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RESEARCH ARTICLE

Plant diversity and phenological pattern in the montane wet temperate forests of the southern Western Ghats, India

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Abstract Plants diversity and phenological pattern of the trees were monitored in a montane wet temperate forest (shola) in the Kukkal Forest, Palni hills of the southern Western Ghats, India. Twelve random plots were selected for sampling the vegetation. For phenological studies, twenty-three fleshy fruit trees were identified in the study area and 10 individuals of each species were selected to record the phenological events fortnightly between April 2002 and April 2004. The phenological events were divided into vegetative and reproductive phases. A total of 2279 individuals were inventoried which belong to 83 species, 68 genera and 40 families. About 30% of the species were endemic to the Western Ghats. The most dominant species (≥ 1 cm dbh) was *Psychotria nilgiriensis* var. *astephana* (Rubiaceae), which accounted for 12% of the total sampled individuals. Lauraceae was the dominant family accounting for 20% of the individuals. Fruiting peak occurred in July 2003 and least in June 2002. During the peak period, fruits of 85 individuals of six species were observed. *Syzygium tamilnadensis, Ilex wightiana* and *Beilschmiedia wightii* fruited only once during the two years of study. The number of fruiting species showed no correlation with rainfall ($r = 0.26$, $p = 0.2$), while a correlation was found with fruit abundance ($r = 0.40$, $p < 0.05$). The results indicate that the montane wet temperate forest is unique in their diversity and a conspicuous display in phenology.

Key words plant inventory, species diversity, phenology, montane wet temperate forest, Western Ghats, India.

1 Introduction

The high ranges of the Nilgiris and Palnis of the Western Ghats, India, are noted for their unique flora. The characteristic vegetation is the montane wet temperate forest, also known as the shola forest. Blasco (1970) has recorded 223 plant species known only from the sholas and grasslands of the higher altitude ranges of the Western Ghats. The montane wet temperate forest harbors many endemic and rare plant species that cannot regenerate in grasslands and exposed sites due to lack of tolerance to fire and frost (Meher-Homji, 1967). The extent of montane wet temperate forests has dwindled in the past century due mainly to conversion to plantations. Current threats are mainly from livestock grazing, fuel-wood harvest and agricultural expansion (Somasundaram and Vijayan, 2008).

Information on reproductive phenology and reproductive output, such as seed production, is necessary for understanding vegetative functioning and dynamics, since the reproductive potential of vegetation is fundamental in landscape evolution (Günter et al., 2008). Phenological patterns can be described as the periodic variations in the flowering and fruiting patterns of a species. It could be defined as variations in a) the number of species in flower or fruit, b) the proportion of plants bearing flowers or fruits and c) the abundance of flowers or fruits over time (Blake et al., 1990). Plant phenological studies are fundamental to understand the forest as a resource base for dependent species, populations and communities. Tropical plant communities display conspicuous seasonal pattern in vegetative and reproductive phenophases at both community and species levels (Frankie et al., 1974; Williams-Linera, 1997). Variations in flowering and fruiting can be influenced by both abiotic and biotic factors and thus the plants would choose a favorable time to reproduce. Fruit production has been shown to vary greatly over time in all major blocks of tropical forests of South-East Asia (Leighton and Leighton, 1983). Information on phenological patterns of the natural forests of the Western Ghats, however, is limited (Murali and Sukumar, 1994; Kannan and James, 1999; Sundarapandian et al., 2005) and studies are scanty in the montane wet temperate forest.

Therefore, the present study aims to conduct an inventory of plant diversity in the montane wet temperate forest and monitor its phenological events, es-

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pecially for the fleshy fruit species which is vital food source for frugivores. Such information can help the conservation, management and restoration of montane wet temperate forests in the Western Ghats.

2 Materials and methods

2.1 Study site

The study was conducted in the montane wet temperate forests (shola) at Kukkal in the Palni hills (10°01′–10°26′N; 77°14′–77°52′E), a range of hills in the Western Ghats, Tamil Nadu (Fig. 1). The Palni hills consist of two well marked topographic divisions, i.e., the Upper Palni and the Lower Palni. The study site in Upper Palnis, with elevations ranging from 1500 to 2450 m, has a moderate climate with mean temperatures of 12 to 23°C in summer and 8.3 to 17.3°C in winter. This area is subject to high winds (Rawat et al., 2003). Rainfall is received from both the SW and NE monsoon winds. Mean annual rainfall for Kodaikanal over a four-year period (2001–2004) was 1690 mm (Fig. 2). The dry season, defined as the number of continuous months with < 100 mm average rainfall, was from December to March (Fig. 2). The underlying geological formations are pre-Cambrian in origin and are comprised of mainly metamorphic rocks, gneisses, charnockites and crystalline schists. The soil texture varies from clay to clay-loam. The soils are acidic in nature and contain a high percentage of iron and alumina. Accumulation of humus in the top layers of the montane wet temperate forest soil gives it a black color (Meher-Homji, 1967). The original extent of the Kukkal shola was over 300 ha, but it has been extensively destroyed due to agricultural expansion, livestock grazing and harvesting of fuel-wood and other products (Matthew, 1999). The undisturbed section of the shola is < 100 ha in area.

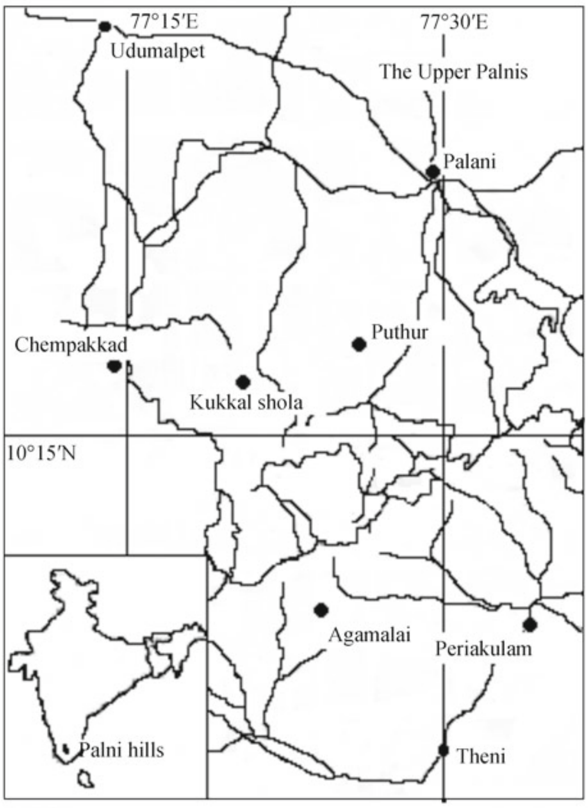

Fig. 1 Map of the Palni hills with the location of Kukkal shola (scale 1:250000)

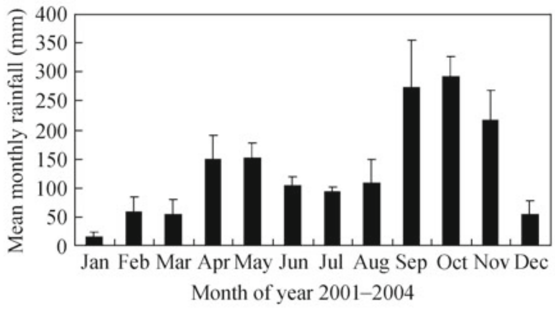

Fig. 2 Mean monthly rainfall in the study region (± S.E.) (2001–2004)

2.2 Methods

We carried out the studies on woody plant inventory and phenology from April 2002 to April 2004. For woody plant diversity studies, twelve 30 m × 30 m plots were randomly selected in Kukkal covering a total area of 1.08 ha. Among the 12 plots, three were in moderately disturbed sites and the rest in undisturbed sites. Each plot was divided into 10 m × 10 m subplots. The plot dimensions were adjusted for slope. Multiple smaller plots enable us to sample a wide variety of habitats within the montane wet temperate forest than do just one large plot. All stems ≥ 1 cm dbh (≥ 3 cm girth at breast height) were identified and their girth were measured at 1.3 m above the ground level. The girth was converted to dbh for analysis. The single-stemmed individuals were tagged with sequentially numbered aluminum tags. For multi-stemmed individuals, each stem was measured and tagged separately. All tagged individuals were identified to species using various floras (Fyson, 1932; Gamble, 1935; Matthew, 1999). Nomenclature of species follows the Flora of Tamilnadu and the Flora of Palni Hills (Nair and Henry, 1983; Henry et al., 1987; Henry et al., 1989; Matthew, 1999). The taxonomic identity of voucher specimens was confirmed at the Herbaria of the Botanical Survey of India, Coimbatore and at the French Institute of Pondicherry.

For phenological studies, a plot of 6 ha was set within the study area to observe the tree phenophases, which accounted for 23 fleshy fruit species. Ten individuals from each species were selected to record phenological events every fortnight following Frankie et al. (1974), Guy et al. (1979) and Wheelwright (1988). The phenological events were divided into vegetative and reproductive (flowering and fruiting) phases. Assigning the values ranging from 0–100% for each phase, an approximate proportion of flowers, fruits and young leaves were recorded (Prasad and Hegde, 1986). Fruits were classified as ripe or unripe (Guy et al., 1979).

2.3 Data analyses

The data for all the plots were consolidated and the total number of species and the number of stems were estimated. Basal area (BA) per individual at 1.3 m above the ground was calculated using the following formula:

$$\mathrm{BA} = \frac{\eth}{4}(\mathrm{dbh})^2$$

For multi-stemmed plants, the basal area for the main trunk was used in the calculations. The basal area of all trees was summed and adjusted to 1 ha to give the basal area estimates per ha ($m^2 \cdot ha^{-1}$) of the forest. Furthermore, a second calculation was performed using the summed values of all stems above 1.3 m for the floristic studies.

Fisher's alpha was used to assess species diversity which is independent of plot size (Fisher et al., 1943; Dallmeier and Comiskey, 1998). To see whether the species abundance pattern followed a log normal distribution, the number of individuals per species was transformed into logarithmic values using base 10, and the species abundance distribution was tested for normality. The geographical distribution of species was noted from the literature (Whitmore, 1972, 1973; Ng, 1978; Ahmedullah and Nayar, 1986; Saldanha, 1996; Ramesh et al., 1997; Matthew, 1999). Regression analysis was employed to determine the relationship between fruiting phenology and environmental factors (Kannan and James, 1999; Sundarapandian et al., 2005).

3 Results

3.1 Phenology of tree species

We selected 23 species of fleshy fruit trees and observed their phenology during a period of two years (from April 2002 to April 2004). The results showed that fruiting peak occurred in July 2003 and least in June 2002 (Fig. 3). During the peak period, fruits of 85 individuals of six species were observed. *Syzygium tamilnadensis, Ilex wightiana* and *Beilschmiedia wightii* bore fruits only once during the two years. In August, only *Trichillia connoroides* was in fruit; whereas in December only *Olea paniculata* and *Measa indica* had fruit, of which the latter was only about 10%.

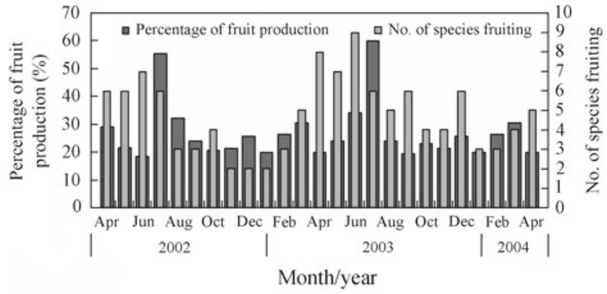

Fig. 3 Fruiting patterns of the fleshy fruit trees from April 2002 to April 2004

3.2 Environmental factors affecting fruiting phenology

There was no correlation between fruit abundance and number of fruiting species ($r = 0.22$, $p = 0.2$) in the Montane wet temperate forest (Table 1). The number of fruiting species showed no correlation with rainfall ($r = 0.23$, $p = 0.2$), while the fruit abundance did show a correlation ($r = 0.40$, $p < 0.05$). Fruit abundance also showed significant correlation with number of rainy days ($r = 0.16$, $p = 0.44$). Maximum number of species in fruit was found only when the number of rainy days was less than six. The fruit abundance did not correlate with the monthly mean maximum temperature, while the number of fruiting species had a significant correlation ($r = 0.39$, $p < 0.05$). Minimum temperature and number of fruiting species showed similar trend ($r = 0.58$, $p < 0.01$). The fruit abundance and relative humidity had no correlation, whereas the number of fruiting species significantly correlated with humidity ($r = 0.32$, $p = 0.05$) (Table 1).

3.3 Species richness, density and basal area

Out of twelve plots laid out, the species-area curve

Table 1 Correlation between environmental factors and fruiting phenology of the trees in Kukkal shola

Parameters	Total fruit production	No. of fruiting species
No. of fruiting species	$r = 0.22$ p = NS	–
Rainfall	$r = 0.40$ $p < 0.05$	$r = 0.23$ p = NS
No. of rainy days	$r = 0.16$ p = NS	$r = 0.14$ p = NS
Monthly mean maximum temperature	$r = 0.16$ p = NS	$r = 0.39$ $p < 0.05$
Monthly mean minimum temperature	$r = 0.18$ p = NS	$r = 0.58$ $p < 0.05$
Relative humidity	$r = 0.27$ p = NS	$r = 0.32$ $p < 0.05$

reached asymptote in the ninth plot (Fig. 4). The species abundance log normal transferred data did not differ significantly, however, there was only one species excessively recorded (Fig. 5) as like in other tropical forests, indicating that the inventory effectively incarcerated the plant diversity in Kukkal shola.

In 1.08 ha shola forest plot 2279 plant individuals belonging to 83 species, 68 genera and 40 families were recorded (Table 2), of which 2130 trees belong to 67 species and 56 genera. A total of 149 lianas belonging to 16 species, 12 genera and 12 families were recorded. Above 10 cm dbh category 45 tree species belonging to 36 genera and 23 families were inventoried (Table 2; Appendix 1).

Fisher's alpha diversity scored 16.9, of which 13.15 were trees and 4.54 were lianas (Table 2). The total basal area estimated in the ≥ 1cm dbh class was 62.01 $m^2 \cdot ha^{-1}$, of which 61.42 $m^2 \cdot ha^{-1}$ were trees and 0.58 $m^2 \cdot ha^{-1}$ were lianas; and in the case of ≥ 10 cm dbh class the basal area was 58.76 $m^2 \cdot ha^{-1}$. For multi-stemmed species, the basal area for all stems was 66.06 $m^2 \cdot ha^{-1}$ for ≥ 1cm dbh class and 61.92 $m^2 \cdot ha^{-1}$ for ≥ 10 cm dbh class.

Psychotria nilgiriensis var. *astephana* (Rubiaceae) was the abundant species accounting for 12% of the total sample, followed by *Maesa indica* (Myrsinaceae, about 10%). *Xantolis tomentosa* var. *elengioides* had the highest basal area (Table 3). *Xantolis tomentosa* var. *elengioides*, *Cassine paniculata* and *Beilschmiedia wightii* were the largest and tallest trees (Somasundaram unpublished).

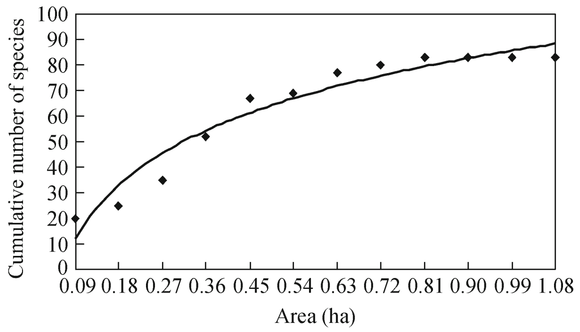

Fig. 4 Cumulative species-area curve for the 12 plots

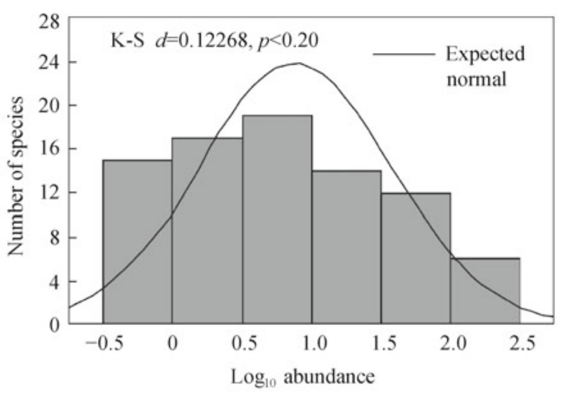

Fig. 5 Log_{10} abundance distribution of species

Species richness and tree diversity showed a decreasing trend with the increase of tree diameter (Table 4). Most species was categorized under ≤ 5 cm dbh with lowest basal area, whereas > 30 cm dbh class had less species with highest basal area. Smaller trees and shrubs had greater species diversity, but not basal area.

Out of 40 families recorded, Lauraceae (16%), Rubiaceae (7%) Myrsinaceae (4%), Symplocaceae (4%), Myrtaceae (4%) and Oleaceae (4%) had the maximum number of individuals. The highest species richness was observed in Lauraceae with 3 genera and 13 species, followed by Rubiaceae with 6 genera as well as species. The highest basal area was observed in Lauraceae (Table 5). Out of 67 tree species, 22 (31%) were distributed in Indo-Malesia, 21 (30%) were endemic to Western Ghats, 11 (16%) restricted to Indian Subcontinent and 2 (3%) restricted to Nilgiri and Palni hills. The only introduced species was *Coffea arabica* in the study plot.

4 Discussion

Compared with other types of wet evergreen forests in the Western Ghats of India, species richness in montane wet temperate forests is relatively lower, but similar to that of shola forests in the Nilgiris. We recorded 83 woody plant species (≥ 1 cm dbh) in the 1.08 ha of forest in Kukkal shola. Of these 67 species were trees. Narendran et al. (2001) have recorded 67 woody species per ha (≥ 3 cm dbh) in shola forest in the Nilgiri mountains which lies about 150 km north of the Palnis. When only trees were considered, there

Table 2 Inventory details of woody plants in the Kukkal Reserve Forest, Palni hills (1.08 ha)

Category	All species		Trees/shrubs		Lianas	
	≥ 1 cm	≥ 10 cm	≥1 cm	≥10 cm	≥1 cm	≥10 cm
No. of individuals	2279	500	2130	487	149	13
No. of stems per ha	2110	463	1972	451	138	12
No. of species	83	49	67	45	16	4
No. of genera	68	40	56	36	12	4
No. of families	40	27	33	23	12	4
Fisher's alpha	16.90	13.45	13.15	12.10	4.54	1.97
Main trunk basal area ($m^2 \cdot ha^{-1}$)	62.01	58.76	61.42	58.47	0.58	0.29
All stems basal area ($m^2 \cdot ha^{-1}$)	66.06	61.92	65.46	61.63	0.60	0.29

Table 3 Floristic information pertaining dominant woody plants (relative density above 1.5%) recorded in Kukkal shola

Species	Family	Habit	No. of individuals	Basal area ($m^2 \cdot ha^{-1}$)		Relative density (%)
				Main trunk	All stems	
Psychotria nilgiriensis var. *astephana*	Rubiaceae	Shrub	282	0.43	0.47	12.37
Maesa indica	Myrsinaceae	Tree	239	0.65	0.68	10.49
Phoebe paniculata	Lauraceae	Tree	175	7.07	7.27	7.68
Symplocos foliosa	Symplocaceae	Tree	167	1.38	1.39	7.33
Neolitsea cassia	Lauraceae	Tree	161	3.00	3.00	7.06
Lasianthus acuminatus	Rubiaceae	Shrub	132	0.19	0.24	5.79
Nothapodytes nimmoniana	Icacinaceae	Tree	86	0.43	0.44	3.77
Beilschmiedia wightii	Lauraceae	Tree	75	7.92	8.04	3.29
Turpinia nepalensis	Staphyleaceae	Tree	75	0.76	0.78	3.29
Symplocos cochinchinensis	Symplocaceae	Tree	74	0.39	0.50	3.25
Rhododendron arboreum subsp. *nilagirium*	Ericaceae	Tree	67	2.09	3.70	2.94
Viburnum cylindricum	Caprifoliaceae	Tree	55	1.00	1.08	2.41
Daphniphyllum neilgherrense	Euphorbiaceae	Tree	46	0.72	0.79	2.02
Vaccinium neilgherrense	Vacciniaceae	Tree	46	0.67	1.18	2.02
Ventilago madraspatana	Rhamnaceae	Liana	45	0.29	0.30	1.97
Casearia zeylanica	Flacourtiaceae	Tree	44	0.55	0.55	1.93
Xantolis tomentosa var. *elengioides*	Sapotaceae	Tree	37	17.65	18.58	1.62
Ardisia rhomboidea	Myrsinaceae	Tree	36	0.05	0.06	1.58
Olea paniculata	Oleaceae	Tree	30	3.68	3.73	1.32

Table 4 Species richness, stem density, species diversity and basal area of different diameter classes in 12 plots (1.08 ha)

dbh class	No. of species	No. of individuals	Fisher's alpha	Basal area ($m^2 \cdot ha^{-1}$)	
				Main trunk	All stems
≥ 1 to ≤ 5	66	1211	14.98	1.21	1.55
> 5 to ≤10	55	568	15.04	2.03	2.59
> 10 to ≤ 20	34	252	10.59	3.85	5.33
> 20 to ≤ 30	24	70	12.90	3.21	4.03
> 30	25	178	7.92	51.70	52.56

were 45 species. Species richness values for the ≥ 10 cm dbh class ranged from 32 to 84 species per ha in low (< 800 amsl) and medium (> 800 to < 1500 amsl) elevation wet evergreen forests in the Western Ghats (Parthasarathy and Karthikeyan, 1997; Parthasarathy, 1999, 2001; Srinivas and Parthasarathy, 2000). Therefore, species richness in Kukkal is at the lower end of the scale. Species richness and alpha diversity are generally lower in the Western Ghats than for Neotropical and S. E. Asian forests where often 300 species per ha have been recorded (Pascal and Pelissier, 1996; Leigh, 1999; ter Steege et al., 2003).

Tree density of 451 stems per ha (≥ 10 cm dbh) was lower than the mean values for low and medium elevation wet evergreen forests in the Western Ghats where stem densities ranged from 446 to 1576 stems per ha (Ganesh et al., 1996; Pascal and Pelissier, 1996; Parthasarathy and Karthikeyan, 1997; Ayyappan and Parthasarathy, 1999; Parthasarathy, 1999, 2001; Srinivas and Parthasarathy, 2000). Stem densities for the wet evergreen forests of the Western Ghats, however, are generally higher than in Africa and South America (Pascal and Pelissier, 1996; Leigh, 1999).

The basal area values (main trunk: 62.01 $m^2 \cdot ha^{-1}$, all stems: 66.06 $m^2 \cdot ha^{-1}$) fell within the range of basal areas (36 to 94 $m^2 \cdot ha^{-1}$) reported in the Western Ghats from low to medium elevation forests (Ganesh et al., 1996; Pascal and Pelissier, 1996; Parthasarathy and Karthikeyan, 1997; Ayyappan and Parthasarathy, 1999; Parthasarathy, 1999, 2001; Srinivas and Parthasarathy, 2000; Swamy et al., 2000).

4.1 Phenology

Consistent and predictable annual cycles in the biotic and abiotic factors which affect tree growth and reproduction over evolutionary time are expected to shape tree phenological patterns (Anderson et al., 2005). The fruiting phenology was examined in this study for a period of two years combined with the environmental factors such as rainfall, temperature and humidity. In Kukkal shola the ripe fruits were present round the year with a peak in July of both years, after the onset of south-west monsoon. Similar pattern was reported in many tropical forests (Sun et al., 1997; Kannan and

Table 5 Family level richness of woody plants in Kukkal shola

Family	No. of species	No. of individuals	Basal area ($m^2 \cdot ha^{-1}$)		Family	No. of species	No. of individuals	Basal area ($m^2 \cdot ha^{-1}$)	
			Main trunk	All stems				Main trunk	All stems
Lauraceae	13	464	26.83	27.16	Elaeagnaceae	1	15	0.07	0.07
Rubiaceae	8	431	0.65	0.74	Theaceae	1	14	0.03	0.05
Myrsinaceae	3	295	0.86	0.93	Rutaceae	1	12	0.03	0.03
Symplocaceae	3	242	1.78	1.90	Acanthaceae	2	10	0.02	0.02
Icacinaceae	2	97	0.53	0.56	Erythroxylaceae	1	10	0.08	0.08
Staphyleaceae	1	75	0.76	0.78	Berberidaceae	2	9	0.01	0.01
Ericaceae	2	68	2.09	3.70	Ulmaceae	2	9	0.67	0.72
Euphorbiaceae	2	59	0.80	0.87	Asteraceae	1	5	0.02	0.02
Caprifoliaceae	1	55	1.00	1.08	Meliaceae	1	5	0.04	0.04
Flacourtiaceae	2	52	0.56	0.56	Tiliaceae	1	5	0.00	0.00
Myrtaceae	3	46	0.72	0.72	Santalaceae	1	4	0.01	0.01
Vaccinaceae	1	46	0.67	1.19	Caesalpiniaceae	1	3	0.00	0.00
Rhamnaceae	1	44	0.29	0.29	Magnoliaceae	1	3	0.06	0.06
Oleaceae	2	37	3.68	3.72	Papilionaceae	2	3	0.01	0.01
Sapotaceae	2	37	17.65	18.59	Loganiaceae	1	2	0.01	0.01
Buxaceae	1	30	0.03	0.05	Apocynaceae	1	1	0.00	0.00
Annonaceae	1	27	0.10	0.10	Elaeocarpaceae	1	1	0.54	0.55
Piperaceae	3	27	0.05	0.05	Hypericinaceae	1	1	0.00	0.00
Celastraceae	2	17	1.20	1.22	Moraceae	1	1	0.01	0.01
Rosaceae	6	16	0.14	0.14	Sapindaceae	1	1	0.01	0.02

James, 1999; Griz and Machado, 2001; Kimura et al., 2001; Bleher et al., 2003; Sundarapandian et al., 2005). After heavy rain, the number of species fruiting decreased, and so did the total fruit production. Lieberman (1982) and Rathcke and Lacey (1985) hypothesized that high water availability is necessary at the time of fruiting to enhance fruit maturation and germination success (assuming no seed dormancy; van Schaik et al., 1993; Justiniano and Fredericksen, 2000).

The number of species in fruit and the total fruit production had a one step lac correlation; however, they all had a sensitive relationship to weather variables at different times. The difference between number of species in fruit and total fruit production was greatly influenced by population density and mean basal area of all tree species. *Olea paniculata* and *Daphniphyllum neilgherrense* had a basal area of 3.68 and 0.72 $m^2 \cdot ha^{-1}$ and it had a significant contribution on fruit production during the drier months.

Rainfall had a significant positive correlation with fruiting at Kukkal, as reported for several other tropical forests (Murali and Sukumar, 1994; Ganesh et al., 1996; Kannan and James, 1999; Sundarapandian et al., 2005). Total monthly rainfall and the number of rainy days, when considered together, had a weak correlation with number of fruiting species, whereas a significant correlation was found with total fruit production. In the case of dry forests, total rainfall and the number of rainy days stimulated fruiting (Balasubramanian, 1990; Murali and Sukumar, 1994; Sundarapandian et al., 2005), whereas in the case of montane forest, as in Kukkal, fruiting was close to the onset of rainfall or at the onset of early rainy season (Ganesh et al., 1996; Sun et al., 1997; Griz and Machado, 2001; Kimura et al., 2001). These phenomena could be attributed to enhance dispersal, escape predation and avoid pathogen infection (Prasad and Hegde, 1986; Sundarapandian et al., 2005).

Total number of species in fruit at Kukkal significantly correlated with both maximum and minimum temperatures. However, in the wet evergreen forests of the southern Western Ghats, only correlation with minimum temperature was found (Ganesh et al., 1996). In the Tai National Park, total fruit production and the number of fruiting species were significantly correlated only with mean minimum temperature (Anderson et al., 2005). The number of plants in fruit had a significant correlation with relative humidity. But total fruit production had a weak correlation as in the evergreen forests in the southern Western Ghats (Ganesh et al., 1996).

The temperature had a significant effect on fruiting, which may also have a secondary effect on the flowering phenology. Anderson et al. (2005) suggested that temperature and rainfall were not the primary factors affecting fruiting; however, they may deviate from the normal annual fruiting cycle. The tree size classes had a significant influence on fruiting duration and length.

4.2 Endemism

Compared with other studies in the middle and low elevation evergreen forests of the Western Ghats (Ramesh et al., 1997), the number of Western Ghats endemics (30%) recorded was comparatively lower. Most of the species were distributed in Indo-Malesian region, whereas only 3% of the species were restricted in Nilgiri and Palni hill tops. In recent geological time scale these forests have been isolated from the wet forests of the middle and lower elevation where warmer and wetter climatic condition prevailed in this sub continent. Balsco (1970) reported 18 endemic species to the Palni hills, including many herbs.

4.3 Family level characteristics

The similarity in family-level dominance in the tropical rain forests worldwide was reported by Gentry (1988). In the lowland Neotropical forests the dominant family was Leguminosae, in tropical rain forest was Dipterocarpaceae and in the mid elevations Lauraceae, Euphorbiaceae and Clusiaceae tend to replace these families. The present study implies the dominance of Lauraceae and Rubiaceae families. The dominance of Rubiaceae may be correlated with the adoption of lower dbh limit in this inventory, since the Rubiaceae tend to be small trees. In terms of basal area, Lauraceae was the dominant family, like other tropical montane forests (Losos and Leigh, 2004). The similarities in family-level dominance among different tropical forests worldwide might be correlated with the higher taxonomic levels via family- and genus-specific pests and pathogens (Gentry, 1988). Novotny et al. (2002) have shown that host specialization of pests in tropical rain forests tends to be higher at taxonomic levels.

4.4 Lianas

Sixteen species of lianas were recorded, of which four were > 10 cm dbh and overall it contributed 9% of the total density. The liana density and species richness were similar to other tropical forests (Ganesh et al., 1996; Muthuramkumar and Parthasarathy, 2000). The maximum number of species belongs to Rhamnaceae and Annonaceae. Four (25%) Western Ghats endemics were recorded which was higher than the Veerapuli and Kalamalai Forest Reserve of the southern Western Ghats (Swamy et al., 2000).

The montane wet temperate forests of the Western Ghats are facing severe anthropogenic pressure due to fire wood collection and livestock grazing. These shola species are unable to regenerate in open conditions because these evergreen broad-leaved species are intolerant to frost and fire (Meher-Homji, 1967). It may be noted that there has been a loss of 25% shola forest in the last decade alone. Further, the shola forests constitute only 0.3% of the vegetative cover of the Palni Hills (Amarnath et al., 2003). The Kukkal shola is the only large and continuous patch of forest with a large number of matured trees. Matthew (1999) has reported that several plant species in the Palni ranges are threatened with extinction. The larger trees are essential for maintaining their gene pool as well as continuous food supply for the vertebrate frugivores in the forest. Therefore, it is imperative to enforce the strict conservation measures to protect this montane wet temperate forest patch.

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Appendix 1 Woody plant species (≥ cm dbh) recorded in Kukkal Shola in the Southern Western Ghats

Species	Family	Habit	No. of individuals
Psychotria nilgiriensis var. *astephana* (Hook.f.) Deb & Gang.	Rubiaceae	Shrub	282
Maesa indica (Roxb.) DC.	Myrsinaceae	Tree	239
Phoebe paniculata Nees.	Lauraceae	Tree	175
Symplocos foliosa Wight.	Symplocaceae	Tree	167
Neolitsea cassia (L.) Kosterm.	Lauraceae	Tree	161
Lasianthus acuminatus Wight.	Rubiaceae	Shrub	132
Nothapodytes nimmoniana (Graham) Mabberley	Icacinaceae	Tree	86
Beilschmiedia wightii (Nees) Benth. ex Hook. f.	Lauraceae	Tree	75
Turpinia nepalensis Wall. & Wight & Arn.	Staphyleaceae	Tree	75
Symplocos cochinchinensis (Lour.) Moore subsp. *laurina* (Retz.)	Symplocaceae	Tree	74
Rhododendron arboreum J. E. Smith subsp. *nilagirium* (Zenk.) Tagg	Ericaceae	Tree	67

(To be continued)

Appendix 1 (continued)

Species	Family	Habit	No. of individuals
Viburnum cylindricum Buch. - Ham. ex D. Don	Caprifoliaceae	Tree	55
Daphniphyllum neilgherrense Thw.	Euphorbiaceae	Tree	46
Vaccinium neilgherrense Wight.	Vacciniaceae	Tree	46
Ventilago madraspatana Gaertn.	Rhamnaceae	Liana	45
Casearia zeylanica Thwaites	Flacourtiaceae	Tree	44
Xantolis tomentosa (Roxb.) Rafin. var. *elengioides* (A. DC.)	Sapotaceae	Tree	37
Ardisia rhomboidea Wight.	Myrsinaceae	Tree	36
Olea paniculata R. Br.	Oleaceae	Tree	30
Sarcococca saligna (D. Don) Muell.-Arg.	Buxaceae	Shrub	30
Desmos lawii (Hook. F. & Thoms.) Safford	Annonaceae	Liana	27
Syzygium densiflorum Wall.ex Wight & Arn.	Myrtaceae	Tree	25
Myrsine wightiana (Wall. Ex DC)	Myrsinaceae	Tree	20
Syzygium tamilnadensis Rathakr. & Chithra nom.	Myrtaceae	Tree	19
Litsea glabrata (Wall. Ex Nees) Hook.f.	Lauraceae	Tree	16
Elaeagnus kologa Schlecht.	Elaeagnaceae	Liana	14
Eurya nitida Korth.	Theaceae	Tree	14
Glochidion velutinum Wight.	Euphorbiaceae	Tree	13
Piper trichostachyon (Miq.) C. DC.	Piperaceae	Liana	13
Toddalia asiatica (L.) Lam.	Rutaceae	Liana	12
Gomphandra coriacea Wight.	Icacinaceae	Tree	11
Neolitsea scrobiculata (Meisner) Gamble.	Lauraceae	Tree	11
Cassine paniculata (Wight & Arn.) Lobr.-Callen	Celastraceae	Tree	10
Erythroxylum moonii Hochr.	Erythroxylaceae	Tree	10
Piper mullesua Buch.-Ham. Ex D. Don	Piperaceae	Liana	10
Flacourtia indica (Burm. F) Merr.	Flacourtiaceae	Tree	9
Tarenna asiatica (L.) Kuntze ex K. Schum,. var. *asiatica forma rigida* (Wight)	Rubiaceae	Shrub	9
Debregeasia longifolia (Burm. f.) Wedd	Ulmaceae	Tree	8
Mahonia leschenaultii (Wall. ex Wight & Arn)	Berberidaceae	Tree	8
Xenacanthus pulneynensis (Clarke) Bremek	Acanthaceae	Shrub	8
Jasminum brevilobum A. DC.	Oleaceae	Liana	7
Cinnamomum perrottetii Meisner	Lauraceae	Tree	6
Euonymus crenulatus Wall. ex Wight & Arn.	Celastraceae	Tree	6
Cissampelopsis walkeri (Arn.) C. Jeffrey & Y.L. Chen	Asteraceae	Liana	5
Grewia glabra Blume. non Rottler ex Spreng.	Tiliaceae	Tree	5
Litsea wightiana (Nees) Hook.f.	Lauraceae	Tree	5
Ophiorrhiza roxburghiana Wight.	Rubiaceae	Tree	5
Trichilia connaroides (Wight & Arn.) Bent var. *connaroides*	Meliaceae	Tree	5
Neolitsea fischeri Gamble.	Lauraceae	Tree	4
Osyris quadripartita Salz.	Santalaceae	Shrub	4
Prunus ceylanica (Wight) Miq.	Rosaceae	Tree	4
Caesalpinia decapetala (Roth) Alston	Caesalpiniaceae	Tree	3
Michelia nilagirica Zenk.	Magnoliaceae	Tree	3
Piper argyrophyllum Miq.	Piperaceae	Liana	3
Rosa leschenaultiana Red. & Thory ex Wight & Arn.	Rosaceae	Liana	3
Rubus ellipticus Smith.	Rosaceae	Shrub	3
Cinnamomum malabatrum (Burm. F.) Blume	Lauraceae	Tree	2
Cinnamomum wightii Meisner	Lauraceae	Tree	2
Coffea arabica L.	Rubiaceae	Shrub	2
Crotalaria formosa Graham ex Wight & Arn.	Papilionaceae	Shrub	2
Cryptocarya bourdillonii Gamble	Lauraceae	Tree	2
Cryptocarya neilgherrensis Meisner	Lauraceae	Tree	2
Gardneria ovata Wall.	Loganiaceae	Liana	2
Litsea floribunda (Blume) Gamble	Lauraceae	Tree	2

(To be continued)

Appendix 1 (continued)

Species	Family	Habit	No. of individuals
Photinia integrifolia Lindl. var. *sub-lanceolata* Miq.	Rosaceae	Tree	2
Rubus rugosus Smith var. *thwaitesii*	Rosaceae	Shrub	2
Strobilanthes lurida Wight.	Acanthaceae	Shrub	2
Syzygium lanceolatum (Lam.) Wight & Arn.	Myrtaceae	Tree	2
Berberis tinctoria Lesch.	Berberidaceae	Shrub	1
Celtis tetrandra Roxb.	Ulmaceae	Tree	1
Chasalia curviflora (Wall. Ex Kurz) Thw. var. *ophioxyloides*	Rubiaceae	Shrub	1
Derris brevipes (Benth.) Baker var. *brevipes*	Papilionaceae	Liana	1
Dodonaea viscosa (L.) Jacq	Sapindaceae	Tree	1
Elaeocarpus glandulosus Wall.	Elaeocarpaceae	Tree	1
Ficus drupacea Thunb.	Moraceae	Tree	1
Gaultheria fragrantissima Wall.	Ericaceae	Tree	1
Hedyotis stylosa R.Br. ex Wight & Arn.	Rubiaceae	Shrub	1
Hypericum japonicum Thunb. ex Murr.	Hypercinaceae	Shrub	1
Isonandra perrottetiana A. DC.	Sapotaceae	Tree	1
Mussaenda hirsutissima (Hook. F.) Hutchinson	Rubiaceae	Liana	1
Rauvolfia densiflora (Wall.) Benth. Ex Hook. f.	Apocynaceae	Shrub	1
Rubus racemosus Roxb.	Rosaceae	Shrub	1
Symplocos pendula Wight.	Symplocaceae	Tree	1

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