Floristics and dry matter dynamics of tropical wet evergreen forests of Western Ghats, India

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Floristic composition, structure, diversity, biomass, litterfall and net primary productivity (NPP) of tropical evergreen forests on four contiguous hill ranges of Western Ghats, India were studied. The forest on the study site was analysed by randomly laying eight quadrats (20 m × 20 m) within each representative plot of 1 ha. Biomass of the tree and shrub components was estimated using species-specific allometric equations. The litter input was quantified by placing three litter traps (50 cm × 50 cm × 15 cm) in each quadrat. The net biomass accumulation was computed and compared among the sites studied. The stand density ranged from 257 to 644 individuals ha^{-1} and basal area between 29 and 42 m^2 ha^{-1}. Shannon and Simpson's indices ranged from 1.5 to 3.7 and 0.1 to 0.16 respectively, and with beta diversity of 2.01. Total stand biomass averaged from 440 to 571 Mg ha^{-1}, of which trees contributed 90.2–92.2% and remaining 8.8–9.8% by shrubs and herbs. The standing litter ranged from 3.5 to 4.2 Mg ha^{-1} and litter production from 4.0 to 5.7 Mg ha^{-1} yr^{-1}. The average NPP was 23.7 Mg ha^{-1} yr^{-1}, of which 64.7% was contributed by trees, 13.6% by shrubs, 2.7% herbs and 19.1% by litter. Turnover rate and turnover time ranged from 0.93 to 0.95 yr^{-1} and 1.05 to 1.08 yrs respectively. The study showed that tropical evergreen forests in Brahamagiri and Kadmakal ranges of Western Ghats are ecologically rich both in terms of structure and biomass production compared to other tropical rain forests of the world, however Padnailkannad and Pattighat sites were severely affected by biotic stresses which demand attention for conservation and management of these fragile ecosystems.

Keywords: Biomass, compartment model, litterfall, net primary productivity, tropical evergreen forest, Western Ghats.

TROPICAL forests are one of the richest and complex terrestrial ecosystems supporting a variety of life forms and have a tremendous intrinsic ability for self-maintenance. However, many of these forests are losing this ability due to excessive biotic interferences such as anthropogenic perturbations and uncontrolled grazing. Consequently, these forests are disappearing at an estimated rate of 15–17 m ha/yr (ref. 1). Furthermore, this comes at a time when our knowledge of their structure and functional dynamics is woefully inadequate[2]. The conservation of biological diversity has become a major concern for the sustainable development of the society and ecosystem. Understanding qualitative and quantitative information in relation to structural and functional dynamics is essential for biodiversity conservation and sustainable management of fragile ecosystems.

The Western Ghats of India, also known as Sahyadri, harbours rich and diverse tropical forests because of the geographical location, stable geology, equable climate, heavy rainfall and good soil conditions. Physiographically, these forests are not only rich with high species diversity but also contain several palaeo-endemic species, which are botanical 'relicts' of ancient and unique vegetation types[3]. Because Western Ghats is considered one of the main centres of the biodiversity in India with high species diversity and high levels of endemism, it is now recognized from a global perspective as one of the 25 biodiversity hotspots for conservation priorities[4–6]. During the last few decades, these forests were severely disturbed due to indiscriminate logging, expansion of agriculture, construction of hydroelectric dams, roads and raising monoculture plantations like *Hevea brazilensis*, *Acacia mangium*, *Acacia auriculiformis*, *Tectona grandis*, *Cocos nucifera*, etc. Overexploitation combined with faulty land management practices has resulted in 171 species of higher plants and 10 species of mammals becoming endangered and a few of them are on the verge of extinction[7,8]. Besides the endangered species, the diversity of the other species is decreasing and leading to the formation of secondary forests. The periodical monitoring of the forests in ecological hotspots becomes mandatory to frame suitable strategies for the conservation and management of these ecosystems. Despite the great ecological significance of Western Ghats, only a few studies were made to understand either the structure or the functioning of this ecosystem[4,8–10]. However, many of these studies were site-specific and non-random in nature which could not explain the true nature at the ecosystem level. The structural analysis of vegetation is essential for understanding the floristic composition, stand density, basal

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area, vertical stratification and community types, whereas diversity is useful for deriving information on species richness, distribution and rate of changes in species composition. Both structure and diversity of vegetation have strong functional role in controlling ecosystem processes[11]. On the other hand, the estimation of woody biomass is also necessary for determining the status and flux of biological materials in an ecosystem[12]. If the forest biomass is to be measured and analysed in its proper context as a part of production, this gives an overall status of ecosystem functioning. The present study aims to quantify species composition, structure, biomass, litterfall and net primary productivity of tropical evergreen forests of the Western Ghats.

Study area

Four contiguous hill ranges in Western Ghats, viz. Pattighat, Brahamagiri, Padnailkannad and Kadmakal, representing a typical wet evergreen forest ecosystem, were selected for quantifying ecosystem structure and function. For convenience of the presentation of the results and discussion, these hill ranges are denoted serially as site 1 (Pattighat), site 2 (Brahamagiri), site 3 (Padnailkannad) and site 4 (Kadmakal) respectively. The sites are situated mainly in Kodagu and parts of North Kanara districts of Karnataka and spread between 12°25′N to 12°35′N lat. and 75°25′E to 75°45′E long. (Figure 1). The criteria for the selection of these sites were differences in altitude, rainfall, temperature and degree of biotic interferences. The characteristics of different sites are presented in Table 1. The climate is tropical and characterized by high humidity, heavy rainfall with cold nights and high windy days. The annual rainfall was received from the south-west monsoon during June–September and accounts for 80% of the total rainfall. The maximal and minimal temperatures found were 36°C in April and 8°C in December respectively.

Methodology

The forest stand on each study site was analysed by randomly laying eight quadrats (20 × 20 m) within each representative plot of 1 ha. A total of 32 quadrats were laid in the three sites. DBH (diameter at breast height) at 1.37 m and total height of the trees were measured. Similarly, diameter of the shrub species at 15 cm above the ground level and total height were measured.

Vegetation was quantitatively analysed for frequency, density, basal area and abundance[13]. Importance value index (IVI) of the species was calculated as the sum total of relative frequency, relative density and relative basal area[14]. Species diversity parameters for tree and shrub layers were determined using basal cover values from the Shannon–Weiner information function[15]. Concentration of dominance was measured following Simpson's index method[16]. Vegetation was also measured for species richness[17], equitability[18] and beta diversity[19].

Biomass of the tree components (stem, branch, leaves and roots) was estimated using species-specific allometric equations developed by Rai[20] and depicted in Table 2. For shrub component, the equations developed by Singh and Mishra[21] were used. Herbaceous biomass was estimated by harvesting the total plants at monthly intervals from three randomly distributed plots of 50 × 50 cm size from each sampling quadrat. Total biomass of the stand was computed by adding the individual biomass of tree, shrub and herbaceous layers.

Forest floor litter was collected from eight 50 × 50 cm randomly laid quadrats at bimonthly intervals in each site. The collected litter was categorized into (i) leaf litter, (ii) wood litter and (iii) herbaceous litter. The fresh weight of the litter was measured in the field itself whereas dry weight was measured after oven drying at 80°C till constant weight was attained. Fresh to dry weight ratio for each component was determined which was used for the determination of component wise standing litter.

The litter input (litterfall) to the forest floor was measured for two consecutive years by placing three litter

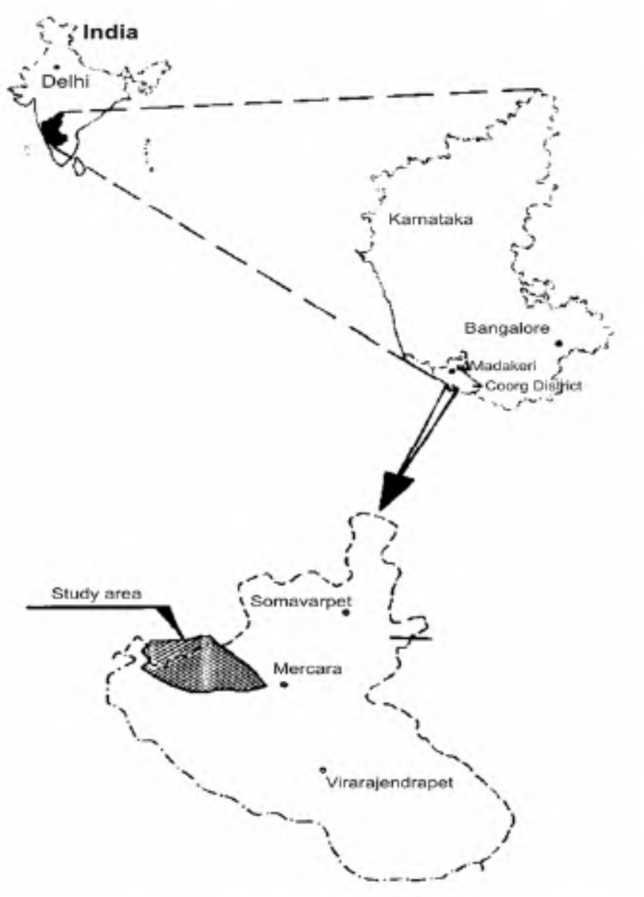

Figure 1. Location map of the study area.

Table 1. Characteristics of the study sites

Characteristics	Site 1	Site 2	Site 3	Site 4
Range	Pattighat	Brahamagiri	Padnailkannad	Kadmakal
Altitude (m)	450–1000	800–1500	500–1100	600–1300
Mean annual temperature (°C)	26.6 ± 2.2	24.6 ± 1.8	26.6 ± 1.6	25.6 ± 1.2
Rainfall (mm)	2800 ± 35	3200 ± 40	2800 ± 70	3000 ± 50
Radiation (MJ ha^{-1} yr^{-1})	5800 ± 160	5230 ± 110	5600 ± 120	5400 ± 160
Soil type	Oxisol	Oxisol	Oxisol	Oxisol
Biotic interferences	High	Low	High	Low-medium

Table 2. Allometric equations for biomass estimation of tropical evergreen forests of Western Ghats, India[20]

	Bole			Branch			Foliage			Root		
Species	*a*	*b*	r^2	*a*	*b*	r^2	*a*	*b*	r^2	*a*	*b*	r^2
Calophyllum elatum	–1.502	0.9638	0.99	–1.502	0.9638	0.99	–4.62	1.732	0.87			
Canarium strictum	–1.746	1.066	0.98	–1.746	1.066	0.98	–3.275	1.559	0.78			
Corallia brachiata	–1.67310	1.059	0.95	–1.6731	1.059	0.95	–2.28	1.87	0.93			
Dipterocarpus indica	–1.5876	1.0327	0.99	–1.5876	1.0327	0.99	–3.27	2.277	0.95			
Holigrana sp.	–0.4342	0.7473	0.96	–0.4342	0.7473	0.96	–1.959	1.726	0.69			
Palaquium ellipticum	–1.73089	1.0677	0.99	–1.7308	1.0677	0.99	–0.3672	1.174	0.77			
Persea macrantha	–1.0782	0.4248	0.98	–1.0782	0.4248	0.98	–0.966	1.193	0.55			
Syzygium utilis	–1.7018	1.0712	0.98	–1.7018	1.0712	0.98	–2.818	1.133	0.97			
Garcinia cambogia	–1.4011	0.9838	0.99	–1.4011	0.9838	0.99	–6.51	1.039	0.91			
Garcinia indica	–1.4735	0.4931	0.98	–1.4735	0.4931	0.98	–3.299	1.458	0.87			
Landea anamallyanum	–1.3843	0.9826	0.99	–1.3843	0.9826	0.99	–4.157	1.639	0.94			
Euphoria longana	–1.268	0.9826	0.98	–1.268	0.9826	0.98	–3.619	1.610	0.74			
Pooled equation	–0.9242	0.9706	0.94	–0.9242	0.9706	0.94	–8.255	1.693	0.89	–1.089	1.695	0.88
Pooled shrub equation*	–2.9407	0.8745	0.98	–2.9404	0.8745	0.98	–3.025	2.542	0.95	–2.0849	2.4481	0.97
Equation for trees	$\log Y = a + b \log D^2H$			$\log_e Y = a + b \log_e D$			$\log Y = a + b \log D$			$\log Y = a + b \log D$		
Equation for shrubs	$Y = a + b \log D$			$Y = a + b \log D$			$Y = a + b \log D$			$Y = a + b \log D$		

Y, Biomass in kg; *D*, DBH in cm; *H*, height in meters; *a*, intercept; *b*, regression coefficient (slope); r^2, coefficient of determination.
*Adopted equations from Singh and Mishra[21].

traps (50 × 50 cm) in each quadrat. A total of 24 litter traps were placed for a given site. Litter was collected at bimonthly intervals and separated into leaf, wood and herbaceous components. The litter samples were oven dried at 80°C and dry weights were determined. The total litterfall was obtained by adding the leaf, wood and herbaceous litter components.

Based on the field data, 20 diameter classes (distributed across all species) were recognized, ranging from 30–40 cm to > 200 cm size classes. Five individuals in each DBH class across all the tree species and five individuals of all the shrub species were marked in October 1993 and measured for DBH and height in three successive years (1993, 1994 and 1995). DBH was measured by tree calipers and height by Ravi's multimeter. Biomass for bole, branch, coarse root and foliage was estimated by employing allometric regression equations (Table 2) using DBH and height measurements of 1993 (B1), 1994 (B2) and 1995 (B3). The net biomass accumulation for 1993–1994 (B2–B1) and 1994–1995 (B3–B2) were computed. The average biomass production of individual components (trees and shrubs) was calculated as {(B3–B2) + (B2–B1)/2}. To the foliage biomass, accumulation of annual leaf fall was added to represent annual leaf production and similarly wood litter was added to the branch and stem components to represent annual branch and stem components respectively. In this study, we assumed the mortality of roots as 1/5 of the annual leaf litter which was adopted in many earlier studies[22–25]. The net production of tree layer, shrub layer, herbaceous layer and total litterfall was added to obtain net primary productivity of forest vegetation.

The data on standing biomass, litterfall and net production was analysed in one-way of variance to see variability in different sites. The statistical analysis was made in Anova-1 module in MSTAT-C statistical package. The significant difference between treatment means was compared using Duncan's multiple range tests at $P \leq 0.05$.

Results and discussion

Physiognomically, the vegetation of evergreen forests is organized in three distinct layers, viz. upper storey,

Table 3. Floristic composition of tropical evergreen forests of Western Ghats, India

Emergents	Main storey	Under storey	Climbers	Bamboos and Reeds	Canes
Vateria indica L.	*Artocarpus hirsutus* Lam.	*Amoma canarana* Hirron.	*Agrostistachys indica* Hir.	*Bambusa bambos* Roxb.	*Calamus rotang*
Calophyllum elatum Bedd.	*Artocarpus heterophyllus* Lam.	*Actionodaphne hookeri*	*Clematis gouriana* Roxb.	*Ochlandra scriptoria* Denn.	*Calamus rheedii*
Kingiodendron pinnatum D.C.	*Bischofia javanica* Bl.	*Canthium dicoccum* T&B	*Connarus wightti* HK	*Bambusa brandisii*	*Calamus lacciferus*
Mangifera indica L.	*Calophyllum elatum Wild*	*Carallia brachiata* Merr	*Combretum latifolium* Bl.	*Ochlandra rheedii*	*Calamus pseudotenius*
Canarium strictum Roxb.	*Canarium strictum* Roxb.	*Dryptes alata* Bedd	*Dalbergia sympathetica*	*Ochlandra travancorica*	*Calamus travancoricus*
Lophopetalum wightianum	*Cinnamomum zeylanicum* Blume.	*Eugenia zeylanica* Wgt.	*Entada pursaetha* D.G.		
	Diospyros ebenum Koen.	*Eugenia corymbosa* Lamk.	*Massaandra laxa* Gamb.		
	Dysoxylum malabaricum Bedd.	*Ficus virens* Aiton.	*Toddalia asiatica* Lem.		
	Elaeocarpus tuberculatus L.	*Garcinia indica*			
	Holigarna arnottiana	*Garcinia morella*			
	Holigarna caustica	*Garcinia cambogia* Desr.			
	Mesua ferrea L.	*Gordonia obtusa*			
	Mangifera indica L.	*Humboldta brunoise* Wall.			
	Palaquium ellipticum Engl.	*Ixora arborea* Roxb.			
	Persea macrantha Kosterman	*Oroxylum indicum* Vent.			
	Pterygota alata Roxb.	*Litsea floribunda*			
	Poeciloneuron indicum Bedd.	*Mallotus philippinensis*			
	Syzygium gardneri Thw.	*Myristica malabarica* Lamk.			
		Myristica dactyloides Gaertn.			
		Sterculia guttata Roxb.			
		Syzygium laetum Gandhi			
		Symplocos cochinchinensis			
		Symplocos racemosa Roxb.			
		Manilkara roxburghiana			

middle storey and ground vegetation (Table 3). The upper or main storey vegetation was dominated with tall emergents ranging in height from 25 to 40 m. The common emergent in moist sites along the ridges of the streams was *Vateria indica*, whereas *Calophyllum elatum*, *Canarium strictum* and *Palaquium ellipticum* were distributed in higher altitudes (800–1100 m). The other commonly found main storey species were *Artocarpus hirsutus*, *Artocarpus heterophyllus*, *Acrocarpus fraxinifolius*, *Canarium strictum*, *Mesua ferrea*, *Pterygota alata*, *Poeciloneuron indicum*, *Syzygium gardneri* and *Persea macrantha.* In understorey, the prominent species were *Actinodaphne hookeri*, *Canthium dicoccum*, *Drypetes alata*, *Garcinia* sp., *Litsea floribunda*, *Oroxylum indicum*, etc. The woody climbers (lianas) consisted mainly of *Agrostistachys indica*, *Clematis gouriana*, *Combretum latifolium* and *Toddalia asiatica*. Among bamboos, *Bambusa brandisii*, *Bambusa bambos*, reeds like *Ochlandra rheedii* were prominent in the region. Canes like *Calamus travancoricus*, *Calamus rotang* and *Calamus lacciferus* were also present in the study area. The epiphytes were common in open areas and many mosses and lichens were present on trunks and branches of trees and numerous ferns persist along the fringes of rivulets.

Number of tree species at the study sites ranged from 28 to 38 species ha^{-1}. Higher number was found in sites 2 and 3, whereas lowest in site 4 (Tables 4 and 5). The number of tree species estimated in the Western Ghats by other workers was in the Silent Valley[26] 84 ha^{-1}, in Nelliampathy[27] 30 ha^{-1} and in Kakachi[28] 45 ha^{-1}. Proctor *et al.*[29] opined that in a variety of tropical rain forests, the species range from 20 to 233 trees ha^{-1}. The density of the trees across various sites, in the present studies, ranged from 263 to 438 trees ha^{-1}, whereas shrub density varied from 243 to 309 shrubs ha^{-1} (Tables 3 and 4). Maximum density of trees was recorded in site 2 followed by sites 4, 3 and 1. Unlike trees, shrub density was maximum at site 3 preceded by sites 2, 4 and 1. Density of tree layer in these forests is within the range reported by Pascal[10], and Sundarapandian and Swamy[30] in different parts of tropical forests of Western Ghats. Pascal[10] reported 257–644 trees ha^{-1} in various bioclimatic types of evergreen forests of Western Ghats. However, the density of understorey shrubs was lowest in the study area

Table 4. Structure of tropical evergreen forests in different sites of Western Ghats, India

	Tree layer											
	Site 1			Site 2			Site 3			Site 4		
Species	Den. ha^{-1}	B.A. $m^2\ ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2\ ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2\ ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2\ ha^{-1}$	IVI
Vateria indica	19.0	4.6	28.3	50.0	3.1	24.5	6.0	2.5	11.4	113.0	9.7	76.0
Myristica malabarica	28.0	1.4	22.7	106.0	7.4	55.2	63.0	4.3	51.5	41.0	3.6	27.0
Hopea wightiana	6.0	0.1	4.6	3.0	0.4	3.3	25.0	2.6	21.5	0.0	0.0	0.0
Poecilonveron indicum	22.0	1.5	22.4	0.0	0.0	0.0	3.0	0.3	3.0	0.0	0.0	0.0
Dysoxylum malabaricum	16.0	2.3	19.2	16.0	1.3	12.9	3.0	1.3	2.9	10.0	1.3	10.5
Eugenia gardneri	3.0	0.1	3.2	22.0	5.3	24.8	19.0	2.3	17.8	22.0	3.4	17.9
Microtropis stocksii	0.0	0.0	0.0	13.0	0.7	7.8	0.0	0.0	0.0	0.0	0.0	0.0
Myristica canaricus	0.0	0.0	0.0	22.0	1.1	12.5	0.0	0.0	0.0	22.0	1.3	13.9
Clonea dentate	6.0	0.4	7.1	10.0	0.8	8.6	0.0	0.0	0.0	3.0	1.0	4.6
Artocarpus heterophyllus	3.0	0.2	4.0	3.0	0.2	2.7	0.0	0.0	0.0	0.0	0.0	0.0
Sgzygium cumini	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	2.4	0.0	0.0	0.0
Manilkara roxburghiana	0.0	0.0	0.0	10.0	1.5	9.0	16.0	0.7	10.3	0.0	0.0	0.0
Pterocarpus marsupium	0.0	0.0	0.0	3.0	0.4	3.3	6.0	0.3	3.6	0.0	0.0	0.0
Mitragyna parviflora	10.0	0.7	7.6	0.0	0.0	0.0	3.0	0.0	2.1	3.0	0.6	6.5
Diospyros ebenum	10.0	1.1	11.0	10.0	1.3	8.6	16.0	0.7	10.3	13.0	0.7	10.2
Acrocarpus fraxinifolius	0.0	0.0	0.0	0.0	0.0	0.0	25.0	1.3	17.0	0.0	0.0	0.0
Terminalia bellerica	0.0	0.0	0.0	0.0	0.0	0.0	10.0	1.4	10.9	0.0	0.0	0.0
Euphoria longana	6.0	0.4	7.1	10.0	0.5	6.4	6.0	0.3	5.0	13.0	0.5	9.8
Zizyphus xylopyrus	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	2.5	0.0	0.0	0.0
Gardenia gummifera	0.0	0.0	0.0	10.0	0.2	2.7	10.0	0.3	7.0	6.0	1.3	6.0
Gymnosporia montana	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	2.2	0.0	0.0	0.0
Glochidion ellipticum	10.0	0.1	5.8	3.0	0.1	2.5	6.0	0.1	4.3	0.0	0.0	0.0
Mangifera indica	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.3	6.5	3.0	0.6	3.9
Olea dioica	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.4	3.2	0.0	0.0	0.0
Mesua ferrea	13.0	1.9	16.6	3.0	0.1	2.3	16.0	0.9	12.2	0.0	0.0	0.0
Olax imbricata	0.0	0.0	0.0	6.0	0.2	4.8	13.0	0.4	6.0	0.0	0.0	0.0
Calophyllum elatum	10.0	1.1	12.8	3.0	1.1	5.1	6.0	0.4	5.4	10.0	0.3	6.8
Evodia roxburghii	0.0	0.0	0.0	3.0	0.2	2.6	3.0	0.1	2.3	0.0	0.0	0.0
Vitex altissima	3.0	0.3	4.1	10.0	0.6	5.9	6.0	0.1	4.4	3.0	0.8	4.2
Kingiodendron pinnatum	0.0	0.0	0.0	0.0	0.0	0.0	13.0	1.2	12.1	6.0	0.2	5.6
Artocarpus hirsutus	3.0	1.6	8.5	13.0	2.3	13.4	16.0	1.4	13.6	6.0	0.9	7.2
Holigarna grahamii	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	3.0	0.0	0.0	0.0
Palaguium ellipticum	3.0	0.1	3.1	3.0	0.3	2.8	13.0	0.5	8.6	0.0	0.0	0.0
Dipterocarpus indicus	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.7	9.2	13.0	0.8	6.7
Myristica magnifica	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.8	9.0	0.0	0.0	0.0
Garcinia tinctoria	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.3	2.9	0.0	0.0	0.0
Holigarna caustica	3.0	0.1	3.3	3.0	1.8	2.7	3.0	0.3	2.8	0.0	0.0	0.0
Hopea parviflora	0.0	0.0	0.0	6.0	1.1	7.3	3.0	0.3	0.1	0.0	0.0	0.0
Garcinia morella	13.0	0.9	13.0	10.0	1.5	10.4	3.0	0.1	2.5	0.0	0.0	0.0
Ficus mysorensis	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.4	3.2	0.0	0.0	0.0
Dryptes alata	3.0	1.1	6.8	10.0	2.2	13.8	3.0	0.1	2.3	13.0	2.2	14.9
Eugenia caryophyllus	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.4	3.3	0.0	0.0	0.0
Dillenia pentagyna	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1	2.3	0.0	0.0	0.0
Dalbergia latifolia	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.3	2.8	0.0	0.0	0.0
Ougeinia dalbergoides	22.0	1.1	14.1	0.0	0.0	0.0	3.0	0.7	4.5	0.0	0.0	0.0
Lagerstroemia lanceolata	3.0	1.6	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syzgyium sp.	3.0	0.4	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spondias pinnata	10.0	1.7	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Litsea floribunda	3.0	0.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.7	6.7
Michelia sp.	6.0	0.1	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pecia macrantha	6.0	0.3	7.9	3.0	0.2	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Semicarpus anacardium	3.0	0.6	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anacardium occidentalis	3.0	0.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clousinea sp.	3.0	0.1	3.6	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.6	2.8
Elaeocarpus sp.	3.0	0.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	2.7
Holigarna arnottiana	3.0	1.3	8.8	3.0	1.5	8.9	0.0	0.0	0.0	0.0	0.0	0.0
Dryopteris oblongifolia	0.0	0.0	0.0	38.0	0.3	5.9	0.0	0.0	0.0	0.0	0.0	0.0

(*Contd*)

Table 4. (*Contd*)

	Tree layer											
	Site 1			Site 2			Site 3			Site 4		
Species	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI
Albizia procera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.7	4.5
Lagerstroemia parviflora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	1.3	5.2
Commiphora caudata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.4	4.3
Antiaris toxicaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.5	7.6
Tetrameles nudiflora	3.0	1.7	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scolopia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	2.7
Garcinia indica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	1.7	9.3
	263.0	29.0		438.0	41.8		375.0	29.5		394.0	39.3	

Den., Density; B.A., Basal area; IVI, Important value index.

when compared with the earlier reports. This may be ascribed to frequent shrub thinning and to annual ground fires, which were responsible for the mortality of young regenerants in several patches of these forests. The basal area values ranged from 29.02 to 41.78 $m^2 ha^{-1}$ in tree layer and 0.48 to 0.92 $m^2 ha^{-1}$ in shrub layer. The highest basal areas of tree and shrub layers were observed at site 2, followed by site 4. Basal area in these forests was lower in range compared to the basal area of 60–70 $m^2 ha^{-1}$ reported by Pascal[10] in evergreen forests of Western Ghats. However, the present estimates are comparable to the basal area range of 33.7–48.7 $m^2 ha^{-1}$ reported by Rai and Proctor[9] in four evergreen forests of Karnataka, India. The lower basal area resulted due to indiscriminate logging in certain patches, especially at sites 1 and 3. Besides, the lower amount of precipitation and poor site fertility might be responsible for the lower basal areas in these forests. However, the basal area distribution in tropical evergreen forests of Western Ghats reported in this study is comparable to the Puertorican wet evergreen and Sarawak rain forests of Asia. In Puertorican[31] and Sarawak[29] evergreen forests, the basal area ranged from 20 to 75 $m^2 ha^{-1}$ and 28 to 57 $m^2 ha^{-1}$ respectively.

At site 1, *Vateria indica*, *Myristica malabarica*, *Poeciloneuron indicum*, *Myristica ferrea* and *Ougeinia dalbergioides* recorded higher density and basal area compared to all other species (Table 4). Due to high density and basal area, these species have higher IVI. In the shrub layer, *Poeciloneuron indicum*, *Vateria indica* and *Myristica malabarica* recorded higher density and basal area. *Vateria indica*, *Myristica malabarica* and *Poeciloneuron indicum* associations were predominant plant communities in the tree layer and *Poeciloneuron indicum* and *Myristica malabarica* in the shrub layer, at site 1 (Tables 4 and 5).

Density, basal area and IVI were higher for *Myristica malabarica*, *Vateria indica* and *Eugenia gardneri* in the tree layer and *Myristica malabarica*, *Vateria indica* and *Dysoxylum malabaricum* in the shrub layer at site 2. At site 3, *Myristica malabarica* and *Hopea wightiana* recorded higher basal area and density. *Myristica malabarica*, *Vateria indica* and *Eugenia gardneri* in the tree layer, whereas *Myristica malbarica*, *Myristica ferrea* and *Eugenia gardneri* in the shrub layer exhibited higher IVI values at this site. At site 4, *Vateria indica*, *Myristica malabarica* and *Eugenia gardneri* had maximum basal area, density and IVI values in the tree layer, whereas it was higher for *Euphoria longana*, *Myristica malabarica* and *Dipterocarpus indicus* in the shrub layer (Tables 4 and 5).

Shannon index (H') values were higher in tree layer compared to shrub layer. It ranged from 2.01 to 3.7 in tree layer and 1.5 to 2.9 in shrub layer (Table 6). Among the four sites studied, H' was highest at site 2 for the tree layer and at site 1 for the shrub layer. The concentration of dominance (Simpson index) for tree and shrub layers was highest at sites 3 and 4. Species richness and equitability for the tree layer were higher in sites 2 and 1. In the shrub layer, these values were higher in sites 2 and 3 (Table 6). The species richness ranged from 7.2 to 16.3, while equitability varied from 1.3 to 2.4. Computed beta diversity (regional diversity) of the four sites was 2.01 for the Western Ghats forest ecosystem (Table 6). Results exhibit that these forests are ecologically rich in species diversity and complexity. These are in agreement with earlier reports[20,26]. The higher Shannon index compared to the Simpson's index indicates an inverse relationship between these two indices. However, the Shannon index values (2.01–3.7) were lower in range compared to the Silent Valley tropical rain forests (3.8–4.8). Pascal[10] reported Shannon index between 3.6 and 4.3 at different altitudes of the Western Ghats. The higher species concentration and lower diversity at sites 3 and 4 resulted from the dominance of *Myristica malabarica* at site 3 and *Vateria indica* at site 4. The species diversity is lost due

Table 5. Structure of tropical evergreen forests of Western Ghats

	Shrub layer											
	Site 1			Site 2			Site 3			Site 4		
Species	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI	Den. ha^{-1}	B.A. $m^2 ha^{-1}$	IVI
Vateria indica	44.0	0.1	26.8	35.0	0.1	48.2	13.0	0.0	12.6	10.0	0.0	15.2
Myristica malabarica	38.0	0.1	47.3	38.0	0.3	31.7	66.0	0.1	51.5	28.0	0.1	38.4
Poeciloneuron indicum	44.0	0.3	52.4	3.0	0.0	6.7	6.0	0.0	8.2	0.0	0.0	0.0
Euphoria longana	13.0	0.0	18.5	19.0	0.0	18.7	0.0	0.0	0.0	60.0	0.2	83.3
Dysoxylum malabaricum	13.0	0.0	22.4	38.0	0.0	28.4	3.0	0.0	3.7	60.0	0.0	6.4
Eugenia gardneri	0.0	0.0	0.0	19.0	0.1	24.5	25.0	0.0	14.2	6.0	0.0	18.5
Pterocarpus marsupium	3.0	0.0	3.8	35.0	0.0	25.4	10.0	0.0	11.9	0.0	0.0	0.0
Mesua ferrea	6.0	0.0	6.6	0.0	0.0	0.0	28.0	0.1	33.2	0.0	0.0	0.0
Clousinea dentate	3.0	0.0	3.7	3.0	0.0	6.3	0.0	0.0	0.0	3.0	0.0	9.5
Dipterocarpus indicus	0.0	0.0	0.0	16.0	0.0	16.3	6.0	0.0	6.9	13.0	0.1	20.4
Syzygium utilis	13.0	0.0	19.8	6.0	0.0	5.6	19.0	0.0	9.4	13.0	0.0	10.9
Olax imbricate	3.0	0.0	6.5	6.0	0.0	11.3	10.0	0.0	11.7	0.0	0.0	0.0
Hopea wightianum	10.0	0.0	12.6	0.0	0.0	0.0	19.0	0.0	11.8	0.0	0.0	0.0
Palaquium ellipticum	3.0	0.0	4.1	0.0	0.0	0.0	10.0	0.0	12.0	0.0	0.0	0.0
Mytragyna parviflora	3.0	0.0	4.3	0.0	0.0	0.0	6.0	0.0	8.1	0.0	0.0	0.0
Calophyllum elatum	6.0	0.0	8.3	0.0	0.0	0.0	3.0	0.0	4.2	0.0	0.0	0.0
Manilkara roxburghiana	0.0	0.0	0.0	3.0	0.0	6.3	10.0	0.0	13.1	3.0	0.0	6.3
Glochidion ellipticum	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	13.1	0.0	0.0	0.0
Diospyros ebenum	3.0	0.0	4.3	19.0	0.0	18.3	10.0	0.0	13.1	3.0	0.0	6.4
Syzygium cuminii	6.0	0.0	9.2	0.0	0.0	0.0	3.0	0.0	3.9	0.0	0.0	0.0
Garcinia morella	3.0	0.0	4.6	3.0	0.0	5.0	13.0	0.0	11.2	3.0	0.0	6.1
Elaeocarpus sp.	3.0	0.0	4.0	0.0	0.0	0.0	6.0	0.0	6.0	0.0	0.0	0.0
Myristica canaricus		0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.7	0.0	0.0	0.0
Gymnosporia montana	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	6.3	0.0	0.0	0.0
Canthium dioccum	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.3	0.0	0.0	0.0
Kingiodendron pinnatum	3.0	0.0	4.9	13.0	0.1	15.9	3.0	0.0	3.2	3.0	0.0	5.8
Toddalia asiatica	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.4	0.0	0.0	0.0
Carallia brachiata	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.4	0.0	0.0	0.0
Acrocarpus fraxinifolius	3.0	0.0	5.8	0.0	0.0	0.0	3.0	0.0	3.4	0.0	0.0	0.0
Amoma canarica	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	5.2	0.0	0.0	0.0
Gardenia gummifera	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	6.5	0.0	0.0	0.0
Dryptes alata	6.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	10.9
Litsea floribunda	3.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eugenia dalbergoides	3.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lophopetalum wighitianum	3.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Garcinia indica	3.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clerodendron sp.	0.0	0.0	0.0	3.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0
Xanthophyllum flavescens	0.0	0.0	0.0	3.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0
Gomphandra tetrandra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	23.1
Canthium parviflorum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.0	0.0	33.5
Clerodendrum speciosum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	5.3
Artocarpus hirsutus	0.0	0.0	0.0	10.0	0.0	8.6	0.0	0.0	0.0	0.0	0.0	0.0
	243.0	0.8		271.0	0.9		309.0	0.5		267.0	0.5	

Den., Density; B.A., Basal area; IVI, Important value index.

Table 6. Floristic diversity of tropical evergreen forests of Western Ghats

	Site 1		Site 2		Site 3		Site 4		
Index	Tree	Shrub	Tree	Shrub	Tree	Shrub	Tree	Shrub	Region
Shannon index	3.1	2.4	3.7	2.6	2.3	2.9	2.0	1.5	
Simpson's index	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	
Species richness	8.6	10.4	12.7	16.3	7.9	8.3	8.1	7.2	
Equitability	2.4	1.8	1.8	1.6	1.5	2.2	1.3	1.4	
Beta diversity									2.0

Table 7. Component-wise standing biomass (Mg ha^{-1}) and net primary production (NPP) (Mg ha^{-1} yr^{-1}) of trees, shrubs, herbs and total vegetation of evergreen forests of Western Ghats

Layer	Site 1		Site 2		Site 3		Site 4		Mean	
Trees	Biomass	NPP	Biomass	NPP	Biomass	NPP	Biomass	NPP	Biomass	NPP
Bole	234.3^c	6.1^c	262.2^b	6.2^b	219.3^d	4.1^d	316.0^a	6.5^a	258.0 ± 42.6	5.7 ± 1.1
Branch	144.2^c	3.9^c	162.8^b	3.9^b	128.9^d	2.6^d	168.1^a	4.1^a	150.5 ± 17.9	3.6 ± 0.7
Foliage	25.9^c	3.6^d	44.6^a	4.8^a	30.3^b	3.8^c	23.5^d	4.2^b	31.1 ± 9.5	4.1 ± 0.5
Root	24.8^b	2.0^c	26.8^a	2.3^a	19.0^d	1.1^d	20.9^c	2.1^b	22.9 ± 3.6	1.9 ± 0.5
Total	429.2^c	15.5^c	496.4^b	17.2^a	397.3^d	11.6^d	526.6^a	16.9^b	462.4 ± 59.5	15.3 ± 2.6
Shrubs										
Wood	32.1^b	0.9^c	49.2^a	1.2^a	24.0^d	0.7^d	24.5^c	1.1^b	32.5 ± 11.8	1.0 ± 0.2
Foliage	23.8^b	1.4^c	30.0^a	2.4^a	10.4^d	1.4^d	11.8^a	1.8^b	19.0 ± 9.5	1.7 ± 0.5
Root	5.4^b	0.4	7.1^a	0.6	3.6^d	0.6	3.7^c	0.5	5.0 ± 1.7	0.5 ± 0.1
Total	62.0^b	2.7^c	86.3^a	4.2^a	38.1^d	2.6^d	39.9^c	3.4^b	56.4 ± 22.6	3.2 ± 0.7
Herbs										
Foliage	0.1^c	0.1	0.2^a	0.2	0.1^b	0.1	0.1^b	0.1	0.1 ± 0.05	0.1 ± 0.05
Root	0.3^c	0.3^b	0.7^a	0.7^a	0.5^b	0.5^b	0.5^b	0.5^b	0.5 ± 0.16	0.5 ± 0.16
Total	0.4^c	0.4^c	0.9^a	0.9^a	0.6^b	0.6^b	0.7^b	0.7^b	0.7 ± 0.21	0.7 ± 0.21
Litter (Standing/litter fall)	3.5^d	3.7^d	4.0^b	5.0^a	3.8^c	3.9^c	4.2^a	4.5^b	3.7 ± 0.30	4.3 ± 0.59
Total vegetation	491.2^c	22.4^c	587.7^a	27.7^a	439.8^d	18.8^d	571.3^b	25.8^b	523.6 ± 69.4	23.7 ± 3.9

Figures followed by same superscript (a, b, c, d) within a row did not differ significantly at $P \leq 0.05$.

to indiscriminate logging in these areas and poor site conditions. Sites 1 and 2 had higher H' compared to sites 3 and 4. This may be due to the microclimate and topographic effects which have direct impact on the spatial diversity of vegetation. In the shrub layer, H' values were lower compared to the tree layer, indicating poor shrub diversity. Moreover, higher concentration of dominance was present in a few individuals only. This may be due to sharing of large portion of resources by a few species in the shrub layer (understorey). This is in conformity with the findings of Singh and Singh[32] in the dry tropical forests, where only a few species were dominant in the shrub layer.

Plant biomass in the tree layers of different sites ranged from 397 to 527 Mg ha^{-1} (Table 7). Statistical analysis showed a significant variation among the sites for aboveground ($P \leq 0.05$), belowground ($P \leq 0.001$) and total biomass ($P \leq 0.05$) in the tree and shrub layers. The herbaceous biomass did not vary among the sites. In the tree layer, 95% of the total biomass was from above ground. On an average, 56% of the biomass was accumulated in the main stem or bole, 33% in the branch, 6.7% in the foliage and 5.1% in the roots. The order of decrease was stem < branch < foliage < root. The shrub biomass ranged from 38.1 to 86.3 Mg ha^{-1}. Of the total shrub biomass, wood (stem + branches), foliage and root components contributed 57.5%, 33.7% and 8.8% respectively. Herbaceous biomass ranged from 0.4 to 0.9 Mg ha^{-1} and litter (standing) from 3.5 to 4.2 Mg ha^{-1}. Total standing biomass of vegetation in the tropical evergreen forests of the study area ranged from 439.8 to 587.7 Mg ha^{-1} with a mean biomass of 523.6 Mg ha^{-1} (Table 7). Trees and shrubs accounted for 88.4% and 10.8% biomass, whereas herbs and litter contributed to only 0.8% of the total standing biomass. The biomass estimates of the present study are within the range and comparable to the standing biomass of other tropical forests (Table 8). Proctor *et al.*[29] estimated 434–669 Mg ha^{-1} biomass of the tropical evergreen forests of Sarawak. The lower belowground biomass (5%) in the present study, compared to the tropical evergreen forests, where it was 15–20% of the total biomass[33–37] is ascribed to non-accounting of fine root biomass, which may be 2–3 times or even higher than the coarse root biomass as evidenced in several studies[31,32,36–39]. However, the fine root biomass estimates were not made in the present study. The higher biomass at sites 2 and 4, compared to other two sites, is ascribed to higher tree density and basal area in these sites.

Litterfall is an important indicator of primary production and recycling processes. In the present study, it ranged from 3.9 to 5.2 Mg ha^{-1} yr^{-1} with a mean of 4.5 Mg ha^{-1} yr^{-1} (Table 9). Among the different components, leaves contributed 83.8% of the litterfall, followed by wood (12.3%) and herbs (4%). Analysis of variance showed significant differences in total litter production ($P \leq 0.05$) and leaf litter ($P \leq 0.05$). However, no significant differences were observed between wood and herbaceous litter. Quantity of litterfall was low compared to that reported by Dantas and Philipson[40], where they observed 8.1 Mg ha^{-1} yr^{-1} litterfall for a primary forest and 5.1 Mg ha^{-1} yr^{-1} for a

Table 8. Comparative account of biomass of certain tropical forests of the world

Forests	Location	Standing biomass (Mg ha^{-1})		Total biomass (Mg ha^{-1})
		Above ground	Below ground	
Tropical lower montane rain[44]	New Guinea	310	39	349
Tropical wet[45]	Cambodia	322	60	382
Tropical wet[31]	Global pattern	213–1173	11–135	269–1186
Tropical rain[29]	Sarawak	–	–	210–650
Tropical rain[9]	India	420–649	14–20	434–669
Tropical rain[46]	Thailand	295–371	31–33	326–404
Tropical rain[51]	Ghana	233	54	287
Tropical montane wet[52]	Venezuela	347	73	420
Tropical moist[53]	Global	326	55	381
Tropical moist[54]	Brazil	316	11	327
Tropical moist[55]	Ivory Coast	243	48	291
Tropical dry deciduous[32]	India	42–78	9–16	53–94
Eucalypt stands[24]	India	–	–	7.68–126.7
Poplar stands[25]	India	70–143	19–34	89–176
Tropical evergreen (Present study)	Western Ghats (India)	416–552.9	17–35	439–587

Table 9. Annual litterfall (Mg ha^{-1} yr^{-1}) in tropical evergreen forests of Western Ghats, India

Component	Site 1	Site 2	Site 3	Site 4	Mean
Leaf	3.3^d	4.3^a	3.4^c	3.9^b	3.7 ± 0.46
Wood	0.5^d	0.7^a	0.5^c	0.6^b	0.6 ± 0.10
Herb	0.3^c	0.7^a	0.5^b	0.5^b	0.5 ± 0.16
Total	4.1^d	5.7^a	4.4^c	5.1^b	4.8 ± 0.72
Turnover rate k/yr	0.9	1.0	0.9	0.9	0.9 ± 0.05
Turnover time	1.1	1.1	1.1	1.1	1.1 ± 0.01

Figures followed by same superscript (a, b, c, d) within a row did not differ significantly (at $P \leq 0.05$) according Duncan's multiple range test.

secondary forest of Amazonian terra firme. Proctor *et al.*[29] reported litterfall in the range of 3–10 Mg ha^{-1} yr^{-1} for a variety of tropical forests. Richards[41] reported a higher litterfall of 8.8 and 5.8 Mg ha^{-1} yr^{-1} for tropical low lands and mixed rain forests respectively. The present litterfall estimates are slightly higher in range compared to those estimated by Rai and Proctor[9], where they ranged between 3.4 and 4.2 Mg ha^{-1} yr^{-1} in tropical evergreen forests of Western Ghats. Turnover rate (k) was calculated following Jenny *et al.*[42], who proposed ($k = A/(A + F)$) equation, where A is the annual litterfall and F the amount of the litter at a steady state. Turnover time (t) is the reciprocal of turnover rate and is expressed as $t = 1/k$. In the present study, A is the litterfall measured in litter traps plus aboveground herbaceous litter and F is the lowest value of litter of standing crop on the forest floor within the annual cycle. The turnover rate (k) ranged from 0.92 to 0.96 yr^{-1} and the turnover time was 1.04 and 1.08 years, which is comparable to the other tropical evergreen forests[40,43].

Total net production was highest in site 2 followed by sites 4 and 1 (Table 7). It varied from 18.8 to 27.7 Mg ha^{-1} yr^{-1} with a mean net primary productivity (NPP) of the tropical evergreen forests as 23.7 Mg ha^{-1} yr^{-1}. Among the different vegetation layers, tree layer contributed maximum NPP in all the four sites studied, followed by shrub and herbaceous layers. The contribution of aboveground production (stem, branches and foliage in all the layers) was significantly higher than the belowground root production. The contribution of NPP was in the order: stem < branch < root < leaf. Herbaceous layer productivity was low and ranged between 0.2 and 0.6 Mg ha^{-1} yr^{-1}. Analysis of variance indicated significant differences in NPP for aboveground ($P \leq 0.05$), belowground ($P \leq 0.01$) and total ($P \leq 0.05$) production. However, no significant difference was observed in shrub and herbaceous layer productivity. Average net productivity (Table 7) revealed that biomass accumulated in the tree layer was 65%, in the shrub layer 14% and in the herbaceous layer 2.7% only. The litter production from all these layers accounted for 19.1% of the total NPP. The aboveground productivity was nearly five times higher (83%) than the belowground productivity. The NPP in these forests was lower in range compared to Thailand's rain forests[44], which was estimated as 28.6 Mg ha^{-1} yr^{-1}. Murphy and Lugo[31] estimated 13–28 Mg ha^{-1} yr^{-1} for different tropical evergreen forests of the world. NPP of these forests are within the range and comparable with the estimates made

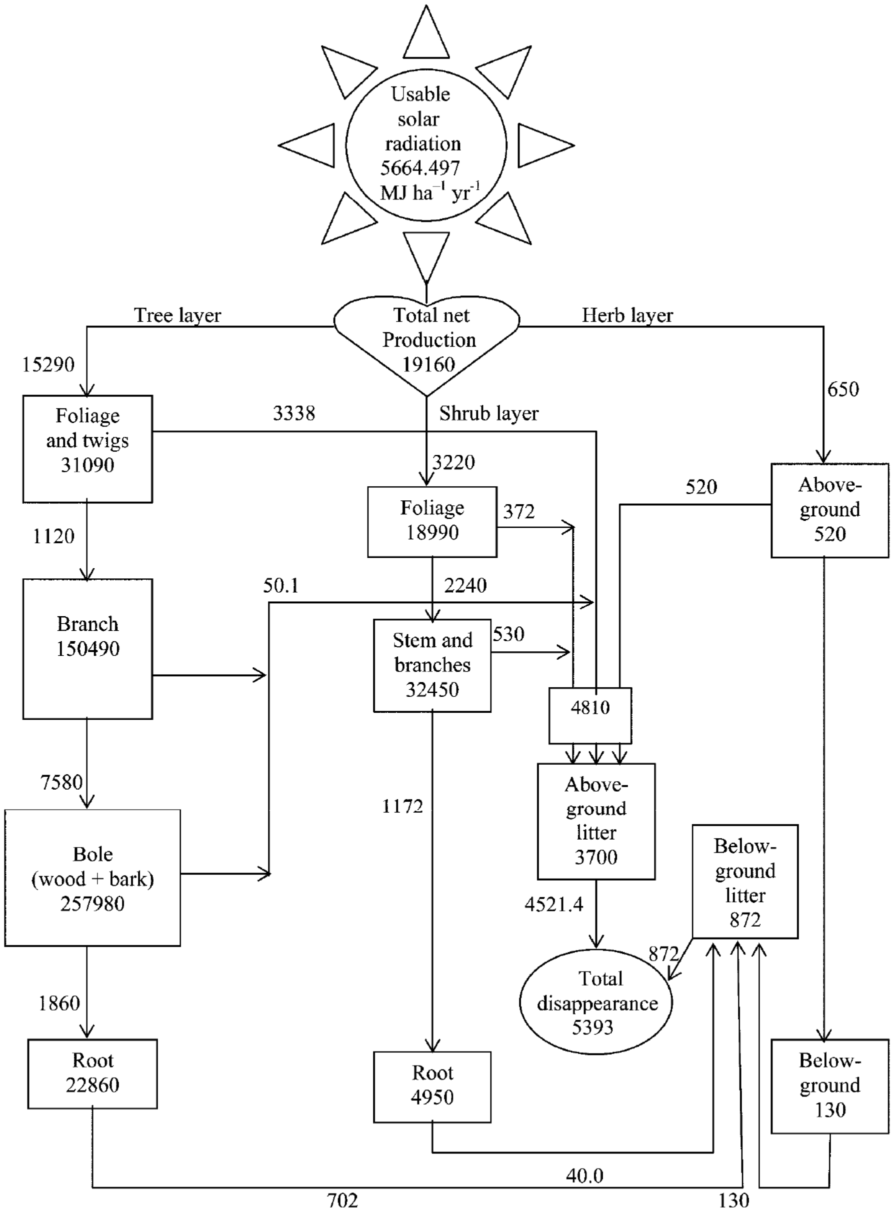

Figure 2. Compartment model for dry matter distribution in tropical ever green forest of Western Ghats. Rectangles represent compartments for standing crop of dry matter, arrows represent net flux rate. Circular, leaf and oval shaped enclosures represent the total annual values of photosynthetically active radiation (MJ ha^{-1} yr^{-1}), total net production (kg ha^{-1} yr^{-1}). Compartment values are in kg ha^{-1} and turnover rates are in kg ha^{-1} yr^{-1}.

by various workers for different tropical forests (Table 7). In the present study, the net productivity of roots was comparatively lower than that reported earlier[32,45]. This is because in the present study only the coarse root productivity was accounted. NPP in site 2 was comparatively higher than all other three sites, which is attributed to rapid increment in diameter and height of trees and shrubs. The luxuriant ground vegetation also resulted in higher production of herbaceous and shrub layers in the site. Favourable microclimate (high rainfall and radiation), higher soil fertility and minimum biotic interferences were the other reasons attributed to higher NPP at site 2.

A compartment model of dry matter transfer is depicted in Figure 2. The mean annual solar radiation was 5664 MJ ha^{-1} yr^{-1}. Of this, 47% was photosynthetically active radiation incident on the forest vegetation. The total net production of vegetation was 19,160 kg ha^{-1} yr^{-1}, of which the tree layer accounted 79.8%, the shrub 16.8% and the herbaceous layers 3.4%. In the tree layer, about 26.7% of net production (NPP) was allocated to leaves and 23.7% to branches, 37.4% to stem and 12.2% to roots. Similarly in the shrub layer, the foliage accounted for 30.4%, aerial woody component (stem + branches) accumulated 53.1% and roots 16.5% of the productivity.

In the herb layer 80% of the biomass accumulated in above ground parts and the remaining 20% in the roots.

The restitution of biomass through litter formation was 4810 kg ha^{-1} yr^{-1}. Of the total litterfall from tree layer, 87.9% constituted leaf litter and remaining 12.1% as wood litter. The biomass restitution in terms of dry matter is equals 31.5% of the total annual production of trees and 25.1% of the total vegetation. The mean standing litter crop on the forest floor (tree + shrub + herbs) was 4160 kg ha^{-1}. Decomposition of the litter at the soil surface, given by the turnover rate, was 5393 kg ha^{-1} yr^{-1}. This amounts to 96% of the total litterfall. At the end of the annual cycle, only about 271.5 kg ha^{-1} yr^{-1} remained and was carried over to the next year. Mortality of main roots in the tree and shrub layers was negligible in actively growing plants. Ogino[46] assumed that the fine root mortality was equivalent to 1/5th of the leaf litter. We followed this assumption as there were practical difficulties in fine root estimation.

Conclusion

The study indicated that the tropical evergreen ecosystems are dynamic in nature in terms of species diversity and productivity. Brahmagiri (site 2) and Kadmakal (site 4) ranges of Western Ghats were minimally disturbed, as the rate of biomass production and turnover was satisfactory and comparable to other tropical evergreen forests of the world. However, the Pattighat (site 1) and Padnailkannad (site 3) ranges were severely disturbed by fires and biotic stresses that affected the structure, diversity and biomass. In recent years, the mining of limestone in few patches of Kadamkal (site 4) ranges impeded the regeneration of natural vegetation. Besides, the monoculture plantations of *Albizia procera*, *Lagerstroemia parviflora*, *Artocarpus hirsutus* and *Vitex altissima* done as compensatory forestry affected the diversity of evergreen forests at this site. If the biotic interferences and fires are not controlled in sites 1, 3 and 4, these will be invaded by lesser important species like *Macaranga peltata*, *Tetrameles naudiflora*, *Helictres ixora*, *Olea dioca*, etc. and form secondary forests. Recently, Panigrahy *et al.*[47] have also reported the decrease in the area of dense forest and increase in open forest and scrub lands as an indicator of pressure on the core forests in the Western Ghats. Functional ecology of plant communities is often not a part of conservation initiatives, which are mostly based on numerical diversity, levels of community endemism and rates of habitat destruction[6,48,49]. The study recommends adoption of intensive conservation practices in disturbed patches to restore rich diversity and productivity of fragile, tropical evergreen forests of the Western Ghats. The study also showed that overall the system accumulated biomass and there is a possibility to attain the climax stage if the biotic stresses are reduced over a long period. To improve the understanding of ecosystem functions and processes to develop a holistic description of landscape, both intensive studies on small areas and assessment of much larger areas are required[50]. In Indian conditions, the forest cover is below 21% and much of it is under anthropogenic pressure/stress. In such conditions, a strategy is required to conserve whatever remains and restore areas where it is possible, rather than spending time and resources on selecting new biodiversity rich areas.

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