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# Attenuated tree species diversity in human-impacted tropical evergreen forest sites at Kolli hills, Eastern Ghats, India

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**Abstract.** Tree diversity ($\geq$30 cm gbh) in undisturbed and human-impacted tropical evergreen forest sites was investigated in the Kolli hills, Eastern Ghats, India. Four 2-ha contiguous permanent plots were erected, one each in Perumakkai shola (site PS), Vengodai shola (VS), Kuzhivalavu shola (KS) and Mottukkadu shola (MS) at 1000, 1050, 1200 and 1250 m elevation, with increasing human disturbance, to evaluate the difference in tree species composition, stand structure and dynamics. This paper discusses the results of the first survey. A total of 3825 individuals and 78 species from 61 genera and 36 families were enumerated in the 8 ha area. Among the four 2-ha sites, species richness was greatest (58) in the undisturbed site PS and lowest (39) in the highly disturbed site MS. Shannon, Simpson, Hill diversity and evenness indexes revealed a progressive reduction in diversity with increasing disturbance. The asymptote species-area curves imply adequate site sampling. Tree density (1151 to 651 trees ha$^{-2}$) and basal area (106 to 46.6 m$^2$ ha$^{-2}$) decreased from undisturbed to disturbed site, due to selective felling. Single species, *Memecylon umbellatum* dominated sites MS (39%) and VS (26%), while *Nothopegia heyneana*, *Memecylon umbellatum* and *Diospyros ovalifolia* were dominant in PS, and *Meliosma simplicifolia*, *Myristica dactyloides* and *Phoebe wightii* in KS. Based on species abundance, we classify the study area as *Memecylon–Phoebe–Beilschmiedia* association with *Neolitsea* and *Myristica* as codominants. Tree population structure revealed a step-wise decline in girth frequencies with increasing size class in undisturbed site PS, whereas tree density fell sharp (>50%) in medium girth class in the disturbed site MS. Population of the dominant species varied widely. The diversity values of this inventory are compared with similar studies in India and other tropical forests. Evidently, the reduction in species richness (by 52%), basal area (56%) and tree density (58%) in disturbed sites, with 57.6% of species rarity of this tropical evergreen forest, in secluded patches (‘sholas’) of Kolli hills, underlines conservation need to prevent species loss.

**Key words:** anthropogenic activities, conservation, Eastern Ghats, permanent plot, stand structure, tree diversity

## Introduction

The Indian subcontinent, with its rich biodiversity, is one of the 12 mega-diversity centres of the world. The Eastern Ghats, the Western Ghats and the north eastern hills are the main biodiversity hotspots of India. Forests in India were cleared for huge hydroelectric projects, for setting up heavy industries, for urbanisation and so on.

In the late thirties, Indian forests were about 33% of the land surface, but by 1951, this was reduced to about 23%, indicating deleterious human impact on ecosystem. Though human impacts on forests date back to antiquity and even to pre-history, documenting such impacts on genetic diversity of forest trees is a difficult matter and little quantitative data exist (Ledig 1992).

Primary forests of Asia, particularly those of the Western Ghats and the Eastern Ghats of peninsular India are disappearing at an alarming rate due to anthropogenic activities and are replaced by forests comprising inferior species or their land use pattern changed (Parthasarathy 1999). The disappearance of tropical forests comes at a time when our knowledge on their structure and dynamics is woefully inadequate (Hubbell and Foster 1992). Understanding of forest processes is necessary for assessment of potential impacts, the amelioration of effects of disturbance, optimization of productivity and rehabilitation of ecosystem (Congdon and Herbohn 1993).

As there is so much species diversity, tropical trees are especially interesting subjects (Condit et al. 1996) and species diversity is generated by species interaction such as competition and niche diversification (Pianka 1966; Bada 1984), the latter being greatly manifested in the tropics due to high humidity and temperature (Ojo and Ola-Adams 1996). Quantitative plant biodiversity inventories of Indian tropical forests are available from various forests of Western Ghats (Sukumar et al. 1992; Ganesh et al. 1996; Pascal and Pelissier 1996; Ghate et al. 1998; Parthasarathy 1999; Parthasarathy and Karthikeyan 1997a; Ayyappan and Parthasarathy 1999) and on the Coromandel coast (Parthasarathy and Karthikeyan 1997b; Parthasarathy and Sethi 1997), but the Eastern Ghats is poorly studied for these aspects, except those of Kadavul and Parthasarathy (1999a) in the Shervarayan hills and Kadavul and Parthasarathy (1999b) in the Kalrayan hills.

The Indian Eastern Ghats is delimited in the north by Khondmal hills of Orissa State. The middle section extends from Krishna (Andhra Pradesh) to near about Chennai (Tamil Nadu) and includes the Nallamalai, Palkonda; and Velikonda hills. The last section runs in S-SW direction meeting the Western Ghats in the Nilgiris and the conspicuous features are the Javadis, the Kolli hills, the Pachaimalai, the Kalrayan, the Shervarayan and the Biligirirangan hills (Legris and Meher-Homji 1984).

About 7800 tribal families in the Kolli hills depend on the forests for fuel wood, fodder, fruit, herbal medicines and timber resources; the onslaught of human activities go on, particularly closer to the human settlements, resulting in forest depletion. Hence, the present investigation was envisaged with the objective of studying changes in tree species diversity and forest stand attributes with varying human disturbance in the unique and secluded evergreen forests (‘sholas’) of the Kolli hills.

## Materials and methods

### *Study site*

The study site is situated in the Kolli hills (11°10′–11°30′ N lat. and 78°15′–78°30′ E long.) of the Eastern Ghats (E. Ghats), south India (Figure 1a). The Kolli hills like other hills of the southern E. Ghats comprises masses of charnockite associated with gneisses and varied metamorphic rocks. The mountainous part has a thin veneer of soil and the rolling plains possess ferruginous sandy soil.

### *Climate*

Climatological data of Salem (alt. 278 m; lat. and long. 11°39′ N and 78°10′ E), the nearest station to the study site, available for a 30-year period (1951–1980) reveals a mean annual temperature of 28.3 °C and the mean annual rainfall 1014 mm (Figure 2). The mean monthly temperature ranged from 25 °C during December–January to 31 °C in April–May for the same period (minimum temperature 19.2 °C, maximum 37.2 °C). The study site receives bulk of the rainfall during the south-west (June to September) and the north-east (retreating) monsoons (October to November). December to February experience mild winter with cold nights and dewy mornings. During the three dry months (March to May) of summer also, there are occasional showers. Salem records a mean wind speed of 8.0 km $h^{-1}$, and relative humidity ranging from 78% in October to 66% in March at 08:30 hrs for the period 1951 to 1980. The mean total cloud observed during the period was 4.6 Oktas of sky.

### *Vegetation*

Evergreen forest in the E.Ghats occurs in isolated pockets and the Kolli hills with afore mentioned geoclimatic conditions harbours such forests from 900 m above mean sea level. The Kolli hills per se covering an area of 282.93 $km^2$ consists of heterogeneous vegetation along an elevation gradient. The foothills are clothed with scrub vegetation, while with increasing elevation occur dry deciduous, mixed deciduous and evergreen forests. The evergreen forest patches ('sholas') are found with a veritable mixture of species, rendering a scenic beauty. The trees housed in them are robust, tall (~30 m) and branchy with dense crowns. These forests are two to three storeyed. Branches are often clothed with epiphytic moss, ferns, lichens and orchids. Epiphylls are also abundant. Herbaceous and woody vines are not infrequent. They are found on the upper slopes and hill tops and sometimes on steep slopes lower down.

The study was carried out in four patches ('sholas') of evergreen forests called Perumakkai shola (PS), Vengodai shola (VS), Kuzhivalavu shola (KS) and Mottukkadu shola (MS). These sites are located 1 to 7 km apart (Figure1b) and their site attributes are summarised in Table 1.

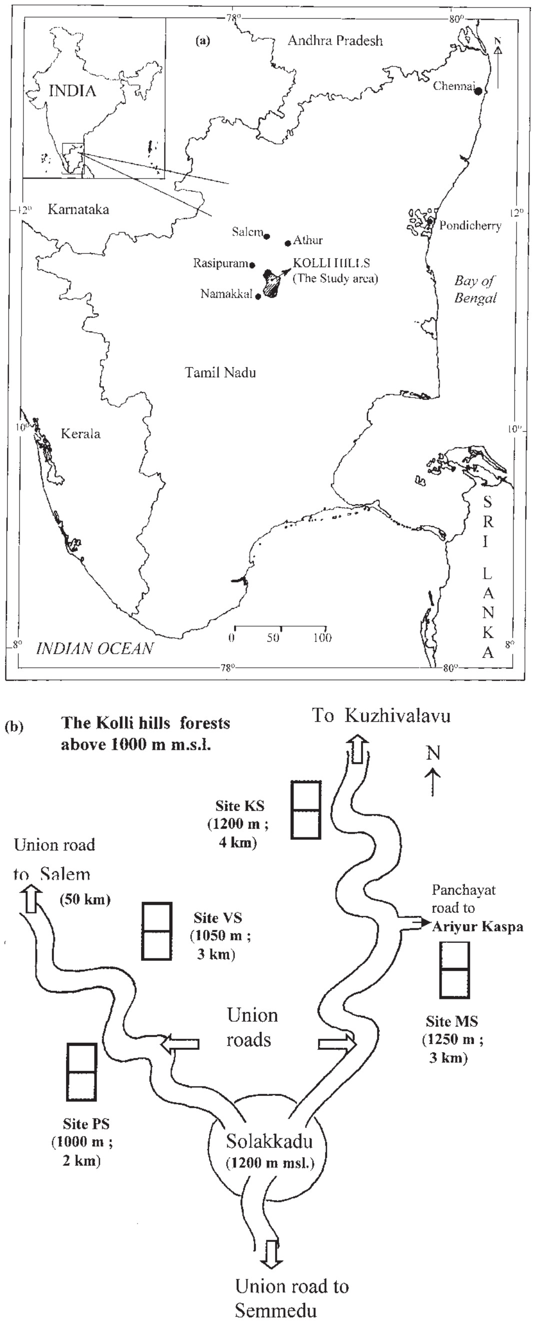


*Figure 1.* Map showing (a) the geographic position of Kolli hills, Eastern Ghats, in Namakkal district of Tamil Nadu state, south India, and (b) a crude toposheet of the four permanent plots in the tropical evergreen forest sites-Perumakkai shola (PS), Vengodai shola (VS), Kuzhivalavu shola (KS) and Mottukkadu shola (MS).

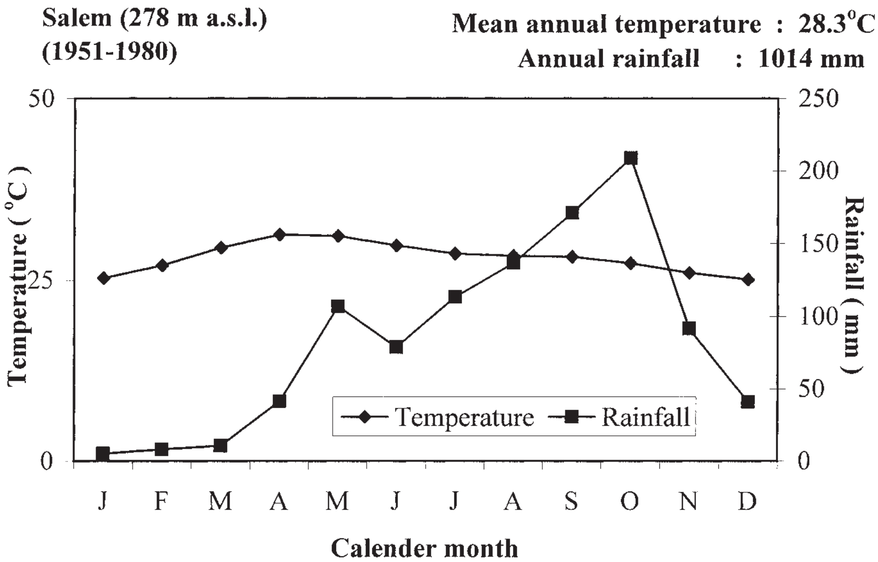


*Figure 2.* Climate diagram of Salem, the nearest climatological station to the Kolli hills.

*Disturbance*

The Kolli hills, though comes under reserve forests category, the population has unlimited and unspecified rights of felling, lopping, herding cattle for grazing, browsing, etc. Shunting of around 20 lorry loads day$^{-1}$, each 10 tonnes, of excavated soil to cement factories, and 40 lorry loads day$^{-1}$, each 10 tonnes, to aluminium factories, for the past 5 years indicates the extent of human exploitation of natural resources. Further, the observation within the study sites, during the period of investigation revealed the following: (a) browsing by cattle, legally, and goats, illegally: ~30 cows and ~50 sheep found every day in the highly disturbed study site MS; (b) firewood collections (from previously chopped branches and regenerating trees) in sites KS and MS; and (c) cultivation of horticultural crops like pineapple, banana, jackfruit, mango, pepper, cloves, etc., and agricultural crops paddy, ragi, tapioca, etc., close to sites KS and MS. Based on the above mentioned major human activities, our four study sites can be graded into relatively undisturbed (site PS), sporadically disturbed (VS), frequently disturbed (KS) and highly disturbed (MS). The increasing order of disturbance shall be represented as PS $<$ VS $<$ KS $<$ MS.

*Field methods*

One plot of 2 ha (100 × 200 m) of largely mature phase forest was investigated in each of the four 'shola' forest sites. The plots were permanently marked and each sub-divided into two hundred 10 × 10 m quadrats to facilitate quantitative biodiversity

*Table 1.* Characteristic features of the four study sites in the tropical evergreen forest of Kolli hills, Eastern Ghats, south India.

| Attribute | Study site: Perumakkai shola (PS) | Vengodai shola (VS) | Kuzhivalavu shola (KS) | Mottukkadu shola (MS) |
|---|---|---|---|---|
| Elevation (above m.s.l.) | 1000 m | 1050 m | 1200 m | 1250 m |
| Topography | Gentle slope and valley, with a seasonal stream | Raised slope | Steep slope | Hill top |
| Slope | 15–20% | 20–25% | 25–30% | 10–15% |
| Disturbance | Relatively none; no tree felling due to religious sentiments, as the site houses primitive temple structures | Relatively none; grazing and tree felling is less | Moderate; heavily grazed; trees felled for fuel wood, fodder and agricultural implements | High; heavily grazed; trees felled for fuel wood, fodder and agricultural implements |
| | Off the union metal road | Off the union metal road | Off the union metal road | Away (1 km) from the union metal road but adjacent to a panchayat mud road |
| Number of closer human settlements (in 1 km radius) | 1 | 1 | 2 | 4 |
| Distance (km) from larger human settlement (Solakkadu) | 2 | 3 | 4 | 1 |
| Forest physiognomy | Trees robust & tall (∼25 m) | Trees robust & tall (∼25 m) | Trees robust & tall (∼30 m) | Boles thin & short (∼15 m) |

inventory. The elevation was determined by using an altimeter. Slope of the land was calculated by using the formula $h'/d'$ (where $h'$ is the vertical distance on the meter stick between the eye height and the line of sight; and $d'$ the horizontal distance from the eye to the meter stick) as in Brower et al. (1989).

All trees ($\geq$30 cm gbh) were appended with sequentially numbered aluminium tags using nails and their girth measured usually at breast height (1.3 m); those with buttresses were measured above the latter. In the case of trees with multiple stems, each stem was measured separately. In addition, the following were recorded: tree height (measured for trees up to 5 m tall and others were estimated), trees multi-stemmed, thorny trees; dead trees; and cut trees.

All trees were identified from their vegetative and reproductive features using the regional floras (Nair and Henry 1983; Henry et al. 1987, 1989; Gamble and Fischer 1915–1935; Matthew 1991) and the field key of Pascal and Ramesh (1987). Voucher specimens were corroborated with the herbarium of Botanical Survey of India, Coimbatore (MH) and deposited in the herbarium of School of Ecology, Pondicherry University.

*Data analyses*

As all the data were collected in $10 \times 10$ m quadrats of the contiguous grid, a sequential arrangement of $10 \times 100$ m was considered for species-area curve. Tree species and structural analysis of the forest are based on the first survey of the four permanent plots conducted during May 1996 to June 1997. Diversity indexes, Shannon (H′), Simpsons's index (D), evenness index (E) and Hill diversity index ($N_a$) were calculated (as in Magurran 1988) as these have low or moderate sensitivity to sample size and have been widely used. Population structure of 4 species, those denser and encountered in all the 4 plots, was prepared.

## Results

*Species richness and diversity*

In the total 8 ha studied, 78 tree species ($\geq$30 cm gbh) in 61 genera and 36 families were inventoried. Greater number of species, 58 and 51 was encountered in the relatively undisturbed Perumakkai shola (PS) and sporadically disturbed Vengodai shola (VS) sites respectively (Table 2). Whereas the frequently and highly disturbed sites, viz., Kuzhivalavu shola (KS) and Mottukkadu shola (MS) had species richness of 42 and 39, indicating an average reduction of 25.6%. The genus and family richness of sites KS and MS also showed an average reduction of 24.5%, compared to the mean of sites PS and VS.

Twenty species (25.6%) were common to all the 4 sites. Diversity as measured by species richness, genus richness and family richness reached its maximum in site PS at 1000 m altitude and gradually diminished with elevation (Table 2). Most diversity indexes also showed a similar trend with elevation and disturbance as did species richness, though the value was slightly low for site VS at 1050 m (Table 2).

Of the total 78 species in 8 ha area, only 15% (12 species) were either deciduous or brevi-deciduous. The buttressed trees were greater (44%) in site KS at 1200 m with steep slope (25 to 30%), and lesser (7%) in MS, where the slope is 10 to 15%, implying a positive correlation of buttressing with slope of land.

Species-area curves for each of the four 2-ha contiguous plots rapidly increased up to 0.5 ha. It continued to increase much more slowly up to 1.5 ha and thereafter the species addition was little to none, with a slight spurt at the end of the curves in sites VS and MS (Figure 3). The species-area accumulation curves approach an asymptote, indicating adequate sampling for each 'shola' patch.

*Table 2.* Consolidated details of quantitative biodiversity inventory of all trees ≥30 cm gbh in four 2-ha plots at four study sites, Perumakkai shola (PS), Vengodai shola (VS), Kuzhivalavu shola (KS) and Mottukkadu shola (MS) in the tropical evergreen forest of the Kolli hills, Eastern Ghats, south India.

| | Site | | | | |
|---|---|---|---|---|---|
| Variable | PS | VS | KS | MS | Total |
| Species richness | 58 | 51 | 42 | 39 | 78 |
| (Species $ha^{-1}$ in parenthesis) | (54, 45) | (46, 35) | (32, 27) | (35, 26) | |
| Genus richness | 48 | 43 | 35 | 33 | 61 |
| Family richness | 31 | 28 | 23 | 22 | 36 |
| Diversity indexes | | | | | |
| Shannon (H′) | 3.296 | 2.791 | 2.870 | 2.376 | 3.340 |
| Simpson's (D) | 0.056 | 0.111 | 0.080 | 0.190 | 0.068 |
| Hill diversity 1 ($N_0$) | 58 | 51 | 42 | 39 | 78 |
| Hill diversity 2 ($N_1$) | 27.01 | 16.30 | 17.63 | 10.76 | 28.21 |
| Hill diversity 3 ($N_2$) | 17.88 | 9.044 | 12.44 | 5.263 | 14.78 |
| Evenness index (E) | 0.812 | 0.710 | 0.768 | 0.649 | 0.767 |
| Stand density (stems $ha^{-2}$) | 1054 | 1151 | 651 | 969 | 3825 |
| (Trees $ha^{-1}$ in parenthesis) | (580; 474) | (632; 519) | (385; 266) | (483; 486) | |
| Mean stand density (stems $ha^{-1}$) | 527 | 575.5 | 325.5 | 484.5 | 478 |
| Stand basal area ($m^2$ $ha^{-2}$) | 106.0 | 93.2 | 103.0 | 46.6 | 348.8 |
| Mean stand basal area ($m^2$ $ha^{-1}$) | 53.0 | 46.6 | 51.5 | 23.3 | 43.6 |
| Number of multi-stemmed trees | 68 | 131 | 75 | 172 | 446 |
| Number of cut trees (stumps) | – | 5 | 33 | 74 | 107 |
| Number of dead trees | 1 | 2 | 24 | 22 | 49 |
| Number of thorny trees | – | – | 4 | 2 | 6 |
| Number of trees buttressed | 194 (18%) | 286 (25%) | 291 (44%) | 71 (7%) | 842 (22%) |

*Tree density and basal area*

In all, 3825 trees ≥30 cm gbh were enumerated in the 8 ha. Stand density showed a wide variation ranging from as low as 266 trees $ha^{-1}$ in KS to 632 trees $ha^{-1}$ in VS, and the mean stand density for the whole 8 ha was 478 trees $ha^{-1}$. The individual 2 ha plots also varied in basal area ranging from 23.3 $m^2$ $ha^{-1}$ in the highly disturbed site MS to 53.0 $m^2$ $ha^{-1}$ in the relatively undisturbed PS. The mean basal area was 43.6 $m^2$ $ha^{-1}$.

As regard to basal area, the individual species that domineered each 2 ha stand was: *Alseodaphne semecarpifolia* var. *angustifolia* of Lauraceae (13.64 $m^2$, 12.8%) in PS; *Beilschmiedia gemmiflora* (Lauraceae; 30.87 $m^2$, 33.13%) in VS; *Meliosma simplicifolia* (Sabiaceae; 17.43 $m^2$, 16.9%) in KS; and *Syzygium cumini* (Myrtaceae; 8.99 $m^2$, 19.2%) in MS (Figure 4).

*Dominance and rarity*

The population density of different species varied considerably in the four study sites (Table 3). Notably sites MS and VS were dominated by single species, *Memecylon*

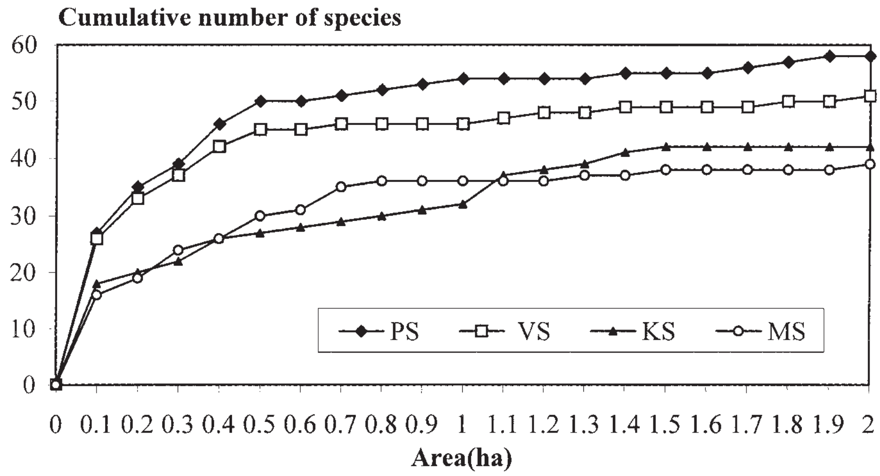


*Figure 3.* Species-area curves for the sites PS, VS, KS and MS.

*umbellatum of* Melastomataceae (39 and 26% of the stand); whereas the other two sites PS, and KS, had a set of three species codominating the stand. *Nothopegia heyneana* (12%), *Memecylon umbellatum* (9.8%) and *Diospyros ovalifolia* (9%) shared major density of site PS, and *Meliosma simplicifolia* (16.7%), *Myristica dactyloides* (12.5%) and *Phoebe wightii* (9.6%) together dominated the forest stand of KS. Overall, in the 8 ha area *Memecylon umbellatum* alone formed 20% of the total stand density. Our study site, based on abundant species, in the tropical evergreen forest of the Eastern Ghats can be classified as *Memecylon–Phoebe–Beilschmiedia* association with *Neolitsea* and *Myristica* as codominants.

Tree species, based on their abundance, captured in each 2 ha study site, were classified into 5 groups: very rare, rare, common, dominant and predominant (Table 4). Plot-wise rarity (rare + very rare) was 31 species (53.4%) in PS, 33 (64.7%) in VS, 29 (69.0%) in KS and 21 (53.8%) in MS. While in the entire 8 ha, with 16 rare (9–30 individuals each) and 28 very rare species (1–8 trees species$^{-1}$), the rarity was 57.6%.

*Importance value index (IVI)*

The IVI depicts the sociological structure of a species in its totality in the community. In Kolli hills, the top 10 species (in terms of IVI) of each plot are shown in Figure 4. The IVI of the species flattened in PS, decreased smoothly in VS and KS while it decreased rapidly in MS: importance values between 20 and 30 were obtained by the first 5 species in PS; whereas in sites VS and KS, the values decreased by around 10 from the first to fourth species; and in MS, the first species scored 70, second and third around 40 and the rest below 30 (Figure 4).

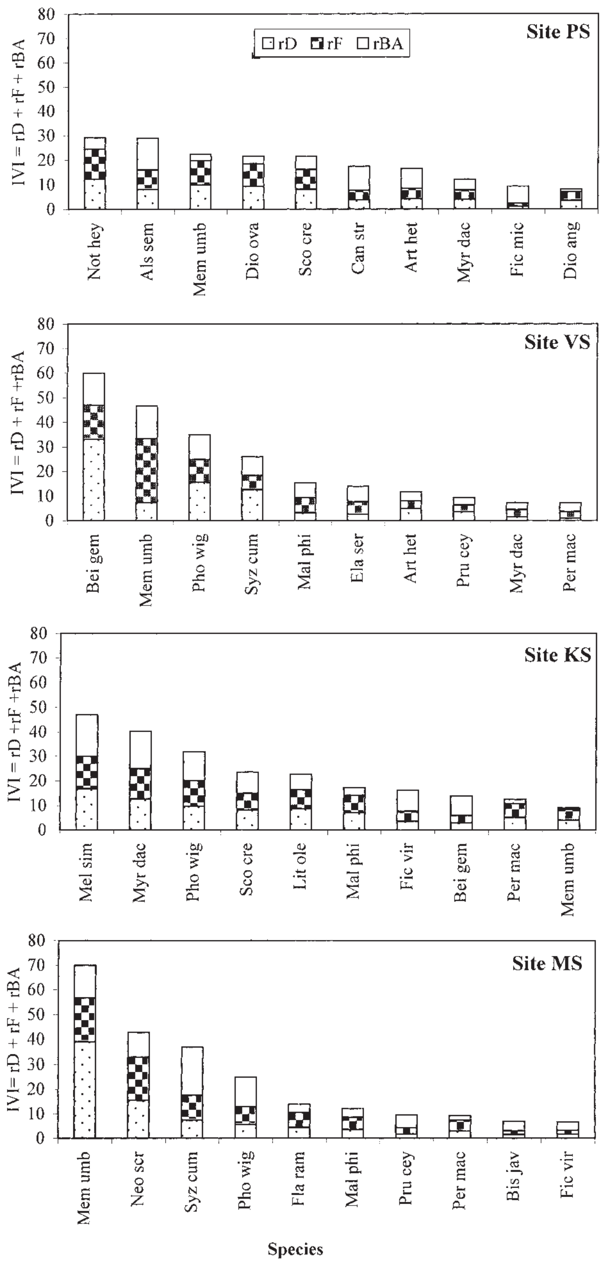


*Figure 4.* Importance value indices (IVI) of the top 10 tree species in each permanent plot of the sites PS, VS, KS and MS. Acronyms (first three letters) of genus and species are used as species code. For complete species name see Table 3. (rD – relative density, rf – relative frequency and rBA – relative basal area).

*Table 3.* Population density of tree species ≥30 cm gbh encountered in each 2 ha plot of sites PS, VS, KS and MS, and in total 8 ha of tropical evergreen forest in the Kolli hills, Eastern Ghats, south India.

| Species | Family | Density (no. of trees) in site | | | | |
|---|---|---|---|---|---|---|
| | | PS | VS | KS | MS | Total |
| *Memecylon umbellatum* Burm.f. | Melastomataceae | 104 | 300 | 26 | 378 | 808 |
| *Phoebe wightii* Meisner | Lauraceae | 6 | 107 | 63 | 54 | 230 |
| *Beilschmiedia gemmiflora* (Bl.) Kosterm. | Lauraceae | 12 | 159 | 19 | – | 190 |
| *Neolitsea scrobiculata* (Meisner) Gamble | Lauraceae | 8 | 19 | 10 | 149 | 186 |
| *Myristica dactyloides* Gaertn. | Myristicaceae | 41 | 35 | 82 | 13 | 171 |
| *Mallotus philippensis* (Lam.) Muell.- Arg. var. *philippensis* | Euphorbiaceae | 13 | 70 | 46 | 34 | 163 |
| *Syzygium cumini* (L.) Skeels | Myrtaceae | 12 | 66 | 2 | 71 | 151 |
| *Scolopia crenata* (Wight & Arn.) Clos var. *crenata* | Flacourtiaceae | 85 | 5 | 53 | – | 143 |
| *Nothopegia heyneana* (Hook.f.) Gamble | Anacardiaceae | 128 | 8 | – | 1 | 137 |
| *Meliosma simplicifolia* (Roxb.) Walp. subsp. *simplicifolia* | Sabiaceae | – | – | 109 | – | 109 |
| *Diospyros ovalifolia* Wight | Ebenaceae | 97 | 2 | – | 7 | 106 |
| *Persea macrantha* (Nees) Kosterm. | Lauraceae | 10 | 32 | 33 | 29 | 104 |
| *Artocarpus heterophyllus* Lam. | Moraceae | 44 | 36 | 8 | 10 | 98 |
| *Alseodaphne semecarpifolia* Nees var. *angustifolia* Meisner | Lauraceae | 84 | 5 | 2 | – | 91 |
| *Elaeocarpus serratus* L. | Elaeocarpaceae | 2 | 59 | 16 | 11 | 88 |
| *Litsea oleoides* (Meisner) Hook.f. | Lauraceae | – | 7 | 57 | 14 | 78 |
| *Prunus ceylanica* (Wight) Miq. | Rosaceae | 17 | 31 | 1 | 16 | 65 |
| *Antidesma menasu* Miq. | Euphorbiaceae | 29 | 25 | 4 | 4 | 62 |
| *Canarium strictum* Roxb. | Burseraceae | 40 | 4 | 16 | – | 60 |
| *Ficus virens* Ait. var. *virens* | Moraceae | 6 | 1 | 23 | 16 | 46 |
| *Meliosma pinnata* (Roxb.) Walp. subsp. *arnottiana* (Walp.) Beus. | Sabiaceae | 23 | 8 | 2 | 12 | 45 |
| *Flacourtia indica* (Burm.f.) Merr. | Flacourtiaceae | 1 | – | – | 42 | 43 |
| *Bischofia javanica* Blume | Bischofiaceae | 4 | 12 | 11 | 14 | 41 |
| *Diospyros angustifolia* (Miq.) Kosterm. | Ebenaceae | 37 | 4 | – | – | 41 |
| *Ligustrum robustum* (Roxb.) Blume subsp. *walkeri* (Decne.) P.S. Green | Oleaceae | 19 | 19 | 1 | – | 39 |
| *Litsea insignis* Gamble | Lauraceae | 23 | 6 | 7 | – | 36 |
| *Memecylon edule* Roxb. | Melostomataceae | 11 | 21 | – | 4 | 36 |
| *Callicarpa tomentosa* (L.) Murr. | Verbenaceae | 5 | 16 | – | 13 | 34 |
| *Cinnamomum malabatrum* (Burm. f.) Blume | Lauraceae | 5 | 25 | 2 | – | 32 |
| *Mimusops elengi* L. | Sapotaceae | 28 | 2 | – | – | 30 |
| *Celtis timorensis* Spanoghe | Ulmaceae | 14 | 14 | 1 | 1 | 30 |
| *Celtis tetrandra* Roxb. | Ulmaceae | 12 | – | 1 | 15 | 28 |
| *Ficus microcarpa* L. | Moraceae | 12 | 2 | 11 | 1 | 26 |
| *Toona ciliata* M. Roem. var. *ciliata* | Meliaceae | 2 | 6 | 10 | 6 | 24 |
| *Aglaia jainii* Viswa. & Ramachan. | Meliaceae | 13 | 5 | 2 | – | 20 |
| *Cipadessa baccifera* (Roth) Miq. | Meliaceae | 7 | – | – | 11 | 18 |
| *Ligustrum perrottetii* A.DC. var. *obovatum* Gamble | Oleaceae | – | – | 1 | 16 | 17 |
| *Canthium dicoccum* (Gaertn.) Teijsm. & Binn. var. *dicoccum* | Rubiaceae | 2 | 8 | 1 | 5 | 16 |
| *Mangifera indica* L. | Anacardiaceae | 11 | 2 | – | – | 13 |

*Table 3.* Continued.

| Species | Family | Density (no. of trees) in site PS | VS | KS | MS | Total |
|---|---|---|---|---|---|---|
| *Euonymus indicus* Heyne ex Roxb. | Celastraceae | 12 | 1 | – | – | 13 |
| *Polyalthia cerasoides* (Roxb.) Bedd. | Annonaceae | 12 | – | – | – | 12 |
| *Miliusa tomentosa* (Roxb.) Sinclair | Annonaceae | 5 | 7 | – | – | 12 |
| *Erythrina stricta* Roxb. | Papilionaceae | 8 | 3 | – | – | 11 |
| *Ficus nervosa* Heyne ex Roth var. *nervosa* | Moraceae | – | 1 | 9 | – | 10 |
| *Ficus tsjahela* Burm. f. | Moraceae | 7 | 1 | – | – | 8 |
| *Pavetta indica* L. var. *indica* | Rubiaceae | 7 | – | – | 1 | 8 |
| *Murraya paniculata* (L.) Jack | Rutaceae | 1 | 3 | 2 | 1 | 7 |
| *Vernonia arborea* Buch.- Ham. | Asteraceae | 6 | – | – | – | 6 |
| *Terminalia paniculata* Roth. | Combretaceae | – | – | 6 | – | 6 |
| *Glochidion malabaricum* Bedd. | Euphorbiaceae | – | 1 | 1 | 4 | 6 |
| *Ficus talbotii* King | Moraceae | 2 | 2 | – | 2 | 6 |
| *Allophylus serratus* (Roxb.) Kurz | Sapindaceae | 6 | – | – | – | 6 |
| *Solanum erianthum* D. Don | Solanaceae | 3 | – | – | 3 | 6 |
| *Mallotus stenanthus* Muell.- Arg. | Euphorbiaceae | 2 | 1 | 1 | 1 | 5 |
| *Ficus benghalensis* L. var. *benghalensis* | Moraceae | 3 | 1 | 1 | – | 5 |
| *Macaranga indica* Wight | Euphorbiaceae | – | – | 2 | 2 | 4 |
| *Oreocnide integrifolia* (Gaudich.) Miq. | Urticaceae | – | – | 4 | – | 4 |
| *Chukrasia tabularis* A. Juss. | Meliaceae | 3 | – | – | – | 3 |
| *Albizia odoratissima* (L.f.) Benth. | Mimosaceae | – | 1 | 2 | – | 3 |
| *Ficus beddomei* King | Moraceae | 1 | 2 | – | – | 3 |
| *Chionanthus ramiflora* Roxb. | Oleaceae | 3 | – | – | – | 3 |
| *Symplocos cochinchinensis* (Lour.) Moore subsp. *laurina* (Retz.) Nooteb. | Symplocaceae | – | 1 | – | 2 | 3 |
| *Breynia vitis-idaea* (Burm. f.) Fischer | Euphorbiaceae | – | – | – | 2 | 2 |
| *Litsea deccanensis* Gamble | Lauraceae | – | 2 | – | – | 2 |
| *Ficus exasperata* Vahl | Moraceae | – | – | – | 2 | 2 |
| *Maesa indica* (Roxb.) DC. | Myrsinaceae | 1 | – | 1 | – | 2 |
| *Schefflera stellata* (Gaertn.) Harms | Araliaceae | 1 | – | – | – | 1 |
| *Caryota urens* L. | Arecaceae | – | 1 | – | – | 1 |
| *Maytenus rothiana* (Walp.) Ramam. | Celastraceae | – | – | 1 | – | 1 |
| *Croton malabaricus* Bedd. | Euphorbiaceae | 1 | – | – | – | 1 |
| *Ficus mollis* Vahl | Moraceae | 1 | – | – | – | 1 |
| *Ochna obtusata* DC. var. *obtusata* | Ochnaceae | 1 | – | – | – | 1 |
| *Canthium rheedii* DC. | Rubiaceae | – | – | – | 1 | 1 |
| *Atalantia racemosa* Wight & Arn. | Rutaceae | – | – | – | 1 | 1 |
| *Salix tetrasperma* Roxb. | Salicaceae | 1 | – | – | – | 1 |
| *Chrysophyllum lanceolatum* (Blume)A. DC. | Sapotaceae | – | – | 1 | – | 1 |
| *Debregeasia longifolia* (Burm.f.) Wedd. | Urticaceae | – | 1 | – | – | 1 |
| *Gmelina arborea* Roxb. | Verbenaceae | – | 1 | – | – | 1 |
| Total | | 1054 | 1151 | 651 | 969 | 3825 |

The dominant species in each site and their score out of 300 were: *Nothopegia heyneana* (IVI = 29.0) and *Alseodaphne semecarpifolia* (28.8) in PS; *Beilschmedia gemmiflora* (60.0) and *Memecylon umbellatum* (46.6) in VS; *Meliosma simplicifolia* (46.9) and *Myristica dactyloides* (40.2) in KS; *Memecylon umbellatum* (69.8) and

*Table 4.* Abundance-based classification of trees ≥30 cm gbh and their species richness in the four study sites of tropical evergreen forest in the Kolli hills, Eastern Ghats.

| Density (trees $ha^{-2}$) | Group | Number of species in site | | | |
|---|---|---|---|---|---|
| | | PS | VS | KS | MS |
| >101 | Predominant | 2 | 3 | 1 | 2 |
| 51–100 | Dominant | 3 | 3 | 4 | 2 |
| 21–50 | Common | 22 | 12 | 8 | 14 |
| 3 to 20 | Rare | 17 | 14 | 8 | 8 |
| 1 to 2 | Very rare | 14 | 19 | 21 | 13 |
| Total | | 58 | 51 | 42 | 39 |

*Neolitsea scrobiculata* (42.6) in MS. The occurrence of the predominant species, *Memecylon umbellatum* (Melastomataceae), in all the sites, 4 species in any 3 sites, 6 in any 2 sites, and 12 species in only one site explains the heterogeneity of the Kolli hills site and that no two patches of tropical evergreen forests will be identical.

*Familial diversity*

Of the total 36 families encountered in 8 ha, only 22 families were captured in the highly disturbed site MS, whereas 31 families were represented in the undisturbed site PS (Table 2). Four families, Moraceae (with 2 genera-*Ficus* and *Artocarpus*, and 10 species), Lauraceae (7 genera and 9 species), Euphorbiaceae (6 genera and 9 species), and Meliaceae (4 genera and 4 species) were the well-represented families (Table 5). Oleaceae and Rubiaceae had 3 species each, while twelve families (33.3%) had 2 species each, and the rest 18 (50%) had only single species in the whole of 8 ha study area.

Lauraceae was the densest family (24.8%) in the forest stand, followed by Melastomataceae (22%), Euphorbiaceae (6.3%), Moraceae (5.3%), Flacourtiaceae (4.8%), Myristicaceae (4.4%), Sabiaceae (4%), Myrtaceae (3.9%) and Anacardiaceae (3.9%) (Table 5). Araliaceae, Ochnaceae, Salicaceae and the only monocot family in the study site Arecaceae, were represented by single individual in the 8 ha.

*Girth class diversity and density*

With increasing girth classes, species richness and density decreased (Table 6). The contribution of lower size class trees (30–60 cm gbh) to species richness ranged from 57.1% in site KS to 90.1% in VS, while for greater girth class (≥210 cm gbh), the contribution was 11.7% (VS) to 36.2% (PS). In KS, the greater species richness was recorded in the 60–90 cm girth-class (64.2%) than the lower size class (30–60 cm).

*Table 5.* The top twenty plant families of trees ≥30 cm gbh and their contribution to total genera (G), species (S) and density (D) in each 2 ha study site and in total 8 ha of quantitative inventory in the Kolli hills, Eastern Ghats.

| Family | Perumakkai shola | | | Vengodai shola | | | Kuzhivalavu shola | | | Mottukkadu shola | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | S | D | G | S | D | G | S | D | G | S | D | G | S | D |
| Lauraceae | 7 | 7 | 148 | 7 | 9 | 362 | 7 | 8 | 193 | 4 | 4 | 246 | 7 | 9 | 949 |
| Melastomataceae | 1 | 2 | 115 | 1 | 2 | 321 | 1 | 1 | 26 | 1 | 2 | 382 | 1 | 2 | 844 |
| Euphorbiaceae | 3 | 4 | 45 | 3 | 4 | 97 | 4 | 5 | 54 | 5 | 6 | 47 | 6 | 7 | 243 |
| Moraceae | 2 | 8 | 76 | 2 | 8 | 46 | 2 | 5 | 52 | 2 | 5 | 31 | 2 | 10 | 205 |
| Flacourtiaceae | 2 | 2 | 86 | 1 | 1 | 5 | 1 | 1 | 53 | 1 | 1 | 42 | 2 | 2 | 186 |
| Myristicaceae | 1 | 1 | 41 | 1 | 1 | 35 | 1 | 1 | 82 | 1 | 1 | 13 | 1 | 1 | 171 |
| Sabiaceae | 1 | 1 | 23 | 1 | 1 | 8 | 1 | 1 | 111 | 1 | 1 | 12 | 1 | 2 | 154 |
| Myrtaceae | 1 | 1 | 12 | 1 | 1 | 66 | 1 | 1 | 2 | 1 | 1 | 71 | 1 | 1 | 151 |
| Anacardiaceae | 2 | 2 | 139 | 2 | 2 | 10 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 150 |
| Ebenaceae | 1 | 2 | 134 | 1 | 2 | 6 | 0 | 0 | 0 | 1 | 1 | 7 | 1 | 2 | 147 |
| Elaeocarpaceae | 1 | 1 | 2 | 1 | 1 | 59 | 1 | 1 | 16 | 1 | 1 | 11 | 1 | 1 | 88 |
| Rosaceae | 1 | 1 | 17 | 1 | 1 | 31 | 1 | 1 | 1 | 1 | 1 | 16 | 1 | 1 | 65 |
| Meliaceae | 4 | 4 | 25 | 2 | 2 | 11 | 2 | 2 | 12 | 2 | 2 | 17 | 4 | 4 | 65 |
| Burseraceae | 1 | 1 | 40 | 1 | 1 | 4 | 1 | 1 | 16 | 0 | 0 | 0 | 1 | 1 | 60 |
| Oleaceae | 2 | 2 | 22 | 1 | 1 | 19 | 1 | 2 | 2 | 1 | 1 | 16 | 2 | 3 | 59 |
| Ulmaceae | 1 | 2 | 26 | 1 | 1 | 14 | 1 | 2 | 2 | 1 | 2 | 16 | 1 | 2 | 58 |
| Bischofiaceae | 1 | 1 | 4 | 1 | 1 | 12 | 1 | 1 | 11 | 1 | 1 | 14 | 1 | 1 | 41 |
| Verbenaceae | 1 | 1 | 5 | 2 | 2 | 17 | 0 | 0 | 0 | 1 | 1 | 13 | 2 | 2 | 35 |
| Sapotaceae | 1 | 1 | 28 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 2 | 31 |
| Rubiaceae | 2 | 2 | 9 | 1 | 1 | 8 | 1 | 1 | 1 | 2 | 3 | 7 | 2 | 3 | 25 |
| Subtotals (20 families) | 36 | 46 | 997 | 32 | 43 | 1133 | 28 | 35 | 635 | 28 | 35 | 962 | 41 | 58 | 3727 |
| Remaining (16 families) | 12 | 12 | 57 | 11 | 8 | 18 | 7 | 7 | 16 | 5 | 4 | 7 | 20 | 20 | 98 |
| Totals | 48 | 58 | 1054 | 43 | 51 | 1151 | 35 | 42 | 651 | 33 | 39 | 969 | 61 | 78 | 3825 |

Except site KS, trends in tree density in various size classes followed a similar fashion, as in species richness, wherein 30–60 cm size class was less dense (103) than 60–90 cm class (150). The stand density contribution by 30–60 cm class ranged from 15.8% (KS) to 64.4% (MS), while the >210 cm class had 8-fold density hike in the site KS (9.9%) as compared to MS (1.2%) (Table 6).

Basal area contribution by different tree size classes exhibited a reverse trend to that of species richness with the exception of site MS. Always the maximum contribution to basal area was found from >210 cm class and minimum from 30–60 cm class, but site MS had greater basal area (20.5%) from 30–60 cm class, and lesser (13.4%) from >210 cm class. In the other 3 plots, the maximum contribution ranging from 22.8% (VS) to 43.1% (PS) was from >210 cm, and the 30–60 cm class contributed 1.9 to 9.0% (Table 6).

*Table 6.* Results of girth class analysis of trees in the four study sites (PS, VS, KS and MS) of tropical evergreen forest in the Kolli hills.

| | Species richness | | | | Shannon (H′) index | | | | Density (trees $ha^{-2}$) | | | | Basal area ($m^2$ $ha^{-2}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Girth class (cm) | PS | VS | KS | MS | PS | VS | KS | MS | PS | VS | KS | MS | PS | VS | KS | MS |
| 30–60 | 50 | 46 | 24 | 32 | 3.002 | 2.435 | 2.661 | 1.741 | 479 | 536 | 103 | 625 | 7.55 | 8.43 | 1.96 | 9.58 |
| 60–90 | 38 | 31 | 27 | 27 | 3.014 | 2.768 | 2.722 | 2.631 | 251 | 229 | 150 | 181 | 11.46 | 10.46 | 7.09 | 8.72 |
| 90–120 | 28 | 25 | 21 | 19 | 2.943 | 2.723 | 2.639 | 2.506 | 99 | 140 | 111 | 76 | 8.54 | 12.73 | 9.96 | 6.95 |
| 120–150 | 27 | 19 | 18 | 14 | 2.908 | 2.211 | 2.385 | 2.469 | 83 | 112 | 96 | 36 | 12.06 | 17.37 | 14.74 | 5.53 |
| 150–180 | 14 | 8 | 18 | 11 | 2.466 | 1.533 | 2.483 | 2.098 | 47 | 60 | 69 | 26 | 10.59 | 13.01 | 14.97 | 5.81 |
| 180–210 | 12 | 8 | 14 | 8 | 2.194 | 1.507 | 2.112 | 1.951 | 33 | 33 | 57 | 13 | 10.01 | 9.87 | 17.47 | 3.74 |
| >210 | 21 | 6 | 15 | 7 | 2.745 | 1.244 | 2.373 | 1.791 | 62 | 41 | 65 | 12 | 45.77 | 21.28 | 36.80 | 6.25 |

*Stand structure*

The forest stand structure of each 2 ha plot (Figure 5) revealed that sites PS, VS and MS had many individuals in the lower girth class (30–60 cm) while site KS showed a slight increase in 60–90 cm size class. A step-wise decline in frequency of individuals with increasing girth class is evident in PS and VS, while the highly disturbed site MS shows a sudden decrease (>50%) in frequency from the second girth class onwards. Basal area of each girth class in the forest stand of the four study sites varied. It increased proportionately with each girth class in KS site and also in PS and VS, except for an increase in 120–150 cm girth class; while the disturbed site MS possessed different girth classes sharing near equal basal area (Figure 5).

*Species population structure*

Population structure of four species occurring in all four sites with leading densities in the total 8 ha, differed widely (Figure 6a–d). *Memecylon umbellatum* and *Neolitsea scrobiculata* were denser only up to 90–120 cm gbh class in all the four sites, while *Phoebe wightii* and *Myristica dactyloides* were represented well in all the four sites and in all the girth classes. Basal area contribution from different girth class individuals of each species in the four study sites varied widely. However, the highly disturbed site MS had a much smaller share of basal area in the larger girth class.

## Discussion

Biodiversity of an area is related to a variety of factors such as topography, climate, soil and natural/human disturbance. Tree species inventories at defined study sites and in minimum diameter classes give a reliable instrument to indicate the diversity level of a study site (Wattenberg and Breckle 1995). The species richness of 78 tree species in the 8 ha of the tropical evergreen forest in Kolli hills of Eastern Ghats reflects its low diversity status. As all the four study sites are located within a distance of 7 km and an elevation between 1000 and 1250 m, the soil, climate and topography largely remain the same. But the difference in human interference between each study site has considerable influence on species richness, from 26 species $ha^{-1}$ in the highly disturbed site MS to 54 species $ha^{-1}$ in the undisturbed site PS (Table 2). This notable twofold decrease between the study sites clearly demonstrates the reduction in tree species diversity in human impacted sites of Indian tropical evergreen forests. The diminishing tree diversity along elevational gradients in Kolli hills is in conformity with Lieberman et al. (1996) and Heaney and Proctor (1990).

The present Kolli hills study sites, compared to semi-evergreen forests of Indian Eastern Ghats, i.e., the Shervarayan hills showing 70 tree species (excluding lianas) in 4 ha (Kadavul and Parthasarathy 1999a), and the Kalarayan hills with 73 species

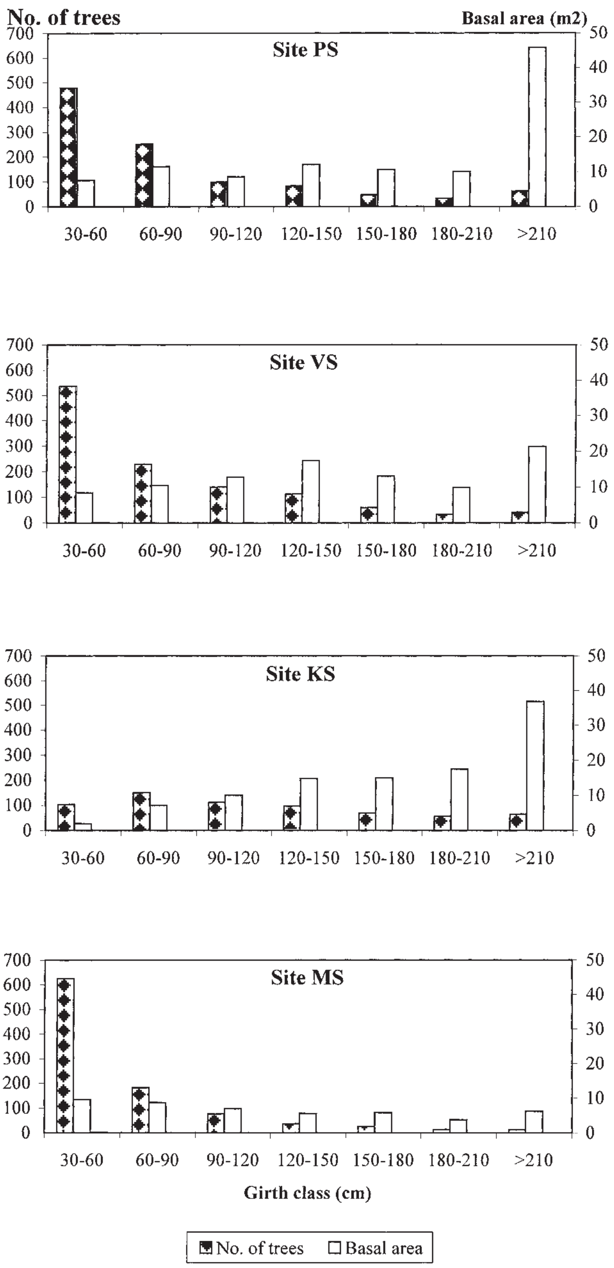


*Figure 5.* Forest stand structure based on tree girth frequency and basal area in various size classes in sites PS, VS, KS and MS.

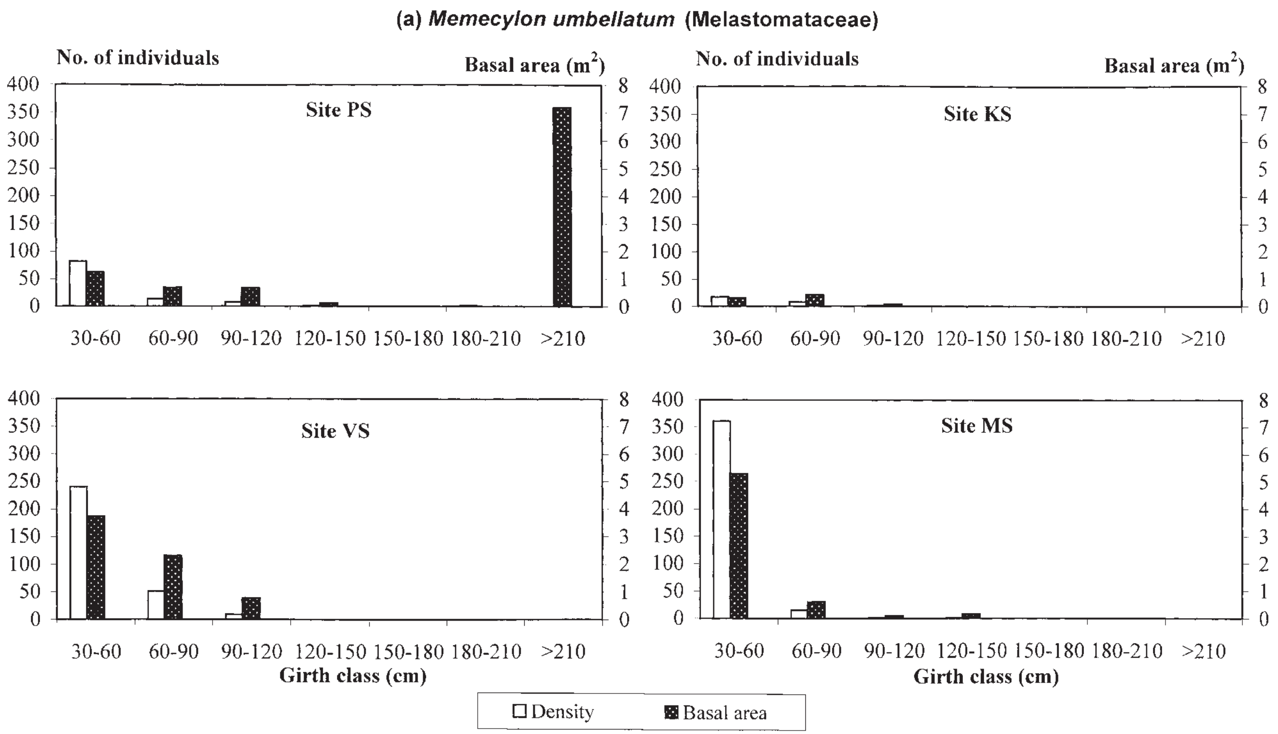


*Figure 6.* Comparative population structure of the four most abundant tree species encountered in all the four sites: (a) *Memecylon umbellatum* (Melastomataceae), (b) *Phoebe wightii* (Lauraceae), (c) *Neolitsea scrobiculata* (Lauraceae) and (d) *Myristica dactyloides* (Myristicaceae).

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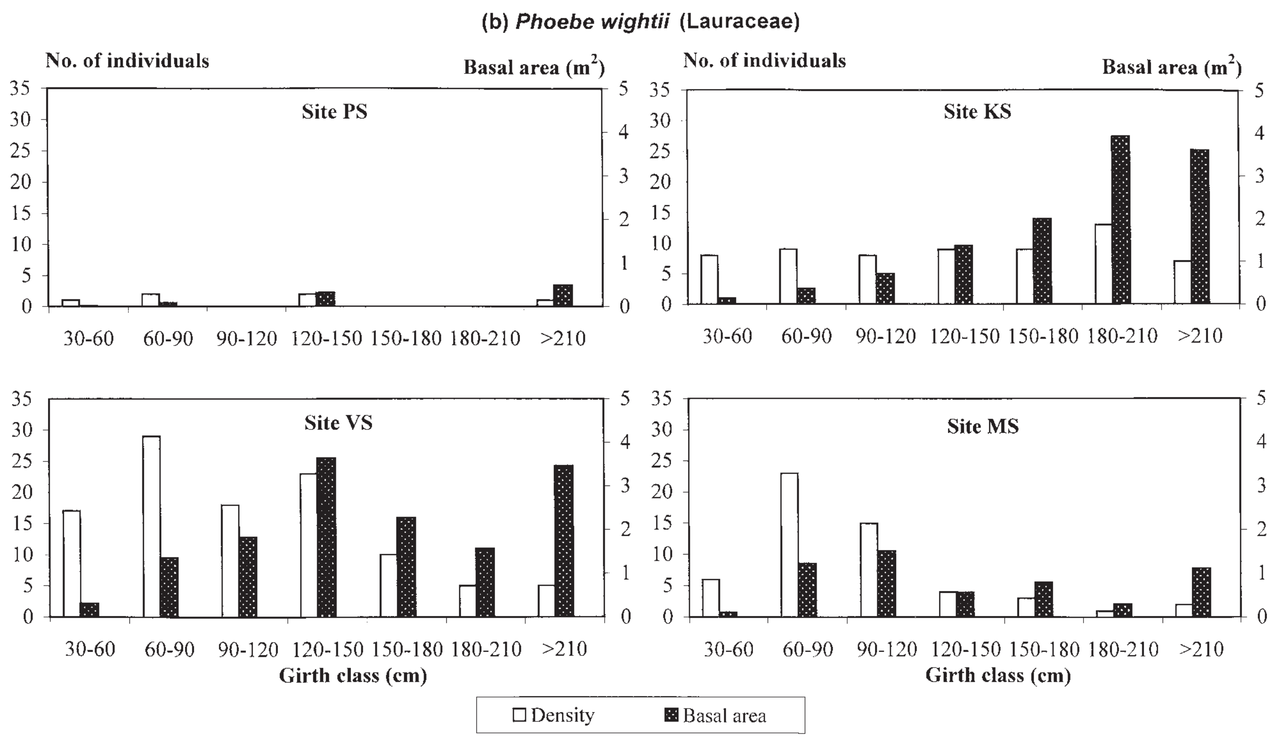


*Figure 6.* Continued.

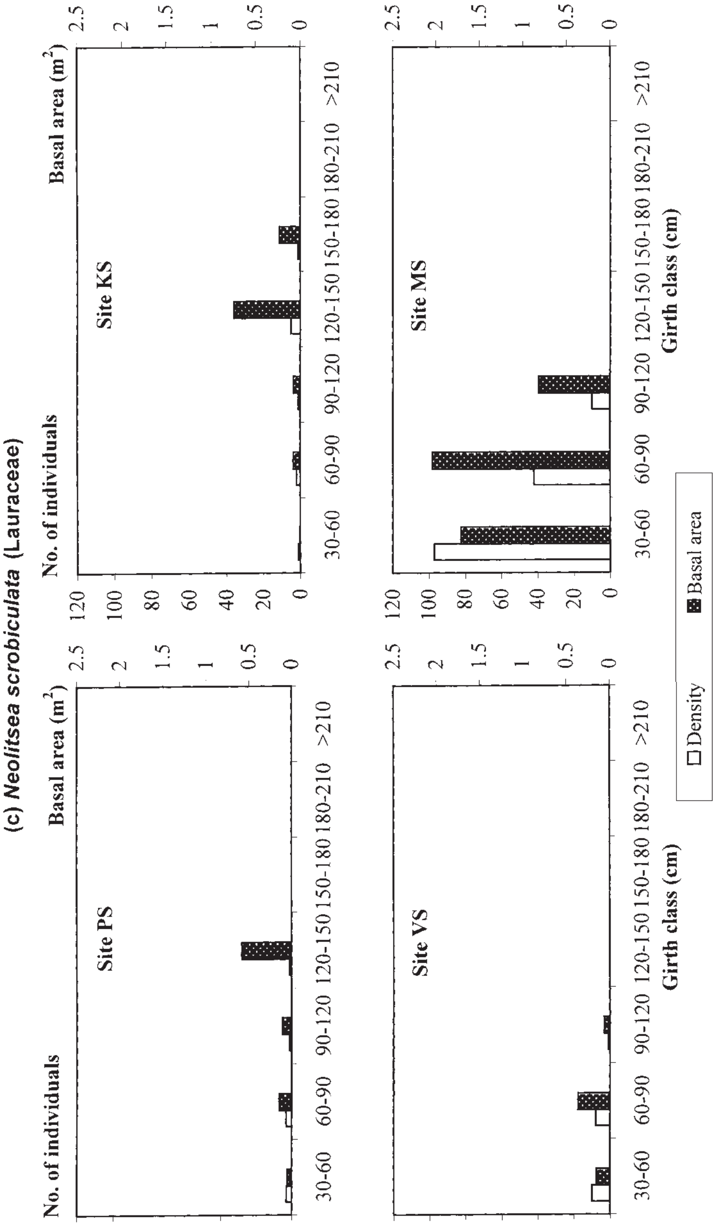


*Figure 6.* Continued.

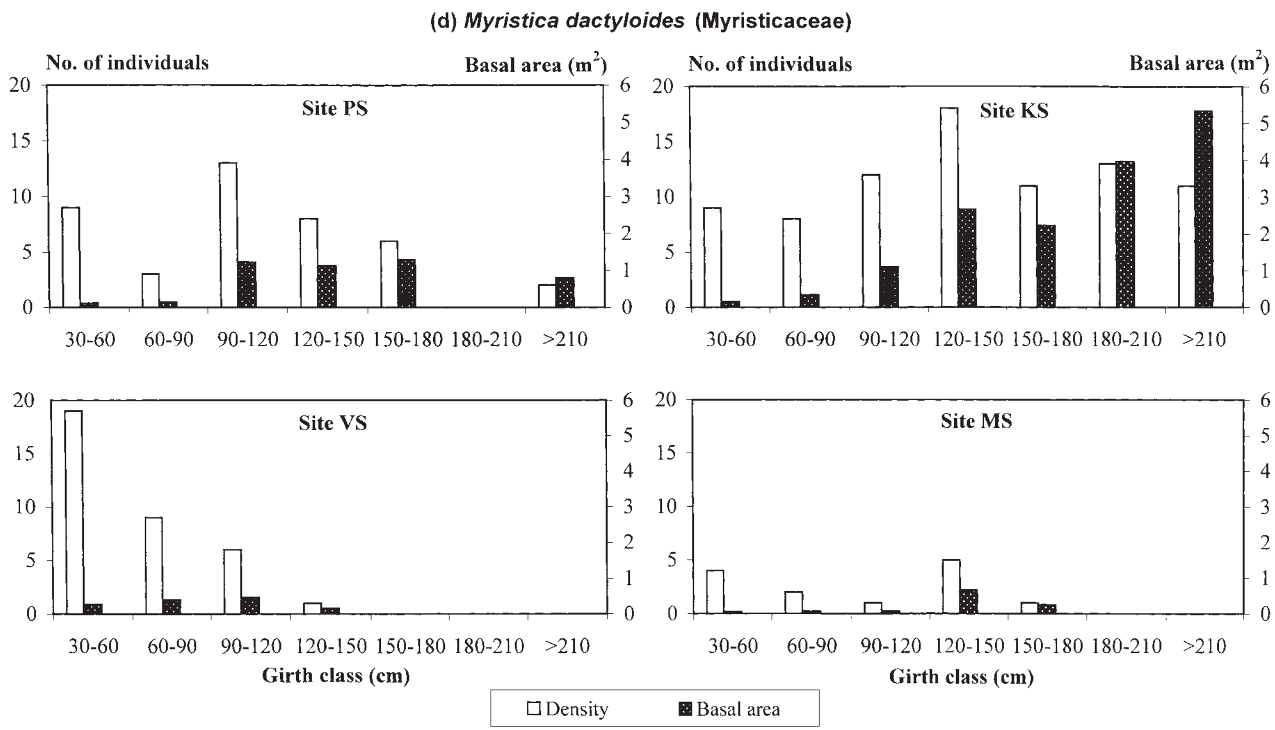


*Figure 6*. Continued.

in 4 ha (Kadavul and Parthasarathy 1999b), have more similar species richness. Also within peninsular India, species richness for the same tree girth threshold in various sites of Western Ghats ranged from 30 species $ha^{-1}$ in Nelliampathy (Chandrashekara and Ramakrishnan 1994), to 57 species $ha^{-1}$ in Mylodai and Courtallum reserve forest (Parthasarathy and Karthikeyan 1997a), 64 to 82 species $ha^{-1}$ in the medium-elevation forest of Kalakad (Parthasarathy 2000), to 80 to 85 species $ha^{-1}$ in high elevation evergreen forests at Kalakad (Parthasarathy 1999), 90 species on a 3.82 ha scale in Kalakad Mundanthurai Tiger reserve (Ganesh et al. 1996) and a range of 52 to 79 species $ha^{-1}$ in the 30 ha of tropical evergreen forest, Varagalaiar, Anamalais (Ayyappan and Parthasarathy 1999). Across the tropics, richness of woody species $\geq$10 cm dbh ranges from a low value of 20 species $ha^{-1}$ in flooded Varzea forest of Rio Xingu, Brazil (Campbell et al. 1992), a medium-value of 137 to 168 species $ha^{-1}$ for the four 1-ha plots of terra firme forest, Central Amazonia (Ferreira and Prance 1998) to 307 species $ha^{-1}$ in Amazonian Ecuador (Valencia et al. 1994). Such a comparison places the present study site in low-diversity forest category like the adjacent Shervarayan and Kalrayan hills of the Eastern Ghats.

The absolute stand density of our four study sites ranged from 266 to 632 trees $ha^{-1}$, with a whole study area average of 478 trees $ha^{-1}$. The Shervarayan and Kalrayan hills of Eastern Ghats, respectively, stocked a range of 640 to 986 trees $ha^{-1}$ (Kadavul and Parthasarathy 1999a) and 367 to 667 trees $ha^{-1}$ (Kadavul and Parthasarathy 1999b). Whereas the tree densities in various tropical evergreen forests of Western Ghats of peninsular India were: 574 to 915 stems $ha^{-1}$ in medium-elevation forest of Kalakad (Parthasarathy 1999); 852 to 965 stems $ha^{-1}$ in high elevation forest of Kalakad (Parthasarathy 2000); 583 stems $ha^{-1}$ in Kalakad–Mundanthurai area (Ganesh et al. 1996); 482 stems $ha^{-1}$ in Mylodai, Courtallam reserve forest (Parthasarathy and Karthikeyan 1997a); a range of 270 to 673 trees $ha^{-1}$ in the 30 ha of Varagalaiar, Anamalais (Ayyappan and Parthasarathy 1999), all these in southern Western Ghats and 635 stems $ha^{-1}$ in Uppangala forest of central Western Ghats (Pascal and Pelissier 1996). Density of trees ($\geq$30 cm gbh) in tropical forests ranges between 245 and 859 (Ashton 1964; Campbell et al. 1992; Richards 1996) with intermediate values of 448 to 617 stems $ha^{-1}$ in Costa Rica (Heaney and Proctor 1990), 436 stems $ha^{-1}$ in Reserva Forestal de San Ramon of Costa Rica (Wattenberg and Breckle 1995), 420 to 777 stems $ha^{-1}$ in Brazil (Campbell et al. 1992) and 639 to 713 stems $ha^{-1}$ in Central Amazonia (Ferreira and Prance 1998).

Thus, Kolli hills is very much within the stand density range of the tropical world and Indian evergreen forests. However, the steep decline in the stand density of sites MS and KS is due to the greater human disturbances such as the felling of trees and cattle browsing. The increased disturbance affects survival of trees from seedling to reproductive stage, ultimately resulting in a sparse stand.

The mean stand basal area 43.6 $m^2$ $ha^{-1}$ (range 23.3 to 53 $m^2$ $ha^{-1}$ for the four study sites) of the Kolli hills is admittedly greater than the pantropical average of 32 $m^2$ $ha^{-1}$ (Dawkins 1959), and the values of Shervarayan hills (34.9 $m^2$ $ha^{-1}$)

and Kalrayan hills (33.7 $m^2$ $ha^{-1}$), the two closer sites in the Eastern Ghats (Kadavul and Parthasarathy 1999b). The mean basal area value of the Kolli hills is also greater than the values for the comparable girth threshold of ≥30 cm gbh of several other tropical forests: 28.1 and 30.8 $m^2$ $ha^{-1}$ respectively of dry evergreen forest sites of Kuzhanthaikuppam and Thirumanikkuzhi (Parthasarathy and Karthikeyan 1997b) and Puthupet (Parthasarathy and Sethi 1997) on the Coromandel coast of south India; 24.2 $m^2$ $ha^{-1}$ of Malaysia (Poore 1968), 27.6 to 32.0 $m^2$ $ha^{-1}$ and 25.5 to 27.0 $m^2$ $ha^{-1}$ of Brazilian Amazon (Campbell et al. 1986, 1992); 27.8 and 41.67 $m^2$ $ha^{-1}$ of Costa Rica (Lieberman and Lieberman 1987; Watternberg and Breckle 1995); 32.8 to 40.2 $m^2$ $ha^{-1}$ of Central Amazonian upland forest (Ferreira and Prance 1998); 42.6 $m^2$ $ha^{-1}$ of Courtallam reserve forest in the Indian Western Ghats (Parthasarathy and Karthikeyan 1997a); 39.7 $m^2$ $ha^{-1}$ of Uppangala forests, central Western Ghats, India (Pascal and Pelissier 1996); and 25.91 to 47.75 $m^2$ $ha^{-1}$ in the 30 ha of Varagalaiar, Anamalais, southern Western Ghats (Ayyappan and Parthasarathy 1999). But a value of present study is lesser than: 53.3 to 94.6 $m^2$ $ha^{-1}$ and 55.3 to 78.3 $m^2$ $ha^{-1}$ of Kalakad, southern Western Ghats, India (Parthasarathy 1999; Parthasarathy 2000) and the values of a couple of other tropical forests: 47 (for alluvium) to 49.5 $m^2$ $ha^{-1}$ (for slope forest) of New Caledonia (Jeffre and Veillon 1990), and 62 $m^2$ $ha^{-1}$ of Monteverde, Costa Rica (Nadkarni et al. 1995).

Lauraceae is the most important (25%) individualised family in the Kolli hills study area. This feature of a single family dominance with 25% contribution is similar to the Shervaryan hills, the other Indian Eastern Ghats site, where the family Oleaceae (26.6%) dominated (Kadavul and Parthasarathy 1999a) and with Jengka forest reserve, Malaysia, where the Euphorbiaceae with 24.6% dominated (Ho et al. 1987). Based on family dominance, the Kolli hills at 1000 m altitude and above is a Lauraceae–Melastomataceae formation.

Moraceae (10 species), Lauraceae (9), and Euphorbiaceae (7) were the most speciose families in the tropical evergreen forest of Kolli hills, while in the adjacent Shervarayan hills Euphorbiaceae (8 species) and Rubiaceae (5 species) were most speciose (Kadavul and Parthasarathy 1999a). Broad-leaved forests in Taiwan showed Lauraceae (9 species) and Rubiaceae (7) as dominants (Hara et al. 1997). In Central Amazonian upland forests, Leguminosae, Lauraceae, Sapotaceae, Chrysobalanaceae, and Moraceae were the richest families (Ferreira and Prance 1998). According to Keel and Prance (1979) in undisturbed habitats dominance increases as a function of stress. Jacobs (1987) suggested that it is a sequel of past damage. The occurrence of Melastomataceae (1 genus, *Memecylon*, with 2 species) with the maximum number of individuals (39%) in our highly disturbed site MS, is notable. The drastic variation in tree species composition and abundance between the four sites, is evidently due to anthropogenic activities, especially in sites MS and KS.

Site-wise species rarity ranged from 53.4% (PS) to 69.0% (VS), and for the entire 8 ha it was 57.6%, the latter value surpassing the values of many global tropical forests: 50% rarity in West Java (Meijer 1959), 55.4% in New Guinea (Paijmans

1970), 38% in Malaysia (Poore 1968) and 40% in Barro Colorado Island, Panama (Thorington et al. 1982), but slightly lesser than the rarity (59%) of Jengka forest reserve, Malaysia (Ho et al. 1987). Many tropical species tend to be locally abundant in certain areas and relatively rare in others (Hubbell and Foster 1983). The occurrence of small population tree species, particularly mono-individual species, is highly correlated with tree species diversity of the local forest vegetation and they are crucial elements of local biodiversity (Cao and Zhang 1997). The greater species rarity of the present study site attaches corresponding significance to the site value and its conservation.

The trend of decreasing diversity and density with increasing girth class (Table 6) is in conformity with the studies of Hara et al. (1997), Jeffre and Veillon (1990), Kadavul and Parthasarathy (1999a), Newbery et al. (1992) and Paijmans (1970). Sites PS and VS had typical reverse J-shaped structure for girth frequency (Figure 5). As exemplified by undisturbed site PS, mature stands with good regeneration were reported from Jengka forest reserve, Malaysia (Poore 1968; Ho et al. 1987), Costa Rica (Lieberman et al. 1985), Brazilian Amazon (Swaine et al. 1987; Campbell et al. 1992), Sungei Menyala in Malaysia (Manokaran and Kochummen 1987), Mudumalai in India (Sukumar et al. 1992) and in Monteverde, Costa Rica (Nadkarni et al. 1995). Disturbed sites KS and MS respectively had low density in smaller and larger girth classes. The lack of J-shaped structure for basal area in highly disturbed site MS (Figure 5) indicates the extent of tree felling. This corroborates our field observation during this investigation. In site KS, smaller girth class trees are easy to cut and transport as head-loads since the site is closer to union road. Whereas off the road privacy offered by its location, qualifies MS for voracious chopping of larger size trees.

A low mean stand basal area (23.3 $m^2$ $ha^{-1}$) of the disturbed site MS is due to selective felling of larger girth class trees and increased stand basal area (51.5 $m^2$ $ha^{-1}$) in KS is a sequel of unchopped larger stems. When forest stand is thinned, medium-sized boles are bound to attain greater biovolume increment due to lesser competition by saplings and wider spacing of trees (Parthasarathy 2000). The difference in species population can be attributed to ecological amplitude of a species. *Memecylon umbellatum* and *Neolitsa scrobiculata* represented only up to 90 to 120 cm girth class in all the four sites, implying their low girth potential. Contrastingly, *Phoebe wightii* and *Myristica dactyloides* were equally represented in all the size classes, owing to their greater ecological amplitude.

## Conclusion

The diversity of trees is fundamental to total rainforest biodiversity, because trees provide resources and habitat structure for almost all other rainforest species (Cannon et al. 1998). As human activities keep escalating with ever-increasing population, ecosystems near human settlements are made fragile. Hence documenting tree diversity in disturbed forest sites and thereby emphasizing the need for site conservation formed the nucleus of this investigation. The tropical evergreen forests of Kolli hills found in secluded patches ('sholas') are unique. The sites investigated have a high percentage (57.6%) of species rarity. The greater human impact observed in MS has resulted in reduction of species by 52% (26 species as against 54 of PS) and 56% less basal area. Tree density was also reduced to 58% in KS, the other disturbed site (266 as against 632 trees of VS). All these data indicate the deleterious effects of anthropogenic activities on plant diversity. Intensive research focussing on specific reproduction strategies of rare tree species is needed to answer questions needed to develop a conservation strategy. Understanding the ecology of tree species is central to sustainable forest management and conservation (Pinard et al. 1999). The need for conservation arises from the multiple benefits offered by biodiversity. Hence proper and stringent forest conservation measures would rescue species loss, particularly, in the fragmented 'shola' forests of the Kolli hills.

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