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Biodiversity Inventory as a Tool to Determine Forest Degradation: a Case Study from Tropical Forests of Bodamalai, Eastern Ghats, India

L. ARUL PRAGASAN AND N. PARTHASARATHY
Department of Ecology and Environmental Sciences, Pondicherry University, Puducherry 605 014, India
Email: parthapu@yahoo.com

ABSTRACT

This study aims to assess the status of forest degradation through inventory of tree species in the tropical forests of Bodamalai, Indian Eastern Ghats. The Bodamalai complex was divided into ten 6.25 km x 6.25 km grids. Within each grid a 0.5 ha transect (5 m x 1 km) was inventoried for tree diversity. A total of 64 tree species (≥ 30 cm girth at breast height) representing 50 genera and 32 families were recorded from the total 5 ha area inventoried. The stand density, basal area and AGB for the total 5 ha area were 1449 stems, 27.72 m^2 and 315.91 Mg, respectively. A positive correlation was obtained between altitude and stand density, species richness, basal area and AGB, and also with density of evergreen species. While a negative correlation was obtained between altitude and the density of dominant species *Euphorbia antiquorum* (one of the indicator species of scrub/ degraded forests). This reveals that tropical forests of Bodamalai located at low altitudes are prone to high degradation. Although, Bodamalai is included under reserve forest category, the human population has unlimited and unspecified right of firewood collection, felling, lopping and herding cattle for grazing, browsing, etc. Further, illegal extraction of *Santalum album* (sandal wood), one of the valuable bioresources is also witnessed. We recommend the following for developing the degraded forest land of Bodamalai: (i) to create awareness on forest degradation among the local people, (ii) planting some important indigenous trees and (iii) to organize a village committee for maintenance of afforested landscape.

Key Words: Tree Diversity, Forest Stand Structure, Above-ground Biomass, Topography, Forest Land Degradation, Bodamalai; Eastern Ghats

INTRODUCTION

Tropical dry forests are the most threatened tropical terrestrial ecosystems (Vieira and Scariot 2006), due to increasing rates of deforestation or clear cutting during the past three or more decades (Lambin et al. 2003; Asner et al. 2005). Populations of naturally growing woody species valued for their contribution to human livelihoods are threatened with extinction. Most at risk are those existing in human inhabited areas outside protected areas that are subjected to high population pressure and to a variety of land use demands (Tabuti 2007). Habitat fragmentation occurs when a continuous habitat is subdivided as a result of either human activities (e.g., agricultural clearing, timber harvest) or natural events such as fires and hurricanes (Saunders et al. 1991). Habitat loss and the resulting fragmentation are two of the major factors contributing to the decline of several biological populations. Some species or populations at risk are dependent on the existence and extent of specific habitats, and the loss of these habitats can directly or indirectly impact such species (Dale et al. 1999, Hernandez-Stefanoni 2005).

Degradation of forest land is difficult to quantify and monitor directly; it is often assessed indirectly through its consequences within the ecosystem such as change in floristic composition, species diversity, soil fertility and forest regeneration characteristics (Hitimana et al. 2004). According to Bourgeron (1983) and Hitimana et al. (2004), vertical structure of a forest includes its differentiation into layers between the ground and the canopy or in other words, they are stratified into vegetation layers of different heights. Horizontal structure of a forest is composed of diameter size distribution of tree species considered individually or as a community (Davis and Johnson 1987, Philip 1994, Hitimana et al. 2004). Estimation of above-ground (AGB) is also and essential aspect to study the effects of deforestation (Ketterings et al. 2001) and also a useful measure for comparing structural and functional attribute of forest ecosystems across a wide range of environmental conditions (Brown et al. 1999, Mani and Parthasarathy 2007). Diameter distributions are commonly used to assess the disturbance effect within forests (Hett and Loucks 1976, Denslow 1995) and to detect trends in regeneration patterns (Poorter et al. 1996). Moreover, tree density distribution across different classes indicates how well the growing forest is utilizing site resources. A few small-to-medium sized trees per hectare may imply that land is not being fully utilized by the tree crop (Hitimana et al. 2004).

Forests in India were cleared for huge hydroelectric projects, for setting up heavy industries, for urbanization and so on. In the late 1930s, 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 exists (Ledig 1992). Primary forests, 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 composing inferior species or their land use pattern changed (Parthasarathy 1999, Chittibabu and Parthasarathy 2000). The disappearance of tropical forests comes at a time when our knowledge on their structure and dynamics is woefully inadequate (Hubbell and Foster 1992). Biodiversity inventory as a tool for guiding conservation planning at a local scale is under-used, especially in tropical countries where technical capacity is often limited (Gordon and Newton 2006). Hence, this study was undertaken to assess the status of degradation by determining tree species richness, composition, stand structure, density, dispersion patterns and aboveground biomass (AGB) in the tropical forests of Bodamalai, which would be useful for better planning for its conservation.

Study Area

Bodamalai (11° 30'-11° 39' N Latitude, 78° 8'-78° 21' E Longitude) lies in the Eastern Ghats in the State of Tamil Nadu (Figure 1). It covers an area of 156 km^2, with altitude ranging from 300 m to 1155 m (above sea level). It 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.

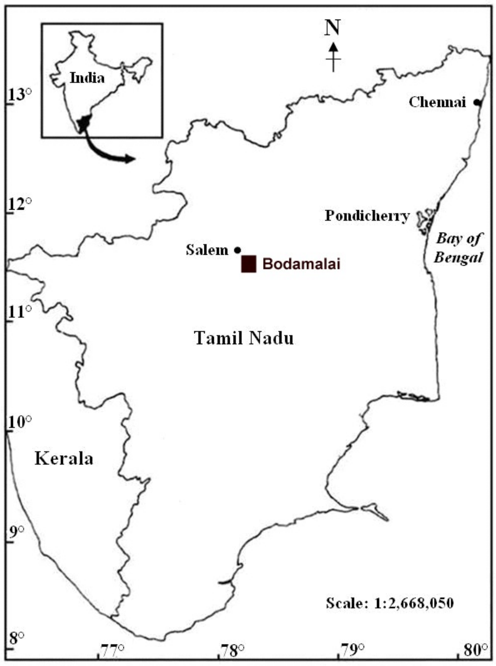

Figure 1. Map showing the location of Bodamalai

Climate

Climatological data of Salem (alt. 278 m; lat. and long. 11° 39' N and 78° 10' E), the nearest station to the study area, available for 2006-07 reveals a mean annual temperature of 28 °C and the annual rainfall 808 mm. The mean monthly temperature ranged from 26 °C during October-December to 31 °C in March-May. The study area receives bulk of the rainfall during the south-west (June to September) and the north-east monsoons (October to December). Rainfall was negligible during winter (January-February), while it was occasional during summer (March-May). The relative humidity ranged from 68% in May to 85% in October at 8:30 hr.

Vegetation

Bodamalai lie between the five major hill complexes of southern Eastern Ghats, namely, Kolli hills on the south, Pachaimalais on the south-east, Shervarayan on the north and Chitteri and Kalrayan hills on the north-east direction. The forests of Bodamalai harbour thorn to mixed deciduous forest, and they are 2- to 3-storeyed. Though the forests of Bodamalai fall under reserve forests category, the population has unlimited and unspecified rights of firewood collection, felling, lopping, herding cattle for grazing, browsing, etc. Further, encroachment of forest area for cultivation is evident.

FIELD METHODS

The Bodamalai forest area was divided into ten 6.25 km x 6.25 km grids. Within each grid a 0.5 ha transect (5 m x 1 km) was marked and further sub-divided into fifty 5 m x 20 m transects as workable units. All live trees ≥ 30 cm girth at breast height (gbh) were identified and their girth measured at 1.3 m from ground level. Regional floras (Gamble and Fischer 1915-1935, Matthew 1991) were used for identification of trees. Voucher specimens were collected and confirmed with the herbarium of our department and French Institute (IFP), Pondicherry and are deposited in the herbarium of Department of Ecology and Environmental Sciences, Pondicherry University.

Data Analysis

Statistical package, Biodiversity Professional (version 2) was used for determining diversity indices such as Shannon (H') and Simpson (D), Berger-Parker dominance index (d), and also for raising species-area curve, plotted with 50 numbers of randomization. The importance value index (IVI) was used to understand a species' share in the tree community (as per Cottom and Curtis 1956). IVI of a species is defined as the sum of its relative dominance, relative density and relative frequency. Above-ground live biomass was estimated using a linear equation Y = 11.27 + 6.03 (BA) + 1.83 (H), where 'Y' is biomass per tree in kg, 'BA' is basal area and 'H' is height of the tree (Murali et al. 2005, Mani and Parthasarathy 2007). The non-metric multidimensional scaling (NMS) ordination was performed based on the data of species richness, diversity index, stand density, basal area, and percent contribution of thorny and evergreen species; trees with dry fruit to stand density, using PC-ORD package, to detect likeness of the ten grids studied in the tropical forests of Bodamalai.

RESULTS

Species Richness and Diversity

A total of 64 tree species (≥30 cm gbh) representing 50 genera and 32 families were recorded from the ten 0.5 ha transects (totaling to 5 ha) in the tropical forests of Bodamalai, Indian Eastern Ghats (Table 1). Species richness was as low as 9 species per transect in grid 9 to 37 species in grid 3. In the 5 ha studied, Simpson's diversity index (D) was 0.06, indicating that only 6 species out of 100 taken at random were composed of different species and Shannon diversity index (H') was 1.4. Berger-Parker dominance index (d) was 0.16. Among the ten grids studied in Bodamalai, a positive correlation was obtained between Simpson's diversity index (D) and Berger-Parker dominance index (d) (r_s = 0.93, P < 0.05). Species-area curve showed a rapid increase in species number up to three hectares and thereafter it increased gradually, revealing the heterogeneity of species composition within the ten transects of Bodamalai (Figure 2). Out of 64 species recorded in the tropical forests of Bodamalai, 36 species are deciduous, 16 species are evergreen and 12 species are brevi-deciduous. Single factor ANOVA revealed that there was a significant difference in the composition of evergreen, brevi-deciduous and deciduous tree species in the ten grids ($F_{(2,27)}$ = 23.87, P <0.05). Contribution of non-thorny species to total species richness was greater (49 species, 77 %) in Bodamalai forests than the thorny species (15, 23 %).

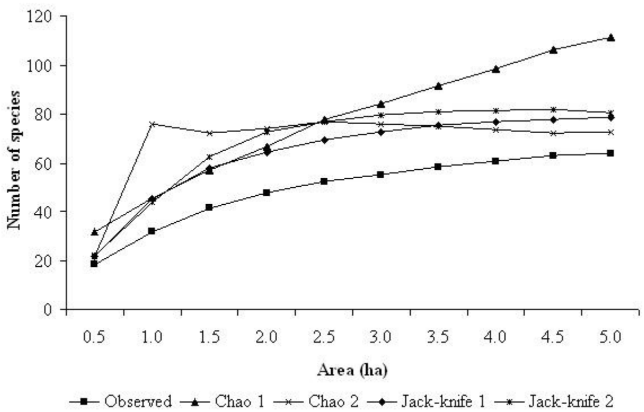

Figure 2. Species-area curve for the tropical forests of Bodamalai, Eastern Ghats, India

Table 1. Tree species inventory in the tropical forests of Bodamalais, southern Eastern Ghats, India

Variable	**Grid 1**	**Grid 2**	**Grid 3**	**Grid 4**	**Grid 5**	**Grid 6**	**Grid 7**	**Grid 8**	**Grid 9**	**Grid 10**	**Total**
Species richness	27	36	37	24	18	16	21	17	9	10	64
No. of genera	23	32	33	19	15	15	17	17	9	10	50
No. of families	18	24	23	15	13	13	14	13	7	9	32
Density (stems / 0.5 ha)	106	206	184	131	100	106	130	227	119	140	1449
Basal area (m^2 / 0.5 ha)	1.6	5.6	7.1	2.3	1.4	1.3	2.2	2.8	1.7	1.8	27.7
No. of multi-stemmed individuals	61	135	99	99	69	68	67	167	35	61	861
Maximum tree gbh (cm)	97.5	137.5	251.5	133	63.5	86.5	243.5	94.5	88	81.5	251.5
Mean tree gbh (cm)	36.6	45.6	52.5	36.2	36.3	34.2	37.1	35.4	39.6	36.7	39.8
Diversity indices											
(i) Shannon H' Log_{10}	1.1	1.4	1.3	1.2	1.0	1.0	1.0	1.1	0.8	0.7	1.4
(ii) Simpson's Diversity (D)	0.13	0.06	0.08	0.07	0.19	0.17	0.13	0.10	0.18	0.24	0.06
Berger-Parker Dominance (d)	0.29	0.12	0.17	0.13	0.41	0.37	0.27	0.16	0.29	0.39	0.16
Altitude (m, above mean sea level)		433	617	635	456	372	377	490	591	499	433

Family Richness

Out of the 32 families recorded in Bodamalai, the most speciose families include Euphorbiaceae and Mimosaceae with 6 species each, followed by Moraceae (5 species), Ebenaceae (4), and Rutaceae and Caesalpiniaceae (3 each). Sixteen families were represented by single species. The top ten families accounted for 58 % of the total species.

Forest Stand Density

A total of 1449 trees (290 stems ha^{-1}) were enumerated within the 5 ha sampled in the tropical forests of Bodamalai. Tree density of the 64 species enumerated in the 5 ha area showed a wide variation (Table 2) ranging from 1 (for 11 species) to 237 stems for *Euphorbia antiquorum*, a lower canopy tree species. Thirty-three species, i.e. 52 % of the total species recorded in Bodamalai, showed aggregated patterns of species distribution and the rest of the species showed random pattern (Figure 3).

Based on their density, species were grouped into five categories viz.:

(1) Predominant species (those with density (f) > 100 individuals: 2 species, *Euphorbia antiquorum* and *Albizia amara* belonged to this category and contributed 28 % and 24 % of the total stand density and basal area respectively.

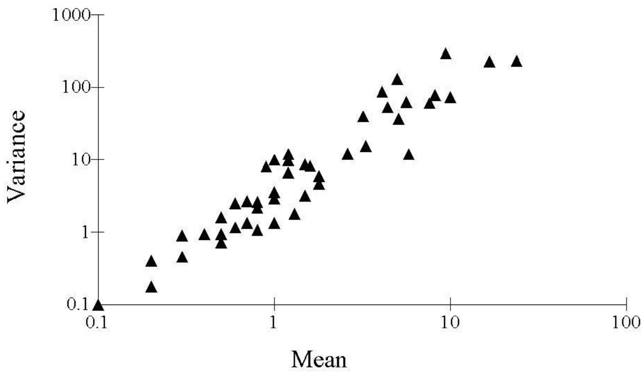

Figure 3. Patterns of species distribution based on the abundance of tree species in Bodamalai

(2) Dominant species (f = 51 to 100): 7 species fall under this category, contributed 36 % and 30 % of the stand density and basal area respectively.

(3) Common species (f = 26 to 50): 6 species fall in this category, contributed 16 % and 13 % of the stand density and basal area respectively.

(4) Rare species (f = 2 to 25): 38 species belonged to this category.

(5) Very rare species (f < 2): 11 species belonged to this category.

Contribution of deciduous species to stand density was maximum 78 %, followed by evergreen (16 %) and brevi-deciduous species (6 %). Single factor ANOVA revealed that there was a significant difference between the plant physiognomic groups in contributing to stand density across the ten grids ($F_{(2, 27)} = 79.82$, $P < 0.05$). Non-thorny species dominated the stand density (62 %) of the tropical forests of Bodamalai. In the ten grids studied, contribution of thorny and non-thorny species did not vary significantly (T-test: $t_{(1, 9)} = -1.47$, $P > 0.05$). Of the 7 fruit types recognized (from 64 species recorded in the tropical forests of Bodamalai), the density of tree species with capsule fruit was high (29 %), followed by, pod, berry, drupe, follicle, samara and nut.

Forest Stand Structure

The total stand basal area was 27.72 m^2 for 5 ha and the mean was 2.8 m^2 per 0.5 ha transect. Out of the ten grids only grids 2 and 3 (relatively located at high altitudes) had basal area greater than the mean stand basal area. The middle canopy tree species *Albizia amara* (Mimosaceae) dominated the stand basal area (3.8 m^2 per 5 ha), followed by *Euphorbia antiquorum* (2.8 m^2 per 5 ha), *Strychnos potatorum* (1.9 m^2 per 5 ha), *Ficus benghalensis*, *Cleistanthus collinus* and *Acacia chundra*. Just 15 species contributed 64 % of the total importance value index (IVI) of the stand. *Euphorbia antiquorum* and *Albizia amara* contributed maximum to IVI followed by *Strychnos potatorum*, *Acacia chundra*, *Chloroxylon swietenia* and *Cleistanthus collins* (Figure 4). Based on size class distribution of trees five girth class were recognized. The lowest girth class (30-60 cm) formed 91 % of the forest stand, and 60 % of the total basal area (Figure 5). Also, maximum number of 58 species was represented in the lowest girth class. Vertically, the stand structure was classified into three canopy layers viz., upper, middle and lower canopy. Contribution of middle canopy tree species to total species richness, density and basal area was maximum in the tropical forests of Bodamalai (Figure 6).

Above-ground Biomass (AGB)

The total AGB of Bodamalai forests was 315.91 Mg per 5 ha. It ranged from a high value of 50.02 Mg per 0.5 ha (at grid 2) to 20.25 Mg per 0.5 ha (at grid 1), with a mean value of 31.6 Mg per 0.5 ha per transect. In the tropical forests of Bodamalai, *Euphorbia antiquorum* (Euphorbiaceae) dominated the forest AGB (42.5 Mg per 5 ha), followed by *Albizia amara* (39.5 Mg per 5 ha), *Chloroxylon swietenia*, *Acacia chundra* and

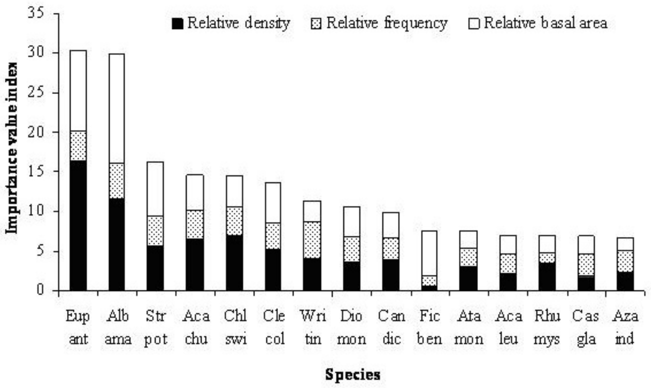

Figure 4. Species importance value index of top 15 tree species based on their relative contribution to density, basal area, frequency in the tropical forests of Bodamalai (for full names of tree species refer Table 2)

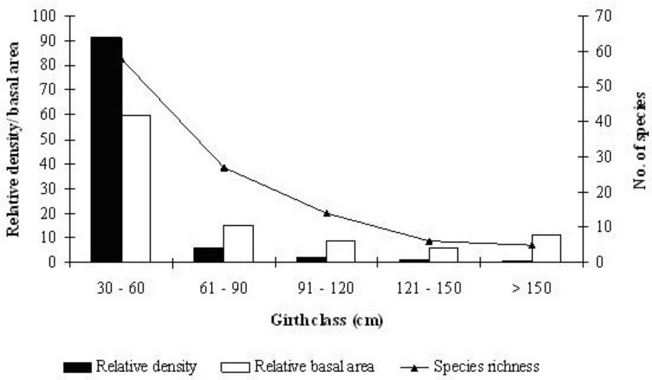

Figure 5. Contribution of tree species to stand structure, basal area and species richness based on girth class distribution in the tropical forests of Bodamalai, Eastern Ghats

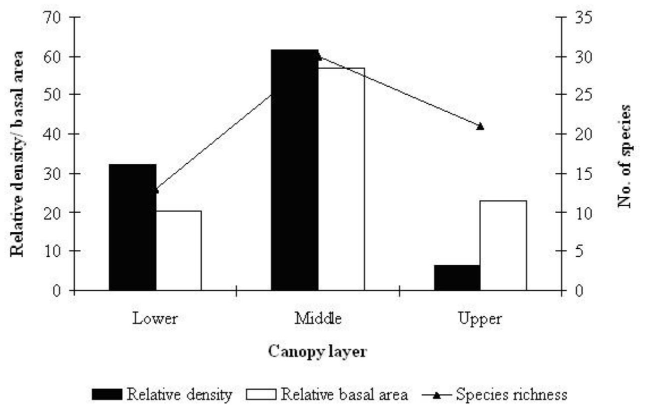

Figure 6. Contribution of tree species to stand structure, basal area and species richness based on canopy layer in the tropical forests of Bodamalai, Eastern Ghats

Table 2. List of tree species (≥30 cm gbh) enumerated in the tropical forests of Bodamalais, Eastern Ghats (T-Thorny, NT-Non-thorny, Canopy: U-Upper, M-Middle, L-Lower, PG-Physiognomy, EG-Evergreen, BD-Brevi-deciduous, D-Deciduous; FT-Fruit type, Ac- Achene, Be-Berry, Ca-Capsule, Dr-Drupe, Fo-Follicle, Nu-Nut, Po-Pod, Sa-Samara; DM-Dispersal mode, Au-Autochory, A-Anemochory, Z-Zoochory; DN-Density, stems (5 ha)$^{-1}$, BA-Basal area, m^2 (5 ha)$^{-1}$, IVI-Importance value index, AGB-Aboveground biomass, Mg (5 ha)$^{-1}$

S N.	Species	Family	T/NT	L/M/U	PG	FT	DM	DN	BA	IVI	AGB
1	*Euphorbia antiquorum* L.	Euphorbiaceae	T	L	D	Ca	Au	237	2.86	30	42.48
2	*Albizia amara* Boiv.	Mimosaceae	NT	M	D	Po	Au	167	3.81	30	39.52
3	*Chloroxylon swietenia* DC.	Flindersiaceae	NT	M	D	Ca	A	100	1.07	14	22.11
4	*Acacia chundra* Willd.	Mimosaceae	T	M	D	Po	Au	94	1.22	15	20.24
5	*Strychnos potatorum* L.f.	Loganiaceae	NT	M	D	Be	Z	82	1.89	16	19.23
6	*Cleistanthus collinus* Benth. & Hook.f.	Euphorbiaceae	NT	M	D	Ca	Z	76	1.43	14	17.79
7	*Wrightia tinctoria* R.Br.	Apocynaceae	NT	M	D	Fo	A	58	0.74	11	12.83
8	*Canthium dicoccum* Merr.	Rubiaceae	NT	M	EG	Dr	Z	56	0.87	9.8	12.78
9	*Diospyros montana* Roxb.	Ebenaceae	NT	M	D	Be	Z	51	1.04	11	11.48
10	*Rhus mysurensis* Heyne ex Wt & Arn.	Anacardiaceae	T	L	D	Dr	Z	50	0.55	6.8	9.00
11	*Atalantia monophylla* (L.) DC.	Rutaceae	T	L	EG	Be	Z	44	0.6	7.5	8.34
12	*Pleiospermium alatum* Swingle	Rutaceae	T	L	EG	Be	Z	41	0.62	6	7.76
13	*Azadirachta indica* A.Juss.	Meliaceae	NT	M	BD	Dr	Z	33	0.43	6.6	7.32
14	*Acacia leucophloea* Willd.	Mimosaceae	T	M	D	Po	Au	32	0.66	6.9	7.84
15	*Cassine glauca* (Rottb.) Kuntze	Celastraceae	NT	M	EG	Dr	Z	26	0.62	6.8	5.83
16	*Cordia domestica* Roth	Cordiaceae	NT	L	D	Dr	Z	18	0.21	4.3	3.98
17	*Erythroxylum monogynum* Roxb.	Erythroxylaceae	NT	L	D	Be	Z	18	0.21	4.3	3.36
18	*Acacia planifrons* Wight & Arn.	Mimosaceae	T	M	D	Po	Au	16	0.2	3.7	3.34
19	*Gardenia resinifera* Roth	Rubiaceae	NT	L	D	Be	Z	15	0.2	3.2	3.20
20	*Ziziphus mauritiana* Lam.	Rhamnaceae	T	M	D	Dr	Z	15	0.25	4.3	3.47
21	*Premna tomentosa* Roxb.	Verbenaceae	NT	M	D	Dr	Z	13	0.17	4.3	2.68
22	*Anogeissus latifolia* (Roxb.) Bedd.	Combretaceae	NT	U	D	Ac	Au	12	0.41	3.3	3.34
23	*Ixora pavetta* Benth.	Rubiaceae	NT	L	EG	Dr	Z	12	0.12	2.7	2.46
24	*Streblus asper* Lour.	Moraceae	NT	M	BD	Dr	Z	12	0.29	2.8	3.02
25	*Alangium salviifolium* (L.f.) Wang.	Alangiaceae	NT	U	D	Be	Z	10	0.11	2.5	2.11
26	*Commiphora caudata* Engl.	Burseraceae	NT	U	D	Dr	Z	10	0.54	4.5	2.40
27	*Ficus mollis* Willd.	Moraceae	NT	U	BD	Be	Z	10	0.72	5.6	2.81
28	*Santalum album* L.	Santalaceae	NT	M	EG	Dr	Z	10	0.09	1.5	2.08
29	*Dichrostachys cinerea* (L.) Wt & Arn.	Mimosaceae	T	L	D	Po	Au	9	0.09	1.4	1.81
30	*Bauhinia racemosa* Lam.	Caesalpiniaceae	NT	M	D	Po	Au	8	0.25	3.8	1.97
31	*Diospyros ferrea* (Willd.) Bakh. var. *buxifolia* (Rottb.) Bakh.	Ebenaceae	NT	L	EG	Be	Z	8	0.1	2.3	1.59
32	*Ficus benghalensis* L.	Moraceae	NT	U	BD	Be	Z	8	1.58	7.6	2.95
33	*Tamarindus indica* L.	Caesalpiniaceae	NT	U	BD	Po	Z	8	1.17	6.2	3.01
34	*Commiphora berryi* Engl.	Burseraceae	T	L	D	Dr	Z	7	0.08	2.2	1.29
35	*Diospyros ebenum* Koen.	Ebenaceae	NT	M	EG	Be	Z	7	0.58	4	1.89
36	*Diospyros melanoxylon* Roxb.	Ebenaceae	NT	M	D	Be	Z	7	0.21	2.2	1.80
37	*Flacourtia indica* Merr.	Flacourtiaceae	T	L	EG	Dr	Z	6	0.1	2.2	1.33
38	*Memecylon edule* Roxb.	Melastomataceae	NT	U	EG	Be	Z	6	0.09	1.7	1.34
39	*Borassus flabellifer* L.	Arecaceae	NT	U	EG	Dr	Z	5	0.29	2.8	1.39
40	*Phyllanthus polyphyllus* Willd.	Euphorbiaceae	NT	M	BD	Ca	Au	5	0.06	1.5	1.02

Table 2. Continued.

S N.	Species	Family	T/NT	L/M/U	PG	FT	DM	DN	BA	IVI	AGB
41	*Sapindus emarginatus* Vahl.	Sapindaceae	NT	M	D	Dr	Z	5	0.08	2	1.11
42	*Drypetes sepiaria* Pax & K.Hoffm.	Euphorbiaceae	NT	M	EG	Dr	Z	4	0.08	1.5	0.84
43	*Ailanthus excelsa* Roxb.	Simaroubaceae	NT	U	D	Sa	Au	3	0.05	1.3	0.83
44	*Dalbergia paniculata* Roxb.	Papilionaceae	NT	U	BD	Sa	Au	3	0.13	1.6	0.93
45	*Euphorbia nivulia* Buch.-Ham.	Euphorbiaceae	T	M	D	Ca	Au	3	0.15	1.2	0.80
46	*Gyrocarpus asiaticus* Willd.	Hernandiaceae	NT	U	D	Dr	A	3	0.12	1.6	0.74
47	*Polyalthia cerasoides* (Roxb.) Hk.f. & Thom.	Annonaceae	NT	M	BD	Be	Z	3	0.02	1.2	0.68
48	*Albizia lebbeck* (L.) Benth.	Mimosaceae	NT	U	BD	Po	Au	2	0.07	1.3	0.54
49	*Allophylus serratus* Kurz	Sapindaceae	NT	L	EG	Be	Z	2	0.03	1.2	0.43
50	*Bambusa arundinacea* (Retz) Roxb.	Poaceae	NT	U	D	Nu	Au	2	0.02	0.7	0.67
51	*Cassia fistula* L.	Caesalpiniaceae	NT	M	D	Po	Z	2	0.02	1.1	0.47
52	*Celtis timorensis* Span.	Ulmaceae	NT	M	EG	Dr	Z	2	0.02	1.2	0.49
53	*Strychnos nux-vomica* L.	Loganiaceae	NT	U	D	Be	Z	2	0.03	0.7	0.47
54	*Drypetes roxburghii* (Wall.) Hurus	Euphorbiaceae	NT	U	EG	Dr	Z	1	0.02	0.6	0.21
55	*Ficus amplissima* Smith	Moraceae	NT	U	BD	Be	Z	1	0.07	0.8	0.35
56	*Ficus nervosa* Roth	Moraceae	NT	U	BD	Be	Z	1	0.06	0.7	0.17
57	*Firmiana colorata* (Roxb.) R.Br.	Sterculiaceae	NT	U	D	Fo	A	1	0.01	0.6	0.21
58	*Holoptelea integrifolia* Planch.	Ulmaceae	NT	M	D	Sa	A	1	0.01	0.6	0.23
59	*Naringi crenulata* (Roxb.) Nicol.	Rutaceae	T	M	D	Be	Z	1	0.01	0.6	0.18
60	*Pterocarpus marsupium* Roxb.	Papilionaceae	NT	U	BD	Sa	A	1	0.01	0.6	0.26
61	*Scolopia crenata* Clos	Flacourtiaceae	T	M	EG	Be	Z	1	0.02	0.6	0.24
62	*Spondias pinnata* Kurz	Anacardiaceae	NT	U	D	Dr	Z	1	0.13	1	0.40
63	*Vitex altissima* L.f.	Verbenaceae	NT	U	D	Dr	Z	1	0.02	0.6	0.25
64	*Ziziphus xylopyrus* Willd.	Rhamnaceae	T	L	D	Dr	Z	1	0.01	0.6	0.20
	Total							1449	27.72	300	315.91

Strychnos potatorum. Top 15 species contributed 77 % of total AGB. Among the five tree species size class recognized, the lowest (30-60 cm gbh) class contributed maximum (89 %) to the total above-ground biomass (Figure 7). Among the plant physiognomic groups, contribution of deciduous species to AGB was maximum (77 %), followed by evergreen (16 %) and brevi-deciduous (7 %). Non-thorny tree species accounted for greater AGB (207.59 Mg per 5 ha, 66 %) than the thorny species (108.32 Mg per 5 ha, 34 %).

Relationship Between Site Attributes and Vegetation Features

In the ten grids studied in Bodamalai forests, the soil and climate remain the same, and the topography and human disturbance varied considerably. At low altitude grids 1, 2 and 6, human disturbances such as felling of trees and cattle browsing was greater than the other seven grids. There was a strong positive relationship between altitude and above-ground biomass in the tropical forests of Bodamalai (Figure 8). A positive correlation was obtained between altitude with stand density (r_s = 0.89, P <0.05), species richness (r_s = 0.58, P <0.05), basal area (r_s = 0.86, P <0.05) and AGB (r_s = 0.93, P <0.05). It also showed a positive correlation with density of evergreen species ((r_s = 0.85, P <0.05). Further, the non-metric multi-dimensional scaling (NMS) ordination (performed using the data of species richness, diversity index, stand density, basal area, dominance index, and percent contribution of thorny and evergreen species; trees with dry fruit to stand density), separated grid 2 and grid 3 from the other grids (Figure 9). The grid 2 (altitude 617 m) and Grid 3 (altitude 635 m) are located in relatively higher

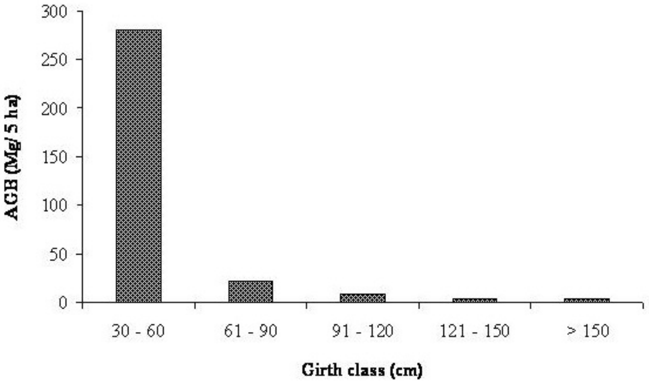

Figure 7. Production of Above ground biomass (AGB) by tree species classified into five girth classes in the tropical forests of Bodamalai, Eastern Ghats

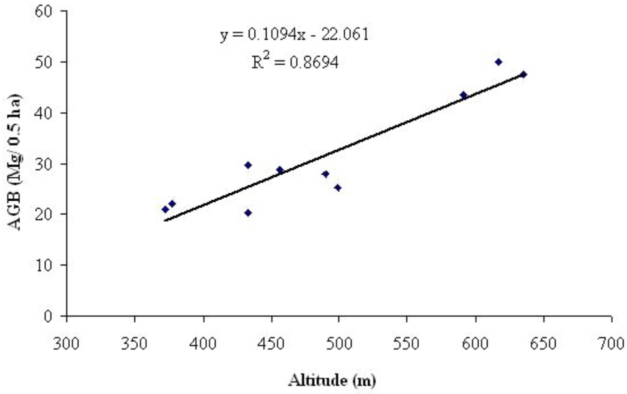

Figure 8. Relationship between altitude and aboveground biomass in the tropical forests of Bodamalai, Eastern Ghats

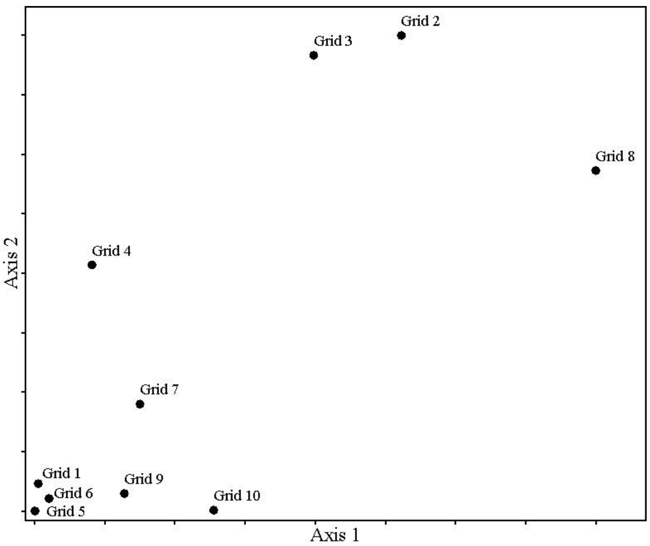

Figure 9. Non-metric multidimensional scaling (NMS) ordination of the ten grids based on species richness, Simpson's diversity index (D), stand density, basal area, Berger-Parker dominance index (d), and percent contribution of thorny and evergreen species; trees with dry fruits to stand density in the tropical forests of Bodamalai, Eastern Ghats

altitudes than the remaining eight grids. This shows that the tropical forests of Bodamalai at low altitudes (grids 1, 2 and 6) are prone to high degradation and they are mostly short-statured with greater thorny species density. Also, their stands dominated by *Euphorbia antiquorum*, contrastingly not even a single individual of it was represented in grid 2 and 3. The stand density of *Euphorbia antiquorum* was negatively correlated with altitude ((r_s = -0.68, P < 0.05) in the tropical forests of Bodamalai, concluding that it can be an indicator species to identify scrub or degraded forest in tropics.

DISCUSSION

Biodiversity of an area is related to a variety of factors such as topography, climate, soil and natural/ human disturbance. In the ten grids studied in Bodamalai forests, the soil and climate remain the same, and the topography and human disturbance varied considerably. Grids 2 and 3 located at relatively higher altitude harboured maximum number of species. The species richness of 64 species recorded in the 5 ha area sampled in Bodamalai, reflects its low diversity status. Although the species richness is low (from a total of 5 ha, area sampled) in Bodamalai, it is nearly equal to the 63 species recorded in a large-scale 50 ha permanent plot at Mudumalai, south India (Sukumar et al 1992), and it is well within the range reported for dry forests, 49 species (Sagar et al. 2003) to 204 species (Gillespie et al. 2000). While richness of woody species (≥ 30 cm gbh) across tropics, ranged from a low value of 20 species ha^{-1} in flooded Varzea forest of Rio Xingu, Brazil (Campbell et al. 1992) to a high value of 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994). A number of studies (Gentry 1988, Clinebell et al. 1995, Gillespie et al. 2000) have found that annual precipitation is directly correlated with species richness of plants along a gradient from dry to wet tropical forests. Interestingly, in Bodamalai, species richness varied in the ten grids studied, though the annual precipitation is similar. This reveals that precipitation is a poor predictor of plant diversity in the tropical forests of Bodamalai, and a similar trend was found within the tropical dry forest of Central America (Gillespie et al. 2000). There are a number of abiotic and biotic factors responsible for species richness (Gillespie et al. 2000). The degree of natural disturbance has often been cited as a critical factor in determining tropical forest species diversity (Connell 1978, Pickett and White 1965, Foster 1990). Anthropogenic disturbances, such as burning, cattle grazing, and wood collection, may also significantly lower plant species richness in tropical dry forests (Budowski 1966, Sabogal 1992, Swaine et al. 1990, Jayasingam and Vivekanantharaja 1994, Maass 1995). A few studies (Sabogal 1992, Murphy and Lugo 1986, Ribichich and Protomastro 1998) found that wood collection and logging lowers the species richness of fuelwood and timber species and favors stress tolerant plants and species that resprout after cutting.

In many areas where wood collection is intense, weedy lianas and vines tend to smother the tropical forest which further lowers species diversity (Savage 1992, Gentry 1995). The invasion of *Lantana camara*, and the abundance of *Pterolobium hexapetalum* were severe, and influences the regeneration of native plant species in the tropical forests at low altitudes of Bodamalai. The mean stand density of Bodamalai (290 stems ha^{-1}) falls within the range reported for tropical forests, 268 stems ha^{-1} at Vindhyan hills (Sagar et al. 2003) to 303 stems ha^{-1} at Mudumalai reserve forest (Sukumar et al. 1992). But it was less than the range reported for tropical deciduous forest (302-692 stems ha^{-1}) at Uttarakannada, India (Bhat et al. 2000). It is generally recognized that species richness is positively associated with species abundance (Denslow, 1995, Condit et al. 1998, Hayek and Buzas 1997, Preston 1962). The species-richness-abundance relationship suggests that large populations are less prone to extinction than small ones (Preston 1962). Based on the relationship between abundance and diversity, habitats supports larger numbers of individuals can support more populations and more species than habitats supporting small numbers of individuals (Huang et al. 2003). The most abundant species are often used to define forest composition (Valencia et al. 2004). Very rare species (represented by <2 individuals) accounted for 17% of the total species of Bodamalai forests. It is closer to that of 20 % of rarity obtained in a tropical forest at Puthupet, south India (Parthasarathy and Sethi 1997), but lesser than that in Barro Colorado Island, Panama (40%, Thorington et al. 1982), in New Guinea (55%, Paijmans 1970) and in Malaysia (59%, Ho et al. 1987).

In most of the studies (Williams-Linera 1990, Parthasarathy and Karthikeyan 1997, Srinivas and Parthasarathy 2000, Mani and Parthasarathy 2005) basal area is used as one of the important aspects for studying the forest vegetation structure. The mean basal area for Bodamalai (5.5 m^2 ha^{-1}) falls within the range for the tropical dry forest (1.3–12.8 m^2 ha^{-1}) at Vindhyan hills (Sagar et al. 2003). Diameter distributions are commonly used to assess the disturbance effect within forests (Hett and Loucks 1976, Denslow 1995). The lack of 'J' shaped structure for basal area in Bodamalai (Figure 5) indicates the extent of tree felling, leading to poor status of forest stand. The lower girth class (30-60 cm gbh) alone had 91 % of the total basal area and trees with higher size classes are illegally cut for their timber value, leaving the forests degraded. Ultimately it lead to reduced level of tree density in Bodamalai, while expanding population structure indicating mature forest stands with good regeneration were reported by Parthasarathy and Karthikeyan (1997) from India, Poore (1968) from Malaysia, Liberman et al. (1985) and Nadkarni et al. (1995) from Costa Rica, and Swaine et al. (1987) and Campbell et al. (1992) from Brazilian Amazon.

Top ten species *Euphorbia antiquorum*, *Albizia amara*, *Chloroxylon swietenia*, *Acacia chundra*, *Strychnos potatorum*, *Cleistanthus collinus*, *Wrightia tinctoria*, *Canthium dicoccum*, *Diospyros montana and Rhus mysurensis* dominated the stand, contributing 53 % of importance value index. Dominance increases as a function of stress, due to past damage (Jacobs 1987), poor drainage (Richards 1996), etc. The dense growth of *Lantana camara* in the Bodamalai forest stand reflects the extent of forest land degradation. In Bodamalai, Euphorbiaceae and Mimosaceeae with 6 species each formed the species-rich families. Similarly, Kadavul and Parthasarathy (1999) reported that Euphorbiaceae (with 8 species) was well represented in tropical semi-evergreen forest in the Shervarayan hills of Eastern Ghats, India. The predominant families Euphorbiaceae and Mimosaceae in Bodamalai, contributed maximum to stand density (44 %) as well as to basal area (24 %). The lower girth class (30-60 cm gbh), contributed maximum to stand density (91 %) and basal area (60 %), revealing that the tropical forests of Bodamalai are disturbed. Similar pattern was reported in the disturbed site of the adjoining forest at Kolli hills of

Eastern Ghats (Chittibabu and Parthasarathy 2000).

Out of 64 species recorded in the tropical forests of Bodamalai, the distribution of 42 % of the species showed a random pattern and 58 % of the species showed aggregated pattern. The predominance of aggregation reflects the restricted distribution of species in Bodamalai. Out of the 33 species with aggregated patterns of distribution, non-thorny species contributed 72 % (24 species). The predominance of aggregation was also reported by Kadavul and Parthasarathy (1999). Aggregation of individuals of the same species may be due to inefficient mode of seed dispersal or opportunity or chance as when numerous saplings are able to grow where a large-tree has died or in a large gap due to wind fall (Richards 1996). Wind-dispersed seeds are better able to colonize degraded areas than vertebrate-dispersed plants. Small seeds and those with low water content are less susceptible to desiccation in open areas, which is a major barrier for the survival of fleshy-fruit seeds, which generally have high water content, soft seed coats, and have low germination percentages in abandoned pastures (Holl 1999, Vieira and Scariot 2006). Also, small, wind-dispersed seeds, in contrast with animal-dispersed seeds, are not strongly affected by fragmentation or hunting (Gillespie 1999, Vieria and Scariot 2006). The impacts of disturbance on the reproductive output of tropical forest trees remain largely unknown due to the complexity of plant-pollinator interactions and the practical difficulties of quantifying these interactions in the forest canopy (Glazoul and McLeish 2001). According to the hypothesis (Cramer et al. 2007) that large-seeded plant species would be more susceptible to forest fragmentation than small-seeded species because large-seeded species rely on a few, extinction prone dispersers. Although 69 % of the total species in Bodamalai are Zoochorous, they contributed only 48 % to total stand density. This may be attributed to the shortage of animal dispersers in the disturbed/ degraded Bodamalai forests.

Above-ground biomass (AGB) is also an important aspect to study the effects of deforestation (Ketterings et al. 2001). The mean AGB of Bodamalai forests was 63.2 Mg ha^{-1}, which is less than the range reported (73.1 Mg ha^{-1} to 173.1 Mg ha^{-1}) for tropical forests of south India (Mani and Parthasarathy 2007). In Bodamalai, species richness, stand density, basal area and AGB increased with increasing altitude. Also, species richness, stand density, basal area and AGB of evergreen tree species positively correlated with altitude. While the density of the dominant species *Euphorbia antiquorum* (which is considered to be an indicator tree species of scrub/ degraded forests) decreased with increasing altitude. This reveals that the tropical forests of Bodamalai located at low altitudes are prone to high degradation.

CONCLUSION

Dry forests once covered more than 40 % of the total area of tropical forests (Murphy and Lugo 1986). They are considered to be one of the most threatened of all the major tropical forest habitats and are argued to deserve a high priority for conservation (Janzen 1988, Gillespie et al. 2000, Gouzalez-Rivas et al. 2006). The sustainable utilization of woody plant species requires as a first step knowledge, including, their ecology and an understanding of the peoples' attitudes to conservation (Tabuti 2007). Topographic variables (elevation, slope, aspect, etc.) have a strong influence on the forests (in Nanjenshan area) and also contributed to the maintenance of species richness (Chao et al. 2000). The major threat believed to be impacting the species by the community are the growing human population, expanding crop agriculture, poor harvesting methods and over-exploitation of species (Tabuti 2007). Although deforestation, largely for the conservation of land to food crops or pastures, is the major destructive force in tropical forests world-wide, other forest disturbances such as the selective harvest of timber have also increased in frequency and extent (Nepstad et al. 1999, Cursan et al. 2004, Asner et al. 2005). As human activities keep escalating with ever-increasing population, ecosystems near human settlements are made fragile. Hence, documenting tree diversity of tropical forests, particularly those of the ill-known dry forests of Bodamalai hills, is important for conservation management. The forests of Bodamalai are low in plant diversity and density but they also support for faunal communities e.g., macaques, jackals, wild bores, etc. *Santalum album* (sandal wood), one of the valuable bioresources is restricted to grid 8 with just 10 individuals and that too represented only in the lower girth class (30-60 cm gbh). Illegal extraction of the species was also witnessed. Although, Bodamalai is included under reserve forest category, the population has unlimited and unspecified right of firewood collection, felling lopping and herding cattle for grazing, browsing, etc. Dry forests can recover their relatively simple nature structure after disturbance more rapidly than wet forest, which have a more complex structure (Ewel 1980, Kennard 2002, Vieira and Scariot 2006). Our study exemplifies that the tropical forests located at low altitudes in Bodamalai are poor in species richness, stand density, basal area and AGB, and invasion of weedy species *Lantana camara* is severe, reflecting degraded status of forest land. We recommend the following for developing the degraded forest land of Bodamalai: (i) to create awareness on forest degradation among the local people (ii) some important indigenous trees such as *Albizia amara*, *Chloroxylon swietenia*, *Acacia chundra*, *Acacia leucophloea*, *Strychnos potatorum*, *Azadirachta indica* and *Wrightia tinctoria* can be used for afforesting the degraded forest lands and (iii) to organize a village committee for monitoring and developing the afforested areas.

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