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BIODIVERSITY RESEARCH

Endemism and sexual systems in the evergreen tree flora of the Western Ghats, India

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ABSTRACT

This study reports the endemism and sexual system in the wet evergreen tree flora of the Western Ghats. A total of 656 species from 66 families and 231 genera were listed. This included a gymnosperm family (Podocarpaceae) and a monocot family (Arecaceae). No family was endemic to the Western Ghats, but 352 species (53%) from 43 families and five genera were endemic. Nearly 35% of the families had no endemics. The largest families with endemics were Dipterocarpaceae (92%), Anacardiaceae (84%), Lauraceae (72%), Fabaceae, Rubiaceae and Myrtaceae (68%). The top five contributing families in the tree flora of the Western Ghats were Euphorbiaceae, Lauraceae, Rubiaceae, Myrtaceae and Annonaceae. The 656 species were largely hermaphrodites (57%) followed by dioecious (20%), polygamous (16%) and monoecious species (5%). The rate of dioecy reported in this study (20%) is higher than reports for Puerto Rico (18%) but lower than the Malaysian rainforest (26%). Structurally, like the Neotropical forests, most evergreen forest types of the Western Ghats could be classified into four ensembles. Yet, the Western Ghats had fewer species than other tropical and Neotropical forests. The proportion of endemics in the ensembles of the Western Ghats ranged from 34% (ensemble IV) to 14% (ensemble I).

Keywords
Endemism, evergreen forest trees, India, sexual systems, Western Ghats.

INTRODUCTION

The wet evergreen forests of the Western Ghats of India are one of the global biodiversity hotspots, being rich in biodiversity and endemic species (Myers *et al.*, 2000). The wet evergreen forests at high, medium and low elevations in the Western Ghats house a number of species, many of which are localized endemics. The dry evergreen forests that occur in some patches on the eastern slopes of the Ghats are also unique in their species composition, which includes some endemic species (Ramesh, 2001).

In the Western Ghats, areas of high endemism and species richness were located in areas with high rainfall and a relatively small dry season. The 'transition zones' from wet evergreen to drier forest types also had several unique species (Ramesh, 2001). The study of biodiversity patterns in the Western Ghats indicates that species richness is highest in the southern-most region (Sundarapandian & Swamy, 1997; Parthasarathy, 1999). The true richness of the region is perhaps underestimated. Although the classical works of Beddome (1869–74), Gamble (1881), Bourdillon (1909), Rama Rao (1914) and other botanists had led to the compilation of an almost complete list of trees, new species continue to be discovered (Sasidharan, 1992; Ramesh & de Franceschi, 1993).

Several studies in the Western Ghats have investigated the underlying causes for endemism. Factors such as bioclimate (Ramesh & Pascal, 1997), edaphic specialization — especially of mono-dominant forests (Kadambi, 1941), insular environment on the isolated mountaintops of the Western Ghats (Subramanyam & Nayar, 1974) and the role of quaternary 'refugia' have been suggested (Gimaret-Carpentier *et al.*, 2003). The role of reproductive biology of species, as a possible explanation for endemism, has not been reported for the Western Ghats. The central question examined in this study is how endemism is distributed with respect to the sexual systems of the entire tree flora of the wet evergreen forests of the Western Ghats. If monoecious and dioecious species were disproportionately represented in the endemics, then the underlying biological causes need to be further studied. This question has not been addressed for the tree flora of the Western Ghats, although selected species have been studied for their pollinator relationships (Devy & Davidar, 2003). In this study, we include all the 656 species listed for the wet evergreen forests of the Western

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Ghats to enable comparison with other Neotropical forests (Bawa *et al*., 1985; Chazdon *et al*., 2003).

METHODS

Listing of evergreen tree species of the Western Ghats

The tree list for the evergreen forests of the Western Ghats was compiled based on fieldwork for the vegetation maps of the Western Ghats, supplemented with data from literature. The species listed occurred in low, medium and high elevation evergreen forests. The habitats sampled were wet and dry evergreen and semi-evergreen forests, and mountain forests or sholas of Western Ghats. A total of 19 floristic types are found in these major forest types (Pascal, 1982a,b; Ramesh *et al*., 1997, 2002).

Endemics

Endemic species were identified following Ahamedullah & Nayar (1986), Nayar (1996) and Ramesh & Pascal (1997).

Sexual systems

Data from field observations, herbaria specimens and literature were used to gather data on the sexual systems of all the tree species. For species like *Hopea jacobii* (Dipterocarpaceae) and *Buchnania barberi* (Anacardiaceae), which have not been collected or reported in the wild for almost a century, floras were used to assign the sexual systems. We also verified the sexual systems in some locations in the field for most members of the following large families: Ebenaceae, Elaeocarpaceae, Euphorbiaceae, Papilionaceae, Sapotaceae and Myrtaceae. When polygamy was reported in floras (e.g. in Clusiaceae), we retained that information.

The species were grouped according to four sexual systems — hermaphrodite (when flowers were described as bisexual), dioecious (when male and female flowers were reported on separate plants), monoecious (when unisexual flowers were reported or observed on same plant but different inflorescence) and polygamous (when monoecious and bisexual flowers were reported on the same plant or inflorescence, or when there were conflicting reports of sexual expression).

Ensembles

The tree species are classified into ensembles I, II, III and IV, based on their potential height in different floristic types of vegetation observed (Hallé *et al*., 1974). Emergent trees were the tallest, growing more than 40 m in height. The trees in ensemble I were shorter than emergent trees, ranging between 30 m and 40 m in height. In ensemble II, trees were usually between 20 m and 29 m high. Ensemble III trees were only 10–19 m high, while the trees of the IV ensemble were between 5 m and 9 m high. Plants with a woody base less than 5 m high were considered shrubs and not included in this study. The canopy trees of the high altitude forest seldom grew taller than 8–10 m, but contained some emergent species. To merge the tree species from different forest types into a single list and assign a uniform vertical stratification, we used the tree heights to standardize their ensemble position. Thus, many species from the high elevation forests were classified into ensemble III or IV.

When a species was found in more than one forest type (e.g. evergreen and semi-evergreen), as well as in different ensembles in these forests (e.g. canopy and understorey), it was classified into a forest type and ensemble in which it was most common. *Hopea parviflora* illustrates this. This species was common in the evergreen forests as a canopy tree, however, as a result of its exploitation during World Wars I and II, it now dominates the understorey in the semi-evergreen forests (Ramesh *et al*., 1996).

We assigned ensemble IV for the following rare species: *Buchanania barberi* (Anacardiaceae), *Polyalthia rufescens* (Annonaceae) and *Polyscias acuminata* (Araliaceae). Unlike *Hopea jacobi*, we could not find any clues in literature or herbarium specimens to assign them into a particular ensemble.

Statistics

To test for the relationship between sexual system and endemism, ensemble and family, we performed a chi-square analysis using Yates correction factor. The analysis was performed for different sexual systems on each of these categories with ensembles as columns and the numbers of endemic and non-endemic species in each row.

Chi-square analysis was used to test for significant differences in the frequency of dioecy or monoecy with respect to endemic category. A significant chi-square value would indicate that there was a significant association between dioecy or monoecy, and endemism.

To examine the differences in distribution curves of the endemic species and the entire tree flora, we used the nonparametric Kolmogorov-Smirnov (KS) two-sample test.

RESULTS

Overview of the tree flora

Of the 656 tree species from the 66 families listed, all families were dicotyledons with two exceptions — Podocarpaceae (gymnosperm) and Arecaceae (monocot). The five largest families — Euphorbiaceae, Lauraceae, Rubiaceae, Myrtaceae and Annonaceae — contributed 258 species (39%).

At the generic level, 231 genera were represented in the 66 families. Generic diversity was higher in some families, for example, Euphorbiaceae (24), while families such as Ebenaceae were represented by a single genus. Majority of the families were represented by one to five genera and species, and less than 5% of the families had more than 60 species.

The detailed characterization of the evergreen tree flora for the Western Ghats is listed in Table 1. The largest number of species was found in ensemble IV, followed by ensemble II which together contributed 407 species (62% of the total species). The familial and the generic diversity were highest in ensembles IV and III.

Table 1 The number of species, endemic species, genera, families and sexual systems of evergreen tree flora in the Western Ghats, India

Ensemble	Number of species	Percentage of species	Number of genera	Number of family	Dominant families in ensembles
Ensemble I	97	14.7*	57	32	
Endemics	48	49.4†	30	19	Anacardiaceae
Hermaphrodites	54	55.6	33	20	Lauraceae
Monoecious	3	3.09	3	3	Dipeterocarpaceae
Dioecious	18	18.5	10	8	Moraceae
Polygamous	22	22.6	13	8	Elaeocarpaceae
Ensemble II	179	27.2*	76	36	
Endemics	101	56.4†	48	29	Lauraceae
Hermaphrodites	98	54.7	47	26	Myrtaceae
Monoecious	9	5.0	7	4	Euphorbiaceae
Dioecious	43	24.0	14	6	Meliaceae
Polygamous	29	16.2	14	11	
Ensemble III	152	23.1*	108	37	
Endemics	75	49.3†	42	21	Rubiaceae
Hermaphrodites	78	51.3	48	28	Euphorbiaceae
Monoecious	11	7.2	8	4	Myrtaceae
Dioecious	37	24.3	16	8	Lauraceae
Polygamous	26	17.1	15	11	Ebenaceae
Ensemble IV	228	34.7*	103	39	
Endemics	128	56.1†	62	26	Euphorbiaceae
Hermaphrodites	145	63.9	61	28	Rubiaceae
Monoecious	18	7.8	9	3	Lauraceae
Dioecious	36	15.7	20	6	Annonaceae
Polygamous	29	12.7	18	14	Melastomataceae

Total number of tree species listed is 656, of which 352 (53%) are endemic.
*Derived from the total number of species ($n = 656$).
†Derived from the total number of species in each ensemble.

Sexual systems and endemism

In the overall tree flora, species with hermaphrodite flowers (57%) were dominant, followed by dioecious (20%) and polygamous species (16%). Monoecy was restricted to 5% of the species. A similar pattern was observed for the endemic species (58% were hermaphrodites, 21% dioecious, 15% polygamous and 5% monoecious). Rubiaceae, Myrtaceae, Annonaceae and Fabaceae had many hermaphrodites. Families composed exclusively of hermaphroditic species (44%) were higher than families with only dioecious (six families) or polygamous (seven families) species. More than one sexual system was observed for 35% (23/66) of the families.

Of the 66 families in the evergreen tree flora, 58% were represented by a single sexual system and 24% had two types. Flacourtiaceae was the only family represented by all the sexual systems. For families with single sexual systems, 68% were hermaphrodites, 15% polygamous and 13% dioecious.

Although the actual number of endemic dioecious and monoecious species was greater than expected, there was no significant association between dioecy or monoecy, and endemism in the evergreen tree flora of the Western Ghats (Table 2). The chi-square test revealed no significant difference in the proportional distribution of species belonging to different sexual systems in each of the categories of the endemics and the entire flora ($\chi^2 = 0.02$, ns).

Endemism in families

In the flora of evergreen trees, no family is endemic to the Western Ghats. However, five genera *viz*. Poeciloneurone, Blepharistemma, Pseudoglochidion, Meteoromyrtus and Otonephelium were endemic. Despite the presence of 352 endemic species from 43 families, nearly 35% of the families did not have any endemics. In families such as Chrysolabalanceae (*Atuna indica* and *A. travancorica*), Combretaceae (*Terminalia travancorica*) and Malvaceae (*Julostylis polyandra*), all the representative species occurring in the evergreen forests of the Western Ghats were endemic. The five largest families with the endemic species were Dipterocarpaceae (92%), Anacardiaceae (84%), Lauraceae (72%), Fabaceae, Rubiaceae and Myrtaceae (68%).

Unlike the distribution of species, where 87% of the families had less than 20 species, the distribution of endemism peaked in families with 41–60 species. The two curves were significantly different when the distributions were compared using KS two-sample test ($D = 0.69$, $n = 66$, $P < 0.05$).

Table 2 Dioecy, monoecy and endemism in the evergreen flora of the Western Ghats, India

Class	Total species in flora	Dioecy			Monoecy		
		Number observed	Number expected	Chi-square	Number observed	Number expected	Chi-square
Endemic	352	74	70.4	0.3 NS	18	21.5	1.2 NS
Non-endemic	304	60	63.5		23	19.4	
Total	656						

To verify association between dioecy or monoecy, and endemism, we used chi-square analysis. A significant chi-square value could be interpreted as an association between the dioecy and endemics.

DISCUSSION

The Western Ghats mountain chain is similar to only those in Queensland, Australia and Madagascar. Mountain chains on both locations support luxurious evergreen forests and are parallel to the coast. The total number of tree species recorded in the evergreen forests of the Western Ghats (656) was lower than for the tropical rainforests of Australia (1100 species; Kershaw & Whiffin, 1989), which was lower than in Madagascar (4220 species of shrubs and trees; Schatz, 2001). Evergreen forests of Ecuador also housed many more species than the Western Ghats. The top 10 families alone had about 1537 species of trees and treelets (Jorgensen & Leon-Yanez, 1999). The top five families reported from these forests are Melastomataceae, Lauraceae, Rubiaceae, Mimosaceae and Annonaceae. The dominant families in Barro Colorado Island (BCI) were Moraceae, Euphorbiaceae, Arecaceae, Sapindaceae and Burseraceae, while the total number of species reported was 1212 (Croat, 1979).

Endemism

Increased rates of endemism are often associated with isolated colonization events. The occurrence of 53% of endemic tree flora falls within the estimate provided for dicots by Chatterjee (1939) for British India. The overall estimation of endemics was 11,124 species, across 1831 genera from 173 families. Of these, 2045 endemic species were identified for peninsular India south of Tropic of Cancer (Chatterjee, 1939). Another estimate puts the endemism in the Western Ghats flora at 48% (of 4000 species, Nair & Daniel, 1986). This might seem lower than the estimates for Sri Lanka, which has 3368 species from 1294 genera across 192 families (Bandaranaike & Sultanbawa, 1969). Of these about 326 endemic species were confined to the lowland wet zones (Alston, 1931). The endemism in tree flora for Sri Lanka was estimated at 60% (Gunatilleke, 1978). The rates of endemism were highest for Madagascar flora with 96% of the total 4220 species of trees and shrubs, and 191 native genera being endemic to the Islands (Schatz, 2001). For the Brazilian Mata Atlântica or the Atlantic tropical forests, about 440 species of which 53% of the tree species were endemic (Mori & Boom, 1981). Only in the Amazon region, endemism has been associated with substrate specificity (Gentry, 1992).

Ramesh & Pascal (1991) have analysed the bioclimatic aspects of endemism in the evergreen tree flora in the Western Ghats, and found maximum diversity of endemic species at the transition zones (between dry and wet forest types). The bioclimatic patterns appear to operate at a global scale explaining why some tropical forests have so many species (Liegh *et al.*, 2004).

But the majority of endemics in the Western Ghats were endangered by their position in vertical stratification (ensemble IV). Small trees are less likely to be protected compared to canopy, timber-yielding species of ensemble I or II.

Sexual system

In the Western Ghats, the largest number of dioecious species (43) is reported in ensemble II followed by III (37) as compared to monoecious or polygamous species. This is similar to the observations of Jones (1955) and Momose *et al.* (1998). Croat (1979) found that more medium to large trees was dioecious than small trees (Table 3).

There was no significant association between dioecy and monoecy and endemism in the evergreen tree flora of the Western Ghats. The frequency of dioecy in the evergreen tree flora of the Western Ghats (20%, Table 4) is much less than the reports from other tropical sites. These values were higher than the estimate for the total Indian flora (6%; Steiner, 1988). Bawa (1980) summarized the data on dioecious tree flora from 10 geographical regions, and showed that the frequency of dioecious species varied from 3% to 28% of the total flora. The values for the Western Ghats were higher as compared to other island floras (Puerto Rico 18%, Taiwan 7.1%) and the mountain flora of Tanzania (12%; Rodgers & Homewood, 1982), but lower than 22% obtained for semideciduous forests in Costa Rica (Bawa & Opler, 1975), 21% for BCI (Croat, 1979) and 26% for the Malaysian rainforest (Ashton, 1969). The rate of dioecy reported in this study should be considered a conservative estimate due to incomplete taxonomic surveys. Until observations are made on populations throughout the Ghats, our knowledge of the species grouped as polygamous will remain ambiguous. Further, new species have been discovered within the past decade, some of which are now known to be extremely restricted and endemic, and our knowledge of them remains incomplete.

Table 3 Comparison of sexual systems across ensembles in the tree flora of the Tropics

	Hermaphrodite			Dioecious			Monoecious			Polygamous		
	I	II, III	IV	I	II, III	IV	I	II, III	IV	I	II, III	IV
Nigeria*	41	50	49	37	37	38	22	13	13			
Sarawak†	75	62	58	8	19	2	16	19	39			
BCI‡	63		78	21		12	15		7	1		3
Western Ghats§	55	52	62	18	23	15	3	6	8	22	16	12

Values indicate percentage of species.
Data sources:
*From Jones (1955).
†From Momose *et al.* (1998).
‡From Croat (1979).
§Present study for the Western Ghats.

Table 4 Comparison of the sexual systems in different floras

	Percentage of species				
Regions	Hermaphrodite	Monoecious	Dioecious	Polygamous	Total species
SW of W. Australia[1]	90.04	2.55	4.43	2.99	3886
S Australia[2]	89.01	5.85	4.19	0.95	2102
Barro Colorado Island[3]	76.40	10.90	8.75	4.29	1212
Jamaica[4]	64.29		21.40	14.30	56
Venezuela[5]	69.44*		30.60		36
Mexico[6]	57.98	12.20	23.40	6.38	188
Nigeria[7]	46.67	15.00	38.30		60
Tanzania[8]	73.28	6.87	12.60	7.25	262
Sarawak[9]	66.18	11.00	21.30	1.47	136
Costa Rica[10]	67.88	9.93	22.20		302
Puerto Rico[11]	73.43	17.70	8.86		463
Western Ghats	57.16	6.10	20.60	16.20	656

Notes: [1]McComb (1966); [2]Parsons (1958); [3]Croat (1979); [4]Tanner (1982); [5]Sobrevila & Arroyo (1982); [6]Bullock (1985); [7]Jones (1955); [8]Rodgers & Homewood (1982); [9]Momose *et al.* (1998); [10]Bawa & Opler (1975); [11]Flores & Schemske (1984).
*Includes monoecious species.

Studies from the Neotropics show that dioecy has ecological correlates. One of the correlates relevant to this study is woodiness, which could explain why there are more dioecious species in higher ensembles rather than ensemble IV (Croat, 1979; Bawa *et al.*, 1985; Bullock, 1985; Fox, 1985; Steiner, 1988). There was no significant association between dioecy, monoecy and endemism. The actual numbers of dioecious and monoecious species were not greater than expected. The non-significant differences could be due to phylogeny. Most endemics were from large families and had closely related species.

The maximum richness of monoecious species in the Western Ghats was in ensemble IV (18). This was similar to the observations for Sarawak (Momose *et al.*, 1998). In BCI and Nigerian forests, monoecious species were more frequent in the upper storey. In the low-elevation Dipeterocarp forests of Sarawak, 14% of tree species were monoecious compared to 10% in the semideciduous forests of Costa Rica (Bawa & Opler, 1975). The mountain flora of Tanzania contained 7% of monoecious species. However, low levels of monoecy were observed in the tree flora of the Western Ghats (6%). If polygamous species were also added to the group (following criterion adapted in some studies), then 19% of the trees were monoecious. The polygamous species were more frequent in ensemble I (22%) in the Western Ghats, whereas in BCI flora, they were more frequent in the understorey (Table 4).

The high numbers of endemic species in the evergreen forests of the Western Ghats indicate that the threat of species loss is real and high when coupled with possible negative impacts of alien plant invasions, uncontrolled harvest of timber or fruits, inappropriate burning and development. Our knowledge will improve when populations of endemic species are monitored at regular intervals.

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