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INVENTORIES OF UNDERSTORY PLANTS IN A TROPICAL EVERGREEN FOREST IN THE ANAMALAIS, WESTERN GHATS, INDIA

J. Annaselvam & N. Parthasarathy*

Salim Ali School of Ecology and Environmental Sciences, Pondicherry University, Pondicherry – 605 014, India

Abstract. Species diversity, population density and dispersion of all understory plants were inventoried in a 30-ha permanent plot, by regular sampling of three thousand 4 m^2 quadrats, distributed evenly 100 quadrats in each hectare in a tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. It is a closed-canopy evergreen forest with even tree distribution and natural tree fall gaps. A total of 155 species of understory plants was recorded, of which 65% were annuals. There were 142 species of angiosperms, representing 43 families and 13 species of pteridophytes in 10 families. Species-wise, herbs were dominant (41%) and density-wise, shrubs were abundant (57%). The most abundant species were *Nilgirianthus barbatus* (IVI 29%), *Pellionia heyneana* (12%) and *Ecbolium viride* (8%). Acanthaceae (15 species), Papilionaceae (12), and Asteraceae (9) were well-represented. The richness estimators employed for species and family accumulation curves after 100 times randomization of sample order, have stabilized the curves at 28th and 27th hectares respectively, indicating that the 30 ha area was sufficient to capture all understorey plants of the evergreen forest. The similarity in species composition between the thirty 1 ha subplots was 70 to 90%. The total population density of understorey plants was 218,471 individuals in the 30 ha plot sampled (mean 73.8 per 4 m^2 quadrat). Thirty-five species occurred in tree fall gaps and forest edges, 9 species in canopy-closed areas and the remaining in both closed-canopy and gap areas. Thirteen species (8.4%) of weeds have invaded the forest. The majority (65%) of understorey plants are autochorous dispersal type, bearing capsule, dust diaspore etc., the remaining bearing berries, drupes and grains are meant for dispersal by lower-storey and ground birds, ants, etc. A 10% sample of this survey (300 quadrats, distributed 10 per ha) marked for biomonitoring, would provide further data on understorey plant dynamics. *Accepted 22 October 1999.*

Key words: *Acanthaceae*, *India*, *population density*, *species dominance*, *tropical forest*, *understorey diversity*, *Western Ghats*.

INTRODUCTION

Most biodiversity studies in tropical evergreen forests have concentrated on tree species, the understory plants (shrubs, undershrubs, herbaceous climbers, herbs, etc.) were rarely included in such inventories. Gentry & Dodson (1987) investigated the contribution of non-tree species to total species richness in lowland rain forest in western Ecuador. Most understorey plant studies were conducted on small scales (–0.1 ha – Smith 1970, Hall & Swaine 1981, Gentry & Dodson 1987), while Poulsen & Pendry (1995) recorded the abundance and species richness of ground herbs in three 0.25 ha plots at each of three altitudes in Bukit Belalong, Borneo. In four studies, the whole 1 ha plot was enumerated: in the unflooded moist tropical rain forest of Amazonian Ecuador (Poulsen & Balslev 1991); all pteridophytes in the same site (Poulsen & Nielsen 1995); all ground herbs in the lowland rain forest in northwest Borneo (Poulsen 1996a) and in three 1 ha plots at 3 elevations of the tropical evergreen forest in Agumbe, Western Ghats, India (Gopisundar & Parthasarathy, ms). Based on an analysis of relationship between canopy trees and ground flora in a tropical rain forest in Singapore, Turner *et al.* (1996) remarked that the ground herbs might prove to be a good indicator of forest succession status. As such ,the conditions on the ground in a closed-canopy forest are characterized by low light intensities and high humidity (Poulsen 1996b)

Large-scale inventories on understorey plants are lacking from Indian tropics. Hence the present study was undertaken, aiming at a large-scale, detailed, quantitative inventory of understorey plants in a tropical evergreen forest, taking a total of three thousand 4 m^2 sample units, distributed evenly within the 30 ha permanent plot. The objectives of the present study were to investigate the species richness, abun-

* Author for correspondence
e-mail: bioinpú@iitm.ernet.in

dance and distribution of understorey plants in the first census and biomonitor a 10% sample (300 quadrats) for spatio-temporal changes in their abundance, by periodical recensus. This paper presents the results of the first phase enumeration of understorey plants.

STUDY AREA

The study was conducted in the tropical evergreen forest at Varagalaiar, within the Indira Gandhi National Park (11,711ha) and Wildlife sanctuary (84,149 ha) near Topslip, Anamalais, Western Ghats. It is located (10°25' N, 76°52'E) in Coimbatore district of Tamil Nadu, south India (Fig.1). The elevation of our study site ranges from 600 ro 660 m asl. The site receives bulk of rains from the southwest (June-September) and meagre during northeast (October-December) monsoons, and experiences four to five months (January to April) of dryness, but a few days of summer showers are received during this period. Mean annual rainfall is 1600mm, recorded at Topslip, located 27 km west of Varagalaiar. The study site is closer (0.5 km) to an elephant training camp. A bridle path diagonally traverses the study area, which was once used by the elephant camp people for taking the tamers into the forest. The study site lies between two perennial rivers Kurampalli and Varagalaiar. The water flow in Varagalaiar is meagre during summer. A portion of plot (28, 29, 30 hectares) was affected by ground fire 2 years ago. There are savanna woodlands ro the northeast of the study site.

About 26 families in the nearby settlement (with a total population of 100 residents) are employed in the elephant camp for taming the elephants. The camp dwellers invade forest for their fire wood requirement, collecting edible fruits, honey, dammar, rattan and ginger.

The vegetation of our study site is a closed-canopy tropical evergreen forest with a few natural tree fall gaps. In our study site a total 13,393 trees (Ayyappan & Parthasarathy 1999) and 348 lianas (≥ 30 cm girth at breast height (gbh) (Murhuramkumar & Parthasarathy ms) were enumerated in the 30 ha plot. Predominant trees in the typically four-storeyed evergreen forest include *Dipterocarpus indicus*, *Vateria indica*, *Callophyllum polyanthum*, and *Bombax ceiba* as emergents, *Poeciloneuron indicum*, *Palaquium ellipticum*, *Polyalthia fragrans*, *Syzygium densiflorum* in the upperstorey, *Reinwardtiodendron anamallayanum*, *Fahrenheitia zeylanica*, *Dimocarpus longan*, *Myristica dactyloides*, etc. form the middle-storey, and *Baccaurea courtallensis*, *Cleidion spiciflorum*, *Drypetes longifolia*, *Prismatomeris albidiflora* etc. constitute the lowerstorey. Major lianas include *Olax scandens*, *Piper nigrum*, *Chilocarpus atrovirens*, *Kuntsleria keralense*, *Gnetum ula*, and the rattan *Calamus gamblei*. The deciduous species formed 23% of tree species richness and 11% of tree density (Ayyappan & Parthasarathy 1999). Major fauna in the study area include tiger, panther, elephant, nilgiri langur, lion-tailed macaque, malabar giant squirrel and birds such as hill myna, racket-tailed drongo, imperial pigeon, hornbills, etc.

METHODS

Fieldwork was carried out in two phases: September-October 1997 and December 1997 to May 1998. A 30 ha permanent plot (500 x 600 m^2) was established to conduct research on plant biodiversity and long-term biomonitoring of forest dynamics. To facilitate understorey plant inventories, each hectare was divided into hundred 10 m^2 grids. In each 10 m^2 grid, a 4 m^2 quadrat was laid at the bottom right, uniformly in the whole 30 ha area, thus forming a total sample of 3000 quadrats (which covered closed-canopy and tree fall gap areas) to enumerate all the understorey plants : herbs (small plants < 1 m tall, with no woody stems), undershrubs (small plants 1 to 1.5 m tall with moderately woody stems), shrubs (> 1.5 m to 5 m tall with woody stem and branching at low-levels without a distinct trunk) and herbaceous climbers. In this study, the habit herbs not only include the typical dicot and monocot herbaceous forms but also other sub-categories like gingers, grasses, sedges and pteridophytes which are prominent on the forest floor. Some species which are generally epiphytic, but sometimes encountered on the ground as facultative herbs were excluded, so also the treelets. Voucher specimens of each species of understorey plants were collected (for rare species, a portion of rhe plant was collected or if rhe plant was available outside the quadrat collection was made outside the quadrats), processed methodically, labeled and deposited in the herbarium of School of Ecology, Pondicherry University.

Data analysis. For species diversity, Shannon, Simpson, and evenness indices (Magurran 1988) were calculated. Density of species is taken as total number

of individuals in the 30 ha plot. Frequency of a species was taken as the number of sampling units in which the species were recorded. The importance value index (IVI) was calculated for all species by summing up the values of relative density and relative frequency i.e. for a rotal of 200 only. Family importance value index (FIV) was calculated by modifying the formula of Mori *et al.* (1983) by summing up the relative family diversity and density as mentioned below:

(a) family relative diversity = the number of species in a family present in the sample/the total number of species in the sample,

(b) family relative density = the number of individuals in a family / total number of understorey plants in the sample.

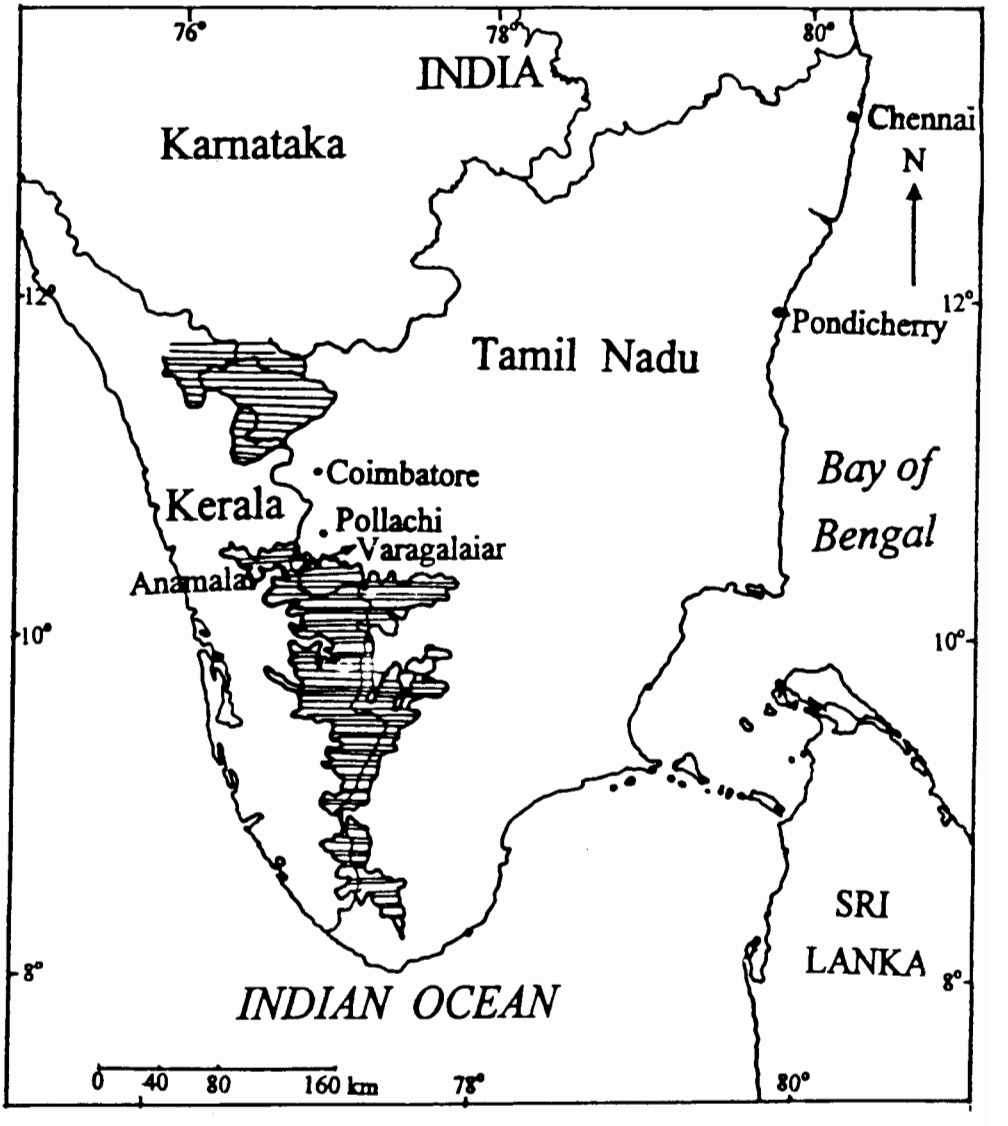

FIG. 1. Map showing the location of Varagalaiar study site in the Anamalais,Western Ghats, India.

Sorensen's similarity index (Greig-Smith 1983) was calculated for the thirty 1 ha subplots. Species-area and family-area curves were raised (1) by sequential arrangement of thirty 1 ha subplots by serpenting between one side to other and (2) by using the program EstimateS (version 5, R. K. Colwell, http://viceroy.eeb.uconn.edu/estimates) based on mean species-accumulation and family-accumulation curves, after 100 times randomization of sample order. Chazdon *et al.* (1998) suggested that the incidence based estimators, Incidence-based Coverage Estimator (ICE) and Chao2, best satisfied the requirements of an ideal estimator, which are graphically represented by plotting the estimators and observed species richness against the cumulative number of hectares sampled. The effects of non-random spatial distribution of species richness were examined by altering the degree of patchiness within our data set, maintaining relative and absolute species abundance constant. This is done by Estimators program (Colwell., l.c.) by defining the patchiness parameter 'A' as 0, 0.5 and 0.75 for random, patchy and highly patchy respectively.

RESULTS

Species richness and diversity. A total of 155 species of understorey plants that belonged to 132 genera and 53 plant families was enumerated in the 30 ha plot (Table 1). Species richness ranged from 17 to 83 species ha^{-1} and 1 to 31 species per $4m^2$ sample quadrat (Table 1). In the 30 ha area, in forty quadrats no species were encountered. Based on Sorensen index, the similarity in species composition of the thirty 1 ha subplots was 70 to 90%. The Shannon, Simpson, Hill diversity 1,2 and 3 and all evenness indices are given in Table 1.

Of the 155 species of understorey plants enumerated, 65 were herbs, 21 undershrubs, 18 shrubs, 17 herbaceous climbers, 13 pteridophytes, 9 gingers, 8 grasses and 4 sedges. Their per cent contribution is depicted in Fig. 2a. Shrubs were abundant by habit, with 123,492 individuals (57%) in the total enumeration (Fig. 2b).

Species-area curve. Species accumulation curves, both the observed and estimated, attained an asymptote at various scales. The incidence based estimators namely ICE and Chao2 best satisfied for our data set (Fig. 3). It reached stable values of 162.47 and 161.06 respectively after the 13th hectare, while the observed curve stabilized at 28 hectare (Fig. 3). After analysing the patchiness parameter (random, moderately patchy and highly patchy) for the observed species, nearly 50% of the species accumulated in the 3rd hectare itself (Fig. 4). This patchiness analysis showed that the understorey plants of Varagalaiar were slightly non-random in distribution.

TABLE 1. Results of biodiversity inventory of understorey plants in the 30 ha plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, south India.

Variable	
Species richness	155
Range per hectare	17-83
Mean (s.d.)	44 (15.3)
Range per 4 m^2 quadrat	1-31
Mean (s.d.)	5.6 (3.7)
Number of genera	132
Number of families	53
Total population density	218,471
Range per hectare	2939-12403
Mean (s.d.)	7282 (2192)
Range per 4 m^2 quadrat	1-393
Mean (s.d.)	72 (62)
Diversity indices	
Shannon	2.43
Simpson	0.23
Hill diversity 1	155.00
Hill diversity 2	11.36
Hill diversity 3	4.44
Evenness index1	0.48
Evenness index 2	0.07
Evenness index 3	0.07
Evenness index 4	0.39
Evenness index 5	0.33

Family-area curve. The family-area curve (Fig. 5) reveals that of the 53 families represented in the 30 ha, based on the incidence estimators ICE and Chao 2, it attained an equilibrium at 19th hectare, while the observed family-area curve stabilized at 27th hectare.

Population density of species, dominance and rarity. A total of 218,471 individuals of understorey plants was enumerated in the 30 ha plot sampled. Dicotyledons formed 76%, moncotyledons 19% and pteridophytes 5%. The density of understorey species varied considerably in the 30 hectares with a four-fold difference

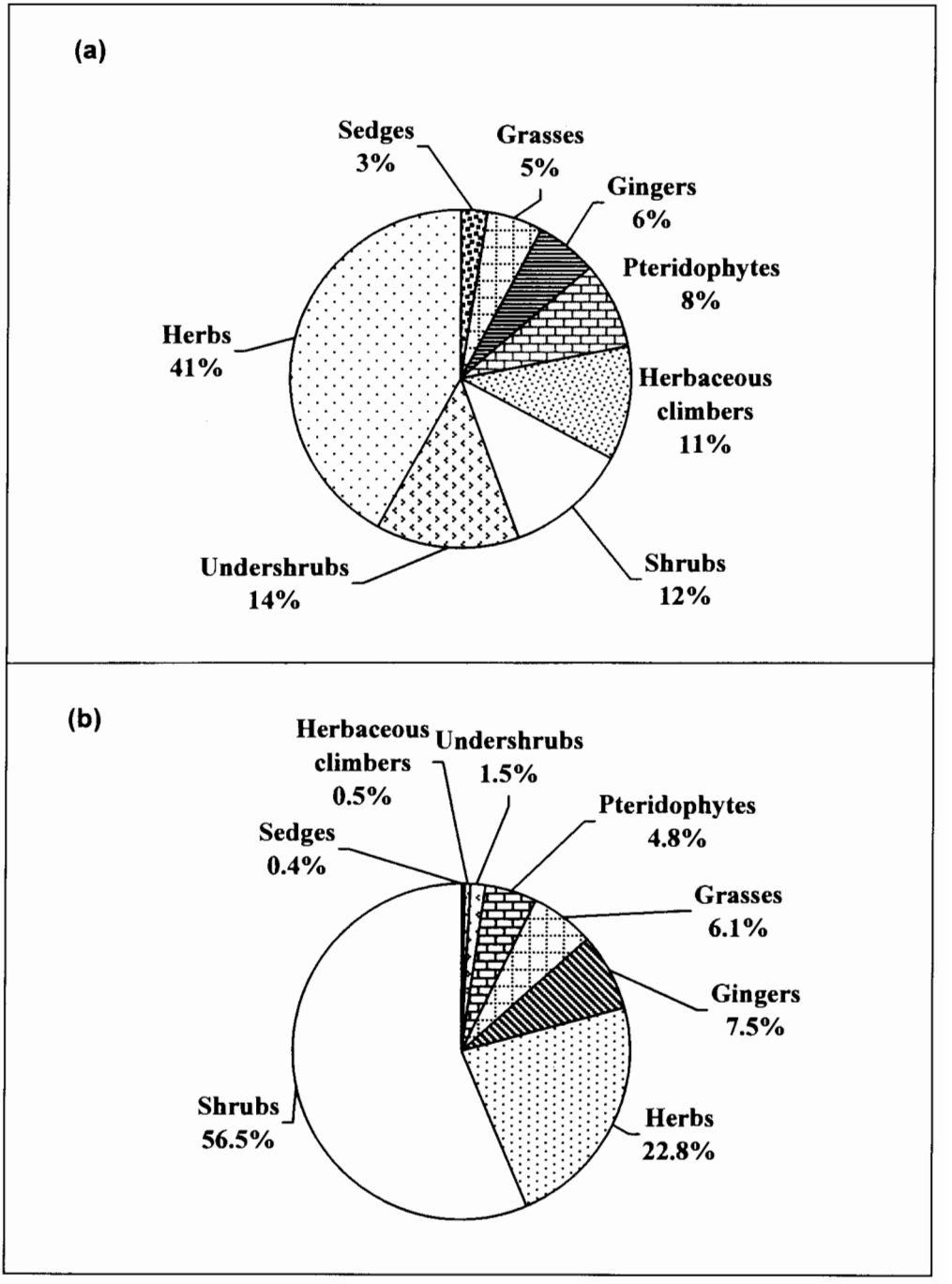

FIG. 2. (a) Habit-wise percentage of understorey species in the tropical evergreen forest at Varagalaiar, Western Ghats. (b) Habit-wise per cent abundance of understorey plants in the tropical evergreen forest at Varagalaiar, Western Ghats.

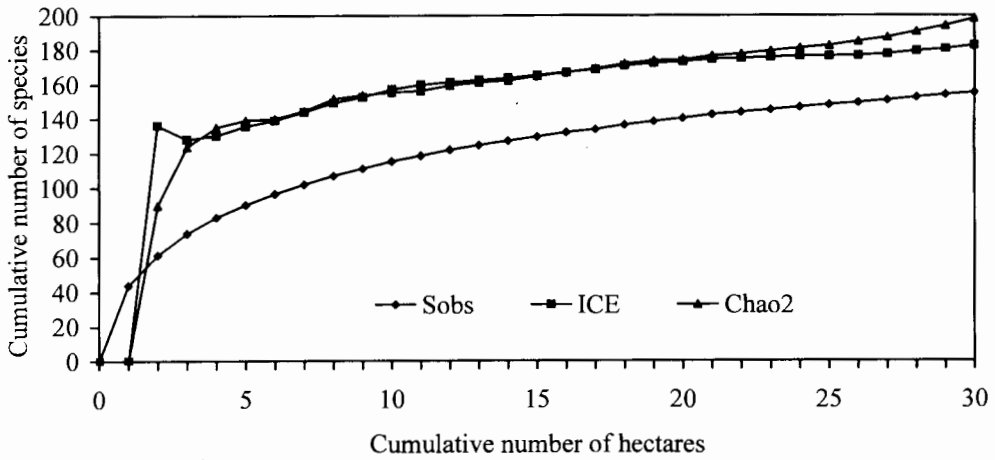

FIG. 3. Species-area curve of understorey plants in the 30 ha area of tropical evergreen forest at Varagalaiar, Western Ghats.

between the least dense 2 hectare to densest 13 hectare.

The population density of the 155 understotey species varied considerably (Table 2). Of the total 155 species, 3 species (2%) were predominanr, with a population density > 10000 individuals in the total area (Table 2), 19 species (12%) were dominant (frequency (f) = < 10000 to > 1000); 41 species (27%) were common (f = < 1000 to > 100); 59 species (38%) were rare (f = < 100 to > 10) and 38 species (21%) were very rare (f = < 10). The three predominant species, which together contributed 65% of the understorey plant density and 48% of IVI, are *Nilgirianthus barbatus* of Acanthaceae (96,818 individuals; IVI 57.15), *Pellionia heyneana* of Urticaceae (29,275 individuals; 22.95) and *Echolium viride* of Acanthaceae (16,150 individuals; 15.43) (Table 2). Notable common species include the grass, *Paspalum*

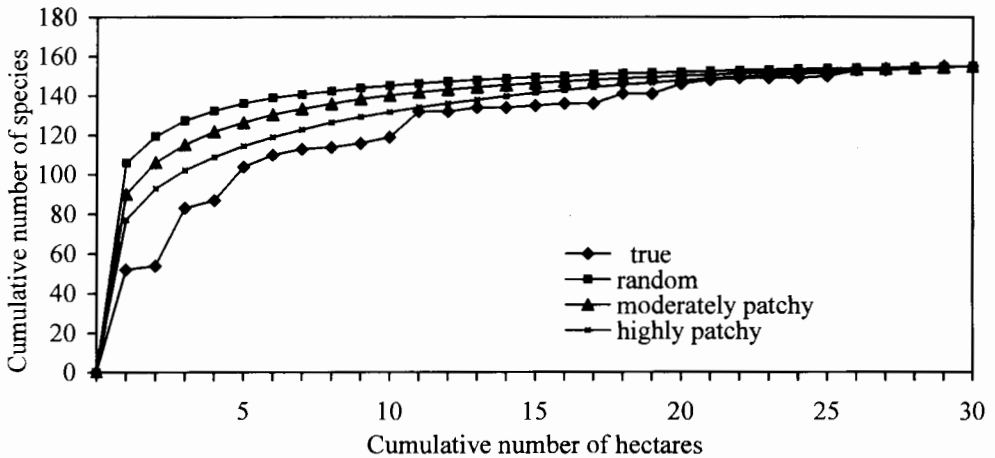

FIG. 4. Effect of random (■), moderately patchy (▲) and highly patchy (×). Relative and absolute abundances of understorey plants were unchanged from the observed field dara (◆).

TABLE 2. Population density, number of hectares and quadrats of occurrence and importance value index (IVI) of all understorey plants in the 30 ha plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India.

Species	Family	Density in 30 ha	Occurrence in number of		IVI*
			ha's	Quadrat	
1. *Nilgirianthus barbatus* (Nees) Bremek.	Acanthaceae	96818	30	2172	57.15
2. *Pellionia heyneana* Wedd.	Urticaceae	29275	29	1616	22.95
3. *Ecbolium viride* (Forssk.) Alston	Acanthaceae	16150	30	1361	15.43
4. *Cyrtococcum oxyphyllum* (Steud.) Stapf	Poaceae	6839	30	923	8.58
5. *Bolbitis semicordata* (Moore) Ching	Bolbitidaceae	5855	30	688	6.74
6. *Amomum hypoleucum* Thw.	Zingiberaceae	5550	30	769	7.08
7. *Stachyphrynium spicatum* K. Schum.	Marantaceae	5470	29	414	4.95
8. *Oplismenus compositus* (L.) P.Beauv.	Poaceae	5406	27	643	6.27
9. *Chromolaena odorata* (L.) King & Robinson	Asteraceae	4065	23	300	3.63
10. *Strobilanthes caudatus* T. And.	Acanthaceae	3683	14	208	2.91
11. *Curculigo trichocarpa* (Wight) Ben. & Raiz.	Hypoxidaceae	3032	30	638	5.16
12. *Amomum cannicarpum* (Wight) Benth.	Zingiberaceae	3012	30	403	3.76
13. *Globba marantina* L.	Zingiberaceae	2880	20	413	3.76
14. *Aneilema montana* (Wight) Clarke	Commelinaceae	2702	29	499	4.18
15. *Zingiber macrostachyum* Dalz.	Zingiberaceae	2557	30	623	4.85
16. *Selaginella tenera* (Hk.et Grew) Spring	Selaginellaceae	1634	16	120	1.46
17. *Murdannia zeylanica* Brueckner var. *longiscapa* (Clarke) R.Row & Kammathy	Commelinaceae	1597	25	230	2.09
18. *Schumannianthus virgatus* Rolfe	Marantaceae	1285	12	70	1.00
19. *Pteris multiaurita* Ag.	Pteridaceae	1273	30	408	2.99
20. *Dracaena terniflora* Roxb.	Agavaceae	1232	30	630	4.29
21. *Zingiber wightianum* Thw.	Zingiberaceae	1104	27	315	2.37
22. *Lepidagathis incurva* Buch.-Ham.ex D.Don	Acanthaceae	1081	13	109	1.14
23. *Paspalum conjugatum* Berg.	Poaceae	889	13	96	0.97
24. *Elatostemma lineolatum* Wight	Urticaceae	866	14	102	1.00
25. *Cyathula prostrata* (L.) Blume	Amaranthaceae	777	12	109	1.00
26. *Lepianthes umbellata* (L.) Rafin.	Piperaceae	769	21	154	1.26
27. *Scleria lithosperma* Sw.	Cyperaceae	673	12	83	0.80
28. *Curcuma amada* Roxb.	Zingiberaceae	642	8	136	1.10
29. *Pteris pellucida* Presl.	Pteridaceae	634	29	305	2.09
30. *Lantana camara* L.	Verbenaceae	468	7	56	0.54
31. *Hibiscus furcatus* Willd.	Malvaceae	464	16	94	0.77
32. *Pseudarthria viscida* (L.) Wight & Arn.	Papilionaceae	417	14	93	0.74
33. *Christella dentata* (Forsk) Brow. & Jermy	Thelypteridaceae	402	20	116	0.87
34. *Adiantum incisum* Forsk.	Adiantaceae	394	12	33	0.38
35. *Costus speciosus* J.E.Smith	Costaceae	380	13	83	0.66
36. *Pouzolzia zeylanica* (L.) Benn.	Urticaceae	375	3	9	0.22
37. *Commelina paludosa* Blume	Commelinaceae	374	16	78	0.63
38. *Ophiopogon intermedius* Don	Haemodoraceae	367	27	189	1.28
39. *Ageratum conyzoides* L.	Asteraceae	351	15	46	0.43
40. *Cyanotis papilionacea* Schult.f.	Commelinaceae	293	1	4	0.16
41. *Abrus pulchellus* Wall.	Papilionaceae	276	21	157	1.05
42. *Elephantopus scaber* L.	Asteraceae	257	7	35	0.32

TABLE 2. Continued.

Species	Family	Density in 30 ha	Occurrence in number of		IVI*
			ha's	Quadrat	
43. *Desmodium gangeticum* (L.) DC.	Papilionaceae	250	20	102	0.72
44. *Phaulopsis imbricata* (Forssk.) Sweet	Acanthaceae	249	7	21	0.24
45. *Lindernia ruellioides* (Colsm.) Pennell	Scrophulariaceae	220	2	15	0.19
46. *Mimosa pudica* L.	Mimosaceae	203	5	23	0.23
47. *Zingiber officinale* Roscoe	Zingiberaceae	201	13	61	0.45
48. *Synedrella nodiflora* (L.)Gaertn.	Asteraceae	197	7	27	0.25
49. *Cissus repens* Lamk.	Vitaceae	192	17	100	0.68
50. *Floscopa scandens* Lour.	Commelinaceae	182	7	24	0.23
51. *Rostellularia procumbens* (L.) Nees	Acanthaceae	182	5	18	0.19
52. *Staurogyne glauca* (Nees) Kuntze	Acanthaceae	178	4	13	0.16
53. *Geophila repens* (L.) I.M.Johnston	Rubiaceae	162	9	28	0.24
54. *Microlepia spluncae* (L.)Moote	Dennstaedtiaceae	157	15	78	0.53
55. *Sida cordata* (Burm.f.) Borssum	Malvaceae	145	8	32	0.26
56. *Urena lobata* L.	Malvaceae	142	7	36	0.28
57. *Bolbitis appendiculata* (Willd.) I.Watsuki	Bolbitidaceae	136	9	25	0.21
58. *Arisaema tortuosum* Schott.	Araceae	133	9	68	0.46
59. *Stephania japonica* (Thunb.)Miers	Menispermaceae	133	18	59	0.41
60. *Drymaria cordata* (L.)Willd.	Caryophyllaceae	127	3	7	0.10
61. *Sida rhombifolia* L.	Malvaceae	121	7	28	0.22
62. *Vernonia cinerea* (L.) Less.	Asteraceae	106	4	11	0.11
63. *Thottea siliquosa* (Lam.) Ding Hou	Aristolochiaceae	105	9	41	0.29
64. *Desmodium triflorum* (L.) DC.	Papilionaceae	98	1	6	0.08
65. *Anaphyllum beddomei* Engl.	Araceae	97	19	47	0.32
66. *Torenia bicolor* Dalz.	Scrophulariaceae	95	2	7	0.08
67. *Peperomia pellucida* (L.) H.B.K.	Piperaceae	92	1	3	0.06
68. *Dendrocalamus strictus* (Roxb.) Nees	Poaceae	89	7	17	0.14
69. *Senecio scandens* Buch.-Ham. ex D.Don	Asteraceae	83	7	16	0.13
70. *Cyperus killingia* Engl.	Cyperaceae	80	4	8	0.08
71. *Veronica buabaumii* Speedwell	Scrophulariaceae	75	2	7	0.08
72. *Hedyotis nitida* Wt.& Arn.	Rubiaceae	68	7	21	0.16
73. *Murdannia nudiflora* (L.) Brenan	Commelinaceae	62	4	8	0.08
74. *Tragia bicolor* Miq.	Euphorbiaceae	62	5	14	0.11
75. *Phyllanthus maderaspatensis* L.	Euphorbiaceae	60	3	5	0.06
76. *Tainia bicornis* (Lindl.) Reichb.f.	Orchidaceae	57	4	7	0.07
77. *Cyclea peltata* (Lam.) Hook. f.& Thoms.	Menispermaceae	53	14	45	0.29
78. *Dendrocnide sinuata* (Blume) Chew	Urticaceae	50	4	8	0.07
79. *Eupatorium glandulosum* HB & K	Asteraceae	50	2	4	0.05
80. *Aneilema ovalifolia* (Wight) Hook.f.	Commelinaceae	49	1	7	0.06
81. *Haplanthodes neilgherryensis* (Wight) Majumdar	Acanthaceae	47	2	5	0.05
82. *Dioscorea bulbifera* L.	Dioscoreaceae	46	7	19	0.13
83. *Andrographis macrobotrys* Nees	Acanthaceae	43	4	9	0.07
84. *Pogostemon paniculatus* (Willd) Benth.	Lamiaceae	43	6	8	0.07
85. *Arisaema leschenaultii* Bl.	Araceae	42	6	25	0.17
86. *Centotheca lappacea* (L.)Desv.	Poaceae	42	5	11	0.08
87. *Gloriosa superba* L.	Liliaceae	40	4	12	0.09
88. *Hedychium coronarium* Koen.	Zingiberaceae	40	3	3	0.04

TABLE 2. Continued.

Species	Family	Density in 30 ha	Occurrence in number of		IVI*
			ha's	Quadrat	
89. *Eranthemum capense* L.	Acanthaceae	38	1	2	0.03
90. *Pogostemon heyneanus* Benth.	Lamiaceae	36	4	9	0.07
91. *Vigna umbellata* (Thunb.) Ohwi & Ohashi	Papilionaceae	35	6	12	0.09
92. *Isachne* sp.	Poaceae	30	4	6	0.05
93. *Rungia pectinata* (L.) Nees	Acanthaceae	30	3	4	0.04
94. *Solena angulata* (Chakravarthy) Babu	Cucurbitaceae	30	15	21	0.14
95. *Cyperus iria* L.	Cyperaceae	29	2	3	0.03
96. *Rubia cordifolia* L.	Rubiaceae	27	4	13	0.09
97. *Chlorophytum nimmonii* (Graham) Dalz.	Liliaceae	25	4	12	0.08
98. *Laportea interrupta* (L.) Chew	Urticaceae	25	7	9	0.06
99. *Colocasia esculenta* (L.)Schott	Araceae	24	3	5	0.04
100. *Setaria palmifolia* (Koen.) Stapf.	Poaceae	24	2	4	0.03
101. *Begonia malabarica* Lamk.	Begoniaceae	22	5	5	0.04
102. *Solanum torvum* Sw.	Solanaceae	22	3	7	0.05
103. *Adenostemma lavenia* (L.) Kuntze	Asteraceae	18	3	8	0.06
104. *Gymnopetalum wightii* Arn.	Cucurbitaceae	18	8	12	0.08
105. *Dictyospermum scaberrimum* (Blume) Morton ex Hara	Commelinaceae	17	6	6	0.04
106. *Naravelia zeylanica* (L.) DC.	Ranunculaceae	17	4	6	0.04
107. *Pilea melastomoides* (Poir.) Blume	Urticaceae	17	3	3	0.03
108. *Ophiorrhiza mungos* L.	Rubiaceae	16	4	6	0.04
109. *Argostemma verticillatum* Wall.	Rubiaceae	15	1	1	0.01
110. *Argyreia hirsuta* Wight & Arn.	Convolvulaceae	15	6	11	0.07
111. *Cyrtococcum trigonum* (Retz.) A. Camus	Poaceae	15	4	6	0.04
112. *Anisocampium cumingianum* Presl.	Athyriaceae	14	3	4	0.03
113. *Spermacoce ocymoides* Burm. f.	Rubiaceae	14	1	2	0.02
114. *Colebrookea oppositifolia* J.E. Smith	Lamiaceae	13	2	4	0.03
115. *Cyperus nutans* Vahl var.eleusinoides (Kunth) Haines	Cyperaceae	13	1	1	0.01
116. *Hemionitis arifolia* (Burm.f.) Moore	Cheilanthaceae	13	1	1	0.01
117. *Hydrocotyle javanica* Thunb.	Apiaceae	13	2	2	0.02
118. *Dicliptera foetida* (Forssk.) Blatter	Acanthaceae	10	1	1	0.01
119. *Dioscorea pentaphylla* L.	Dioscoreaceae	10	2	4	0.03
120. *Impatiens verticillata* Wight	Balsaminaceae	10	1	1	0.01
121. *Ipomoea eriocarpa* R.Br.	Convolvulaceae	10	1	2	0.02
122. *Psychotria nilgiriensis* Deb & Gang.	Rubiaceae	10	3	6	0.04
123. *Crotalaria verrucosa* L.	Papilionaceae	9	2	3	0.02
124. *Cyclosorus interruptus* (Willd.) H.Ito.	Thelypteridaceae	9	1	4	0.03
125. *Plectranthus barbatus* Andr.	Lamiaceae	9	1	1	0.01
126. *Arachniodes aristata* (Forsk.f.) Tindale.	Aspidiaceae	8	2	3	0.02
127. *Desmodium motorium* (Houtt.)Merr.	Papilionaceae	8	1	2	0.02
128. *Nervilia aragoana* Gaud.	Orchidaceae	8	3	3	0.02
129. *Solanum erianthum* D. Don	Solanaceae	8	1	3	0.02
130. *Tropidia angulosa* (Lindl.) Blume	Orchidaceae	8	1	1	0.01
131. *Asystasia chelonoides* Nees	Acanthaceae	7	2	3	0.02
132. *Desmodium triangulare* (Retz.) Merr.	Papilionaceae	7	1	3	0.02

TABLE 2. Continued.

Species	Family	Density in 30 ha	Occurrence in number of		IVI*
			ha's	Quadrat	
133. *Desmodium triquetrum* (L.) DC.	Papilionaceae	7	3	5	0.03
134. *Galinsoga parviflora* Cav.	Asteraceae	6	1	1	0.01
135. *Thunbergia fragrans* Roxb.	Acanthaceae	6	3	4	0.03
136. *Impatiens kleinii* Wight & Arn.	Balsaminaceae	4	1	1	0.01
137. *Barleria courtallica* Nees	Acanthaceae	3	1	1	0.01
138. *Biophytum sensitivum* (L.) DC.	Oxalidaceae	3	2	2	0.01
139. *Canscora perfoliata* Lamk.	Gentianaceae	3	1	2	0.01
140. *Centella asiatica* (L.) Urban	Apiaceae	3	2	2	0.01
141. *Cynoglossum zeylanicum* (Vahl ex Hornem.) Thumb. ex Lehm.	Boraginaceae	3	1	2	0.01
142. *Habenaria digitata* Lindl. var. travancoria (Hook.f.) Fischer	Orchidaceae	3	3	3	0.02
143. *Ipomoea pestigridis* L.	Convolvulaceae	3	1	1	0.01
144. *Sarcandra chloranthoides* Gard.	Chloranthaceae	3	1	1	0.01
145. *Asparagus gonoclados* Baker	Asparagaceae	2	1	1	0.01
146. *Flemingia strobilifera* (L.) R.Br.	Papilionaceae	2	1	1	0.01
147. *Glycosmis pentaphylla* (Retz.) DC.	Rutaceae	2	1	1	0.01
148. *Ipomoea hederifolia* L.	Convolvulaceae	2	1	1	0.01
149. *Teramnus labialis* Spreng.	Papilionaceae	2	1	1	0.01
150. *Aphyllorchis montana* Reichb.	Orchidaceae	1	1	1	0.01
151. *Ceratopteris thalictroides* (Linn.) Brongn.	Parkeriaceae	1	1	1	0.01
152. *Crotalaria dubia* Graham ex Benth.	Papilionaceae	1	1	1	0.01
153. *Gomphostemma heyneanam* Wall. ex. Benth.	Lamiaceae	1	1	1	0.01
154. *Malaxis intermedia* (A.Rich) Seidenfaden	Orchidaceae	1	1	1	0.01
155. *Theriophonum minutum* (Willd.) Baillon	Araceae	1	1	1	0.01
Total		218471		16930	200.00

* Importance Value Index (IVI) calculated for 200 i.e. summing relative density + relative frequency only eliminating relative dominance, as basal cover area was not determined.
Relative density = (Number of individual of each species / total number of individuals of all species) x 100
Relative frequency = (Number of quadrats in which each species occurs / sum of frequency of all species) x 100

conjugatum, the wild turmeric *Curcuma amada*, and *Ophiopogon intermedius*. The dicot shrub *Sarcandra chloranthoides* and the aroid *Theriophonum minutum* were very rare. In the study area, 13 species (8.4%) of weeds have invaded. Prominent among them include *Lantana camara*, *Chromolaena odorata*, and *Peperomia pellucida*. Floristically, *Argostemma verticillatum*, a Rubiaceaean herb reported rare in India, grows here characteristically on moist rocks.

Spatial dispersion of understory plants. Of the total 155 species, ten species occurred in all the 30 hectares (Table 2), 21 species were dispersed in 15 to 29 hectares, 88 species in 2 to14 hectares and 36 species occurred in only one hectare in the whole study area, notably *Cyanotis papilionacea*, *Eranthemum capense*, *Gomphostemma heyneanum*, etc. (Table 2).

In toto 35 species (23%) occurred in forest edges where light intensity is high (e.g., *Drymaria cordata*, *Flemingia strobilifera*, *Synedrella nodiflora*, etc.), 9 species (6%) which appear to be essentially skiophytes, occurred in closed-canopy areas (e.g., the ground orchids *Aphyllorchis montana*, *Tropidia angulosa*, *Sarcandra chloranthoides*, and *Barleria courtallica*, etc.), while the remaining 71% of species occurred both in tree fall gaps and closed canopy areas.

Family composition. Of the total 53 plant families of understorey plants in the study area, 43 families were angiosperms, 29 families dicotyledons with 92 species, 14 families monocotyledons, with 50 species and 10 families were pteridophytes (13 species). Family-wise, their contribution to genera and species, population density and family importance value (FIV), varied among the 53 plant families (Table 3). Species-rich families include Acanthaceae (15 species), Papilionaceae (12 species) and Asteraceae (9 species), followed by Zingiberaceae, Poaceae, Commelinaceae (8 species each), Rubiaceae (7 species), Urticaceae, Orchidaceae (6 species each), Lamiaceae and Araceae (5 species each). Twenty-three families (43%) were represented by single species (Table 3). Family importance value index (FIV) was greatest for Acanthaceae (66), Urticaceae (18), Zingiberaceae (12.5) and Poaceae (11); moderate (> 1 to 10) for 27 families which include Papilionaceae, Commelinaceae, Orchidaceae, etc., and less than 1 for 22 families such as Amaranthaceae, Verbenaceae, Costaceae, Mimosaceae, etc.

Fruit types of understorey plants. Among the understorey plants, 23 species (15%) produce dust diaspores (including the pteridophytes), 60 species (39%) capsules, 17 species (11%) achenes, 16 species (10%) bear berries, 13 species (8.4%) legumes, 12 species (7.7%) nutlets, 8 species (5%) grains (caryopsis) and 6 species (4%) produce drupes. The majority of species are autochorous and a few (19% berries, drupes and grains) are meant for dispersal by ground birds, ants etc.

DISCUSSION

The species diversity of understorey plants in Varagalaiar is nearly equal to the tree diversity enumerated there, i.e., 148 species of trees in the same 30 ha permanent plot (Ayyappan & Parthasarathy, ms), while in the tropical rain forest at Singapore, Turner *et al.* (1996) have recorded a herbaceous diversity lower than the canopy trees (449 tree species and 59 herb species). In practice for biological communities the Shannon diversity index (H') does not seem to exceed 5.0 (Washington 1984). For the understorey plants of Varagalaiar forest the H' of 2.43 appears moderate. Simpson index (1-D) ranges from 0 (low diversity) to almost 1. The value of 0.23 for our site is a moderate figure.

The observed species-area curve almost saturated in the 25 hectare with only one ecotone species, *Flemingia strobilifera* added up in the 29 hectare. This is because portions of the 28, 29 and 30 hectare were affected by ground fire 2 years ago, thus resulting in the invasion of this savanna species; while the curve reached the stable values after the 13 ha, using the program EstimateS.

In our study area, annual plants were dominant (65%), whereas Poulsen & Balslev (1991) in Amazonian rainforest, and Hall & Swaine (1981) in Ghana have recorded all ground herbs to be perennials. The absence of annuals seems to be a general characteristic of rain forests (Hall & Swaine 1981). The prevalence of annuals in our study area could be due to the availability of a variety of microhabitats such as tree fall gap areas, river banks and human disturbance

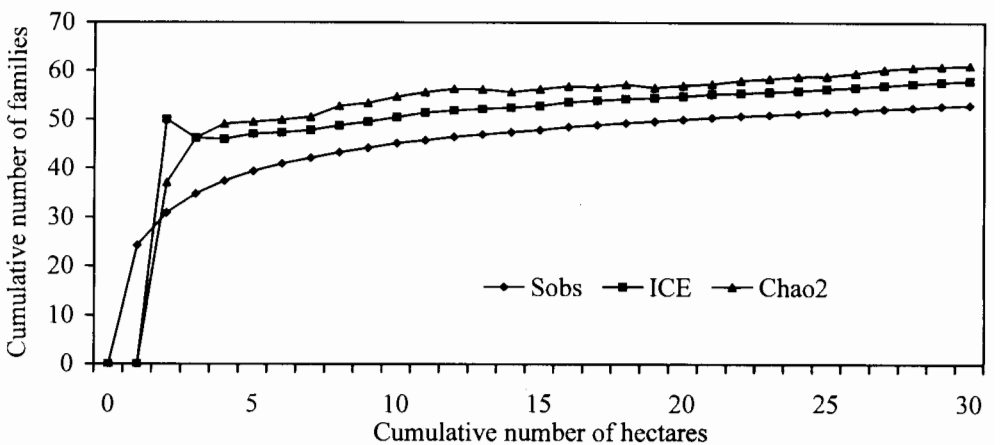

FIG. 5. Family-area curve of understorey plants in the 30 ha area of tropical evergreen forest at Varagalaiar, Western Ghats.

TABLE 3. Family-wise contribution to species, geneta, population density and family importance value index (FIV) of understorey plants in the 30 ha plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats. Families are arranged in decreasing FIV.

Sl.no.	Family	Species richness	Genera	Density	FIV
1	Acanthaceae	15	15	118525	63.93
2	Urticaceae	6	6	30608	17.88
3	Zingiberaceae	8	5	15986	12.48
4	Poaceae	8	7	13334	11.26
5	Papilionaceae	12	8	1112	8.25
6	Asteraceae	9	9	5133	8.16
7	Commelinaceae	8	6	5276	7.58
8	Rubiaceae	7	7	312	4.66
9	Marantaceae	2	2	6755	4.38
10	Bolbitidaceae	2	1	5991	4.03
11	Orchidaceae	6	6	78	3.91
12	Araceae	5	4	297	3.36
13	Lamiaceae	5	4	102	3.27
14	Malvaceae	4	3	872	2.98
15	Cyperaceae	4	2	795	2.94
16	Convolvulaceae	4	2	30	2.59
17	Pteridaceae	2	1	1907	2.16
18	Scrophulariaceae	3	3	390	2.11
19	Hypoxidaceae	1	1	3032	2.03
20	Piperaceae	2	2	861	1.68
21	Thelypteridaceae	2	1	411	1.48
22	Selaginellaceae	1	1	1634	1.39
23	Menispermaceae	2	2	186	1.38
24	Euphorbiaceae	2	2	122	1.35
25	Liliaceae	2	2	65	1.32
26	Dioscoreaceae	2	1	56	1.32
27	Cucurbitaceae	2	2	48	1.31
28	Solanaceae	2	1	30	1.30
29	Apiaceae	2	2	16	1.30
30	Balsaminaceae	2	1	14	1.30
31	Agavaceae	1	1	1232	1.21
32	Amaranthaceae	1	1	777	1.00
33	Verbenaceae	1	1	468	0.86
34	Adiantaceae	1	1	394	0.83
35	Costaceae	1	1	380	0.82
36	Haemodoraceae	1	1	367	0.81
37	Mimosaceae	1	1	203	0.74
38	Vitaceae	1	1	192	0.73
39	Dennstaedtiaceae	1	1	157	0.72
40	Caryophyllaceae	1	1	127	0.70
41	Aristolochiaceae	1	1	105	0.69
42	Begoniaceae	1	1	22	0.66
43	Ranunculaceae	1	1	17	0.65
44	Athyriaceae	1	1	14	0.65
45	Cheilanthaceae	1	1	13	0.65
46	Aspidiaceae	1	1	8	0.65
47	Boraginaceae	1	1	3	0.65
48	Chloranthaceae	1	1	3	0.65
49	Gentianaceae	1	1	3	0.65
50	Oxalidaceae	1	1	3	0.65
51	Asparagaceae	1	1	2	0.65
52	Rutaceae	1	1	2	0.65
53	Parkeriaceae	1	1	1	0.65
	Total	155	132	218471	200.00

TABLE 4. Summary of understorey plant inventories in various tropical forests. (H-herbs; S-shrubs)

Forest type	Location	Plot size and dimension	Number of			Dominant		Reference
			Plants	Species	Families	Families	Species	
Tropical forest	El verde, Puerto Rico	0.1 ha		48				Smith (1970)
Tropical wet evergreen	Nueng F.R., Ghana	0.1 ha		47				Hall & Swaine (1981)
Tropical dry forest	Capeira, Ecuador	0.1 ha	2854 H 742 S	50 29				Gentry & Dodson (1987)
Tropical wet forest	Rio Palengue, Ecuador	0.1 ha	1220 H 531 S	39 39				Gentry & Dodson (1987)
Tropical moist forest	Jauneche, Ecuador	0.1 ha	944 H 219 S	18 16				Gentry & Dodson (1987)
Moist tropical forest	Cuyabeno, Amazonian Ecuador	1 ha; 100,10 m^2 quadrats	10960	96	25	Pteridophytes Araceae Marantaceae	*Pariana radiciflora* (grass)	Poulsen & Balslev (1991)
Moist tropical forest	Cuyabeno Amazonian Ecuador	1 ha; 10 m^2 sub plots	4637	50			*Adiantum terminatum*	Poulsen & Nielsen (1995)
Evergreen lowland rain & lower montane rain forest	Brunei	0.75 ha; three 50 m^2 plot	9431	121	26	Zingiberaceae (24) Araceae (14) Gesneriaceae (10)	*Ptyssiglottis psychotrifolia* *Begonia* sp. *Selaginella dielsii*	Poulsen & Pendry (1995)
Dipterocarp forest	Batu Apoi Forest Brunei	1 ha; Three 20 m^2 sub plots	6264	92	13	Pteridophytes (21) Zingiberaceae (18) Araceae (17)	*Mapania monostachya*	Poulsen (1996a)
Dipterocarp forest	Batu Apoi Forest Brunei	Two 1-ha plots	6264 2479			Zingiberaceae (46) Araceae (35)		Poulsen (1996b)
Tropical rain forest	Central Catchment Nature Reserve Singapore	0.2 ha		59		Araceae (10) Cyperaceae (6)	*Taenitis bleshnoides*	Turner *et al.* (1996)
Tropical lowland evergreen forest	Agumbe, central Western Ghats, India.	Three 1-ha plots	3965 7067 16358	29 29 21		Rubiaceae (7) Piperaceae (3) Verbenaceae (3)	*Psychotria nigra* *P. dalzelli* *Bolbitis subcrenatus*	Gopisundar & Parthasarathy, (ms)
		Total	27390	55	28			
Tropical evergreen forest	Varagalaiar, Anamalais, Western Ghats, India.	30 ha; 3000, 4 m^2 nested quadrats covering 4.8 ha.	218471	155 Range ha^{-1} (17-83)	53	Acanthaceae (15) Papilionaceae (12) Asteraceae (9) Zingiberaceae (8)	*Nilgirianthus barbatus* *Pellionia heymeana* *Echolium viride*	Present study

(like using bridle path in the core forest area, collecting minor forest produce, etc.,) is in line with the observation of Junk & Piedade (1993) in the Amazon flood plain, near Manaus. Most of the perennials occurred in the forest interior.

The variation in plot size and dimension considered in various understorey plant inventories has resulted in considerable differences in the richness and density of understorey plants (Table 4). Evidently, the species richness of the evergreen lowland rain forest and lower montane rain forest of Brunei was greatest with 121 species in 0.75ha (Poulsen & Pendry 1995) (Table 4).

In Varagalaiar site, which is located in the southern Western Ghats, Acanthaceae, Papilionaceae, Asteraceae, and Zingiberaceae were the dominant plant families, while in the ground flora of Agumbe region of the central Western Ghats, Rubiaceae, Piperaceae, and Verbenaceae were dominant (Gopisundar & Parthasarathy, ms) (Table 4).

The predominance of Acanthaceae, Papilionaceae, Asteraceae, Zingiberaceae, Commelinaceae, Rubiaceae, and Orchidaceae in our understorey plant inventory is coincident with the report of Richards (1996) in other tropical rain forests. Most tropical rain forest studies have reported a low or patchy distribution of ground flora (Whitmore 1990), but our Varagalaiar study site in the Western Ghats harbored a fairly high diversity and even distribution of understorey plants.

The dominance of capsule type of diaspore in the understorey plants of Varagalaiar is due to the remarkable diversity of the members of Acanthaceae, Commelinaceae and Malvaceae. Fifteen per cent of the understorey plants produce dust diaspores in Varagalaiar, whereas Kelly *et al.* (1994) reported dust diaspores as the predominant dispersal unit in the lower montane rain forest of Venezuela.

The initial census of forest understorey plants sampled in the 30 ha permanent plot yielded baseline data on the extent of species diversity and distribution in a tropical evergreen forest in the Western Ghats. The proposed recensus of the 10% sample of the total enumeration (i.e., 300 quadrats marked for biomonitoring, out of the total 3000 sample units) would prove profitable to address questions on the spatio-temporal variation in the understorey plant component of the evergreen forest, which are expected to be useful in forest conservation and management.

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