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IMPACT OF DISTURBANCE ON COMPOSITION, STRUCTURE, AND FLORISTICS OF TROPICAL MOIST FORESTS IN UTTARA KANNADA DISTRICT, WESTERN GHATS, INDIA

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Abstract. Impact of disturbance on forest stand density, basal area , dbh class distribution of density and basal area, species richness, species diversity and similarity index was assessed through monitoring six, one-hectare, permanent forest plots after a period of 24 years in tropical moist forests of Uttara Kannada district, Western Ghats, India. It was observed that all sites lost trees due to removal by people and mortality. Loss of trees was more in sites that are easily accessible and closer to human habitation. In spite of a decrease in tree density, an increase in basal area was observed in some forest plots, which could be on account of stimulatory growth of surviving trees. Decrease in basal area in other sites indicates greater human pressure and overexploitation of trees. Preponderance of lower girth class trees, and a unimodal reverse 'J-shaped' curve of density distribution as observed in majority of the sites in the benchmark year, was indicative of regenerating status of these forests. The decrease in number of species in all forest sites was due to indiscriminate removal of trees by people, without sparing species with only a few individuals, and also due to mortality of trees of rare species. Higher species richness and diversity in the lowest dbh class in most of the sites in the benchmark year is indicative of the existence of favorable conditions for sylvigenesis. The decrease in the similarity index suggests extirpation of species, favoring invasion and colonization by secondary species. To minimize human pressure on forests and to facilitate regeneration and growth, proper management planning and conservation measures are needed.

Key words: Human disturbance, tree density, species diversity, tropical forests, southern India.

INTRODUCTION

Tropical forests have received much attention in recent years on account of their biological richness, high productivity, and also for their important role in carbon cycle and watershed protection. They are subjected to different kinds of human disturbances and natural perturbances affecting their composition, structure, and floristics. Since the forests are dynamic entities, the process of recovery can affect their original state. But the time required to reach the climax stage depends on the type and intensity of the disturbance. Long-term monitoring of vegetation provides the information relevant to the processes of recovery, and an understanding of stand dynamics, helps to develop suitable management options and conservation plans.

The Western Ghats in southern India has been identified as one of the 18 global botanical biodiversity hotspots (Myers 1988, 1990) and is well known for providing a great variety of ecological and environmental services. In recent years, however, the

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forests of this hill-chain have been subjected to intensive human disturbances, as well as natural calamities, leading to erosion of species richness, disruption of closed canopy, invasion and spread of secondary species and weeds, resulting in changes in structure and floristic composition. There are descriptive studies dealing with the qualitative aspects of the forests of the Western Ghats (Champion & Seth 1968, Rai & Proctor1986, Pascal & Pelissier 1996), but very few studies have attempted a quantitative assessment of the dynamics of this region (Rai 1983, Bhat *et al.* 2000, Pomeroy *et al.* 2003). The aim of the present study is to assess the impacts of disturbances on the tree density, structure, composition and floristics in tropical moist forests of Uttara Kannada district, Western Ghats over 24 years (1984 – 2008).

MATERIALS AND METHODS

Study area. This study was conducted in Uttara Kannada district (13°55' to 15°31'N, 74°9' to 75°10'E) of the Western Ghats, part of peninsular India. Comprising an area of 10,200 km^2, the district is characterized by hilly terrain with gentle slopes and broad valleys and an altitude ranging from the sea coast to a little over 1000 m. It is one of the most forested tracts of southern India. Topographically the district may be divided into three zones: the flat and narrow coast, abruptly rising ridge, and the flatter elevated eastern zone that joins with the Deccan Plateau. The district receives rainfall from the SW monsoon, largely restricted to the months from June to September. Annual rainfall in the district ranges from 350 cm near the coast to more than 500 cm at some places along the ridge of the hills. The eastern side of the district receives about 120 cm rainfall annually.

The natural vegetation of the district is evergreen/semi-evergreen type along slopes, and towards the east of the ridge it is moist deciduous type (Pascal 1986). Puri (1960) classified the forest facing the western slope as tropical wet evergreen forest and included the eastern part in the tropical moist deciduous forest type. Champion & Seth (1968) classified the forest on the western slope as tropical evergreen type and included the forest of the eastern zone in the category of South-Indian moist deciduous type. Considering the abundance of species, Pascal (1988) classified the vegetation of the lower elevation of the district as *Persea macarantha – Diospyros* spp. – *Holigarna* spp., type and forests of the summits of plateau as *Memecylon umbellatum – Syzygium cuminii – Actinodaphne angustifolia* type. In evergreen/semi-evergreen forests (henceforth called evergreen forests), *Hopea wightiana, Bischofia javanica, Holigarna arnottiana, Flacourtia montana, Ixora brachiata*, etc., dominate the canopy, while the undergrowth consists of *Strobilanthus* spp., *Calamus* spp., *Uvaria* spp., etc. In moist deciduous forests, *Xylia xylocarpa, Lagerstroemia microcarpa, Terminalia tomentosa, T. paniculata, T. bellerica*, etc., are the emergent tree species, with undergrowth including *Psychotria dalzelli, Eupatorium odoratum, Wagatea spicata* and *Ziziphus* spp. Based on rainfall and vegetation types the district can be broadly divided into an evergreen/semi-evergreen forest zone and drier secondary/moist deciduous zone.

The forests of the district have been classified administratively as reserve forests (RFs), minor forests (MFs), and leaf-manure forests (LMFs). The RFs account for more than 60%, MFs for about 15%, and the leaf-manure forest (LMFs), locally known as "Soppina bettas", constitute about 5% of the total geographical area of the district. The management system is different for these three forest categories: (i) in RFs, wood and timber extraction is highly regulated by the state and access to people is banned, (ii) in MFs, extraction of the forest products is not regulated and there is an open access system, set aside for meeting the biomass demands of local people, (iii) in LMFs, leaf and dry wood extraction is permitted only to assigned farmers under certain privileges. Brief descriptions and important features of the study sites are given in Table 1.

Methods. Representative areas from two forest land use categories, RFs and MFs, were selected in evergreen and moist deciduous vegetation zones in Sirsi and Kumta blocks of the district. In each forest category, plots measuring 100 m x 100 m (1ha) were demarcated. There were six, 1-ha forest plots representing, 4 RFs, of which two were from the moist deciduous and the other two from the evergreen forest zone. Of the 2 MFs, one is in the moist deciduous forest zone and the other is in the evergreen forest zone. Levels of biotic disturbances in these sites were assessed based on distance from human settlements, accessibility, incidence of fire, trails and paths, and livestock grazing. All woody plants (which include tree saplings, shrubs, lianas, climbers, etc.) with a girth of > 10 cm at breast height (GBH, breast height = 132 cm) were counted as trees. For convenience during enumeration, each plot was split into 5 strips

TABLE 1. Brief description and some salient features of the study sites located in two vegetation zones of Uttara Kannada district.

Vegetation Zone	Secondary/Moist deciduous zone			Evergreen/Semi-evergreen zone		
	Sugavi	Bidralli	Sonda	Chandavar	Nagur	Santgal
Land use category	Minor forest (MF)	Reserve forest (RF)	Reserve forest (RF)	Minor forest (MF)	Reserve forest (RF)	Reserve forest (RF)
Level of biotic disturbance	Moderate	High	High	Very High	Moderate	Minimum
Approximate distance from nearest human settlements (km approx.)	<2 km. Few houses in settlements	<0.25 km	<1 km	<0.25 km	<1 km	>3 km
Accessibility	Easily accessible	Easily accessible	Easily accessible	Easily accessible	Easily accessible	Difficult
Number of families (during 1984)	18	19	24	28	29	27
Dominant trees	*Terminalia bellerica* *Terminalia paniculata* *Terminalia tomentosa* *Lagerstroemia microcarpa* *Adina cordifolia* *Randia spinosa* *Phyllanthus emblica*	*Xylia xylocarpa* *Lagerstroemia microcarpa* *Adina cordifolia* *Schleichera oleosa* *Terminalia paniculata* *Randia spinosa*	*Terminala paniculata* *Terminalia tometosa* *Xylia sylocarpa* *Xantolis tomentosa* *Flacourtia montana* *Ervatamia heyneyana* *Aoporosa lindleyana*	*Hopea wightiana* *Lagerstroemia microcarpa* *Alseodaphne semicarpifolia* *Aporosa lindleyana* *Flacourtia montana* *Ixora brachiata*	*Hopea wightiana* *Holigarna arnottina* *Pterospermum spp.* *Aporosa lindleyana* *Myrstica attenuata*	*Bishcofia javanica* *Dysoxylum binectariferum* *Nephopodytes foetida* *Nothopegia colebrookiana*
Undergrowths	*Acacia caesia* *Allophyllus cobbe* *Clerodendrum infortunatum* *Murraya koengii* *Pavetta spp.* *Wagatea spicata*	*Allophylus cobbe* *Murraya koengii* *Breynia spp.* *Clerodendrum infortunatum* *Eupatorium odoratum*	*Grewia microcos* *Psychotria flavida*	*Grewia microcos* *Psychotria flavida* *Strobilanthus spp.* *Uvaria spp.*	*Draecena ternifolia* *Glycosmis pentaphylla* *Psychotria flavida* *Uvaria spp.* *Neolitsea spp.*	*Eugenia macrocephala* *Leea spp.* *Calamus spp.* *Ancestrocladus henyanus* *Glycosmis pentaphylla* *Gymnosporia rothiana* *Tarenna zeylanicum*
% Composition of evergreen species	18	24	47	50	66	76
% Composition of deciduous species	82	76	53	50	34	24

(20 x 100 m) and each tree was numbered with an embossed metal tag. At the time of enumeration, branches of a tree > 10 cm GBH were noted as stems and they were marked as A, B, C, etc., and their GBH measured. GBH values were converted to diameters at breast height (dbh) and these values are used in the present paper. A black strip was painted on each tree and stem at breast height. Plants were identified to species level following Cooke (1967), but in case of uncertainty, they were identified to genera or family levels and doubtful entities were called as unknown I, II, III… etc. After the comple-

tion of the benchmark enumeration of all the 6 plots in 1984, annual growth measurement continued in the subsequent years up to 2008. Girth measurements of surviving trees and stems continued yearly by putting the tape exactly on the black strip, i.e. the mark of the benchmark year at 132 cm height. The number of dead trees and number of trees removed by people were recorded during yearly measurements.

Species diversity index (H) was estimated following Shannon-Weaver (1949).

Change in species similarity in a site over 24 years was assessed following Sørenson's Similarity Index (S).

RESULTS

I. *Impact of disturbance on stand density and tree density distribution in different dbh-classes.*

After 24 years it was observed that all sites lost trees, ranging from 23.7% in Sugavi MF to 60% in Chandavar MF (Table 2). Decrease in the number of trees was due to removal by people and also the natural death of trees. Though the number of trees removed over 24 years varied in different sites, when the percentage loss of trees due to removal was considered it was minimum in Santgal RF (5.5%) and maximum in Chandavar MF (54.8%), but mortality of trees was lowest (5.2%) in the latter site and highest (37.6%) in the former. Removal of trees by people exceeded mortality of trees in Bidralli RF, Sonda RF, Chandavar MF and Nagur RF, but in Sugavi MF and Santgal RF mortality was higher than the removal of trees by people.

In all forest sites the lowest dbh class (10 cm) contained the highest number of trees in the benchmark year, ranging from 36.5 % in Sugavi MF to 64.85% in Nagur RF (Fig.1). Tree density distribution in different dbh classes in Sugavi MF, Sonda RF, Chandavar MF, Nagur RF, and Santgal RF, in the benchmark year increased, more or less unimodally and showed a reverse 'J-shaped' curve. But in Bidralli RF it was hump-shaped, indicating a higher number of trees in medium dbh classes. After 24 years there was considerable change in distribution of tree density in the dbh classes. In all forest sites a decrease in stem density was observed in 10-cm class and an increase in the 30-40 cm classes, rendering the dbh distribution curve unimodal and/or bimodal hump-shaped in Sugavi MF, Chandavar MF, Bidralli RF, and Sonda RF. Though there was a slight decrease in tree density in the lowest dbh class in Nagur and Santgal RFs, the density distribution curve was more or less closer to the reverse 'J-shape', indicating a lesser effect of loss of trees in each class.

An examination of the total number of trees removed and dead over 24 years in different dbh classes revealed that, a higher number of small-sized trees were removed and dead in all sites, leading to greater loss of tree density in lower dbh classes (Fig. 2).

II. *Impact of disturbance on stand basal area and distribution of basal area in dbh classes*

In spite of the loss of trees in all forest sites over 24 years, an increase in basal area was observed in Sugavi MF, Sonda, Nagur and Santgal RFs, but a reduction in Bidralli RF and Chandavar MF (Table 3). Considering the percentage change in basal area after 24 years, it was clear that maximum loss occurred in Chandavar MF (6.57%) and maximum increase was in Nagur RF (104.96%).

TABLE 2. Change in tree density due to removal and death in a period of 24 years in study sites in Uttara Kannada district.

Study site	No. of trees (no./ha) during the year		Loss of trees due to		Net and % change in number of trees		Rate of loss of trees (no. of trees/yr) due to	
			Removal	Death				
	1984	2008	No. of trees removed & (%)	No. of dead trees & (%)	Net change in number of trees	% change	Removal	Death
Sugavi MF	405	309	44 (10.9)	52 (12.8)	-96	-23.70	2	2
Bidralli RF	306	168	93 (30.4)	45 (14.7)	-138	-45.10	4	2
Sonda RF	692	394	189 (27.3)	109 (15.8)	-298	-43.06	8	5
Chandavar MF	580	232	318 (54.8)	30 (5.2)	-348	-60.00	13	1
Nagur RF	1619	867	559 (34.5)	193 (11.9)	-752	-46.45	23	8
Santgal RF	964	549	53 (5.5)	362 (37.6)	-415	-43.05	2	15

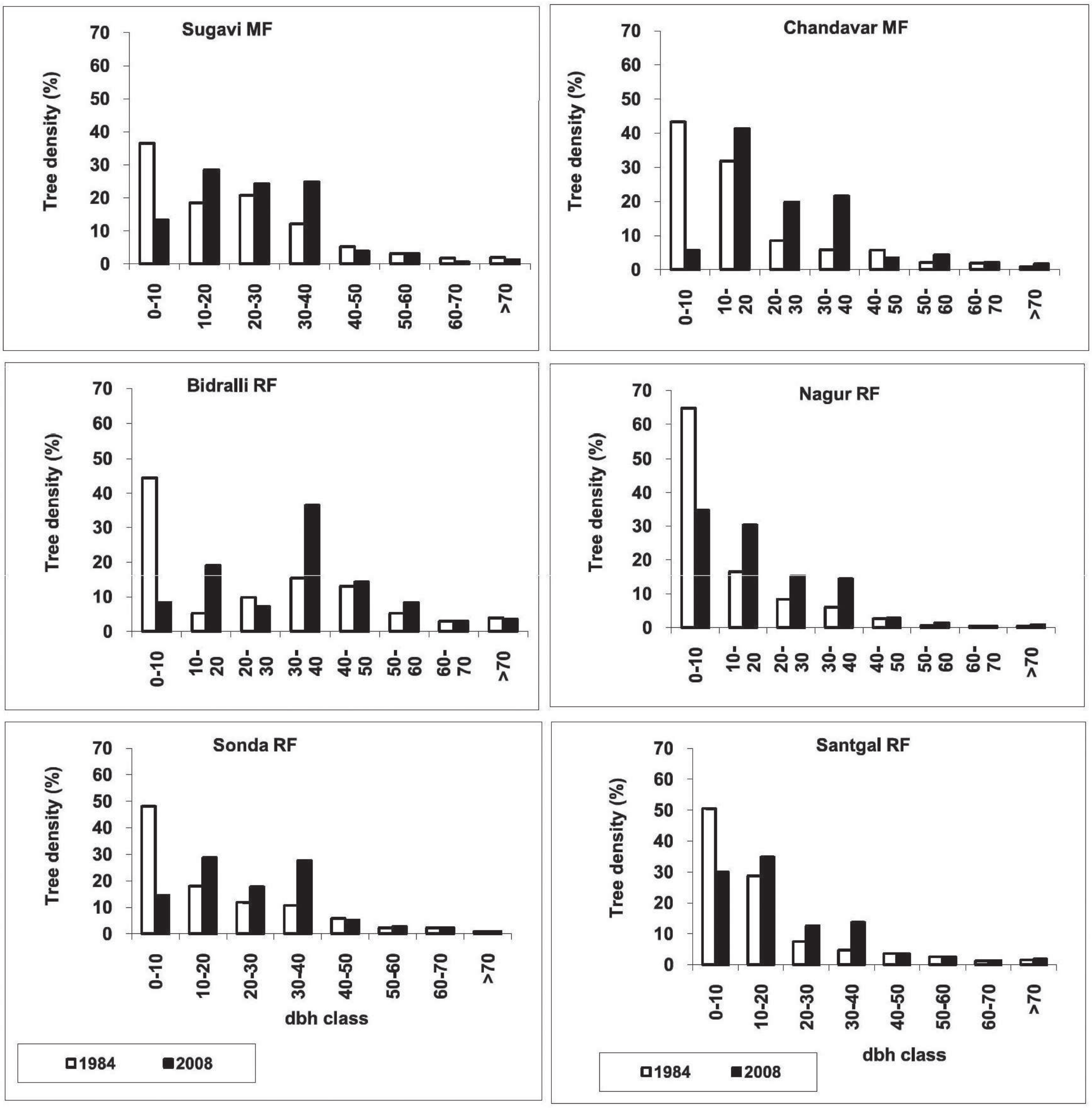

FIG. 1. Tree density (in %) in 1984 and 2008 in different dbh classes in study sites in Uttara Kannada district.

In forest sites, except in Bidralli RF, the lowest dbh class had the lowest basal area in the benchmark year and also 24 years later (Fig. 3). Except Santgal RF, in other sites more basal area was shared by individuals in 20-60 cm classes. The dbh class distribution of basal area in Santgal RF was more or less 'J-shaped', indicating less basal area in lowest dbh class and a progressive increase in higher dbh classes. A similar trend continued even after 24 years at this site. In other sites it was unimodal, in Sugavi MF, Bidralli and Nagur RFs. It was bimodal in Sonda RF and multimodal in Chandavar MF, suggesting the prominence of medium-sized trees.

III. *Impact of disturbance on floristic composition*

Over the period of 24 years all sites lost species, ranging from 3 in Sugavi MF to 16 species/ha in Nagur RF (Table 4). But percentage-wise, minimum loss of species was in Sugavi MF (8.82%) and maximum in Bidralli RF (29.03%). It is interesting to note that the number of species was higher in the lowest dbh class (10 cm) in the benchmark year, and comprised more than 50% of the total number of species observed in each forest site (Table 5). But after 24 years, the number of species decreased in the lowest dbh class and a considerable change in the number of species was also observed in other dbh classes.

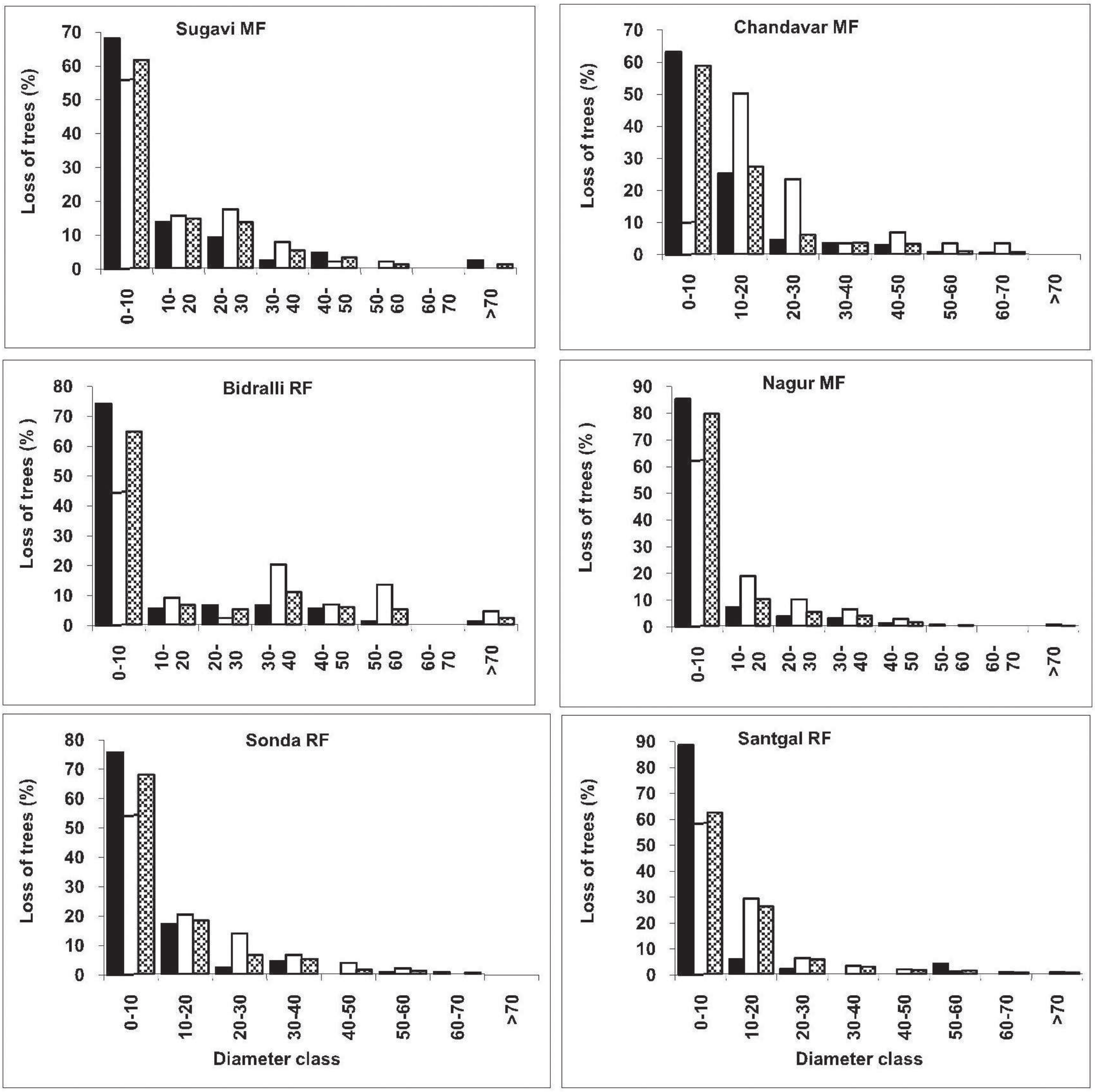

FIG. 2. Trends in total loss of trees (▩), loss of trees due to felling (■) and death (□) in different diameter classes in study sites in Uttara Kannada district.

TABLE 3. Change in basal area in a period of 24 years (1984-2008) in study sites in Uttara Kannada district.

Study site	Basal area (m^2/ha) during		Net change in basal area	% change
	1984	2008		
Sugavi MF	22.52	24.33	1.81	8.04
Bidralli RF	26.42	25.07	-1.35	-5.10
Sonda RF	32.62	33.66	1.04	3.18
Chandavar MF	21.75	20.32	-1.43	-6.57
Nagur RF	20.95	42.94	21.99	104.96
Santgal RF	32.13	37.06	4.93	15.35

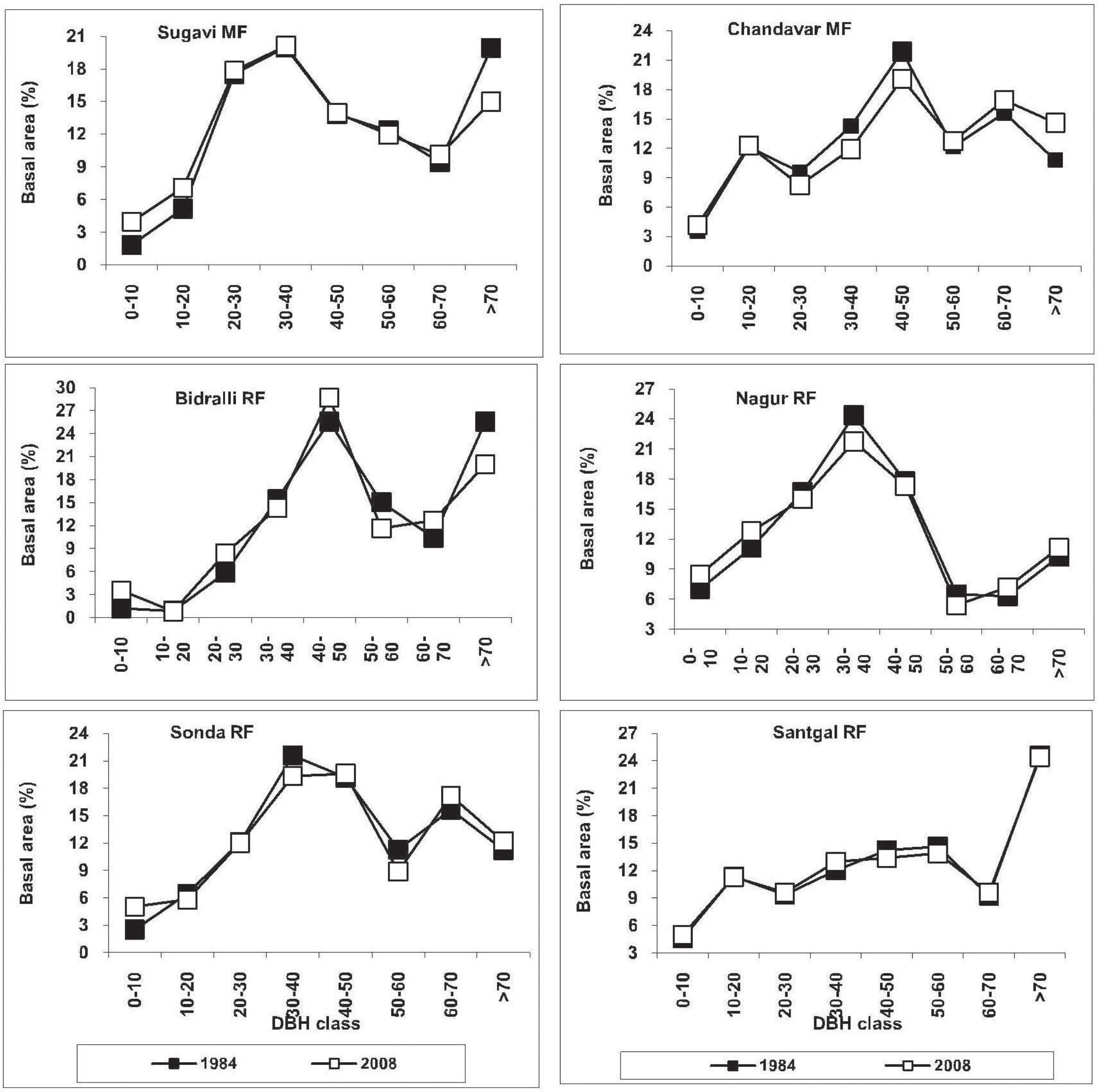

FIG. 3. Basal area (in %) for the years 1984 (■) and 2008 (□) in different dbh classes in study sites of Uttara Kannada district.

The species diversity index in the benchmark year ranged from 2.06 in Nagur RF to 3.16 in Santgal RF, but after 24 years it decreased in all sites except Chandavar MF, in which it increased marginally (Table 4). In the benchmark year the species diversity index was high in the lowest dbh class in all sites except Nagur RF, in which it was maximum in the 20-30 cm class (Table 5). Because of this species loss, Sørenson's Similarity Index showed a decreasing trend after 24 years at all sites. After 24 years, the maximum similarity among species was observed in Sugavi MF (95.38%) and the minimum in Bidralli RF (83.64%; Table 4).

DISCUSSION

I. *Impact of disturbance on stand density and distribution of trees in dbh classes*

From long-term monitoring of six, 1-ha forest sites, for a period of 24 years in Uttara Kannada district in Western Ghats, it was evident that removal of trees by people and tree mortality were the prime reasons for the decrease in the tree density in all sites. Studies have reported dependency of rural population on forests for meeting various biomass requirements, leading to forest degradation (Singhal *et al.* 2003, Arjunan *et al.* 2005, Davidar *et al.* 2007). Decrease

TABLE 4. Change in species richness (no. /ha), species diversity index, and similarity index in a period of 24 years in study sites in Uttara Kannada district.

Study site	Species richness in the year		Net change in species richness and (% change)	Species diversity index in the year		Net change in species diversity index and (% change)	Change in Sørenson's Similarity Index (%) between the years 1984 & 2008
	1984	2008		1984	2008		
Sugavi MF	34	31	-3 (-8.82)	2.50	2.41	-0.09 (-3.61)	96.9
Bidralli RF	32	23	-9 (-28.13)	2.30	1.73	-0.58 (-25.03)	83.0
Sonda RF	51	40	-11 (-21.57)	3.16	2.97	-0.19 (-5.92)	88.9
Chandavar MF	47	39	-8 (-17.02)	3.01	3.06	0.04 (1.36)	90.9
Nagur RF	58	42	-16 (-27.59)	2.07	1.96	-0.11 (-5.23)	83.5
Santgal RF	63	48	-15 (-23.81)	3.13	2.96	-0.18 (-5.73)	86.8

in stem density with disturbance intensity has been reported by Ramírez-Marcial *et al.* (2001) in a montane rainforest in Mexico. Decreases in tree density have been reported as a consequence of tree- cutting for domestic use (Smiet 1992) and of selective and commercial extraction of timber (Elouard *et al.* 1997, Pomeroy *et al.* 2003). According to Karanth *et al.* (2006), village size, distance from the village, and proximity to other villages were significant predictors of disturbance level. Forests close to settlements are invariably more intensively exploited than more remote forests (Sagar *et al.* 2003, Ramacharitra 2006). In the present study it was observed that removal of trees by people was higher in Chandavar MF (54.8%), Bidralli RF (30.4%), Nagur RF (34.5%), and Sonda RF (27.3%), marginal in Sugavi MF (10.9%), and lowest in Santgal RF (5.5%, Table 2). The first four sites are very close to human settlements and easily accessible (Table 1), so are subjected to greater human pressure and overexploitation leading to the decrease in tree density. But in the case of Sugavi MF, though not inaccessible it was less exploited because, there are few houses in the nearby settlements and they are scattered near the forest site. So human pressure on the forest is less and few trees are removed by people. In the case of Santgal RF, which is hilly terrain and not easily accessible, removal of trees by people over 24 years was very low (5.5 %), but tree mortality was very high (37.6%, Table 2), with an annual rate of mortality of 1.5%, which is within the reported range of 1-2% mortality/year for tropical forests (Swaine *et al.* 1987). This suggests that, irrespective of land-use category and restrictions on extraction by the community, biomass needs are met from forests close to villages. Tree death is independent of tree size (Swaine *et al.* 1987), and it may be due to reaching the end of the life span, end of growth, pathogen attack, herbivores, senescence, drought, suppression, or on account of natural calamities such as uprooting, breaking, falling of branches, fire etc (Lutz & Halpern 2006). Removal of a higher number of trees than the number that die naturally, as observed in Chandavar MF, Bidralli, Sonda and Nagur RFs, is an indication of greater demand for biomass. Such a situation certainly leads to a decrease in stand density unless recuperation takes place through recruitments or coppicing. Canopy opening leads to the invasion of secondary species of inferior quality, affecting the quality of the forest and its regeneration (Parthasarathy 1999, Bhuyan *et al.* 2001, Upadhaya *et al.* 2004). The occurrence of species such as *Eupatorium odoratum* or

TABLE 5. Change in species richness and diversity index in different dbh classes in study sites of Uttara Kannada district.

dbh class (cm)	Species richness and Shannon-Wiener diversity Index	Study sites																	
		Sugavi			Bidralli			Sonda			Chandavar			Nagur			Santgal		
		No. of species/ diversity index in the year		Net change & (%)	No. of species/ diversity index in the year		Net change & (%)	No. of species/ diversity index in the year		Net change & (%)	No. of species/ diversity index in the year		Net change & (%)	No. of species/ diversity index in the year		Net change & (%)	No. of species/ diversity index in the year		Net change & (%)
		1984	2008		1984	2008		1984	2008		1984	2008		1984	2008		1984	2008	
10	Species Richness	20	15	-5 (25.0)	20	10	-10 (50.00)	42	22	-20 (47.62)	29	8	-21 (72.41)	45	27	-18 (40.00)	50	29	-21 (42.00)
	Shannon-Wiener diversity index	2.22	0.95	-1.27 (57.21)	2.32	0.43	-1.89 (81.46)	2.93	2.73	-0.2 (6.83)	2.67	1.88	-0.79 (29.59)	1.72	1.61	-0.11 (6.39)	3.04	2.71	-0.33 (10.85)
20	Species Richness	11	18	7 (63.63)	9	8	-1 (11.11)	23	24	1 (4.35)	25	21	-4(16)	32	21	-11 (34.37)	34	32	-2 (5.88)
	Shannon-Wiener diversity index	1.27	1.55	0.28 (22.04)	2.04	1.32	-0.72 (35.29)	2.54	2.61	0.07 (2.75)	2.38	2.15	-0.23 (9.66)	2.04	1.71	-0.33 (16.17)	2.52	2.54	0.02 (0.79)
30	Species Richness	16	12	-4 (25.00)	7	4	-3 (42.86)	20	19	-1(5)	17	15	-2 (11.76)	20	17	-3 (15.00)	24	21	-3 (12.50)
	Shannon-Wiener diversity index	1.57	1.29	0.28 (17.83)	1.29	1.20	-0.09 (6.98)	2.48	2.61	0.13 (5.24)	2.42	2.48	0.06 (2.48)	2.08	1.78	-0.3 (14.42)	2.77	2.63	-0.14 (5.05)
40	Species Richness	11	12	1 (9.09)	7	5	-2 (28.57)	13	14	1 (7.69)	13	14	1 (7.69)	17	13	-4 (23.53)	16	11	-5 (31.25)
	Shannon-Wiener diversity index	1	1.05	0.05 (5.00)	1.13	0.83	0.3 (26.55)	1.77	2.04	0.27 (15.25)	2.22	2.44	0.22 (9.9)	2.08	1.82	-0.26 (12.5)	2.3	1.97	-0.33 (14.34)
50	Species Richness	10	11	1 (10.0)	8	8	0	7	10	3 (42.86)	12	11	-1 (8.33)	11	9	-2 (18.18)	8	12	4 (50.00)
	Shannon-Wiener diversity index	0.56	0.68	0.12 (21.43)	0.95	1.05	0.1 (10.53)	1.76	1.99	0.23 (13.06)	2.13	2.21	0.08 (3.75)	2.17	1.65	-0.52 (23.96)	1.64	1.97	0.33 (20.12)
60	Species Richness	9	9	0	4	3	-1(25)	5	5	0	10	7	-3 (30.00)	6	9	3 (50.00)	6	5	-1 (16.67)
	Shannon-Wiener diversity index	0.39	0.37	-0.02 (5.13)	0.66	0.54	-0.12 (18.18)	1.9	1.37	-0.53 (27.89)	2.25	1.9	-0.35 (15.56)	1.61	1.94	0.33 (20.49)	1.58	1.32	-0.26 (16.45)
70	Species Richness	5	5	0	4	6	2 (50.00)	6	5	-1 (16.17)	10	9	-1 (10.00)	5	6	1 (20.00)	9	6	-3 (33.33)
	Shannon-Wiener diversity index	0.21	0.26	0.05 (23.81)	1	1.23	0.23 (23.00)	1.63	1.49	-0.14 (8.58)	2.27	2.16	-0.11 (4.85)	1.59	1.58	-0.01 (0.63)	2.09	1.57	-0.52 (24.88)
>70	Species Richness	6	4	-2 (33.33)	6	4	-2 (33.33)	3	4	1 (33.33)	4	6	2 (50.0)	5	7	2 (40.00)	7	7	0
	Shannon-Wiener diversity index	0.25	0.18	-0.07 (26.00)	1.63	1.24	-0.39 (23.93)	1	1.27	0.27 (27.00)	1.33	1.67	0.34 (25.56)	1.55	1.84	0.29 (18.71)	1.57	1.67	0.1 (6.37)

Lantana camera in open spaces in Chandavar MF, and Bidralli and Sonda RFs, indicates a deteriorating condition of the site. The presence of light-tolerant, low-quality tree species, such as *Olea dioica*, *Careya arborea*, *Ficus asperrima*, or *Randia spinosa* in the study sites suggests the opening of canopy and degradation

Very often the health of the forest stand is assessed by plotting the size distribution. The presence of more small-sized trees than large-sized ones is considered as an indication of a regenerating forest. But, lower numbers of juveniles is treated as an indicator of the degeneration status of the stand (Condit *et al.* 1998). In the present study the dbh class distribution of tree density in the benchmark year was an expanding, more or less unimodal, reverse 'J-type' in all sites except Bidralli RF (Fig. 1), suggesting a higher number of small-sized trees and regenerating forests. Such a negative exponential curve is in concurrence with the reports from tropical forests (Poore 1968, Lieberman *et al.* 1985, Ho *et al.* 1987, Ganesh *et al.* 1996, Pascal & Pelissier 1996). A preponderance of young individuals in regenerating forests has been reported from Costa Rica (Nadkarni *et al.* 1995), the Brazilian Amazon (Campbell *et al.*1992), and the Western Ghats in India (Rai & Proctor 1986). But after 24 years, the shape of the curve changed to a bi/multi-modal hump shape in Sugavi and Chandavar MFs, Bidralli and Sonda RFs. There was little change in Nagur and Santgal RFs, which have maintained more or less a reverse 'J-shape' of the curve, suggesting that they have maintained their size-class distribution of tree density and, according to Richards (1996) and Mori *et al.* (1989), they are regenerating. The bi/multi-modal hump-shaped curve noted in other forest sites indicates a loss of more trees in lower dbh classes, and if the current trend continues the regeneration process in these sites is likely to decline.

Change in tree density distribution in dbh classes could be due to an increase or decrease in the tree basal area. Death and removal of trees by people facilitates the availability of light, nutrients, and moisture to surviving trees, stimulating their growth and leading to an increase in basal area and shifting to the next class. Stress conditions such as competition for light, nutrients, moisture and pathogen attacks may lead to a decrease in basal area, thereby shifting trees to a lower dbh class. This affects the dbh class distribution leading to a change in the shape of the density distribution curve (Fashing *et al.* 2004).

In the present study it was observed that in all sites, loss of trees was higher in the lowest dbh class (Fig. 2). The total number of dead trees exceeded the total number of cut trees in Sugavi MF and Santgal RF, suggesting less disturbance (Table 2). Removal of trees and mortality create gaps and reduce overcrowding. According to Obiri *et al.* (2002), species regenerating in gaps grow quickly and tend to be straight and tall, and they are commonly harvested for poles. Straightness in trees could be due to overcrowding in the lower stratum. McKenzie (1988) was of the opinion that if the gaps were dominated by gap-adapted species then such selective harvesting might lead to successional collapse. Selective removal of good-quality species for specific uses from a particular dbh class and non-selective tree cutting for fuel wood have been reported as affecting the forest composition and structure (Smiet 1992). Daniels *et al.* (1995) observed a reduction in tree density in different height classes in disturbed sites, especially in the height categories of 2-4 m and over 8 m. They concluded that decline in tree density in the former height category was on account of the favored size of poles for use by villagers, while the latter height category is favored as timber. The removal of a higher number of trees in the lowest dbh class seen in the present study suggests that people need them in bulk quantity to meet their various needs. Such pressure is higher in forest sites closer to human habitation because cutting small-sized trees, head-loading, and transporting them is legally permitted and does not require any skill or extra labor. So anybody can afford to collect small stems including women and children. But removal of large trees is an offence and requires skill in felling, sizing, and transporting to a destination. Legal prosecution and prohibition of the cutting of large trees might have deterred the people from cutting them, so the loss of large-sized trees is less in all sites.

Higher mortality of trees in the lower dbh classes was observed in all forest sites. Though the rate of mortality in forests is reported as independent of tree size (Lieberman & Lieberman 1987), a higher mortality rate in smaller-sized trees has been reported by Turner (2001). Higher mortality of small-sized trees has been attributed to fire and elephant trampling in dry deciduous forest (Sukumar *et al.* 1998). Natural death, stress conditions such as overcrowding, competitive inability to access enough light, moisture and nutrients etc., lead to higher mortality in small-sized trees (Lutz & Halpern 2006).

The observed higher proportion of mortality in lower dbh classes can be attributed to one or more of the above stress conditions prevailing in a particular forest site.

II. *Impact of disturbance on stand basal area and its distribution in dbh classes*

Though all forest sites lost trees, an increase in basal area was observed in Sugavi MF, and in Sonda, Nagur, and Santgal RFs (Table 3). Loss of trees opens the canopy, facilitates the availability of more light to lower strata, and reduces competition for moisture and nutrients. These conditions are reported to stimulate the growth of surviving neighboring trees by increasing the basal area (Swaine *et al.* 1987, Sukumar *et al.* 1998) and they compensate for the moderate loss of basal area due to dead and cut trees. So an increase in basal area in Sugavi MF, Sonda, Nagur and Santgal RFs could be attributed to the stimulated growth of surviving trees. A decrease in basal area could be caused either by the death of trees or physiological changes such as hydration and dehydration, or could be due to debarking, bole-rotting, death of parts and decay of trees (Anonymous 1978). Human-induced disturbances (mainly the extraction of timber and removal of trees by people for domestic use) have been reported as leading to a reduction in basal area (Elouard *et al.* 1997, Pomeroy *et al.* 2003). Though the surviving trees continue to grow, if the basal area of the stand continues to decline, it signals the deterioration of the stand and a trend towards degradation. According to Smiet (1992), basal area values are correlated with disturbances and in highly disturbed sites a low basal area is expected. So the reduction in basal area in Bidralli RF and Chandavar MF could be attributed to greater human pressure on these forest sites.

The distribution of basal area in different dbh classes showed a hump-shaped unimodal curve in Sugavi MF, and in Sonda, Bidralli, and Nagur RFs. It was multi-modal in Chandavar MF, while in Santgal RF it was more or less close to a 'J-shaped' curve. The hump-shaped distribution of basal area indicates that medium-diameter trees occupy the highest proportion of the basal area. According to Sen *et al.* (2008), increasing concentration of individuals in higher diameter classes implies declining growth of the standing crop, as mature and old trees with negligible increment are replacing young individuals with high growth vigor. So if individuals in lower dbh classes are lost, the size class consistency is affected. The 'J-shaped' distribution of basal area observed in Santgal RF is similar to climax forest, suggesting that larger trees shared highest proportion of basal area. Such a situation indicates consistency in the growth rate of individuals in different dbh classes and a stable condition of the stand.

III. *Impact of disturbance on species richness, diversity, and similarity*

All forest sites lost species over the 24-year period. Loss of species over a period of time has been reported by Fashing *et al.* (2004). According to Primack & Hall (1992), species with small population sizes are more prone to local extinction because the mortality of a few individuals may lead to total loss of the population in a location. A large number of tree species comprising only a few individuals has been reported in tropical forests by Thorington *et al.* (1982), for Barro Colorado Island, Panama and by Parthasarathy and Karthikeyan (1997) for the Western Ghats. Terborgh (1992) has emphasized that the activities of humans do more to accelerate species loss than the operations of internal biological processes. Cutting of mature trees for timber, collection of fuel wood, and livestock grazing have been shown to change forest organization and botanical composition in Meghalaya, northeast India (Mishra *et al.* 2004). In the Western Ghats dependency of people on forests for meeting their biomass needs has also been reported by Mani & Parthasarathy (2006). In the present study it was noted that species with only a few individuals have been lost in all sites (Appendix I); see also Primack & Hall (1992). Species with high timber quality with few individuals, such as *Gmelina arborea* and *Dalbergia latifolia*, are removed by the local community, leading to local extinction.

According to Parthasarathy (2001), species diversity in a given forest area depends on climate and geographic location, but human interaction in the past and present also affects it. Overexploitation leads to disturbance and fragmentation of forests resulting in loss of rare and shade-tolerant species (Hill & Curran 2001). Following fragmentation, species richness also declines over time (Turner & Corlette 1996). Decline in species richness and loss of trees have direct effects on the species diversity. In the present study it was observed that over 24 years, species diversity decreased in Sugavi MF, and in Bidralli, Sonda, Nagur, and Santgal RFs, but in Chandavar MF a marginal increase in species diversity was observed (Table 4). Removal and death of trees might have increased the population dominance of some species, leading to a decrease in evenness, resulting in lower species diversity. But in Chandavar MF, on account of disturbance, the dominance of some species was reduced and evenness was increased, that led to slight increase in species diversity.

Since all sites lost species, Sørenson's Similarity Index decreased when the sites were compared for similarity between the benchmark year and after 24 years. Local extinction favors invasion and colonization by alien species, thus adversely affecting the stand quality and structure, as well as the regeneration and floristics of the forests.

In the present study it was observed that more species were present in the lowest dbh class in all sites in the benchmark year, but the number of species decreased after 24 years in this class. Decrease in species number could be attributed to mortality and removal of trees belonging to rare species, or to a shift of individuals to the next lower or higher class. According to Appolinário *et al.* (2005), disturbance plays a major role in sylvigenesis, promoting a higher number of species and thus higher diversity. Canopy openings formed by disturbances are known to offer favorable microenvironments and growth of early secondary species (Denslow 1980). So removal of more trees and higher mortality in the lowest dbh class creates gaps, favoring the occurrence of more species in gaps and hence diversity increased in the lower dbh classes. But indiscriminate exploitation by people and mortality of trees over a period of time might have led to a change in species richness and diversity in these size classes.

CONCLUSION

Long-term monitoring of six, one-hectare, tropical moist forest plots in Uttara Kannada district in the Western Ghats, India, over a period of 24 years, revealed that deliberate removal of trees by people and mortality are the prime causes of decreases in stand density. In spite of the loss of trees, increase in basal area in some sites is the result of a stimulated growth effect on surviving trees, helping to rebuild the forest structure. The loss of a greater number of trees and species in the lower dbh classes indicates the possibility of the elimination of an important stratum of the forest that supports both the future trees of the stand and greater diversity. Exhaustion of usable resources on the outskirts of the forest leads to increasing pressure on the interior core area, with adverse effects on the forest. Legal categorization and prohibition of extraction by the local community has little effect on anthropogenic pressure on forests, but the key factors in deciding extraction pressure are village size, distance, accessibility, and approachability. Unless a suitable management package is evolved and implemented, and conservation measures are taken to reduce and control human pressure, under the current regime, loss of species and forest degradation will continue in the Western Ghats region of southern India. Ensuring the availability of much-needed biomass on the forest fringes, or providing alternatives that replace the dependency of the local community on biomass, could be options to avert such a trend and to save the species richness of this biodiversity hotspot.

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Additional material available on the ECOTROPICA homepage (http://www.gtoe.de/?page_id=113):
Appendix I: List of species and number of trees (no. /ha) in different study sites in Uttara Kannada district and loss of trees over a period of 24 years (1984-2008).

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