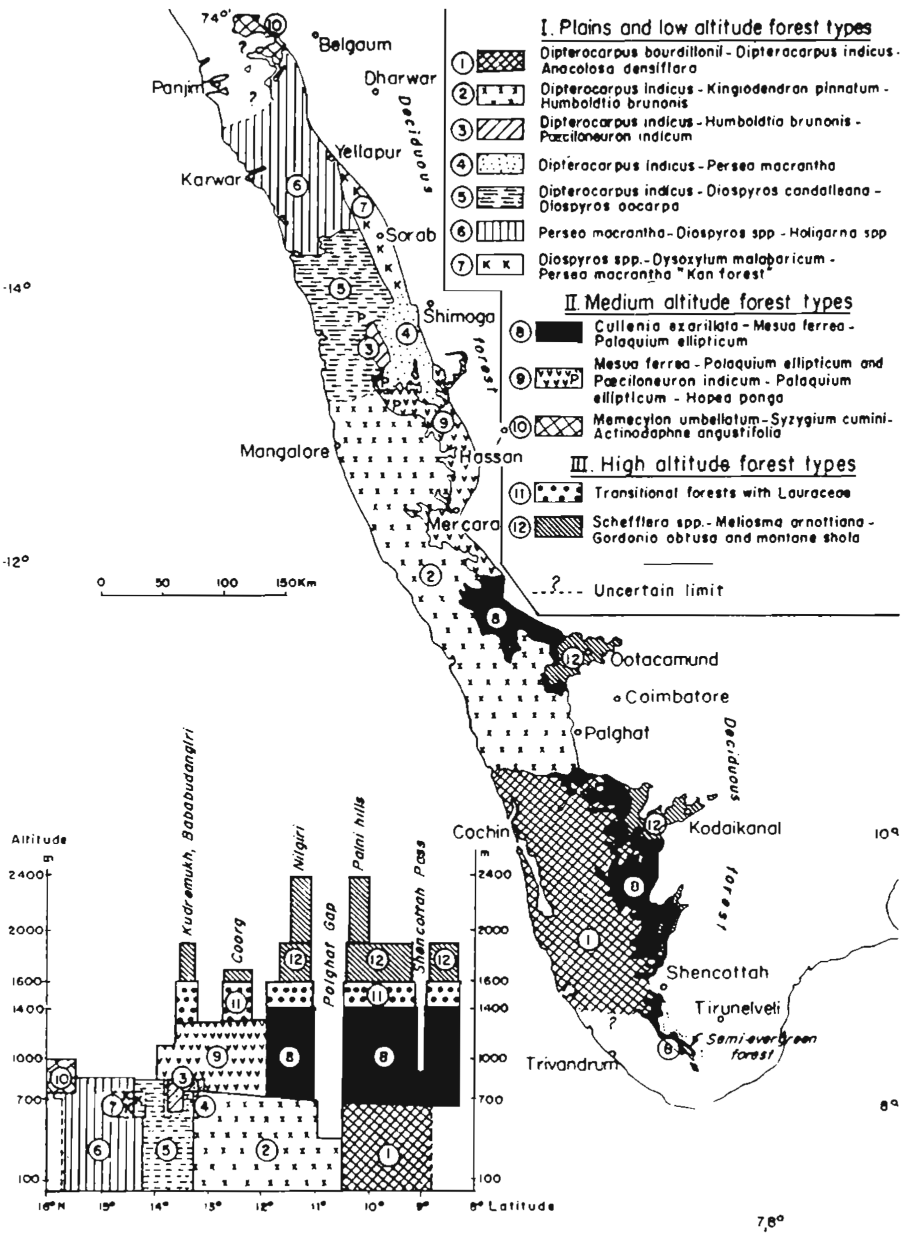
— Another type of anomaly concerns not the nature of the formations but their floristic composition and the relative densities of the species. For example, the floristic richness of some forests is abnormally low for an evergreen forest with a dominance of a small number of species. Such is the case of the *Poeciloneuron indicum* forest in Bhagvati region, where this species locally represents 80-100 per cent of the big trees. It is quite probable, but not yet proved, that the high concentration of *Poeciloneuron* is due to an edaphic peculiarity.

These examples show that at times there exists a discrepancy between the climate and the nature of the plant formations. This discrepancy is generally not very common and often affects only small areas. It can, however, lead to erroneous conclusions while reconstructing the climate with evidence from fossil pollen.

Climates of the evergreen forest types of the Western Ghats

The evergreen continuum is divided into different forest types based on their structure (high and low forests), floristic composition, relative density of species, etc.

The potential area under each of these forest



Text-figure 2—Distribution of potential area of the major evergreen forest types in the Western Ghats.

types according to latitude and altitude is shown in Text-figure 2. The potential area is derived from climatic criteria. Edaphic conditions which locally do not permit the development of dense forests are not considered at the small scale of the map in Text-figure 2. Thus mangroves are not depicted. This figure does not show the present distribution which is greatly reduced, especially in the coastal zone, but in a way shows the probable maximum extent which existed prior to destruction by man.

The continuum is thus divided into 13 major types. Seven types in the plains and low elevations (less than 850 m), one of which is determined more by the water holding capacity of the soil than by the regional climate.

These are replaced by 4 medium elevation types (850-1400 m) which after a transitional zone, are followed by 2 high elevation types (1250-2400 m). The overlappings in the altitudinal gradation arise out of differences in exposure and from the discrepancy induced by the lengthening of the dry season towards the north.

The principal relationships between these forest types and the climate are summarized in Table 1. Contrary to observations in Africa, the evergreen formations tolerate fairly long dry seasons. For

Table 1—Relationships between the climax forest types and bioclimates

				Altitude (m)	Latitude	RAINFALL (mm)	TEMPERATURE (C°) t	m̄	T	DRY SEASON (month)
EVERGREEN AND SEMI EVERGREEN CLIMAX FORESTS	High forests	Low elevation types	Dipterocarpus bourdillonii Dipterocarpus indicus - Anacolosa densiflora	0 to 600/700	8°50' to 10°30'	2000-5000	>22	>15	25—30	2—4
			Dipterocarpus indicus - Kingiodendron pinnatum - Humboldtia brunonis	0 to 650/750	10°30' to 13°15'	2000-6000	>20	≥14	25-31	4—5
			Dipterocarpus indicus - Humboldtia brunonis - Poeciloneuron indicum	700/750 to 850	13°05' to 13°45'	5000-8000	>20	≥12.5	25-27	4.5 slope 5-5.5 plateau
			Dipterocarpus indicus - Persea macrantha	650 to 850	13°10' to 13°50'	>2000	20-23	13-16	25-29	5—6
			Dipterocarpus indicus - Diospyros candolleana - Diospyros oocarpa	0 to 850	Coastal and slope:13°15' to 14°15' plateau:13°45' to 14°25'	3500-7000	>20	>15	25-30	5-6 slope 6-7 plateau
			Persea macrantha - Diospyros spp. - Holigarna spp.	0 to 750/800	Coastal and slope:14°15' to15°45' plateau:14°25' to 15°45'	2000-6000	>23	≥15	28-31	6—7
			Diospyros spp. Dysoxylum malabaricum - Persea macrantha = Kan forest	550 to 750	14°10' to 14°45'	1500-2000	23-24.5	>18	26.5-28.5	6—7
		Medium elevation types	Cullenia exarillata - Mesua ferrea - Palaquium ellipticum	600/700 to 1400	8°20' to 11°55'	3000-5000	16-23	9-18	24-25	2—5
			Mesua ferrea - Palaquium ellipticum	850(W)750(E to 1250/1300	11°55' to 13°30'	2000-5000	17-22	<15	23-25	4—5
			Poeciloneuron indicum - Palaquium ellipticum - Hopea ponga	idem	13°05' to 13°25'	5000-7000	18-20	<15	23-25	4—5
	Low forests		Memecylon umbellatum - Syzygium cumini - Actinodaphne angustifolia	700/800 to 850/1400	15°30' to 19°45'	5000-6500	17-22.5	<15	25-30	5—7
		High elevation types	Sub-montane : Schefflera spp. - Meliosma arnottiana - Gordonia obtusa	1250 to1800		≥2000	13.5-17	9-13	20-25	3—6
			Montane : Shola type	>1800		900-6000	<13.5	<10	16-20.5	0—4

t = mean temperature of the coldest month; T = mean temperature of the hottest month
m = mean of minimum of the coldest month of a year; m̄ = mean of m

example, the *Persea macrantha-Diospyros* spp. *Holigarna* spp. type, located between 14°15′ and 15°45′N latitudes, remains perfectly evergreen while the dry season approaches 7 months. However, one must take into account the water supply from the almost daily occult precipitation (for example, dew) over the plateau. In fact, the dry season calculated regionally does not truly reflect the dryness effectively endured by the trees of the forest which is less.

Microclimatic studies carried out in the Attapadi fst (Kerala) where the regional dry season is 4 months have shown that the mean saturation deficit in the undergrowth exceeds 6 mm of Hg during only 3 months in the year and almost never exceeds 10 mm. Even during these 3 months, the soil moisture is always much higher than the pFp. We may therefore conclude that the direct effect of the dry season on the undergrowth is very reduced. These values correspond quite well with those recorded in an evergreen forest in Africa (Cachan & Duval, 1963). It would be interesting to carry out similar studies in a forest of the Western Ghats with a dry season of about 7 months to estimate the actual length and intensity of water stress.

Whatever the intensity of water stress, the variations in the floristic composition of the different forest types are due to the increase in the duration of dry season with latitude and reduction in temperature with altitude.

SPECIES DISTRIBUTION IN THE DIFFERENT EVERGREEN FOREST TYPES

Only arborescent species for which sufficient data are available to attempt a synthesis, are considered. Little is known about the distribution of herbs, lianes and epiphytes for their inclusion here.

Distribution of species in the continuum

The areas of distribution of 127 arborescent species are schematized in Text-figure 3. High altitude formations (1400 m) are not included in this diagram.

54 per cent of the species are found throughout the Ghats (up to 16°N) with an altitudinal zonation (Text-fig. 3 g). Thus these species have a high degree of tolerance to the variations in ecological conditions. They constitute a kind of pool of species common to the different forest types of low and medium elevations. They increase in number with the lengthening of the dry season as a consequence of the gradual disappearance of the less tolerant species.

This group, however, is not homogeneous: some species are confined to banks of river courses (*Bischofia javanica, Elaeocarpus tuberculatus, Vepris bilocularis*...). Others thrive in openings and often behave as pioneer species (*Aporosa lindleyana, Callicarpa tomentosa, Clerodendrum viscosum, Leea indica, Macaranga peltata, Mallotus philippensis, Olea dioica*, etc.). Also these are the species which replace the sensitive species in the large openings consequent to exploitation.

— In contrast, 24 per cent of the species are not, or rarely, found north of the latitude of the Palghat Gap and are confined to regions with a dry season of less than 3 months (Text-fig. 3-a, b). Some species do not extend beyond 9°30′N latitude. Thus they are the species with low ecological amplitude which constitute excellent ecological "markers" for determining the past climates from pollen core samples. Some are confined to small areas where they are common (*Humboldtia vahliana, Hopea utilis, Gluta travancorica, Bentinckia coddapanna, Vernonia travancorica*, etc.). Others are found in larger areas but are rarer (*Taraktogenos macrocarpa, Dysoxylum ficiforme*).

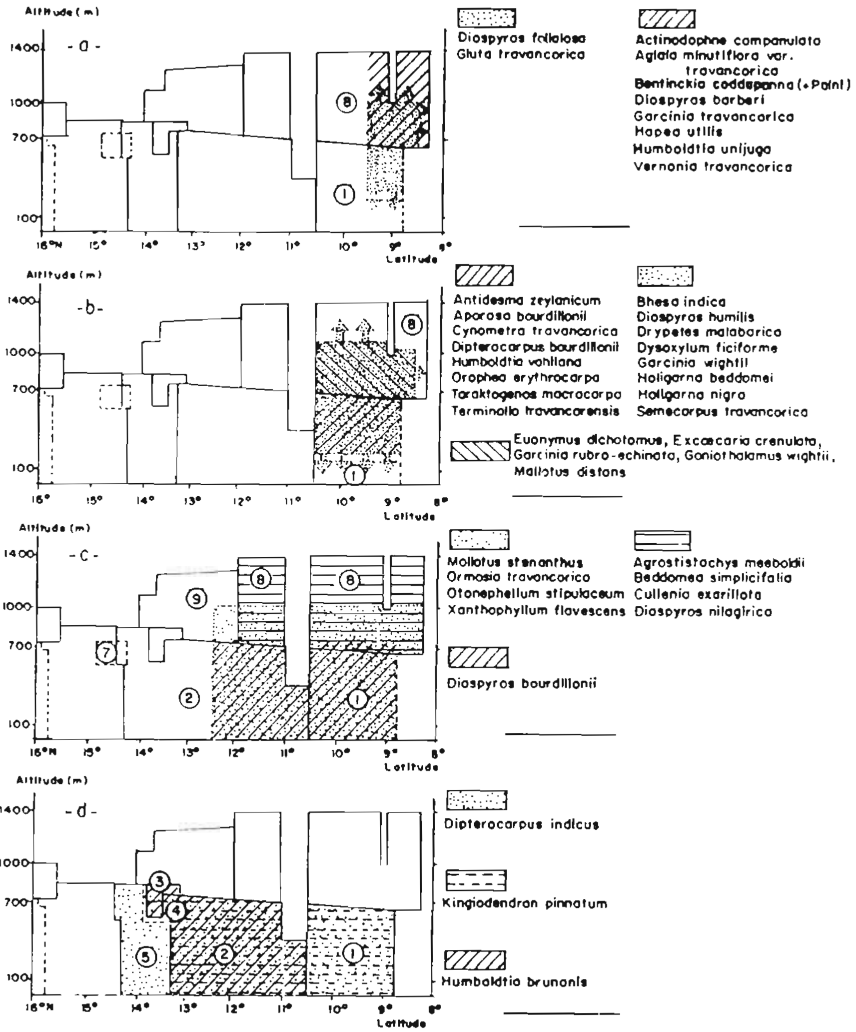
— The area of distribution of 18 per cent of the species is between these two extremes (Text-fig. 3 c, d, e). Their altitudinal gradation, however, indicates different ecological requirements. Thus *Kingiodendron pinnatum* and *Otonephelium stipulaceum* are hardly found above elevation of 650 m, *Dipterocarpus indicus, Drypetes elata, Diospyros bourdillonii* above 850 m; *Vateria indica* above 1100 m; *Mesua ferrea* is more common between 500 and 1200 m, while *Cullenia exarillata* is not found below 600 m.

Lastly, a small number of species (4%) are found in regions with a long dry season (Text-fig. 3f). Some of these species may be found here and there in lower latitudes but become common only at higher latitudes, e.g., *Garcinia talbotii, Diospyros oocarpa*.

Distribution of species in the different forest types

The appearance and disappearance of species in accordance with latitude and altitude determine various floristic compositions, enabling the distinction of the evergreen forest types.

The passage from one forest type to another is generally not abrupt but through a transitional zone which may or may not be spread out in latitude and



Text-figure 3—Distribution of the important species of the dense evergreen forests of the Western Ghats.

altitude. Some species appear or disappear within the same forest type. These variations in the floristic composition of the evergreen forest types can, nevertheless, be schematized (Text-fig. 4).

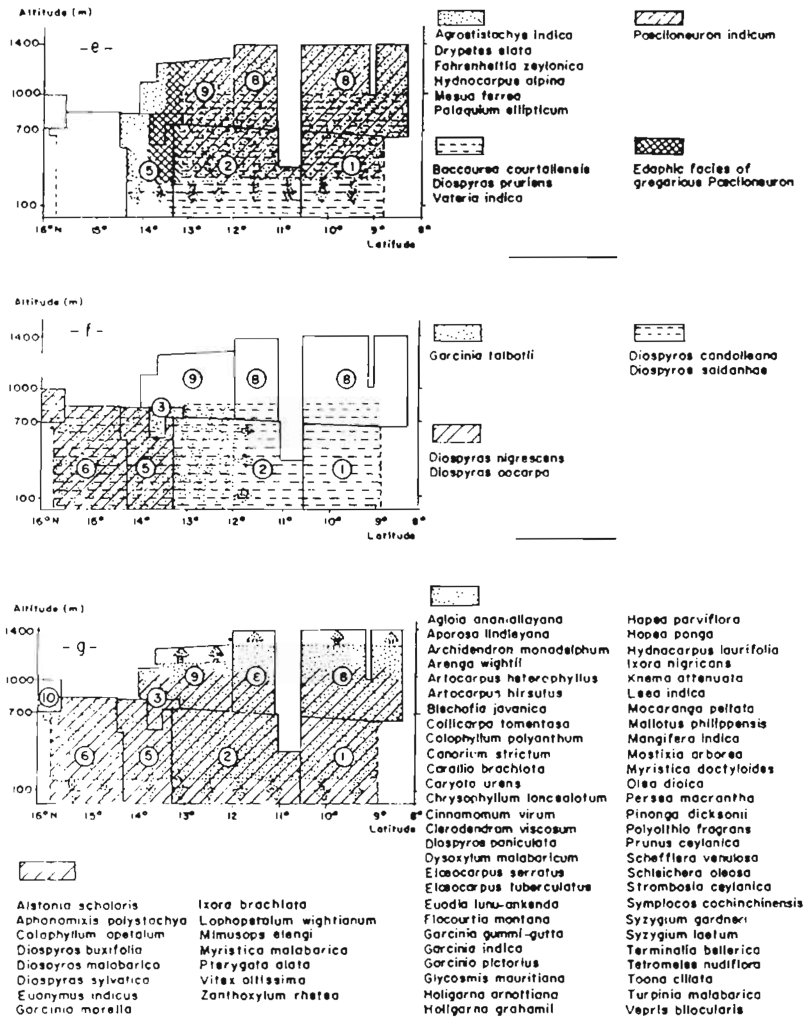
Some general trends can be deduced from this diagram.

— The passage from an evergreen type of the plains or low elevation to another (1 and 2; 2 and 5; 5 and 6) is marked by the disappearance of a small proportion of species between 17.8 and 27.5 per cent. This loss is compensated by the appearance of more or less the same number of new species.

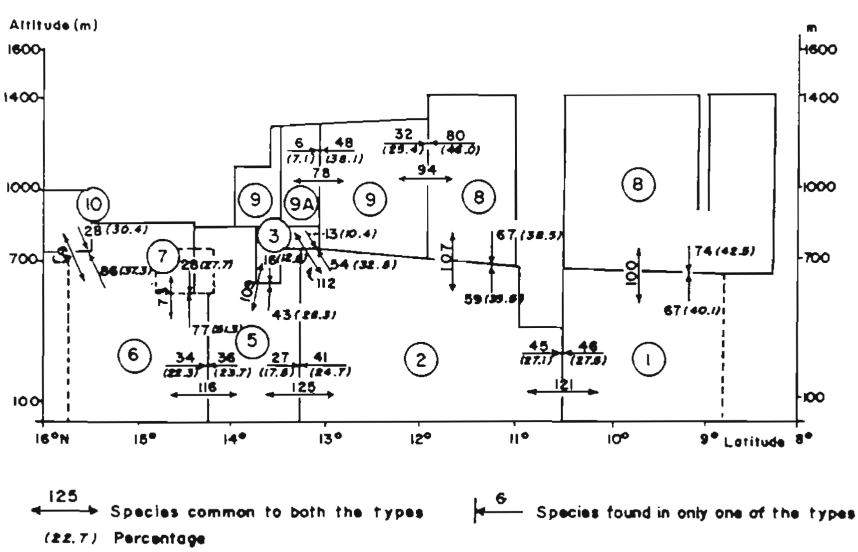
— The passage from a low to medium elevation type is also marked by almost proportionate disappearances and appearances, but the percentages are higher: between 35.5 and 42.5 per cent (1 and 8; 2 and 8). The decrease in temperature entails an important change in the floristic composition. The temperature gradient being generally rapid (fairly steep slope), its effect is more pronounced than that of an increase in the duration of the dry season which is more gradual.

— The passage from one medium elevation type to another is more pronounced than that between the low elevation types. This can be explained by the cumulative selective effect of the fall in temperature and increase in the duration of the dry period which can support only some species.

— When the changes from one type to another are accompanied by a change in edaphic conditions (6 and 7; 6 and 10), the percentage of species which disappear is very high (between 37 and 57.3 per cent) and is not accompanied by the appearance of an equivalent number of new species. In fact, the peculiar edaphic conditions are often very constraining and therefore play a highly



Text-figure 3(contd.)—Distribution of the important species of the dense evergreen forests of the Western Ghats (The legends of the forest types is given in Text-fig. 2)



-Only species with girth ≥ 10 cm are considered.

—The legend of the forest types is given in Text-figure 2

Text-figure 4—Variations in the floristic composition of the different forest types of the Western Ghats (low and medium elevations).

selective role: generally very few species can adapt to these edaphic conditions.

Relative importance of species

The existence of a species pool with species common to the different evergreen types and disappearance-appearance percentages (often less than 40%) from one type to another may lead to the conclusion that these forest types are quite similar. In fact, they are quite different because apart from the differences in their floristic composition, differences also exist in the relative densities of species (number of individuals of a species in a given area). The distribution of species in the south north continuum are considered now; the distribution of species within the forest ecosystem will be dealt with later.

By taking into account the number of individuals of the same species, basal area of these individuals (area of the trunk at a height of 1.30 m from the ground) and their distribution in the forest, it is possible to define the importance value index (IVI) of each species or of a botanical family (by grouping together the IVI of species of the same family). Table 2 compares the IVI (calculated according to the method of Curtis and McIntosh, 1950, 1951) of the first 5 species and of the first 10 according to their rank of importance. This corresponds to 53.8 to 71.7 per cent and 66.5 to 87.2 per cent of the trees, respectively, depending on the forests.

The majority of the forest types have none or only one species in common among the 10 most important species. The maximum observed is 2 species in common among the 5 most important ones. The differences in the distribution of species is therefore more marked than that which can be anticipated by the floristic composition alone. This point should also be considered (with the properties of preservation of pollen) when defining the different forest types from pollen borings.

Relative importance of families

The relative importance of botanical families can be obtained from the IVI of the species.

Evergreen types of plains and low elevations

(i) Dipterocarpaceae is the dominant family up to the northern part of the *Dipterocarpus-Diospyros-Diospyros* type (14°25′N). An interesting floristic relationship can be recognized between the forests of the plains and low elevations of the Western Ghats and the Dipterocarpaceae formations of South-East Asia (Ashton, 1964; Whitmore, 1975). Among the Dipterocarpaceae species common in the Western Ghats are:

— *Dipterocarpus indicus, Hopea parviflora, Hopea ponga* with fairly wide distribution.
— *Vateria indica* which is more important than even *Dipterocarpus* in the *Dipterocarpus-Kingiodendron-Humboldtia* type, but is hardly found to the north of this type (about 13°20′N).
— *Dipterocarpus bourdillonii*, confined to Travancore.

Dipterocarpaceae is also dominant in the semi-deciduous formations of the low elevations of Tirunelveli Hills where *Hopea*, particularly *H. utilis*, becomes very dominant, replacing *Dipterocarpus*.

(ii) This resemblance to the forests of South-East Asia is not found to the north of the *Dipterocarpus-Diospyros* type where the most important family is Ebenaceae.

The *Poeciloneuron* facies, which are considerable in Karnataka, are peculiar: the importance of Clusiaceae, to which *Poeciloneuron* as well as *Garcinia, Mesua* and *Calophyllum* belong, is equal to or even more than that of Dipterocarpaceae.

(iii) Among the other important families of low elevations may be cited:

— Fabaceae in a wider sense, and Caesalpiniaceae in particular, with *Kingiodendron* (big tree) and *Humboldtia brunonis* (undergrowth). The

Table 2—Comparison of the relative importance of species between the forest types

	2	5	6	8	10
2		2(2)	0(0)	0(3)	0(0)
5			0(1)	1(2)	0(0)
6				0(0)	0(0)
8					0(0)

2,5,6,8,10: forest types *(see legend Fig.2)*

0: number of species common to two types with the 5 highest IVI

(0): number of species common to two types with the 10 highest IVI importance of this family decreases with that of Dipterocarpaceae.

— Myristicaceae, which is found in all types, has more or less the same importance everywhere.
— The importance of Euphorbiaceae varies greatly from one type to another. The presence of *Drypetes, Fahrenheitia* and *Mallotus* makes this family quite important in the southern types, but it is more important in some *Poeciloneuron* facies due to the abundance of two moderate sized species: *Agrostistachys indica* and *Cleistanthus malabaricus.* In contrast, it is poorly represented to the north of the *Dipterocarpus-Diospyros-Diospyros* type (most of the preceding species having disappeared), where some heliophilous species of Euphorbiaceae like *Macaranga peltata* and *Aporosa lindleyana* become more abundant. The last mentioned species gives the family great importance in disturbed semi-deciduous or secondary formations.
— The importance of Anacardiaceae, which is always present, varies from one place to another.
— Myrtaceae is always well represented. It includes species of top layer (structural ensemble I, SE I) as well as of the lower structural ensembles.
— The importance of Meliacae is more or less the same as that of Myrtaceae in all the types.
— Some families are always, or almost always, well represented in the undergrowth, but rarely have big trees: Rutaceae, Celastraceae, Melastomataceae (Melastomaceae). This is also the case with Rubiaceae, where *Psychotria, Ixora, Saprosma* and *Lasianthus*, for example, are very common, but contrary to the situation in deciduous forests, have only moderate sized tree species in evergreen forests: *Neonauclea, Tricalysia,* etc.
— Lastly, a number of families are represented by a small number of species or genera with big or moderate sized trees, quite common in most of the types: Sapotaceae (*Palaquium, Mimusops*), Flacourtiaceae (*Hydnocarpus, Flacourtia*), Lauraceae (*Cryptocarya, Cinnamomum, Litsea, Persea*), Sapindaceae (*Dimocarpus, Otonephelium*), Annonaceae (*Polyalthia, Meiogyne*), Elaeocarpaceae (*Elaeocarpus*).

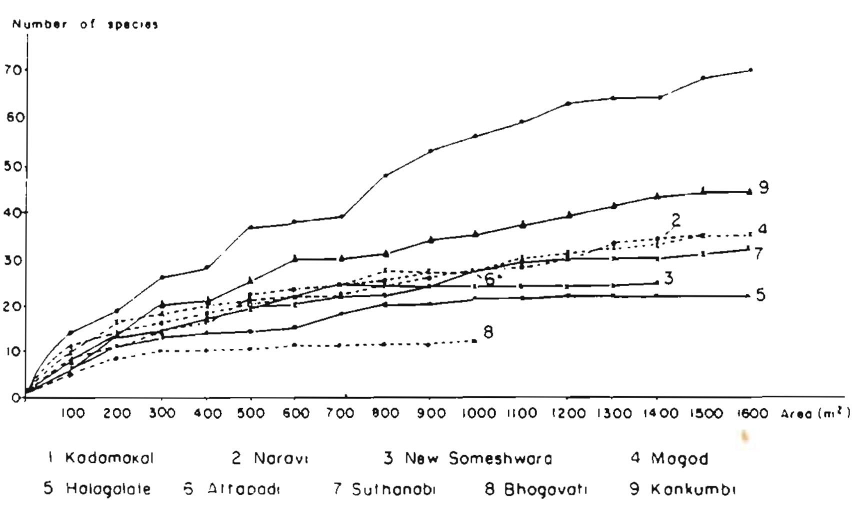
Evergreen types of medium elevations

The floristic composition changes completely with altitude. The Dipterocarpaceae and Ebenaceae which dominate successively from south to north at low elevations, have only a subdued role.

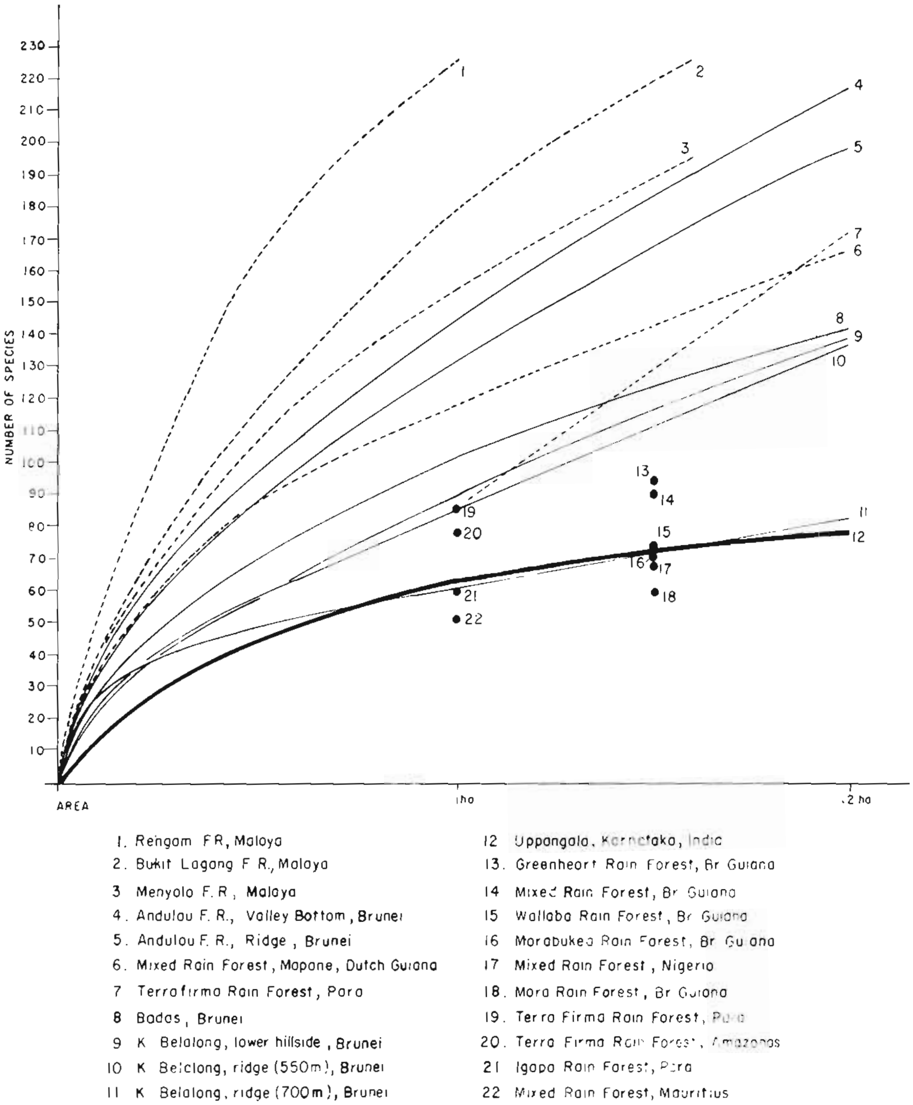
(i) In the *Cullenia-Mesua-Palaquium* type, the most important families are Bombacaceae (uniquely by *Cullenia*), Sapotaceae (particularly *Palaquium*) and Clusiaceae (*Mesua, Calophyllum*), in addition to Meliaceae (*Aglaia anamallayana*-small trees of SE II and III) and Euphorbiaceae (*Agrostistachys, Mallotus, Drypetes*).

(ii) In the *Mesua-Palaquium* type, *Cullenia* has disappeared and with it the importance of Bombacaceae. The other 4 families remain preponderant.

(iii) A few families are found in all the medium elevation types: Elaeocarpaceae, Myristicaceae (whose IVI is comparable to that of low elevation forests), Myrtaceae



Text-figure 5—Species-area curves (girth ⩾ 10 cm) of 9 forests of the Western Ghats.



Text-figure 6—Species-area curves of some wet evergreen forests, for trees exceeding 12 inch girth (after Ashton, 1964).

(comprising big and small trees), Lauraceae (more abundant with increase in altitude), Flacourtiaceae, Staphyleaceae (*Turpinia*), Sapindaceae, Anacardiaceae, Symplocaceae and Dipterocarpaceae (*Hopea*).

Some families such as Icacinaceae (*Gomphandra*) and Rubiaceae are represented only by small trees and their IVI do not correctly convey their constant presence.

(iv) In the *Poeciloneuron* facies, Clusiaceae is the dominant family mostly due to *Poeciloneuron indicum* as well as to *Garcinia, Calophyllum* and *Mesua*. Sapotaceae (*Palaquium*) remains relatively important till the conditions become too constraining. The same is the case with Dipterocarpaceae represented here by *Hopea*, particularly *H. ponga*. The importance of Euphorbiaceae in these facies is enhanced by the abundance of *Cleistanthus malabaricus* and *Agrostistachys indica*. The same is the case for Annonaceae with *Meiogyne pannosa* and Rubiaceae with *Psychotria* spp. and *Lasianthus*. On the other hand, the importance of Meliaceae is greatly reduced.

(v) The *Memecylon-Syzygium-Actinodaphne* type shows a complete floristic change. Melastomataceae, thanks to *Memecylon*, constitutes by far the most important family, ahead of Myrtaceae (*Syzygium*), Oleaceae (*Olea dioica*) and Lauraceae (*Cinnamomum* and *Actinodaphne*). Rubiaceae, which is very common in the undergrowth (*Psychotria, Ixora*), also occupies an important place in this formation.

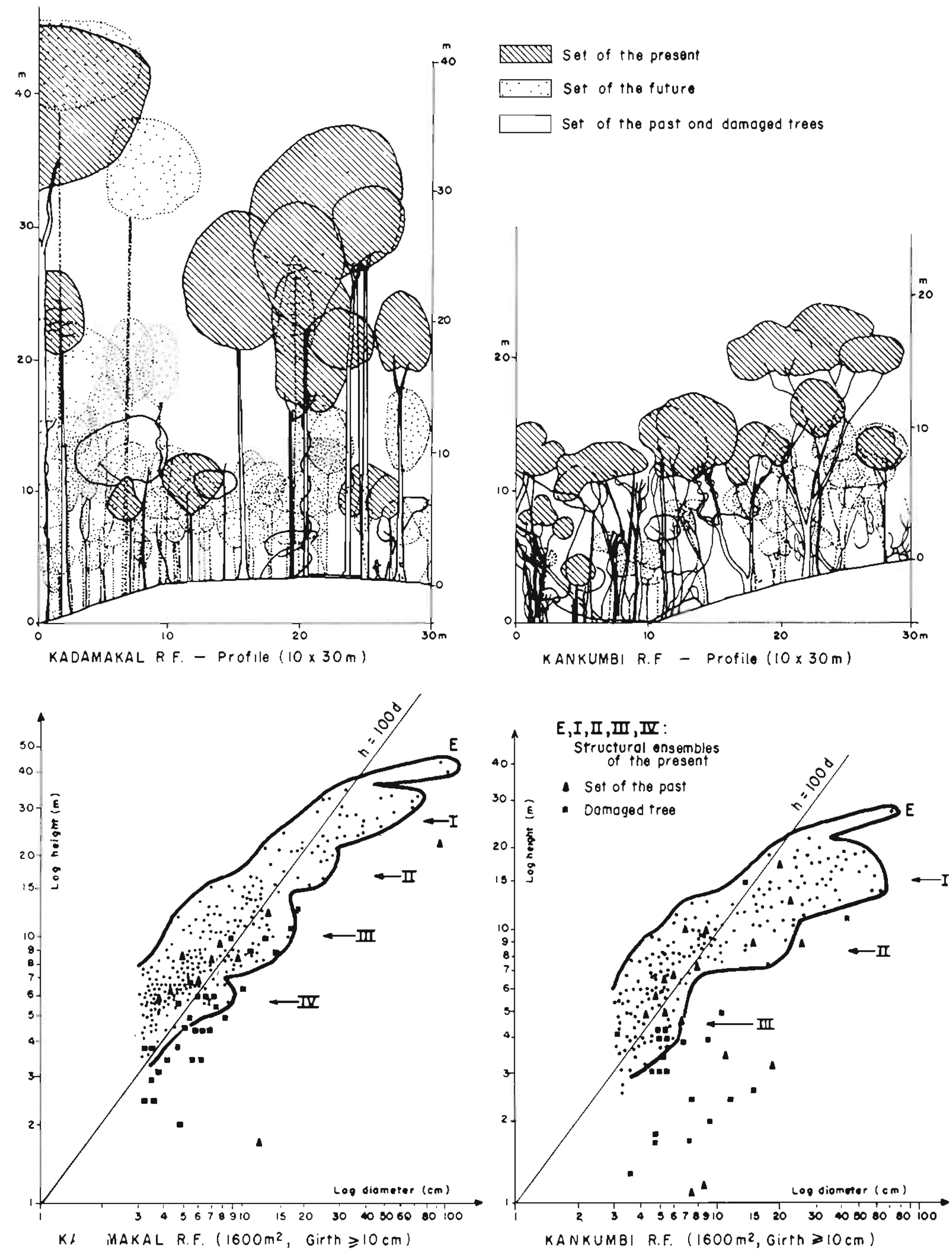
The global floristic variations are therefore much more pronounced than structural variations. Highly varied floristic compositions correspond to similar structures.

Global floristic variations are expressed at the family level:

— gradual changes at low elevations, Dipterocarpaceae-Caesalpiniaceae forests being replaced by Ebenaceae forests;

— distinct changes between low and medium elevations, with the appearance of Bombacaceae-Meliaceae-Sapotaceae-Clusiaceae forests (and then forests without Bombacaceae).

— profound modifications linked to particular



Text-figure 7—Profiles and structural ensembles in a high forest (Kadamakal) and a low forest (Kankumbi) of the Western Ghats (after Pascal, 1984).

Table 3—Distribution of the most common tree species according to Structural Ensembles in Kadamakal Forest in Karnataka

ENSEMBLE I & EMERGENTS	ENSEMBLE II	ENSEMBLE III
Artocarpus hirsutus	*Actinodaphne malabarica*	*Acronychia pedunculata*
Calophyllum polyanthum	*Aglaia anamallayana*	*Agrostistachys indica*
Chrysophyllum lanceolatum	*Aphanamixis polystachya*	*Archidendron monadelphum*
Cryptocarya bourdillonii	*Diospyros crumenata*	*Atalantia wightii*
Dimocarpus longan	*Diospyros pruriens*	*Baccaurea courtallensis*
Diospyros bourdillonii	*Flacourtia montana*	*Blachia denudata*
Diospyros sylvatica	*Garcinia gummi-gutta*	*Blachia umbellata*
Dipterocarpus indicus	*Garcinia indica*	*Casearia ovata*
Drypetes elata	*Garcinia morella*	*Croton malabaricus*
Dysoxylum malabaricum	*Hydnocarpus alpina*	*Dichapetalum gelonioides*
Fahrenheitia zeylanica	*Litsea floribunda*	*Euonymus indicus*
Holigarna arnottiana	*Litsea stocksii*	*Gomphandra tetrandra*
Hopea parviflora	*Nothopegia racemosa*	*Goniothalamus cardiopetalus*
Kingiodendron pinnatum	*Otonephelium stipulaceum*	*Harpullia arborea*
Knema attenuata	*Polyalthia cerasoides*	*Humboldtia brunonis*
Lophopetalum wightianum	*Trichilia connaroides*	*Ixora nigricans*
Mangifera indica	*Walsura trifolia*	*Leptonychia moacurroides*
Mastixia arborea		*Mallotus beddomei*
Mesua ferrea		*Mallotus stenanthus*
Myristica dactyloides		*Meiogyne pannosa*
Myristica malabarica		*Memecylon angustifolium*
Palaquium ellipticum		*Memecylon malabaricum*
Persea macrantha		*Memecylon wightii*
Pterygota alata		*Microtropis stocksii*
Strombosia ceylanica		*Neonauclea purpurea*
Syzygium gardneri		*Nothopegia beddomei*
Vateria indica		*Pinanga dicksonii*
		Psychotria dalzelli
		Psychotria nigra
		Syzygium laetum

facies : *Poeciloneuron* facies; semi-deciduous forest constituting a secondary climax with Melastomataceae-Myrtaceae.

SPECIES RICHNESS AND ENDEMISM

Species richness

In a homogeneous forest type, the floristic richness can be assessed with the help of species-area curves which show the total number of species in relation to area.

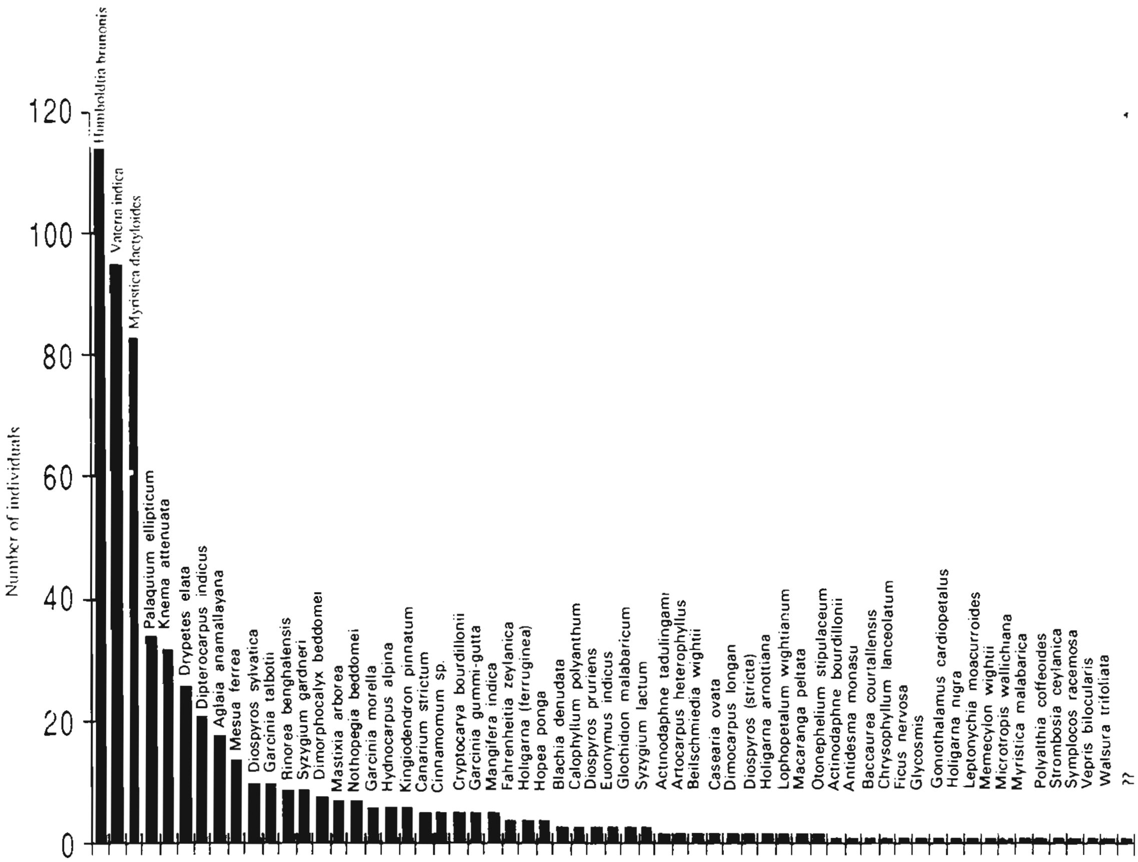
The curves obtained for species with a lower girth limit of 10 cm in small plots (between 1000 and 1600 m²) in evergreen forests of the Western Ghats are shown in Text-figure 5.

Three types of curves can be distinguished:

- a plateau is quickly attained indicating that a majority of the species have already made their appearance in the area studied. The forests here have low floristic richness: Bhagavati corresponds to a crest facies exposed to wind with probably some unfavourable edaphic conditions; New Someshwara corresponds to a forest on a very steep slope; Halagalale is a Kan forest growing in a region with rainfall less than 2000 mm and dry season exceeding 6 months.
- there is no plateau but the slope of the curve is gentle. This is the most common case in the Western Ghats at low (Naravi) as well as medium (Attapadi) elevations.
- the slope is still steep-observed in only 1 of the 9 forests, viz., Kadamakal (in Coorg, Karnataka), where 70 species ($G \geq 10$ cm) are encountered in an area of 1600 m².

The floristic richness of the Western Ghats forests is thus varied and, as a general rule, is higher when the dry season is short and decreases when the forest corresponds to a special facies (steep slope, unfavourable edaphic conditions, etc.).

The floristic richness of the forests of the Western Ghats is compared with those of similar formations in different parts of the world (Text-fig. 6). Data from the forests of Brunei, Malaysia, Amazon and Africa published by various authors is assembled in this figure taken from Ashton (1964) and supplemented by the values obtained in an area of 2



Text-figure 8—Number of individuals per species in 1 ha of Uppangala forest (Karnataka, G ⩾ 30 cm).

ha in Uppangala forest (Coorg, Karnataka) and with the same lower girth limit (DBH ⩾ 10 cm). This forest, which forms part of the Kadamakal RF, is a good example to illustrate the maximum floristic richness attained in the Western Ghats.

The floristic richness of Uppangala forest is among the lowest values shown in Text-figure 6. It is similar to those of the forests of Africa, Mauritius and some forests of Amazon. But generally, the floristic richness of the Amazon forests and specially of the forests of Brunei and Malaysia is double and sometimes even more than three times higher. The highest values recorded till now are in forests of the Malaysian peninsula: Rengam 227 species/ha; Bukit Lagong 227 species/2 ha (Wyatt Smith, 1949). The values obtained in Papua New Guinea (Peijmans, 1970) and Gabon (Hallé *et al.*, 1967), for example, confirm that the evergreen forests of the Western Ghats and of Africa are among the poorest in terms of the number of species.

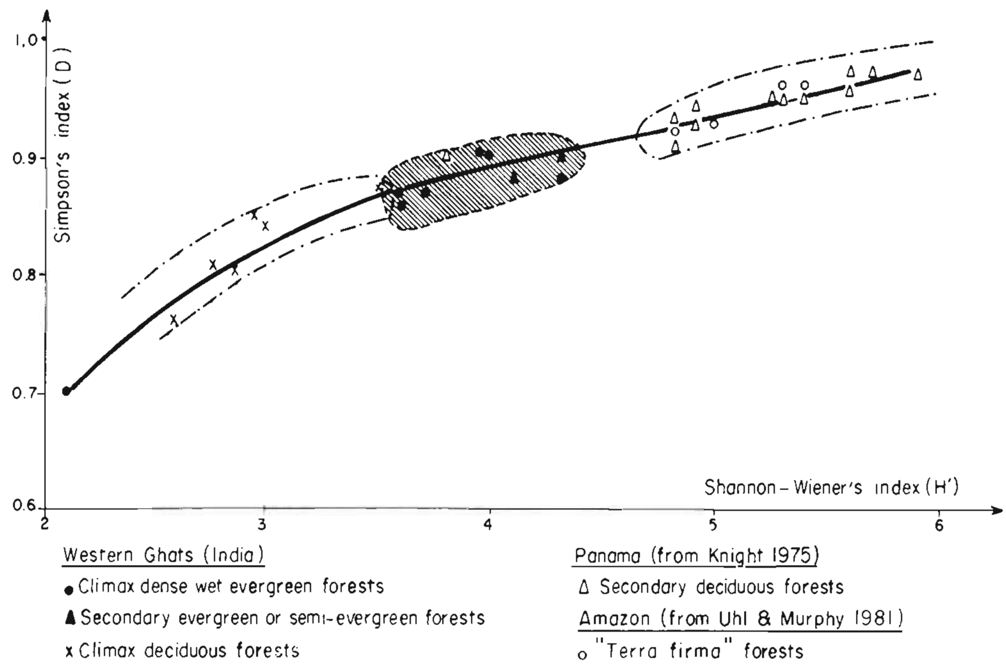
The high floristic richness of the Malaysian forests is probably due to the fact that this region hardly ever left the inter-tropical region during the drift and has benefited from stable climate for a very long period. These favourable conditions enabled the maintenance of the species in this ecosystem on one hand, and speciation to occupy increasingly narrow ecological niches, on the other.

This is not the case with the forests of the Western Ghats. The climatic conditions were varying constantly, at the beginning with the major drift (from (Cretaceous) and later with the eastward uplift, of the Deccan plateau during the Tertiary period. Hence, the plant formations had to adapt more rapidly and speciation within the evergreen forest ecosystem could not be as well developed. This phenomenon is aggravated by the selective process imposed by the dry season whose influence increases with latitude.

Endemism in the Western Ghats

Species considered as endemics are those which are found only in the Western Ghats. The percentages calculated are for tree species only. The percentage of endemism in the Western Ghats is high. The major features of endemism may be summarized as follows:

— At the same latitude, there is no significant difference between the percentages of endemic



Text-figure 9—Distribution of the different types of formations according to the diversity indices.

species in low and medium elevations.

- The highest percentage of endemism is found south of the Palghat Gap, i.e., in regions with the shortest dry season: 43.4 and 44.3 per cent.
- To the north of Palghat, the percentage of endemism does not vary significantly with the lengthening of the dry season. It remains between 34.1 and 37.4 per cent.
- The types and facies corresponding to special edaphic conditions have a higher percentage of endemism: 41.6 and 40.5 per cent in the *Poeciloneuron* formations.

The drier formations have a much lower percentage of endemism, e.g., the semi-evergreen kan forests (26.7%) and the *Memecylon-Syzygium-Actinodaphne* type (26.9 per cent).

These formations have many light-tolerant species whose areas of distribution are much vaster than the Western Ghats. The distribution of the percentages of endemism in the Western Ghats gives rise to a number of questions regarding the past history and origin of the floras; their evolution from the time the Western Ghats were isolated from the other evergreen formations of India; the location of the centres of endemism (the highest percentage of endemism is found when the dry season is shortest), vicariance between species (species which are closely related botanically are relayed in altitude and latitude to occupy the same niche in the ecosystem). The answers to these questions demand specialised studies some of which (centres of endemism) are under way, while others (past history of formations) will be undertaken with the collaboration of various research teams.

SPECIES DISTRIBUTION WITHIN THE FOREST ECOSYSTEM

Species distribution in the structural ensembles

The evergreen forest generally looks like a leafy continuum from the ground up to the canopy in which it is usually difficult to distinguish a stratification. Based on studies of profiles and growth patterns, Oldeman (1974) proposed the notion of structural ensembles which classifies trees as belonging to the sets of the present, past or future and according to a layering within the set of the present. Text-figure 7 shows a simplified example of the profiles, as well as the distribution of trees in the structural ensembles, in a high and a low forest.

Generally, up to elevations of 1400 m the forests have more or less the same structure as that of Kadamakal (Karnataka) : 4 structural ensembles (SE) with structural ensemble I (SE I) comprising straight boled, high forked, trees more than 35 m high and dominated by emergents sometimes exceeding 45 m. The SE I forms an almost continuous cover interrupted only by openings caused by the fall of big trees. Trees of the lower structural ensembles are in 3 layers and are more scattered horizontally.

The low forests begin between 1250 and 1400 m according to exposure and have only 3 (sometimes 2) structural ensembles. The canopy (SE I) is lower, 20 m and at times even less. It is composed of stunted and crooked low branching trees. The distinction between this ensembles and the lower ones is not always clear.

Individuals of the set of the future are found at all levels depending on their age. The different species are therefore distributed according to a layering and the adult trees occupy a well determined place in the forest ecosystem. However, the ultimate size of the trees may vary. Thus depending on whether the growth conditions are more or less favourable the same species may belong to SE II or III (*Humboldtia brunonis*) or even to the base of SE I or summit of SE II (*Drypetes elata, Myristica dactyloides*, etc.). As an example, the distributions of the most common species in the different structural ensembles in Kadamakal forest are shown in Table 3.

Relative density and species diversity

Relative density—The horizontal distribution of species in the forest is not uniform. Some are very common while others are very rare. The relative densities (number of individuals) of species with diameter > 10 cm in 1 ha of Uppangala forest are given in Text-figure 8. This L-shaped distribution is found in the majority of evergreen forests of the world, except in those growing in special facies, particularly edaphic, which are more selective with regard to species.

Three species, *Humboldtia brunonis, Vateria indica* and *Myristica dactyloides* represent 48 per cent of the trees of the forest. *Humboldtia* dominates the undergrowth while the other 2 species belong to SE I. In contrast, 46 per cent of the species are represented by only one or two individuals in 1 ha (and not always by adult trees). The adaptation strategies of the different species are therefore very different. This diversity is also found in the distribution pattern. Most of the species are evenly distributed in the forest (*Vateria indica* and *Humboldtia brunonis*), while others are more gregarious and appear as isolated groups (*Garcinia talbotii*) and still others prefer or are localised exclusively in special ecological conditions, for example, near water course (*Neonauclea purpurea, Vepris bilocularis, Bischofia javanica*...) or in large openings (*Macaranga peltata, Callicarpa tomentosa, Leea indica*...).

Species diversity—The forest ecosystem should be viewed as associations of populations in delicate equilibrium among themselves and with the environment. A good measure for guaging the degree of complexity is provided by indices of species diversity. The most elaborate of these indices (Shannon-Wiener : H, Simpson) takes into account the number of individuals, total and per species, and the number of species. They are therefore different from floristic richness where only the number of species is considered without taking into account their distribution and frequency in the ecosystem.

The species diversity indices in 9 evergreen forests of the Western Ghats are given in Text-figure 9. The values obtained in similar forests in the Amazon (Uhl & Murphy, 1981) and in the secondary deciduous and semi-deciduous forests in India (Pascal, 1986) and in Panama (Knight, 1975) have been added on the same graph to enable a comparison.

With the exception of Bhagvati and New Someshwara forests which correspond to special edaphic and topographic conditions, the value of H′ in all others is between 3.5 and 4.3. These values are lower than those recorded in the Amazonian formations (H′ higher than 4.5). The values in secondary formations in Panama and in Panamberi (India) are also higher. The climax deciduous formations in India have, in their turn, a lower species diversity which decreases with the intensity of their degradation.

CONCLUSION

The evergreen continuum of the Western Ghats of India exhibits a certain number of original features when compared to other formations in the world. This originality lies mainly in the variations in the climatic conditions throughout the continuum which are along 3 main gradients: Rainfall, duration of the dry season and temperature. These climatic gradients determine the structural and floristic changes along the continuum, enabling their distinction into different forest types. Each type is defined by a particular structure and floristic composition. However, the nature of the forest is sometimes determined by edaphic conditions whose importance had often been underestimated.

Another feature of these forests is the low floristic richness as compared to those of other similar forests (except perhaps of Africa) and low species diversity. These parameters are distinctly lower than those of Malaysia and Indonesia in particular. The causes of this relative poverty in species in the Western Ghats forests remain to be studied. The role of continental drift should be one of the important determinant factors. A study of the Andaman forests, which form a kind of link between the Western Ghats and Indonesia, will provide valuable clues in this domain. The present studies are too fragmentary for making an accurate judgement.

Studies carried out on tree growth, leaf production and their decomposition indicate that the functioning of these forests is more similar to that of the semi-deciduous forests rather than to that of the other evergreen forests (at least when the regional dry season exceeds 31/2 months). We can therefore conclude that their apparent homogeneity corresponds to different vulnerabilities.

The high percentage of endemism, specially in the southern part of the continuum, pleads for classifying a part of these forests as reserve forests protecting their genetic heritage whose potentialities are still largely unknown.

In the context of the rapid growth in population and its requirement of wood, the survival of these forests can be ensured only by adopting strict measures to protect the most vulnerable regions and by rational exploitation of the others.

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