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Vegetation structure and composition of tropical evergreen and deciduous forests in Uttara Kannada District, Western Ghats under different disturbance regimes

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Abstract: In the present paper, we present the structure and composition of tropical evergreen and deciduous forests in the Western Ghats monitored under a long-term programme involving Indian Institute of Science, Earthwatch and volunteer investigators from HSBC. Currently, there is limited evidence on the status and dynamics of tropical forests in the context of human disturbance and climate change. Observations made in this study show that the 'more disturbed' evergreen and one of the deciduous plots have low species diversity compared to the less-disturbed forests. There are also variations in the size class structure in the more and 'less disturbed' forests of all the locations. The variation is particularly noticeable in the DBH size class 10 - 15 cm category. When biomass stock estimates are considered, there was no significant difference between evergreen and deciduous forests. The difference in biomass stocks between 'less disturbed' and 'more disturbed' forests within a forest type is also low. Thus, the biomass and carbon stock has not been impacted despite the dependence of communities on the forests. Periodic and long-term monitoring of the status and dynamics of the forests is necessary in the context of potential increased human pressure and climate change. There is, therefore, a need to inform the communities of the impact of extraction and its effect on regeneration so as to motivate them to adopt what may be termed as "adaptive resource management", so as to sustain the flow of forest products.

Resumen: En este artículo presentamos la estructura y la composición de los bosques tropicales perennifolios y caducifolios en los Ghats Occidentales monitoreados en un programa de largo plazo que involucra al Instituto Indio de Ciencia, a Earthwatch y a investigadores voluntarios de HSBC. Actualmente existe poca evidencia sobre el estatus y la dinámica de los bosques tropicales en el contexto del disturbio humano y el cambio climático. Observaciones realizadas en este estudio muestran que los bosques perennifolios –y uno de los caducifolios– 'más perturbados' tienen una diversidad de especies menor que los bosques 'menos perturbados'. También hay variaciones en la estructura de clases de tamaños en los bosques más y menos perturbados de todas las localidades. La variación es particularmente notable en la categoría de 10 - 15 cm de DAP. Respecto a las estimaciones de biomasa, no hubo diferencias significativas entre bosques perennifolios y caducifolios. La diferencia en biomasa entre los bosques 'menos perturbados' y los 'más perturbados' de un tipo de bosque también es baja. La biomasa y el almacén de carbono no han sido impactados a pesar de la dependencia de las comunidades sobre

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los bosques. El monitoreo periódico y de largo plazo del estatus y la dinámica de los bosques es necesario ante el incremento potencial de la presión humana y el cambio climático. Es necesario informar a las comunidades sobre el impacto de la extracción y su efecto sobre la regeneración con el fin de motivarlas a adoptar lo que podría llamarse “manejo adaptativo de recursos”, con el fin de mantener el flujo de productos forestales.

Resumo: No presente artigo, apresentamos a estrutura e composição de florestas tropicais sempre-verdes e caducifólias nos Gates Ocidentais monitoradas sob um programa de longo prazo envolvendo Instituto Indiano de Ciência, Earthwatch e pesquisadores voluntários do HSBC. Atualmente, há evidências limitadas sobre a situação e a dinâmica de florestas tropicais no contexto de perturbação humana e de mudança climática. As observações feitas neste estudo mostram que o estrato sempre-verde "mais perturbado" e uma das parcelas decíduas têm baixa diversidade de espécies em relação às florestas menos perturbadas. Há também variações na estrutura de classes de tamanho nas florestas de todos os locais “mais” e “menos perturbados". A variação é particularmente visível no tamanho do DAP da classe dos 10 - 15 cm. Quando são consideradas estimativas de estoque de biomassa, não houve diferença significativa entre florestas sempre-verdes e as de folha caduca. A diferença de estoques de biomassa entre florestas “menos perturbadas” e “mais perturbadas", dentro de um tipo de floresta, é também baixa. Assim, a biomassa e estoque de carbono não tem sido impactado apesar da dependência das comunidades das florestas. O monitoramento periódico e de longo prazo, do estado e da dinâmica das florestas, é necessário no contexto do aumento potencial da pressão humana e da mudança climática. Há, portanto, uma necessidade de informar as comunidades sobre o impacto da extração e do seu efeito sobre a regeneração, a fim de motivá-las a adotar o que pode ser denominado como "gestão adaptativa de recursos", de modo a sustentar o fluxo de produtos florestais.

Key words: Disturbed forests, species diversity, size class distribution, regeneration, biomass.

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Introduction

Western Ghats is one of the biodiversity ‘hotspots’ of the world. Forests in the Western Ghats like elsewhere in India are on the one hand protected under the Forest Conservation Act of 1980, from conversion, and on the other hand subjected to human use and disturbance. Studies by Ravindranath *et al.* (2006) and Chaturvedi *et al.* (2011) have shown that forests are likely to be adversely impacted by climate change in the coming decades. Further, studies by Rosenzweig (1995) and Jandl *et al.* (2007) have shown that disturbed, fragmented and monoculture forests are likely to be more vulnerable to projected climate change compared to undisturbed forests. Currently, there is limited evidence on the status and dynamics of tropical forests in the context of human disturbance and climate change. In the present paper, we present the structure and composition of tropical evergreen and deciduous forests monitored under a long-term programme involving Indian Institute of Science, Earthwatch and volunteer investigators from HSBC (Hongkong and Shanghai Banking Corporation Limited). The results from first time monitoring of twelve permanent 1-ha evergreen and deciduous forest plots is presented in this paper with particular focus on: (i) Species distribution, density, dominance and biodiversity, (ii) Forest regeneration status, and (iii) Basal area and biomass stocks

Materials and methods

Study area

The Western Ghats in south-India is identified as one of the 34 biodiversity hot spots (Myers 1988, 1990) and they are well known for providing different ecological and environmental services. In recent years, forests of this hill-chain are subjected to intensive human disturbances apart from natural calamities leading to erosion of species richness, disruption of closed canopy, spread of invasive species, and change in structure and functioning. There are descriptive studies dealing with the qualitative aspects of the forests of the Western Ghats (Champion & Seth 1968; Pascal & Pellisier 1996), Rai & Proctor 1986), but very few studies that have attempted quantitative assessment and dynamics of this region (Bhat *et al.* 2000a; Pomeroy *et al.* 2003; Rai 1983).

Uttara Kannada district, the area of study lies between 13° 55' to 15° 31' N lat., 74° 9' to 75° 10' E long. A detailed description of the physical environment of Uttara Kannada district is available in Bhat *et al.* (2000b). This district is richly endowed with forests and about 75 % of the total land area (10,291 km^2) is forested. There are broadly four different categories of forests viz., tropical evergreen, semi evergreen, moist deciduous and dry deciduous. The district receives an average annual rainfall of 3500 mm near the coast to more than 5000 mm along the ridge of the hills and it is mainly from the southwest monsoon, concentrated during the months of June to September. The vegetation of the district is of evergreen/semi-evergreen type along the slopes and towards the east of the ridge, it is moist deciduous (Pascal 1982, 1984, 1986). Champion & Seth (1968) classified the forest on the western slopes as tropical evergreen and those on the eastern side as south-Indian moist deciduous forests.

Permanent plots

Data on species composition, structure and other related parameters were collected from 1-ha (100 m x 100 m) permanent plots in evergreen and deciduous forest types in Sirsi, Siddapur and Mundgod taluks of Uttara Kannada district. There are six 1-ha forest plots representative of evergreen forest zone and another six 1-ha plots representative of deciduous forest zone. Evergreen plots were selected in three locations namely Ekkambi, Tattikai and Hosur. Similarly, deciduous plots were selected at 3 locations namely, Malgi, Hudelakoppa and Togralli. At each location, two 1-ha plots were selected; one 'less disturbed' and one 'more disturbed' based on proximity to human habitation and number of cut stems. At all sites, woody plants, including tree saplings, lianas, climbers, etc., > 10 cm DBH (Diameter at Breast Height) mapped within each permanent plot were identified to the species level following Cooke (1967), but in case of uncertainty they were identified up to genera or family level and doubtful entities were recorded as unknown I, II, III… etc., ensuring within a plot unknown I was a unique species. If there were branches, branches of a tree with a DBH $\geq$ 10 cm were noted as stems and marked respectively as A, B, C etc., and diameter measured and noted. A red strip was painted on each tree and stem at the breast height. For convenience in enumeration, each 1-ha plot has been split into 5 strips (20 × 100 m) and each tree numbered with embossed metal tag. DBH was measured at 1.3 m, except for trees with buttresses, where we report diameter measured 10 cm above the buttresses to minimize errors in biomass estimates (Clark 2004). Shannon Wiener's diversity index (H') and Simpson index was calculated. The KS test was done following Zar (1985) and Morishita-Horn similarity index test as given by Magurran (1988) was performed. Total above-ground biomass was estimated by applying the allometric equation developed by Murali *et al.* (2005).

Results

Species number, density and diversity

Tropical forests are extremely diverse (Simpson index near zero). The twelve sites studied varied in the degree of diversity as estimated using common indices (Table 1). The permanent plots in the evergreen forest type contained trees belonging to 106 species in Tattikai 'more disturbed' plot to 54 species in Ekkambi 'more disturbed' plot. Among the evergreen plots, the number of species was higher in 2 of the 3 'more disturbed' plots (106 and 68 in Tattikai and Hosur, respectively) as compared to 'less disturbed' plots (Table 1). Among the deciduous permanent plots, highest number of species was recorded in Togralli 'more disturbed' plot (75) and the least in Malgi 'more disturbed' plot (31 species). In the deciduous forest plots also, the number of species was higher in 2 of the 3 'more disturbed' plots (Table 1). Interestingly the number of species in the plots of Western Ghats - a biodiversity hotspot are comparable to those reported by Upadhaya *et al.* (2015) for tropical forests of Garo hills of north eastern India.

Expressed on a common area basis, the frequency of species was highest in the Tattikai 'more disturbed' plot followed by Tattikai 'less disturbed' and Hosur 'more disturbed' plots (Table 1). Least number of individuals was recorded in Ekkambi 'less disturbed' plot. Among the six deciduous plots, the highest number of individuals was recorded in Togralli 'less disturbed' plot (1647 individuals) while the least number was in Malgi

Table 1. Summary of floristic attributes of the permanent plots of the Western Ghats.

	Evergreen						Deciduous					
	Ekkambi		Tattikai		Hosur		Malgi		Hudelakoppa		Togralli	
	LD[1]	MD[2]	LD	MD	LD	MD	LD	MD	LD	MD	LD	MD
Number of species	61	54	78	106	62	68	43	31	56	59	59	75
No. of individuals	1087	1656	2131	2920	1409	2089	928	468	1383	1489	1647	1515
Shannon-Wiener index	3.13	2.93	3.33	3.30	2.86	2.85	2.53	2.12	2.73	2.97	3.09	3.14
Simpson index	0.93	0.91	0.94	0.92	0.90	0.87	0.85	0.82	0.90	0.92	0.94	0.91
Evenness index	0.38	0.35	0.36	0.26	0.28	0.25	0.29	0.29	0.29	0.36	0.39	0.33

[1]LD: 'less disturbed'; [2]MD: 'more disturbed'.

'more disturbed' plot (468 individuals). The total number of species recorded and identified per unit area in the evergreen plots is higher than the number of species reported per hectare (32 and 63 species, respectively) in Chandavar and Santgal evergreen forests of same region (Bhat *et al.* 2000a). The same is true in the case of deciduous forest plots also with the number of species much higher than the 18-24 species per ha reported for the same forest type in the same region by Bhat *et al.* (2000a).

Three of the six evergreen plots presented a tree species diversity with Shannon index greater than 3 (Table 1). The highest value was recorded in the evergreen 'less disturbed' plots of Tattikai, followed by 'more disturbed' plots of the same location and Ekkambi less and 'more disturbed' plots, respectively. Both plots in Hosur have slightly lower diversity index as compared to Tattikai and Ekkambi, with the 'more disturbed' plot having the lowest diversity index of 2.85. Among the deciduous plots, 'more disturbed' Togralli plot has the highest diversity of 3.14 and that of the 'less disturbed' plot in the same location is 3.09. The remaining plots have recorded a diversity index in the range of 2.12 to 2.97. The concentration of dominance (Simpson index) among the evergreen plots was highest in Tattikai and Ekkambi 'less disturbed' plots. Results exhibit that these forests are ecologically rich in species diversity and complexity. These are in agreement with earlier reports by Singh *et al.* (1984) & Rai (1983). The higher Shannon index compared to the Simpson's index indicates an inverse relationship between these two indices. However, the Shannon index values in the study locations were lower (2.12 - 3.33) compared to the Silent Valley tropical rain forests (3.8 - 4.8). Pascal (1992) reported Shannon index between 3.6 and 4.3 at different altitudes of the Western Ghats. In general, the results of this study are in line with the Shannon and Simpson diversity indices (1.5 to 3.7 and 0.1 to 0.16, respectively) reported by Swamy *et al.* (2010) for tropical wet evergreen forests.

The distribution of species within a population (according to Pielou Evenness) is uniform in almost all the plots - both evergreen and deciduous and less and 'more disturbed', as well. The heterogeneity is highest in Ekkambi 'less disturbed' plot.

A number of structural and functional differences were observed among the sites. Tree density (> 10 cm DBH) was highest among the evergreen plots in Tattikai 'more disturbed' plot (2920 individuals ha^{-1}) followed by 'less disturbed' plot in the same location and Hosur 'more disturbed' plots, respectively. The number of individuals was lowest in the Ekkambi plots. Among the deciduous plots, highest number of individuals was recorded in the 'more disturbed' Togralli plot (1647 individuals ha^{-1}) and the least in Malgi 'more disturbed' plot (468 individuals ha^{-1}). The recorded number of individuals ha^{-1} are much higher than the number of individuals reported per ha by Swamy *et al.* (2010) for tropical wet evergreen forests of the Western Ghats (257 to 644 individuals ha^{-1}).

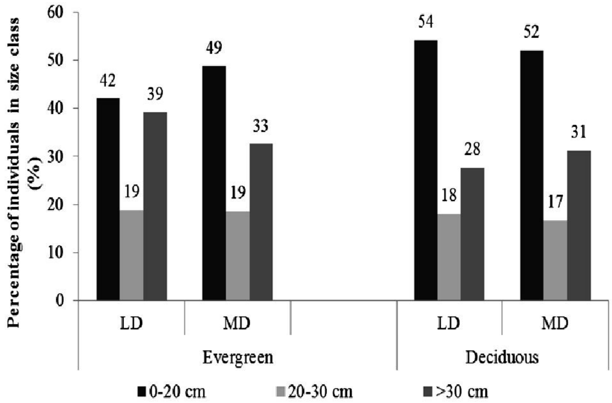


Fig. 1. Overall size class distribution of individuals in evergreen and deciduous forests of Sirsi region of Uttara Kannada district, Western Ghats.

Regenerative capacity of forests

Size class distribution of individuals in a forest plot indicates the regenerative capacity of the forest. When the individuals are distributed among different diameter classes, it is seen that there are variations in the distribution of individuals across the plots. In the less as well as 'more disturbed' evergreen plots, highest percentage of individuals are in the lower most size class of 0 - 20 cm, and about one-third of the individuals are in the largest size class of > 30 cm (Fig. 1).

The distribution of individuals across size classes in the deciduous plots follows a similar pattern as in evergreen plots (Fig. 1), but the lower most size class has > 50 % of individuals and about 30 % is in the highest size class.

A closer look at the distribution of individuals across different size classes in the individual locations of both evergreen and deciduous forest types reveals that there is higher number of individuals in the 'more disturbed' forest plots than 'less disturbed' plots in all locations, except Malgi. Further, it is interesting to note that among the evergreen plots, there is a significant increase in the number of individuals in the 10 - 15 cm size class as compared to the 0 - 10 cm size class and supports the highest number of individuals in all locations, except Hosur where larger trees of > 30 cm are highest.

Overall, among the evergreen plots, about 69 % of the stems are in the smaller size class of 5 - 15 cm DBH, 21 % are in the mid-size class of 15 - 30 cm DBH and about 10 % are in the largest size class of > 30 cm. The distribution is slightly different among the deciduous plots, particularly with respect to the distribution of individuals in the mid and large size class, although the highest percent (about 67 %) is recorded in the lowest size class. However, the percent individuals in the midsize class (~14 %) is lower than that in the highest size class (~19 %). There was no difference or marginal difference in the percent of trees in the lower DBH class (5 - 15 cm) between evergreen and deciduous forest types. This indicates high level of regeneration in the evergreen as well as deciduous forests of the Western Ghats.

Table 2. Maximum difference values of cumulative frequency of size class distribution of evergreen and deciduous forest plots in different locations (KS test). Values in parenthesis indicate critical limit.

Forest type	Location	*P* value
Evergreen	Ekkambi	0.697 (0.05)
	Tattikai	1.000 (0.05)
	Hosur	0.697 (0.05)
Deciduous	Malgi	0.209 (0.05)
	Hudelakoppa	0.697 (0.05)
	Togralli	0.697 (0.05)
	Pooled	1.000 (0.05)

Regeneration among forests: A comparison of size class distribution among the three evergreen plots indicates that, 2 pair-wise comparisons had maximum difference in size class 5 - 10 cm and the other in 20 - 25 cm and 25 - 30 cm class (Table 2). This pattern indicates that the proportion of individuals present in size class 5 - 10 cm determine the difference in size structure in different communities. This may arise from differential recruitment rate from 1 - 5 cm to 5 - 10 cm class or conversely the differential recruitment rate from 5 - 10 to higher classes. Similarly, among the three deciduous plots, 2 pair-wise comparisons indicate maximum difference in the 10 - 15 cm size class while the third pair shows maximum difference in the lowermost size class of 5 - 10 cm.

Community structure and composition

Among the evergreen plots, in Ekkambi 'less disturbed' forest, *Nephelium longana* is the most dominant species followed by *Saraca indica, Aglaia anamalayana, Vitex altissima* while in the 'more disturbed' plot, *Ixora brachiata* dominates, followed by *Aporosa lindleyana* and *Terminalia paniculata*. In the Tattikai plot, *Eugenia zeylanica* dominates the 'less disturbed' plot while in the 'more disturbed' plot, it is *Aporosa lindleyana,* which dominates the vegetation. *Memecylon um-*

Table 3a. Density of top ten species in the less and 'more disturbed' evergreen plots.

	Ekkambi		Tattikai		Hosur	
	LD	MD	LD	MD	LD	MD
Aglaia anamalayana	105					
Aglaia roxburghii					159	
Alangium lamarkii			70			
Allophyllus cobbe		43				
Aporosa lindleyana		247	62	595		69
Calycopteris floribunda		89				
Casaeria tomentosa		74				
Cinnamomum zeylanica						44
Connaris wightii	23					
Diospyros candolleana			99		149	
Eugenia zeylanica			350			
Flacourtia montana	30			127		
Garcinia cambogea			92			
Garcinia morella			205		28	
Holigarna arnotiana			82	100		74
Holigarna grahmii	78	46				
Hopea wightiana					58	686
Ixora brachiata		314	88		113	155
Knema attenuata	48		95	66	136	124
Lauraceae spp.	38					
Memecylon umbellatum					326	80
Mimusops elengi					37	
Murraya koenigii		104				
Neolitsea spp.						41
Nephelium longana	168					
Olea dioica	73	74	169	342	81	189
Psychotria dalzeli				305		
Psychotria flavida				99		
Randia spinosa		77				
Saraca indica	125					
Symplocos beddomei				93		
Symplocos spp.				97		
Terminalia paniculata		192				
Terminalia tomentosa				102		63
Vitex altissima	89				37	

bellatum and *Hopea wightiana* are the dominant species in Hosur less and 'more disturbed' plots, respectively (Table 3a). Among the top species in all the evergreen plots, *Olea dioca* is found in all the plots.

In the deciduous plots, *Terminalia paniculata* dominates in both the Malgi plots, in 'more disturbed' plot of Hudelakoppa and 'less disturbed' plot of Togralli. In the 'less disturbed' plot of Hudelakoppa, *Aporosa lindleyana* is the dominant species while *Leea indica* is the dominant species in Togralli 'more disturbed' plot. *Calycopteris floribunda*, a climber is one of the top 5 species in all the deciduous plots, except 'more disturbed' Togralli plot. *Murraya koenigii* is among the top ten, common to all the deciduous plots (Table 3b).

Comparison of forests within a location

Among the evergreen forest plots, maximum similarity was found between disturbed and 'less disturbed' forests in Hosur, followed by Tattikai (Table 4). Least similarity between the more and 'less disturbed' forests was found in the Ekkambi plots. Among the deciduous plots, Malgi shared least similarity among the more and 'less disturbed' forests while maximum similarity exists, in the other two locations.

Table 3b. Density of top ten species in the less and 'more disturbed' deciduous plots.

Species	Malgi		Hudelakoppa		Togralli	
	LD	MD	LD	MD	LD	MD
Actinodaphne hookeri						33
Adina cordifolia		9				
Aglaia roxburghii						82
Allophyllus cobbe			107	161	151	
Alseodaphne semecarpifolia			25			
Aporosa lindleyana			253			
Calycopteris floribunda	228	70	137	186	145	
Calophyllum wightiana	21					
Careya arborea		19				
Cassia fistula	22					
Casaeria tomentosa					105	171
Ervatamia heyneana	40	5	22			
Grewia tillifolia	57		39	115		
Holigarna grahmii						70
Ixora brachiata						63
Lagerstroemia lanceolata	44	64		42		
Lagerstroemia parviflora		11				
Leea indica					94	376
Macaranga pelatata					69	59
Mallotus philippinensis				73		
Mappia foetida					84	
Murraya koenigii	38		179	95	181	51
Myristica spp.					97	87
Orophea zeylanica						36
Parvia spp.		5				
Randia spinosa			183	171		
Randia uliginosa	30		113	40		
Tectona grandis		89				
Terminalia paniculata	255	146	109	213	194	
Vitex altissima					56	
Xylia xylocarpa		21				
Zizyphus rugosa	22			39		

Basal area and biomass

Basal area is an indicator of growing stock and biomass production. The basal area recorded across the 6 evergreen plots are comparable and ranges from a high of 43.00 m^2 ha^{-1} in 'less disturbed' Ekkambi plot to 34.09 in Tattikai 'more disturbed' plot. Among all the three locations sampled in the evergreen forest type, the basal area recorded in the 'less disturbed' plots is higher than that of 'more disturbed' plots (Table 5).

In the deciduous plots, the basal area is lowest in the 'more disturbed' Hudelakoppa (29.78 m^2 ha^{-1}) and highest in Togralli 'more disturbed' plot (40.10 m^2 ha^{-1}). In this forest type, in two of the three locations (except Togralli), the basal area recorded is slightly higher in the 'less disturbed' plots as compared to the 'more disturbed' plots (Table 5).

Differences in basal area and biomass are mainly related to both the frequency of individuals and their sizes. In both the forest types and in all the 12 plots, trees > 35 cm contribute the most to basal area and it ranges from 27 % (Hosur 'more disturbed' plot) to 74 % (Ekkambi 'less disturbed') among evergreen plots and 68 % (Hudelakoppa 'more disturbed' forest) to 89 % (Malgi 'more disturbed') among deciduous forest plots (Fig. 3).

The contribution of stems belonging to the lower size class of 0 - 35 cm to the total basal area is highly significant in Hosur 'more disturbed' plot (73 %) and significant in both less and 'more disturbed' Tattikai plots (> 60 %). In the other ever-

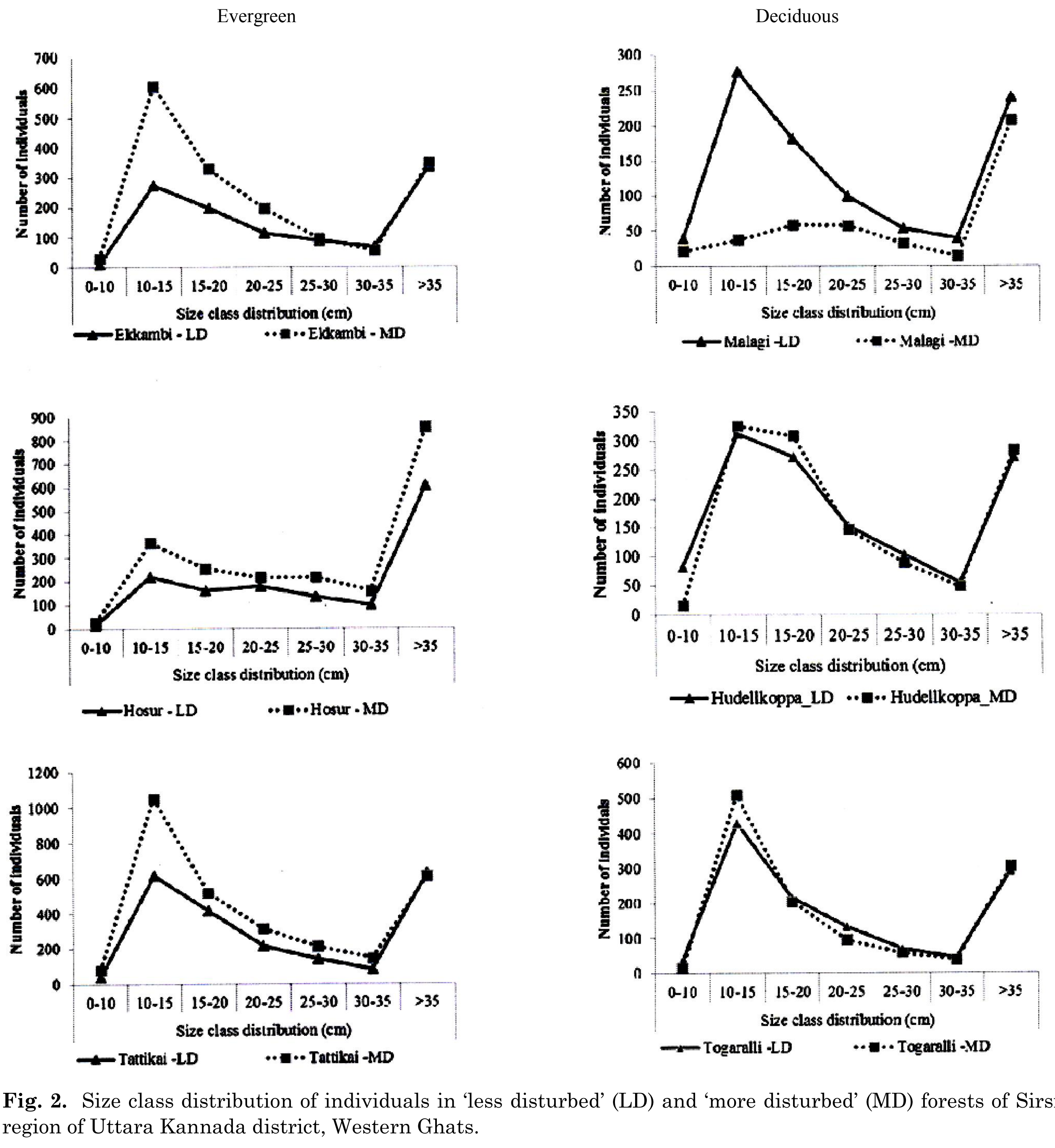
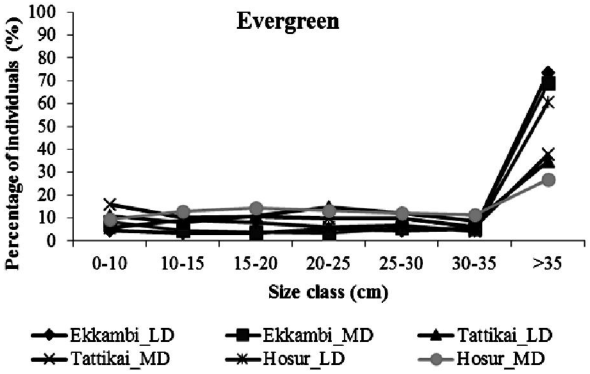


Fig. 2. Size class distribution of individuals in 'less disturbed' (LD) and 'more disturbed' (MD) forests of Sirsi region of Uttara Kannada district, Western Ghats.

green as well as the deciduous plots, the contribution of stems less than 35 cm to the total basal area ranges from 26 to 39 % in the evergreen and deciduous plots, respectively (Fig. 3).

Biomass is calculated using the Murali *et al.* (2005) equation based on basal area. The biomass estimates for the evergreen plots ranges between 267 tonnes in Tattikai 'less disturbed' plot to 332 tonnes per ha in Hosur 'less disturbed' plot (Table 5). Among the deciduous plots, the highest estimated biomass is in 'more disturbed' Togralli plot (302 tonnes ha^{-1}) and the least is in Hudelakoppa 'more disturbed' plot (252 tonnes ha^{-1}). Thus, the average biomass stocks in the evergreen plots is nearly similar (287 ± 24.36 tonnes ha^{-1}) to that estimated for the deciduous plots (280 ± 17.04 tonnes ha^{-1}).

The biomass estimates are within the range of values reported by Swamy *et al.* (2010) for tropical



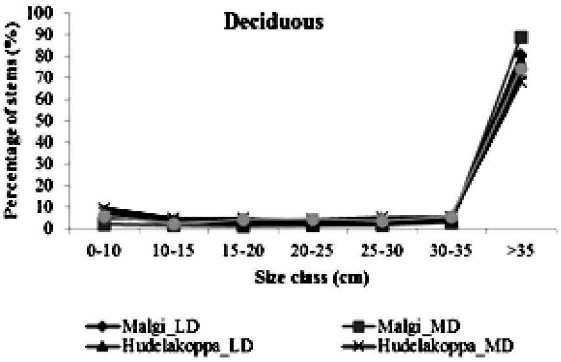


Fig. 3. Percentage basal area contribution of individuals across different size classes.

Table 4. Similarity in species composition among 'more disturbed' and 'less disturbed' forests.

Forest type	Location	Morishita-Horn similarity (%)
Evergreen	Ekkambi	14.5
	Hosur	38.3
	Tattikai	34.7
Deciduous	Togralli	70.6
	Hudelakoppa	82.2
	Malgi	44.2

wet evergreen forests of the Western Ghats. These estimates are all within the range of values reported for other primary neotropical forests by Brown *et al.* (1995), Gerwing & Farias (2000), Chave & Dubois (2001) and Keller *et al.* (2001). The biomass estimates of the present study are also within the range and comparable to the standing biomass of other tropical forests (Table 6). The biomass estimates are, however, higher than those reported by Silva (2015) for forests of Puerto Rico. There are variations and these may be attributed to factors such as forest type, growing conditions, non-random sampling, within site variance, etc. (Francis 1984 & Ku *et al.* 1981).

Discussion and conclusions

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 Mha yr^{-1} (FAO 1995). Furthermore, this comes at a time when our knowledge of their structure and functional dynamics is woefully inadequate (Sundarapandian & Swamy 2000). The conservation of biological diversity has become a major concern for the human society. Understanding structural status and functional dynamics of the forests is essential for biodiversity conservation and sustainable management of fragile ecosystems.

Regeneration in the forests is an indicator of the well-being of the forest. Degradation is argued to reduce species number, stem density and regeneration potential of the forests (Bhat 2000a; Murali 1996 & Murthy *et al.* 2002). Similar observations are made in this study where all the evergreen plots and one deciduous plot (Malgi) shows low species diversity in 'more disturbed' forests compared to the less-disturbed forests. However, in Hudelakoppa and Togralli deciduous plots, higher species diversity was recorded in the 'more disturbed' forests than in less-disturbed forests. This could possibly be attributed to the fact that whenever there is disturbance, particularly of the intermediate-level, the species number tends to increase (Connell 1978). Regeneration may also be affected by human activities such as fire (Sukumar *et al.* 1992, 1998) and logging (Guariguata & Dupuy 1997) or by natural phenomena such as light gaps (Welden *et al.* 1991). The differences however, were not statistically significant.

There are variations in the size class structure of individuals in all the locations. There are differences in size structure of individuals between the more and 'less disturbed' forests of all the locations. The variation is particularly in the DBH size class 10 - 15 cm category. However, there are no major differences in the distribution of individuals in the regenerating 0 - 10 cm category irrespective of whether the plot is more or 'less disturbed', an indicator of disturbance not actually

Table 5. Basal area and biomass in twelve 1-ha permanent plots of the Western Ghats region.

		Location	Number of individuals	Basal area (m^2 ha^{-1})	Biomass (tonnes ha^{-1})*
Evergreen	'less disturbed'	Ekkambi	1087	43.00	417
		Hosur	1409	42.95	417
		Tattikai	2131	34.61	348
	'more disturbed'	Ekkambi	1656	36.53	364
		Hosur	2089	39.04	385
		Tattikai	2920	34.09	344
Deciduous	'less disturbed'	Malgi	928	34.10	344
		Hudelakoppa	1383	33.68	341
		Togralli	1647	36.19	361
	'more disturbed'	Malgi	468	33.67	340
		Hudelakoppa	1489	29.78	308
		Togralli	1515	40.10	393

*includes aboveground tree biomass and belowground biomass (26 % of aboveground biomass.

Table 6. Estimates of biomass across tropical forests.

Forests	Location	Total biomass (t ha^{-1})	Reference
Moist disturbed open-closed forest	Bangladesh	85-190	Drigo *et al.* 1988
Tropical rain forests	Cambodia	348-415	Hozumi *et al.* 1979
Tropical moist dense forests	Cambodia	70-295	FAO 1971
Tropical moist mixed dipterocarp forests	Sarawak, Malaysia	325-385	FAO 1972
Tropical moist evergreen-high yield	Sri Lanka	370-520	
Tropical moist evergreen-medium yield	Sri Lanka	365-470	FAO/UNDP 1969
Tropical moist evergreen-low yield	Sri Lanka	190-400	
Tropical rain forest	Western Ghats, India	458	Rai 1984
Montane rain forests	New Guinea	505	Edwards *et al.* 1977
Tropical dry high to low volume closed forests	India	16-81	GOI 1972
Tropical evergreen forest	Myanmar	10-200	FAO 1985
Tropical wet evergreen forest	Western Ghats, India	439-587	Bhat *et al.* 2000a
Tropical evergreen and deciduous forests	Western Ghats, India	388-525	Present Study

hampering regeneration potential. However, caution needs to be exercised as over time, it may affect the future of the forests. There is, therefore, a need to inform the communities of the impact of extraction and its effect on regeneration so as to motivate them to adopt what may be termed as "adaptive resource management", so as to sustain the flow of forest products.

When biomass stock estimates are considered, there was no significant difference between evergreen and deciduous forests. The difference between 'less disturbed' and 'more disturbed' forests is also lower. Thus, the biomass and carbon stock has not been impacted despite the dependence of communities on the forests. Periodic and long-term monitoring of the status and dynamics of the forests is necessary in the context of potential increased human pressure and climate change.

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