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UNDERSTORY PLANT DIVERSITY IN A TROPICAL EVERGREEN FOREST IN THE KOLLI HILLS, EASTERN GHATS, INDIA

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Abstract. Four 2-ha permanent plots, as two replicates, in undisturbed and human- impacted sites of tropical evergreen forest in the Kolli hills, Indian Eastern Ghats, were inventoried for species richness, abundance, and distribution of understory plants. Eight hundred 4-m^2 quadrats, distributed evenly at 100 quadrats ha^{-1}, and covering 0.32 ha, were sampled. We recorded a total of 9680 individuals belonging to 52 species, 49 genera and 35 families. Disturbed sites harbored lower diversity (22 species ha^{-1}), but greater density (2748 individuals ha^{-1}) compared to the diversity (41 species ha^{-1}) and density (2093 individuals ha^{-1}) of undisturbed sites. Fourteen species (27%) were common to all four sites. About 65% of species with 8% total density was represented by ± 5 individuals ha^{-1}. Species rank-abundance and IVI for the 8 ha showed a dominance of herbs *Cyrtococcum trigonum* (Poaceae, IVI = 54.63) and *Arisaema leschenaultii* (Araceae, 27.53). Total number of dicot, monocot and pteridophyte plant families was 25, 8, and 2, consisting of 37, 12, and 3 species respectively. Lamiaceae (4 species), Acanthaceae (3) and Asteraceae (3) were the most speciose. Herbs constituted the majority of species (21,40%). The study site contained 28 species (54%) of annuals. Six species (12%) were weeds in the understory plants. Considering that the Kolli hills harbor 31% of economically important understory plants, and the reduced species richness (54%) of these plants in the disturbed forest sites with weed invasion, calls for the formulation of effective forest management and conservation strategies. *Accepted 23 November 2000.*

Key words: *Abundance, Eastern Ghats, human impacts, India, tropical forest, understory diversity.*

INTRODUCTION

Plant diversity inventories of tropical forests mainly focus on trees (Gentry 1988), and some authors have stated that non-trees contribute little to the total species of rain forests (Hartshorn 1983, Whitmore 1984). However, Gentry & Dodson (1987) suggested that some tropical forests might possess the most herb-rich plant communities on earth, while Turner *et al.* (1996) concluded that ground herbs might prove to be a good indicator of forest succession status. These statements remain to be substantiated as we lack adequate data (Whitmore 1984, Gentry 1988, Poulsen 1996a, Annaselvam & Parthasarathy 1999).

As the significance of non-trees in contributing to total species richness is increasingly realized, ~0.1-ha-scale quantitative inventories of ground herbs have been undertaken in a few tropical forests (Smith 1970, Hall & Swaine 1981, Gentry & Dodson 1987). Subsequently, inventories of ground herbs were made in three 0.25-ha plots at each of three altitudes in Bukit Belalong, Borneo (Poulsen & Pendry 1995), all pteridophytes in 1ha of the unflooded moist tropical rain forest in Amazonian Ecuador (Poulsen & Nielsen 1995), and all ground flora in 1 ha of the latter study site (Poulsen & Balslev 1991), and in 1 ha of the lowland rain forest in northwest Borneo (Poulsen 1996b). Similar studies in Indian forests include three 1-ha analysis at each of three altitudes in tropical evergreen forest in Agumbe, Western Ghats (Gopisundar & Parthasarathy ms), and the recent large-scale (30ha) permanent plot inventory of tropical evergreen forest in the Anamalais, Western Ghats (Annaselvam & Parthasarathy 1999).

This paper reports the results of a biodiversity inventory of understory plants (shrubs, undershrubs, herbaceous climbers, herbs, etc.) made simultaneously with an inventory of trees and lianas, in two 2-ha replicated plots of relatively undisturbed and human-impacted sites of tropical evergreen forest in the Kolli hills, Eastern Ghats, south India. The results of tree diversity (Chittibabu & Parthasarathy 2000) and liana diversity (Chittibabu & Parthasarathy, in press) are already available. The objectives of this research are

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to assess the species richness, abundance and distribution of understory plants in four sites in the Kolli hills, along the disturbance gradient.

STUDY AREA

The study was conducted in a tropical evergreen forest in the Kolli hills (11°10'-11°30'N; 78°15'-78°30'E) in the Eastern Ghats (E. Ghats), south India (Fig.1). The Kolli hills (282.9 km^2) form a compact block of hills with steep slopes consisting of heterogeneous vegetation along an elevational gradient. Deciduous forests dominate at the lower elevations of < 900 m a.s.l. The evergreen forest patches (locally called "sholas") at 900–1300 m a.s.l. are two to three-storied with robust, tall (~30m), clearly broad-leaved and dense crowned trees. Tree branches are frequently festooned with epiphytic mosses, ferns, lichens and orchids. Epiphylls and herbaceous and woody climbers are also common.

The geological substrate consists of charnockite associated with gneisses and varied metamorphic rocks and a thin layer of ferruginous sandy soil (Legris & Meher-Homji 1984). The ground vegetation is dense, and the ambience is humid and moist, very moist during rains when leeches abound. Climatological data (1951–1980) from the nearest station, Salem (278 m a.s.l.), 50 km from the study site, reveal a mean annual temperature of 28.3°C (minimum 19.2°C and maximum 37.2°C). The study site receives the bulk (500 mm) of its rainfall during the southwest monsoon (June to September) and 300.4 mm during the northeast monsoon (October to November), totalling 1014 mm year^{-1} for the above period. The period December to February experiences mild winters with cold nights and dewy mornings. During the three dry months (March to May) of summer there are occasional showers. The abundance of epiphytes and epiphylls indicate a much greater rainfall at our study site.

Two replicated plots, located 1 to 7 km apart from each other, were selected from undisturbed and disturbed forest sites to investigate the diversity of trees, lianas and understory plants. Sites Perumakkai shola (PS, 1000 m a.s.l.), on a gentle slope and a valley with a seasonal stream, and Vengodai shola (VS, 1050 m a.s.l.), on a raised slope, are relatively undisturbed, as they are distant from human settlements. Sites Kuzhivalavu shola (KS, 1200 m a.s.l.), on a steep slope, and Mottukkadu shola (MS, 1250 m a.s.l.), on a hilltop, are disturbed owing to their proximity to human habitation and anthropogenic activities. One 2-ha contiguous plot (100 m × 200 m), of largely mature-phase forest, was permanently marked in each of the four 'sholas'. Complete details of the study area are available (Chittibabu & Parthasarathy 2000).

The predominant tree species in the study area include *Memecylon umbellatum* (Melastomataceae), *Phoebe wightii* (Lauraceae), and *Olea paniculata* (Oleaceae). A total of 3825 trees (≥ 30 cm girth at breast height, gbh) of 78 species, 61 genera and 36 families was recorded in the total 8-ha area (Chittibabu & Parthasarathy 2000). Liana diversity (≥ 5 cm gbh) of the study area totaled 26 species from 24 genera and 18 families. *Hiptage benghalensis* (Malpighiaceae), *Elaeagnus indica* (Elaeagnaceae), and *Gnetum ula* (Gnetaceae) were the dominant liana species (Chittibabu & Parthasarathy, in press).

METHODS

Fieldwork was undertaken during May 1996 to June 1997. Each 2-ha study plot was sub-divided into 200 10 m × 10 m grids to facilitate quantitative biodiversity inventories of trees (≥ 30 cm gbh) and lianas (≥ 5 cm gbh). Understory plant diversity was investigated in every 4-m^2 (2 m × 2 m) quadrat regularly laid in the 800 10 m × 10 m grid of the total 8 ha of plots. All the understory plants were enumerated and identified in the 800 sample quadrats, besides noting their life-form and fruit types. Based on a review of literature, the term 'understory' includes tree seedlings and saplings, shrubs, lianas, herbaceous climbers and herbs (Blanc & Poulson, ms). Life-forms constituting the understory plants in this study are herbs (non-woody small plants < 1 m tall), undershrubs (small plants of 1 to 1.5 m tall with moderate stem thickness), shrubs (> 1.5 m to 3 m tall with thick stems and branching at ground level without a distinct trunk), and herbaceous climbers. Grasses, sedges, aroids, root parasites and pteridophytes, in this study, are treated separately under the synusia of herbs. This investigation excluded facultative herbs, which are generally epiphytic and occasionally encountered on the forest floor, and treelets.

Voucher specimens were collected and identified using the regional floras (Gamble & Fischer 1915–1935, Matthew 1991), and by reference to the collections at the herbarium of the Botanical Survey of India, Coimbatore (MH), and those lodged in the herbarium of the School of Ecology, Pondicherry University.

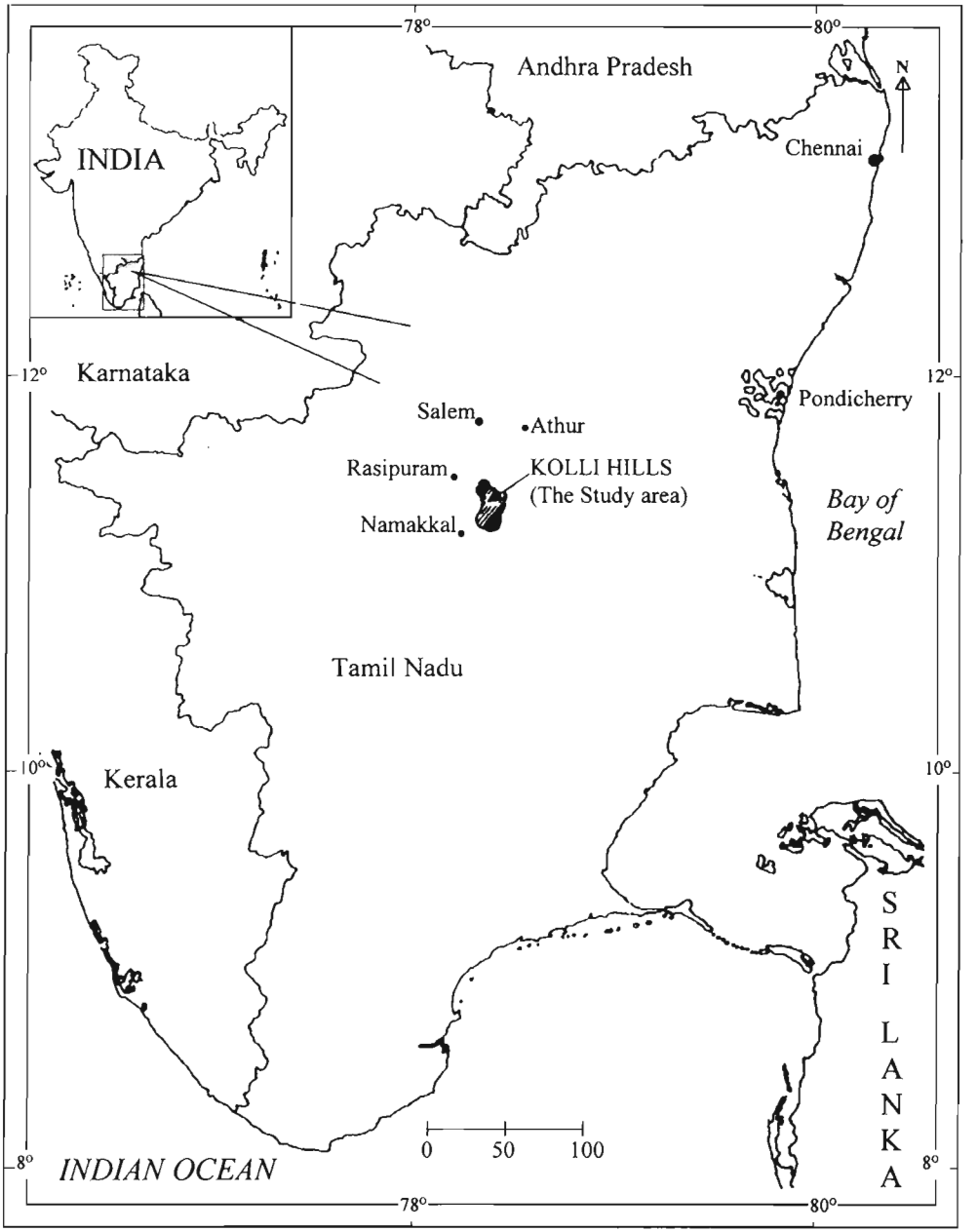

FIG. 1. Map showing the geographic position of the Kolli hills, Eastern Ghats, south India.

Data analysis. Diversity indices, Shannon (H'), Simpson (D), Hill (N_1) and evenness (E_1) (Magurran 1988) were calculated. These indices have low sensitivity to sample size and are widely used. Species-area curves were constructed by sequential summing of sample results obtained from the 10 m × 100 m (0.1 ha) scores. A modified importance value index (IVI) of Curtis & McIntosh (1950), for a score of 200, for each understory species was calculated by summing its relative density and relative frequency. The density of a species is the total number of individuals in the 8-ha samples, and frequency refers to the number of occurrences in the total quadrats. A modified family importance value (FIV) (Mori *et al.* 1983) was calculated by summing the relative diversity [(number of species belonging to that family / total number of species) × 100] and relative density of the individual family.

RESULTS

Species richness and diversity. Understory plant diversity in the four sites of tropical evergreen forest in the Kolli hills totaled 52 species from 49 genera and 35 families (Table 1). Species richness of the individual plots varied. The undisturbed sites PS and VS had 42 and 39 species per plot respectively (41 species ha^{-2}), while the disturbed sites KS and MS harbored 24 and 19 species (22 species ha^{-2}). Population densities of undisturbed sites (PS & VS) and disturbed sites (KS & MS) were respectively 2093 and 2748 individuals ha^{-2}, altogether totaling 9680 individuals in the 8 ha (Table 1). Shannon (H'), Simpson (D), Hill (N_1) and evenness (E_1) indices marginally varied for the four sites (Table 1). Species-area accumulation curves of the four 2-ha plots stabilized at 1.2 ha to 1.4 ha scale (Fig. 2). The asymptote of the curves suggests that the samples captured most of the species in the study plots.

Fourteen species (27%) were common to all four sites. Eight species occurred in three sites, 13 species in two sites, and 17 species in one of the four sites. The undisturbed sites (PS & VS) harbored 24 species (46%) exclusive to them, whereas disturbed sites (KS & MS) had just two such species.

Frequency distribution. The overall trend in distribution of percentage species and their abundance against frequency class of individuals were juxtaposed (Fig. 3). About 65% of species with 8% of total density was represented by 40 or fewer individuals (density ≤ 5 ha^{-1}), while just five species (9.6%), which fell into the classes of > 160 individuals, accounted for 67% of the total understory plant density. Species rank-abundance description for the 8 ha (Fig. 4) showed species one with two-fold greater density than the next ranked species two. From species three onwards the abundance fell sharply, declining to 100 at species 13, and from species 14 to 23 it hovered around 50 individuals. Finally, species 52 had only two individuals in the 8-ha plots.

Species dominance and rarity. Population densities of the understory plant species encountered in each of the 2-ha plots and in the total 8 ha area varied

TABLE 1. Consolidated details of understory plant inventory in each 2-ha plot of sites Perumakkai shola (PS), Vengodai shola (VS), Kuzhivalavu shola (KS) and Mottukkadu shola (MS) in the tropical evergreen forest in the Kolli hills, Indian Eastern Ghats.

Variable	Undisturbed site			Disturbed site			Total
	PS	VS	Mean ha^{-2}	KS	MS	Mean ha^{-2}	
Species richness	42	39	41	24	19	22	52
Number of genera	39	35	37	23	18	21	49
Number of families	32	26	29	20	16	18	35
Population density	2158	2027	2093	2865	2630	2748	9680
Diversity index							
Shannon (H')	2.33	1.93		1.86	2.23		2.51
Simpson (D)	0.23	0.30		0.23	0.15		0.16
Hill (N_1)	10.27	6.87		6.43	9.31		12.36
Evenness (E_1)	0.62	0.53		0.59	0.76		0.64

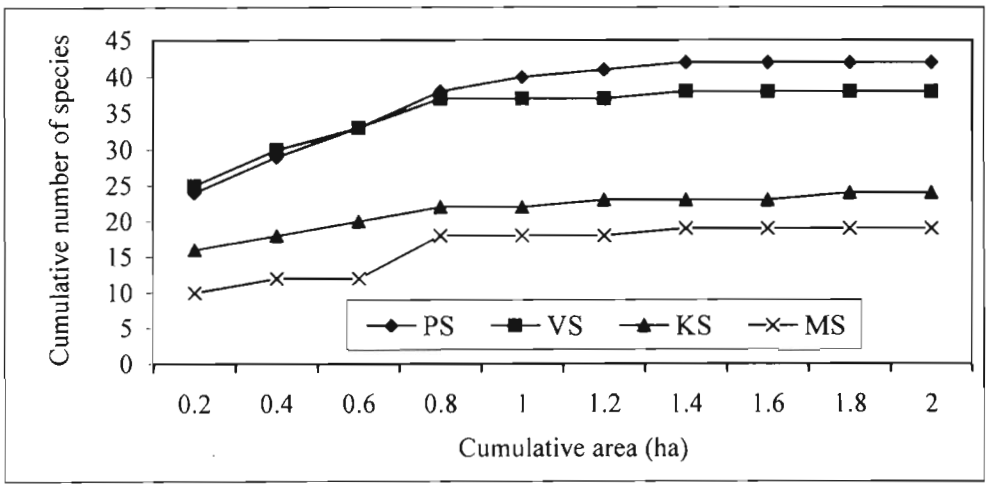

FIG. 2. Species-area curves for the sites PS, VS, KS and MS in the Kolli hills.

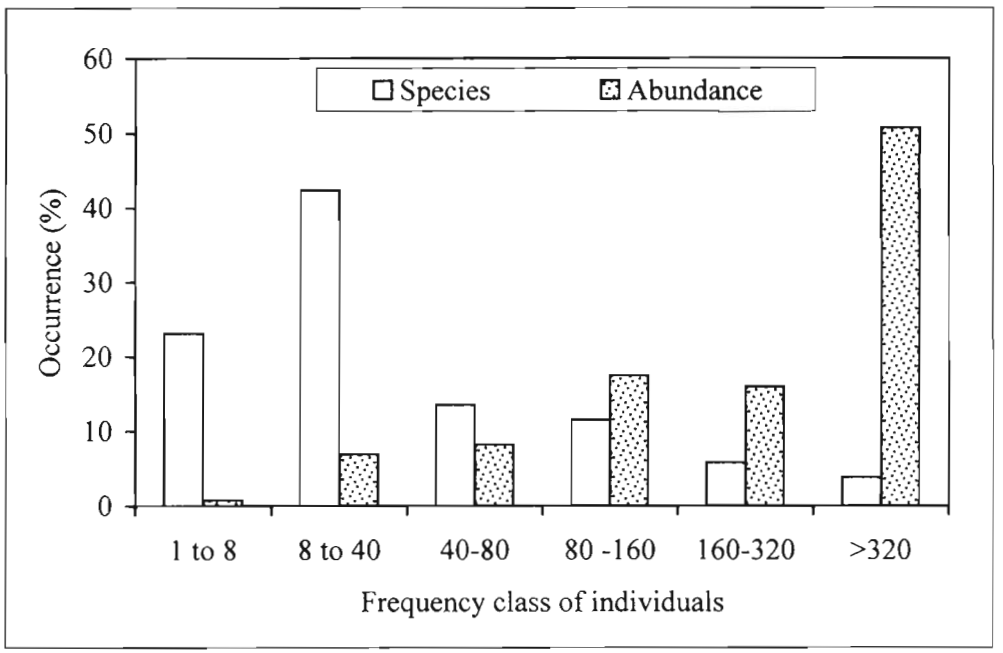

FIG. 3. Percentage occurrence of species and abundance in various frequency classes of individuals in 8-ha plots in the Kolli hills.

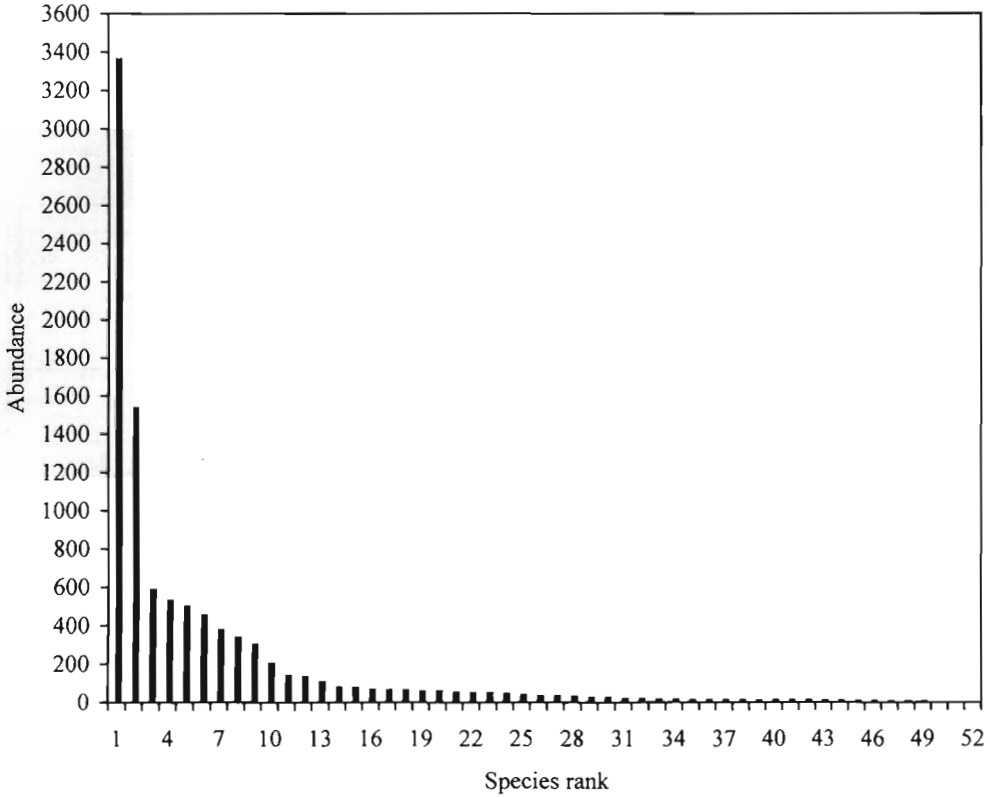

FIG. 4. Species rank-abundance of understory plants in the 8-ha study plots in the Kolli hills.

considerably (Table 2). Species with the highest IVI were also the most abundant. They include *Cyrtococcum trigonum* (Poaceae, IVI = 54.63), *Arisaema leschenaultii* (Araceae, 27.53) *Dryopteris concolor* (Pteridaceae, 12.72), *Paspalum conjugatum* (Poaceae, 10.56) and *Phyllanthus debilis* (Euphorbiaceae, 10.03).

Of the 52 species recorded in the Kolli hills, two species (3.8%) could be graded as predominant, whose density (d) in the total 8-ha was > 801 individuals. Three species (5.8%) were dominant (d < 800 but > 401), eight species (15.4%) were common (d < 400 but > 81), 31 species (59.6%) were rare (d < 80 but > 9) and eight species (15.4%) were very rare (d < 8 but > 1). Thus, the understory plant species rarity (rare + very rare) was 75%.

Family composition. Family diversity of the understory plants in the study sites totaled 35 families with 49 genera. Of them, 33 families (94%) were angiosperms and 2 families (6%) pteridophytes. The angiosperms consisted of 25 families and 37 species (76%) of dicotyledons, and 8 families and 12 species (24%) of monocotyledons. The most species-rich families were Lamiaceae (4 species), Acanthaceae (3) and Asteraceae (3). Ten families were represented by 2 species while the remaining 15 families had only one species in each of them (Table 4). Density-based dominants were Poaceae with 3895 (40%) individuals and Araceae with 1879 (19%) individuals. Family importance value (FIV) index (Table 3) was greatest for Poaceae (44.1) followed by Araceae (23.3), Euphorbiaceae (11.7) and Pteridaceae (10.6).

Ecological aspects. The 52 species and 9680 individuals of the understory plants can be classified into 9 life-forms. Species richness and population density varied from one to 21 species and from eight to 3895 individuals respectively (Fig. 5). As regards species

TABLE 2. Population density of understory plant species in the four 2-ha plots (PS, VS, KS & MS), with their frequency and importance value index (IVI), in the total 8-ha plot of tropical evergreen forest in the Kolli hills.

Species	Family	Density in					Frequency	IVI
		Undisturbed site		Disturbed site		Total		
		PS	VS	KS	MS	8-ha		
1 *Cyrtococcum trigonum* (Retz.) A. Camus	Poaceae	963	800	790	810	3363	628	54.63
2 *Arisaema leschenaultii* Blume	Araceae	7	42	1055	436	1540	367	27.53
3 *Dryopteris concolor* Langsd. & Fisch.	Pteridaceae	100	255	38	197	590	209	12.72
4 *Paspalum conjugatum* Berg.	Poaceae	175	153	139	65	532	160	10.56
5 *Leptochilus decurrens* Blume	Polypodiaceae	274	47	4	176	501	168	7.08
6 *Phyllanthus debilis* Klein ex Willd.	Euphorbiaceae	68	120	6	262	456	199	10.03
7 *Ophipogon intermedius* D. Don var. *intermedius*	Haemodoraceae	1	–	378	–	379	138	6.77
8 *Remusatia vivipara* (Lodd.) Schott	Araceae	50	89	120	80	339	60	9.81
9 *Phyllanthus pinnatus* (Wight) Webster	Euphorbiaceae	32	51	37	181	301	90	7.48
10 *Ageratum conyzoides* L.	Asteraceae	35	38	–	131	204	115	5.75
11 *Rubia cordifolia* L.	Rubiaceae	15	15	7	104	141	91	4.34
12 *Cayratia pedata* (Lam.) Juss. ex Gagnep var. *pedata*	Vitaceae	16	25	5	88	134	84	4.05
13 *Thunbergia fragrans* Roxb. var. *vestita* Nees	Thunbergiaceae	32	12	62	–	106	68	3.25
14 *Dioscorea pentaphylla* L. var. *pentaphylla*	Dioscoreaceae	1	1	76	–	78	55	2.17
15 *Abutilon hirtum* (Lam.) Sweet	Malvaceae	8	8	61	–	77	43	2.06
16 *Peperomia tetraphylla* (Forst. f.) Hook. & Arn.	Piperaceae	15	35	13	3	66	48	1.73
17 *Pilea melastomoides* (Poir.) Blume	Urticaceae	17	27	1	20	65	40	1.84
18 *Cynoglossum zeylanicum* (Vahl ex Hornem.) Thunb. ex Lehm.	Boraginaceae	10	11	10	34	65	42	1.81
19 *Passiflora edulis* Sims	Passifloraceae	36	24	–	–	60	37	2.36
20 *Pteris quadriaurita* Retz.	Pteridaceae	12	37	11	–	60	41	1.57
21 *Passiflora subpeltata* Ortega	Passifloraceae	34	19	–	–	53	36	2.07
22 *Solanum nigrum* L.	Solanaceae	12	12	19	7	50	33	1.85
23 *Anisomeles indica* (L.) Kuntze	Lamiaceae	26	7	–	17	50	30	1.82
24 *Elatostemma lineolatum* Wight var. *lineolatum* Hook. f.	Urticaceae	13	34	–	–	47	33	1.53
25 *Justicia glabra* Koen.ex Roxb.	Acanthaceae	23	15	–	–	38	31	1.28
26 *Cansjera rheedii* Gmel.	Opiliaceae	16	18	–	–	34	31	1.33
27 *Commelina benghalensis* L.	Commelinaceae	20	–	14	–	34	28	1.05
28 *Argyreia pilosa* Arn. Pugill.	Convolvulaceae	13	14	–	5	32	22	1.31
29 *Asparagus racemosus* Willd.	Asparagaceae	14	7	–	5	26	22	0.97
30 *Gymnema sylvestre* (Retz.) R. Br. ex Schultes	Asclepiadaceae	21	4	–	–	25	21	0.92
31 *Hydrocotyle javanica* Thunb.	Apiaceae	20	–	1	–	21	20	0.85
32 *Lantana camara* L. var *aculeatea* (L.) Mold.	Verbenaceae	–	–	10	9	19	17	0.54
33 *Adenostemma lavenia* (L.) Kuntze var. *reticulatum* (DC.) Panigrahi	Asteraceae	–	17	–	–	17	16	0.71
34 *Crotalaria longipes* Wight & Arn.	Fabaceae	–	17	–	–	17	11	0.68
35 *Cassia floribunda* Cav.	Caesalpiniaceae	–	14	–	–	14	12	0.52
36 *Begonia malabarica* Lam.	Begoniaceae	12	–	2	–	14	12	0.46

TABLE 2. Continued.

Species	Family	Density in					Frequency	IVI
		Undisturbed site		Disturbed site		Total		
		PS	VS	KS	MS	8-ha		
37 *Dioscorea oppositifolia* L. var. *oppostifolia*	Dioscoreaceae	6	7	–	–	13	11	0.51
38 *Xenacanthus pulneyensis* (Clarke) Bremek.	Acanthaceae	13	–	–	–	13	10	0.45
39 *Asystasia crispata* Benth.	Acanthaceae	–	12	–	–	12	10	0.41
40 *Murdannia esculenta* (Wall. ex Clarke) Raizada ex R. Rao & Kammathy	Commelinaceae	–	12	–	–	12	9	0.38
41 *Solena amplexicaulis* (Lam.) Gandhi	Cucurbitaceae	11	–	–	–	11	8	0.46
42 *Nicandra physaloides* (L.) Gaertn.	Solanaceae	–	11	–	–	11	8	0.37
43 *Dorstenia indica* Wall. ex Wight	Moraceae	11	–	–	–	11	7	0.24
44 *Balanophora fungosa* J.R. & G. Forst. subsp. *indica* (Arn.) Hansen	Balanophoraceae	5	4	–	–	9	6	0.28
45 *Pogostemon paniculatus* (Willd.) Benth.	Lamiaceae	–	8	–	–	8	6	0.30
46 *Carex lateralis* Kuek.	Cyperaceae	8	–	–	–	8	4	0.21
47 *Acanthophippium bicolor* Lindl.	Orchidaceae	6	–	–	–	6	5	0.25
48 *Scutellaria violacea* Heyne ex Benth.	Lamiaceae	–	–	6	–	6	5	0.22
49 *Chromolaena odorata* (L.) King & Robinson	Asteraceae	–	5	–	–	5	4	0.21
50 *Anisochilus carnosus* (L.f.) Wall. ex Benth.	Lamiaceae	3	–	–	–	3	3	0.13
51 *Piper nigrum* L.	Piperaceae	2	–	–	–	2	2	0.08
52 *Oxalis latifolia* H.B.K. Nov.	Oxalidaceae	2	–	–	–	2	1	0.05
Total		2158	2027	2865	2630	9680	3157	200

richness, herbs constituted the majority of species (21, 40%), followed by herbaceous climbers (12, 23%), shrubs (6, 11.5%), and undershrubs (4, 8%). Grasses and aroids were represented by two species each, while sedges and root parasites by just one species. Pteridophytes, as a group, were represented by three species. The grasses, *Cyrtococcum trigonum* in particular, contributed to the bulk of total population density of understory plants, followed by aroids, herbs and pteridophytes.

The fruit types among the understory plant species in the Kolli hills varied. Thirteen species (25%) bore capsules, 12 species (23%) berries, and five species (9.6%) schizocarps. Drupes, nutlets and dust diaspores of pteridophytes were produced by three species each (5.7%), grains (caryopsis) and pods by two species each (3.8%), and pepo, nut-lets, and follicles by just one species each (2%).

Based on the longevity of the understory plants, 22 species (42%) of non-perennating annuals, 6 species (12%) of perennating annuals, and 24 species (46%) of perennials were recognized at our study sites. The study plots showed six weed species (12%) with 357 (3.6%) individuals. Of these, 59% of individuals occurred in the disturbed sites. The 8-ha study plots harbored 16 species (31%) of both economic and ethnobotanical importance.

DISCUSSION

The attenuated species richness (54%) of understory plants (22 species ha^{-2}) in disturbed sites (KS & MS), compared to the species richness (41 species ha^{-2}) of undisturbed sites (PS & VS), is in line with the diversity of trees ≥ 30 cm gbh (Chittibabu & Parthasarathy 2000) and lianas ≥ 5 cm gbh (Chittibabu & Parthasarathy in press) of the study plots in the Kolli hills (Table 4). With 78 tree species (≥ 30 cm gbh), 26 liana species (≥ 5 cm gbh), and 52 understory species, non-tree species (50%) contributed equally to the total species richness (156 species) of the tropical evergreen forest in the Kolli hills. In 0.1 ha of western

Ecuador rainforest, Gentry & Dodson (1987) reported 67% non-tree species (32% herbs, shrubs and nonepiphytic climbers, and 35% epiphytes).

The greater density (131%) of understory plants in the disturbed sites (2748 individuals ha^{-1}) as against the disturbed sites (2093 individuals ha^{-1}) contrasts with those values obtained from tree and liana inventories. Diversity indices of understory plants in the four study plots did not vary much since the calculation takes into account the density factor also. The increased density values offset the loss in species richness at disturbed sites.

The trend of decreasing diversity along increasing disturbance in the study sites in the Kolli hills can be explained as in the case of tree and liana inventories (Chittibabu & Parthasarathy 2000, Chittibabu & Parthasarathy, in press). Disturbance at the study site includes cattle grazing and browsing and anthropogenic activities, such as collection of fuel-wood, medicinal plants and minor forest produce, and selective tree felling. Disturbed site KS has just one-fifth the tree density (52 stems ha^{-1}) in the smaller girth class (30–60 cm) of the 268 stems ha^{-1} for the same girth threshold in the undisturbed site VS. This indicates that selective tree felling has occurred in the study site (Chittibabu & Parthasarathy 2000). Hence, anthropogenic activities together with intraplot variation of topographic features might result in reduced plant diversity in the disturbed sites. The increase in understory plant density, particularly weeds in the disturbed sites, could be due to diaspore dispersal of a few species facilitated by cattle and human activities.

The distribution of certain understory species shows that there are a variety of microhabitats in the study site. For instance, there were 1491 individuals of the aroid *Arisaema leschenaultii* (which grows in rock crevices) in the disturbed sites (KS &MS) but just 49 individuals in the undisturbed sites (PS &VS). This indicates the presence of many boulders in the disturbed sites and this is corroborated by our field observation. On the other hand, the pteridophytes *Dryopteris concolor*, *Leptochilus decurrens*, and *Pteris quadriaurita*, growing in moist and shady localities, were predominant (725 individuals) in the undisturbed sites compared with their density (426 individuals) in the disturbed sites. Nevertheless, the distribution of plant species could also be due to their ecological amplitude (Chittibabu & Parthasarathy 2000). The uniform abundance of *Cyrtococcum trigonum* could explain its environmental plasticity, being both shade and light tolerant.

A comparison of understory plant diversity in the Kolli hills with those of other tropical forest inventories (Smith 1970; Hall & Swaine 1981; Gentry & Dodson 1987; Poulsen & Balslev 1991; Poulsen & Nielson 1995; Poulsen & Pendry 1995; Poulsen 1996 a, b; Turner *et al.* 1996; Annaselvam & Part-

TABLE 3. Family diversity (richness of species and genera), density, and family importance value (FIV) index of understory plants in the total 8-ha plot in the Kolli hills.

Sl.no. Family	Species	Genera	Density	FIV
1 Acanthaceae	3	3	63	6.4
2 Apiaceae	1	1	21	2.1
3 Araceae	2	2	1879	23.3
4 Asclepiadaceae	1	1	25	2.2
5 Asparagaceae	1	1	26	2.2
6 Asteraceae	3	3	226	8.1
7 Balanophoraceae	1	1	9	2.0
8 Begoniaceae	1	1	14	2.1
9 Boraginaceae	1	1	65	2.6
10 Caesalpiniaceae	1	1	14	2.1
11 Commelinaceae	2	2	46	4.3
12 Convolvulaceae	1	1	32	2.3
13 Cucurbitaceae	1	1	11	2.0
14 Cyperaceae	1	1	8	2.0
15 Dioscoreaceae	2	1	91	4.8
16 Euphorbiaceae	2	1	757	11.7
17 Fabaceae	1	1	17	2.1
18 Haemodoraceae	1	1	379	5.8
19 Lamiaceae	4	4	67	8.4
20 Malvaceae	1	1	77	2.7
21 Moraceae	1	1	11	2.0
22 Opiliaceae	1	1	34	2.3
23 Orchidaceae	1	1	6	2.0
24 Oxalidaceae	1	1	2	1.9
25 Passifloraceae	2	1	113	5.0
26 Piperaceae	2	2	68	4.5
27 Poaceae	2	2	3895	44.1
28 Polypodiaceae	1	1	501	7.1
29 Pteridaceae	2	2	650	10.6
30 Rubiaceae	1	1	141	3.4
31 Solanaceae	2	2	61	4.5
32 Thunbergiaceae	1	1	106	3.0
33 Urticaceae	2	2	112	5.0
34 Verbenaceae	1	1	19	2.1
35 Vitaceae	1	1	134	3.3
Total	52	49	9680	200

TABLE 4. Comparison of diversity of trees, lianas, and understory plants in the four 2-ha plots of tropical evergreen forest in the Kolli hills

Variable	Undisturbed site		Disturbed site		Total
	PS	VS	KS	MS	
Species Richness					
Trees (≥ 30 cm gbh)	58	51	42	39	78
Lianas(≥ 5 cm gbh)	21	16	9	14	26
Understory plants	42	39	24	19	52
Population density					
Trees (≥ 30 cm gbh)	1054	1151	651	969	3825
Lianas(≥ 5 cm gbh)	113	156	25	90	384
Understory plants	2158	2027	2865	2630	9680
Shannon diversity index					
Trees (≥ 30 cm gbh)	3.29	2.79	2.87	2.51	3.34
Lianas(≥ 5 cm gbh)	2.60	2.44	2.02	2.31	2.89
Understory plants	2.33	1.93	1.86	2.23	2.51

hasarathy 1999) becomes increasingly difficult because the considerable differences in plot size, quadrats sampled and synusiae included in various investigations. Yet, the literature survey (Table 4 of Annaselvam & Parthasarathy 1999) reveals that understory plant species richness ranged from 50 species ha^{-1} in moist tropical forest at Cuyabeno, Amazonian Ecuador (Poulsen & Nielsen 1995) to 121 species ha^{-1} in 0.75 ha of evergreen forest in Brunei (Poulsen & Pendry 1995). The Indian Western Ghats inventories yielded 155 understory plant species in 30 ha (17 to 83 species ha^{-1}) of tropical evergreen forest at Va-

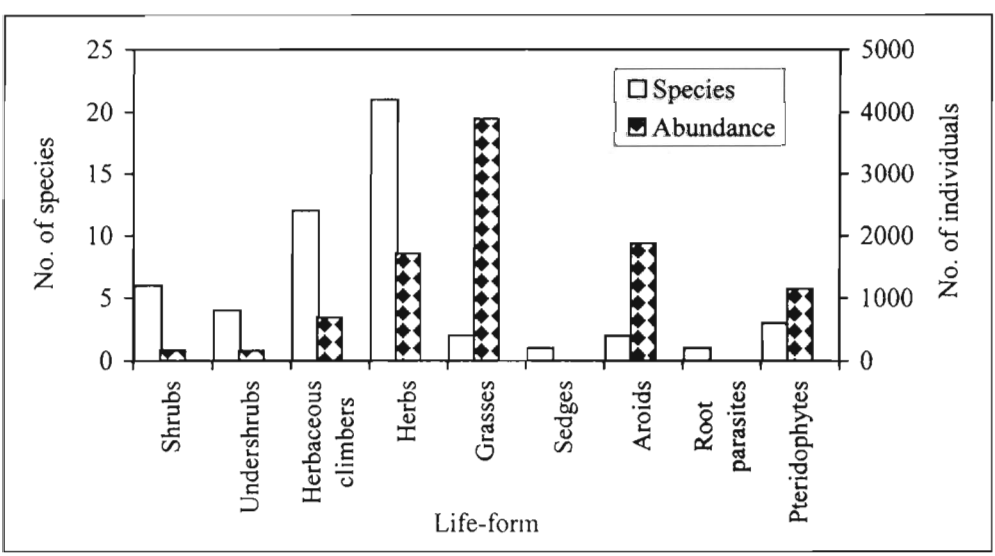

FIG. 5. Total number of species and their abundance in various life-forms of understory plants in the Kolli hills.

ragalaiar, Anamalais (Annaselvam & Parthasarathy 1999), and 55 species in three 1-ha plots (21 to 29 species ha^{-1}) of tropical lowland evergreen forest at Agumbe (Gopisundar & Parthasarathy ms). Hence the present study site with its 52 species in 8 ha (22 to 41 species ha^{-2}) harbors a moderate understory plant diversity.

The 75% species rarity of understory plants in the Kolli hills is due to the occurrence of a greater number of species with fewer individuals. This scenario was also seen in trees (≥ 30 cm gbh) where the species rarity was 57.6% (Chittibabu & Parthasarathy 2000). The low population density of species poses a danger for outbreeding forest species and will reduce reproductive output, as the possibility of reproductive failure through inbreeding increases (Ledig 1992). Intensive research focussing on specific reproduction strategies of rare species would help in the formulation of strategies for sustainable forest management and conservation.

The predominant families Poaceae, Araceae, Euphorbiaceae, and Pteridaceae of our study site in the Kolli hills differ from those of the Indian Western Ghats (Annaselvam & Parthasarathy 1999) and other tropical rain forests (Richards 1996), where Acanthaceae, Papilionaceae, Asteraceae, and Zingiberaceae dominate. In the Kolli hills, the dominance of the herb life-form, with its greater species richness, is in conformity with other findings (Richards 1996, Annaselvam & Parthasarathy 1999). The prevalence of annuals (58%) in the Kolli hills is similar to the studies of understory plants in the Indian Western Ghats (Annaselvam & Parthasarathy 1999) and the Amazonian flood plain, near Manaus (Junk & Piedade 1993), but inventories in the Amazonian rainforest (Poulsen & Balslev 1991) and in Ghana (Hall & Swaine 1981) have recorded 100% perennials. The absence of annuals is a general characteristic of rainforests (Hall & Swaine 1981). The prevalence of annuals in the Kolli hills could be due to the climatic seasonality of the study area, with a three-month dry period, and the availability of a variety of microhabitats. The greater number of weeds in disturbed sites could be due to their better survival strategy. Disturbance opens up areas for invasion of weeds like *Lantana camara* and *Ageratum conyzoides*. Chandrasekaran & Swamy (1995) made similar observations in the southern Western Ghats, India. Weed management should be given immediate attention as such invasions may also lead to a reduction in biodiversity (Ramakrishnan 1991).

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REFERENCES

Annaselvam, J., & N. Parthasarathy. 1999. Inventories of understory plants in a tropical evergreen forest in the Anamalais, Western Ghats, India. Ecotropica 5: 197–211.

Chandrasekaran, S., & P.S. Swamy. 1995. Changes in herbaceous vegetation following disturbance due to biotic interference in natural and man-made ecosystems in Western Ghats. Trop. Ecol. 36: 213–220.

Chittibabu, C.V., & N. Parthasarathy. 2000. Attenuated tree species diversity in human-impacted tropical evergreen forest sites in Kolli hills, Eastern Ghats, India. Biodiv. Conserv. 9: 1493–1519.

Chittibabu, C.V., & N. Parthasarathy. In press. Liana diversity and host relationships in a tropical evergreen forest of Indian Eastern Ghats. Ecol. Res.

Curtis, J.T., & R.P. McIntosh. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31: 434–455.

Gamble, J.S., & C.E.C. Fischer.1915-1935. Flora of the Presidency of Madras. Vol. 1–3. London.

Gentry, A.H. 1988. Changes in plant community diversity and floristic composition on environmental and geographical gradients. Ann. Mo. Bot. Gard. 75: 1–34.

Gentry, A.H., & C. Dodson. 1987. Contribution of nontrees to species richness of a tropical rain forest. Biotropica 19: 149–156.

Hall, J.B., & M.D. Swaine. 1981. Distribution and ecology of vascular plants in a tropical rain forest. The Hague.

Hartshorn, G.S. 1983. Plants. Pp. 118-157 *in* Janzen, D.H. (ed.) Costa Rican Natural History. Chicago.

Junk, W.J., & M.T.F. Piedade. 1993. Herbaceous plants of the Amazon flood plain near Manaus: species diversity and adaptations to the food pulse. Amazoniana 12: 467–484.

Ledig, F.T. 1992. Human impacts on genetic diversity in forest ecosystems. Oikos 63: 87–108

Legris, P., & V.M. Meher-Homji. 1984. The Eastern Ghats: Phytogeographic aspects. Indian Rev. Life Sci. 4: 115–136.

Magurran, A. 1988. Ecological diversity and its measurement. New Jersey.

Matthew, K.M. 1991. An Excursion Flora of Central Tamilnadu, India. Oxford and New Delhi.

Mori, S.A., Boom, B.M., Carvalho, A.M., & T.S. Dos Santos. 1983. Southern Bahian moist forests. Bot. Rev. 49: 155–232.

Poulsen, A.D. 1996a. The herbaceous ground flora of the Batu Apoi forest Reserve, Brunei Darussalam. Pp. 43–57 *in* Edwards, D.S., Booth, W.E., & S.C. Choy (eds.) Tropical rainforest research – current issues. Dordrecht.

Poulsen, A.D. 1996b. Species-richness and density of ground herbs within a plot of lowland rain forest in north-west Borneo. J. Trop. Ecol. 12: 843–851.

Poulsen, A.D., & H. Balslev. 1991. Abundance and cover of ground herbs in an Amazonian rain forest. J. Veg. Sci. 2: 315–322.

Poulsen, A.D., & I.H. Neilsen. 1995. How many ferns are there in one hectare of tropical rain forest? Amer. Fern J. 85: 29–35.

Poulsen, A.D., & C.A. Pendry. 1995. Inventories of ground herbs at three altitudes on Bukit Belalong, Brunei, Borneo. Biodiv. Conserv. 4: 745–757.

Ramakrishnan, P.S. 1991. Ecology of biological invasion: an overview. Pp. 1–19 *in* Ramakrishnan, P.S. (ed.). Ecology of biological invasion in the tropics. International Scientific Publications, New Delhi, India.

Richards, P.W. 1996. The tropical rain forest: an ecological study. London.

Smith, R. F. 1970. The vegetation structure of a Puerto Rican rain forest before and after short-term gamma irradiation. Pp. D103–D140 *in* Odum, H. (ed.). A tropical rain forest. U.S. Atomic Energy Commission, Tennessee, Oak Ridge.

Turner, I.M., Tan, H.T.W., & K.S. Chua. 1996. Relationship between herb layer and canopy composition in a tropical rain forest successional mosaic in Singapore. J. Trop. Ecol. 12: 843–851.

Whitmore, T.C. 1984. Tropical rain forests of the Far East. Oxford.