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PLANT DIVERSITY ALONG DISTURBANCE GRADIENTS IN TROPICAL MOIST DECIDUOUS FORESTS OF EASTERN GHATS OF INDIA

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Abstract

Plant species diversity and community structure were studied in three tropical moist deciduous forest stands of Eastern Ghats of India experiencing different levels of disturbance. The forest stands were classified as undisturbed (UD=4.0 ha), moderately disturbed (MD=4.0 ha) and highly disturbed (HD=4.0 ha) categories based on the types and levels of human-induced disturbances. Twenty four transects, each measuring 0.5 ha (5m×1000m) were laid and 388 species of plants (trees, shrubs, climbers and herbs) were enumerated. A total of 5451 numbers of trees (with $\geq$30 cm GBH) belonging to 101 species under 78 genera and 37 families were recorded from the sample plots. Tree density and basal area showed a declining trend with the increase in disturbance intensity. While the stand density (stems ha^{-1}) varied from 744 in undisturbed to 185.50 in highly disturbed sands, basal area (m^2 ha^{-1}) decreased from 36.95 in undisturbed to 12.54 in highly disturbed forests. The tree density and species richness decreased with increasing girth class; highest number of species and maximum density was recorded for trees of 30-60 cm girth class in all three stands. Shannon, Simpson, Fisher's alpha and Margaleff's indices varied greatly across the stands experiencing different levels of disturbance. Taking into consideration the other life forms within the study area, the dominance of trees in undisturbed forests, shrubs and lianas in moderately disturbed and herbs in highly disturbed forests were observed.

Key words: Tree species, moist deciduous forests, disturbance, biodiversity indices.

Introduction

Tropical forests are biologically rich and they provide ideal habitats for more than half of the plant species diversity of the world (Hubbell and Foster, 1983; May and Stumpf, 2000). However, habitat destruction and other human-induced disturbances have brought about considerable degradation of tropical forests and consequent decline in global biodiversity. The diversity, structure and composition of tropical forests are strongly altered by natural and anthropogenic factors on different spatial scales (Peña-Claros *et al.*, 2012; Sheil and Burslem, 2003; Peres *et al.*, 2006). The relationships between disturbance and plant biodiversity in tropics have been studied by several workers (Pandey and Shukla, 2003; Sagar *et al.*, 2003; Mishra *et al.*, 2004; Zhu *et al.*, 2007; Sahu *et al.*, 2008) and it has been established that, in general, these disturbances modify the environmental conditions, ecosystem processes, availability of nutrients and interaction among plant species (Sheil and Burslem, 2003; Walker, 2012. Besides other indicators, the changes in floristic composition as a result depletion of biological diversity due to human-induced disturbances, is reflected in alteration of community attributes (Dansereau, 1960). The impact of disturbance on the structure and composition of forest may vary depending on the sites, intensity, frequency of interference, the characteristics of forests and their differential responses to disturbances.

Studies carried out in several parts of the world indicate that with increase in the frequency and intensity of disturbance, plant diversity and other associated vegetation attributes decrease (Peltzer *et al.*, 2000; Sapkota *et al.*, 2009; Takafumi and Hiura, 2009; Pretto *et al.*, 2010; Mayor *et al.*, 2012). While some studies suggest that disturbance reduces density, basal area and species diversity in forests (Chittibabu and Parthasarathy, 2000; Ramirez-Marcial *et al.*, 2001; Mishra *et al.*, 2004; Nath *et al.*, 2005; Muhanguzi *et al.*, 2007), others are of the view that intermediate disturbance maintains or even increases species diversity (Mishra *et al.*, 2004; Banda

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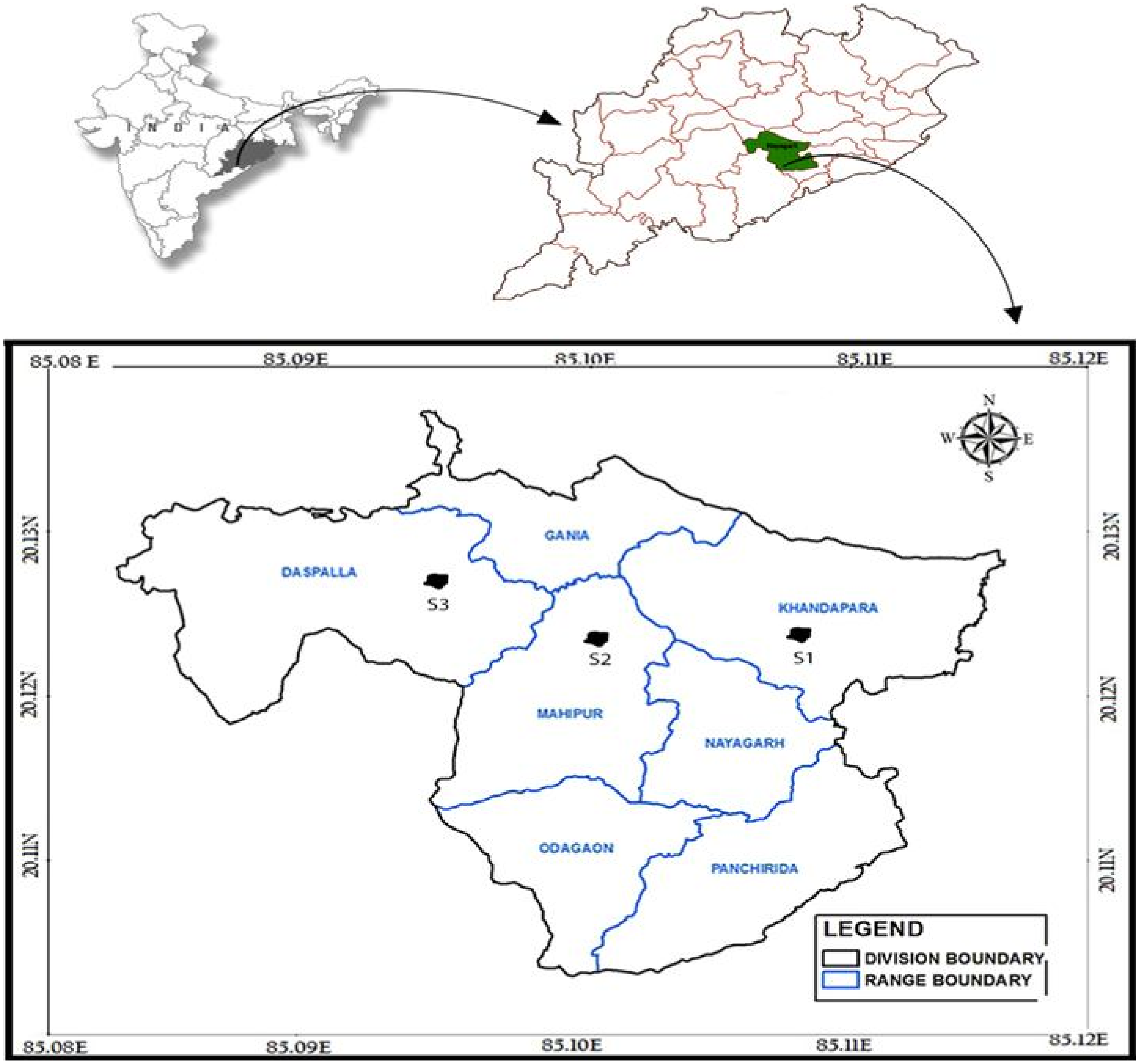

Fig. 1: Location map of Nayagarh Forest Division showing the three study sites (S1, S2, S3).

et al., 2006; Sahu *et al.*, 2008; Budke *et al.*, 2010). Of all plant life-forms, trees, because of their size, volume, dominance and economic and ecological significance are considered as robust indicators of landscape scale level change in forest ecosystems (Khan *et al.*, 1997). In tropical forests, the diversity of tree species varies by geography, habitat parameters and levels of disturbance (Whitmore, 1998). In India, habitat destruction, over exploitation, pollution and invasion of alien species have been identified as major causes of biodiversity loss (UNEP, 2001) and these disturbances determine ecosystem dynamics of forests and tree diversity at the local and regional scales (Burslem and Whitmore, 1999; Hubbell *et al.*, 1999) and are considered important in structuring communities (Sumina, 1994).

Though several studies have been carried out in India to understand the tree species composition, dispersion and diversity along disturbance gradients in the Himalayas (Silori, 2001; Bhuyan *et al.*, 2003; Kumar and Ram, 2005; Uniyal *et al.*, 2010; Pokhriyal *et al.*, 2012; Gautam *et al.*, 2016; Malik *et al.*, 2016), North Eastern India (Rao *et al.*, 1990; Mishra *et al.*, 2004; Dutta and Devi, 2013; Majumdar and Datta, 2015), Western Ghats (Daniels *et al.*, 1995; Sundarpandian and Swamy, 2000; Anitha *et al.*, 2009; Jaykumar and Nair, 2013; Murthy *et al.*, 2016), central and north India (Pandey and Shukla, 1999; Sagar *et al.*, 2003; Sagar and Singh, 2006; Sahu *et al.*, 2008; Kala and Dubey, 2012; Kala, 2015), such information are scanty in respect of the moist and dry deciduous forests of Eastern Ghats region except those of

(Chittibabu and Parthasarathy, 2000; Sahu *et al.*, 2012).

In view of growing threat to biodiversity in Eastern Ghats of India, it is important to assess the impact of human-induced disturbances on natural communities and their structural attributes for formulation of appropriate conservation and management strategies (James *et al.*, 2001; Bhuyan *et al.*, 2003). The present study was undertaken to assess the impact of different intensities of disturbance on tree species diversity and community composition in three forest blocks of Nayagarh Forest Division of Eastern Ghat region of Odisha, India.

Material and Methods

Study area

This study was conducted in representative sample plots in moist deciduous forest patches located in three Reserve forests (Central RF, Radadimaua RF and Sapua RF) of Nayagarh Forest Division, Odisha, India (Fig. 1). The study area lies between 84° 20' - 85° 19' E longitude and 19° 54' - 20° 28' N latitude and occupies an area of 3067.28 sq. kms. The altitude varies in the range of 47m to 932 m above MSL. Out of the three reserved forests, Central RF (9686 ha) of Daspalla range is surrounded by villages such as Similisahi, Pokharigochha, Kutibari; Radadimada RF (4553 ha) of Mahipur range is located close to the villages Maichelli, Singharapalli; and villages such as Jagannath Prasad, Koska, Sidhamala surround the Sapua RF (7984 ha) of Khandapada range. The peripheral villages are dominated by tribal communities and poor people, who largely depend on rain-fed agriculture and NTFP collection from the adjacent forests during lean periods. The villagers regularly collect firewood, wild fruits, vegetables, tubers and other seasonal forest produces and take their domestic animals like cows, goats and sheep to forests for grazing throughout the year. The male members also get involved in illegal timber extraction for own use and sale in cities like Bhubaneswar, Berhampur and Cuttack through local middlemen. The forests of the area experience tremendous biotic pressure and as a result, the structure and composition of forests have been dramatically altered during the last 3-4 decades.

The study area experiences three prominent seasons - hot summer, humid rainy reason and moderately cold winter. The temperature goes up to 44°C in summer to as low as 8°C in winter. The relative humidity ranges from 70% to 90%. The mean annual rainfall is about 1500 mm, most which is received during the monsoon season from June-September. The rock types belong to Khondalite, acid charnockite, garnetiferous granite gneiss, granulites, quartz and sandstones with overlying deposits of laterite and recent alluvium. The soils of the study sites are well-drained, fine loamy in texture and acidic in reaction.

Field methods

The moist deciduous forest patches in Central RF, Radadimaua RF and Sapua RF of Nayagarh Forest Division were identified on the basis of information available in recent Working Plans of State Forest Department for the Nayagarh Forest Division, interaction with forest officials and preliminary survey of composition of the forests, dominant species and their common associates by the authors.

In all three Reserved Forests (Central RF, Radadimaua RF and Sapua RF), the villages are located in the forest fringes and the villagers travel a distance of 1-8 km for collection of NTFP and grazing of animals, the nearby forests being the most frequently visited sites. Based on the distance of sample plots from the nearby village-clusters and intensity of anthropogenic disturbances described above, the sample plots has been classified into highly disturbed (HD), moderately disturbed (MD) and undisturbed (UD) categories. The highly disturbed (HD) forest stands (0.5 ha. × 8) are located within 2 km distance from the village clusters, very close to the roads and experience biotic interferences of highest intensity. The moderately disturbed (MD) sample plots (0.5 ha × 8) lie at a distance of 3-4 km from the villages with moderate

Table 1: Scoring of disturbance factors (estimated, relative impact factors) in Highly Disturbed (HD), Moderately Disturbed (MD) and Undisturbed (UD) stands in tropical moist deciduous forests.

Source of impact	Relative impact		
	HD	MD	UD
Road	5	3	1
Agricultural land	5	2	0
Habitation	5	3	1
Market	4	2	0
Cutting and lopping	4	3	2
Grazing	4	4	2
Scraping	5	2	0
Canopy cover (Based on eye estimation)	2	3	4
Disturbance index based on tree stumps	24.05	9.21	1.71
Total	**58.50**	**31.21**	**11.71**

Note: Disturbance Index= (Number of Tree stumps/Total no of Trees including tree stumps)×100. Canopy cover (Based on eye estimation)=(0-20)%=1, (20-40)%=2, (40-60)%=3, (60-80)%=4, (80-100)%=5.

Table 2: Taxonomic composition of plant species in highly disturbed (HD), moderately disturbed (MD) and undisturbed (UD) forest stands.

	No. of species				No. of	No. of
	HD	**MD**	**UD**	**Total**	**genera**	**families**
Trees	62	72	77	101	78	37
Shrubs	17	35	30	49	39	23
Climbers/Lianas	22	43	27	51	43	21
Herbs	138	122	70	187	121	31
Total	239	272	204	388	281	75

level of disturbances and the sample plots (0.5 ha × 8) of undisturbed (UD) category were taken from forest stands situated at a distance of more than 5 km from the village-clusters and had almost no biotic pressure in terms of resource extraction, grazing and other human impacts. The disturbance factors have been identified and relative impact of each of them has been scored based on field data and visual observations (Table 1).

The human induced disturbances include cutting and lopping of trees, shrubs and lianas for firewood, fodder, house construction; collection of wild fruits, leafy vegetables, tubers for household consumption and sale, removal of ground cover by grazing animals, scraping of forest floors by locals, collection of mahua (*Madhuca longifolia var. latifolia*) flowers in summer season for making a country liquor and setting of fire for cleaning of forest floors for NTFP gathering. The disturbance gradients with estimated relative impact on each of the three tropical moist deciduous forest patches are shown in table 1. Disturbance Index (DI) was calculated as the proportion of number of cut stumps to the total number of standing trees (stems) in a sample plot, expressed as percent (Murali *et al.*, 1996). The sites nearer to roads, agricultural lands, human habitations and local market places exert more collection and utilization pressure. For example, the site with maximum distance from road, agricultural land, habitation or market place was given the impact factor 1 and those located very close was given an impact factor of 5. Grazing by domestic animals, scraping, presence of wild animals and canopy covers were assigned relative impact factor in the scale of 1-5 by direct field observation and eye estimation.

The density, frequency and basal area of the tree species (GBH>30 cm) were estimated in randomly placed belt transects of 1000m × 5 m (0.5 ha) in each forest stand. A total of 24 transects, eight transects in each UD, MD and HD sites were laid for tree enumeration. The number of individuals of each tree species with $\geq$ 30 cm GBH were counted and girth at breast height (GBH) was measured at a height of 1.37 m above the ground. The seedlings/ saplings, shrubs and climbers were enumerated from two 5m × 5m quadrates and herbs from two 1m × 1m quadrates located within each transect for the purpose of comparison of diversity of life forms.

Plants were identified using regional floras (Haines 1921-25 and Saxena and Brahmam, 1994-96) and by comparing the specimens with authentic herbarium specimens available in different Indian Herbaria (CAL, DD, RRL-B, RPRC). The dried and processed herbarium specimens were stored in the Herbarium of Regional Plant Resource Centre (RPRC), Bhubaneswar, India.

Data analysis

In order to make a quantitative assessment of tree diversity, the frequency (percent of all transects in which a species was present), density (ratio of total number of trees to total number of transects) and abundance (ratio of total number of trees to total number of transects of occurrence) were determined. The relative importance of each species in the community was evaluated by calculating the Importance Value Index (IVI), where the relative values of frequency, density and basal area (BA) for a species was derived as the value expressed in terms of percentage of the sum of the values for all the species in the sampled plots (Curtis and Mcintosh, 1950; Mueller-Dombois and Ellenberg, 1974). The girth (GBH) was converted into basal area (BA) as BA= $GBH^2/4\pi$.

The diversity was expressed as Shannon's Index ($H = -\Sigma(n_i/N) \log (n_i/N)$) and dominance by Simpson's index ($Cd = \Sigma(n_i/ N)^2$, where n_i = importance value index of species i, N= sum of importance value indices for the community. Evenness was calculated as Pielou's index ($D= -\Sigma\ p_i^2 / \ln S$), where *S* is the species richness of the

Table 3: Key diversity attributes of trees in highly disturbed (HD), moderately disturbed (MD) and undisturbed (UD) forest stands.

Variable	HD (4ha)	MD (4ha)	UD (4ha)	Total (12ha)
No. of tree species	62	72	77	101
Number of individuals	742	1733	2976	5451
Stand density (No. of stems ha^{-1})	185.50	433.25	744.00	454.25
Total basal area (m2)	50.18	93.10	147.80	291.07
Stand basal area (m2 ha^{-1})	12.54	23.27	36.95	24.26
Maximum tree GBH (cm)	269	300	360	360
Mean tree GBH (cm)	77.11	69.38	69.29	70.38
Shannon-Weiner Index	3.24	3.20	3.42	3.44
Simpson Index	0.11	0.12	0.09	0.10
Evenness Index	0.78	0.75	0.79	0.74

community (Magurran, 1988). Bray-Curtis cluster analysis (single link) and Rarefaction Curves based on abundance of tree species along the disturbance gradients was performed using the software Bio Diversity Pro 2.0.

Results

Species diversity and distribution

A total of 388 species of plants (trees, shrubs, climbers and herbs) were found to occur in 24 transects (12.0 ha) covering Highly Disturbed (HD), Moderately Disturbed (MD) and Undisturbed (UD) forest stands (Table 2). This includes 101 species of trees, 49 species of shrubs, 51 liana/ climbers and 187 herb species. MD stand was the richest in terms of total species diversity (272 species) compared to HD (239 species) and UD (204 species) forest stands. One way ANOVA revealed that the species richness varied significantly across the three stands ($F_{(2, 22)} = 0.5729$, $P = 0.5761$).

The trees occurring in the study sites belonged to 101 species under 78 genera and 37 families and Rubiaceae, Meliaceae, Fabaceae and Euphorbiaceae were the dominant families in terms of species content. While 77, 72 and 62 tree species were recorded from UD, MD and HD stands respectively, 42 species were found to be common to all. As per Bray-Curtis cluster analysis based on tree species composition and abundance, HD, MD, UD stands had an average similarity of 49.54 and UD and MD forests exhibited maximum

Table 4: Density, basal area and IVI of the ten dominant tree species in Highly Disturbed (HD), Moderately Disturbed (MD) and Undisturbed (UD) stands in tropical moist deciduous forests.

Species	HD			Species	MD			Species	UD		
	Ind	TBA (m2)	IVI		Ind	TBA (m2)	IVI		Ind	TBA (m2)	IVI
Shorea robusta Gaertn.	194	31.849	93.854	*Shorea robusta* Gaertn.	751	48.389	99.741	*Shorea robusta* Gaertn.	1202	58.384	83.290
Lannea coromandelica (Houtt.) Merr.	66	2.136	17.393	*Lannea coromandelica* (Houtt.) Merr.	87	6.117	14.755	*Protium serratum* (Wall. *ex* Colebr.) Engl.	139	7.624	13.227
Diospyros melanoxylon Roxb.	33	2.067	12.204	*Terminalia tomentosa* Wt. & Arn.	75	5.420	14.579	*Cleistanthus collinus* (Roxb.) Benth. ex Hook.f.	165	5.000	12.326
Semecarpus anacardium Linn. f.	33	1.120	9.709	*Cleistanthus collinus* (Roxb.) Benth. ex Hook.f.	114	3.440	14.071	*Lannea coromandelica* (Houtt.) Merr.	102	5.723	10.212
Cleistanthus collinus (Roxb.) Benth. ex Hook.f.	30	0.617	8.910	*Schleichera oleosa* (Lour.) Merr.	39	4.965	11.381	*Buchanania cochinchinensis* (Lour.) M. R. Almeida	135	3.631	9.906
Protium serratum (Wall. *ex* Colebr.) Engl.	23	1.306	8.126	*Semecarpus anacardium* Linn. f.	61	1.386	8.173	*Madhuca longifolia var. latifolia* (Roxb.) A. Chev.	64	7.199	9.449
Schleichera oleosa (Lour.) Merr.	18	1.316	8.079	*Dalbergia lanceolaria* spp. *paniculata* (Roxb.) Thoth.	27	3.369	7.709	*Terminalia tomentosa* Wt. & Arn.	56	4.161	7.610
Cassia fistula L.	16	0.614	6.411	*Diospyros melanoxylon* Roxb.	37	1.184	7.205	*Desmodium oojeinense* (Roxb.) H.Ohashi	60	3.824	7.516
Careya arborea Roxb.	18	0.419	5.685	*Protium serratum* (Wall. *ex* Colebr.) Engl.	29	2.117	5.846	*Mallotus philippensis* (Lam.) Mull.-Arg.	95	2.493	6.821
Desmodium oojeinense (Roxb.) H.Ohashi	17	0.760	5.624	*Buchanania cochinchinensis* (Lour.) M.R. Almeida	35	0.616	5.845	*Schleichera oleosa* (Lour.) Merr.	53	2.885	6.645

Note: *Ind: No. of individuals; TBA: Total basal area; IVI: Importance Value Index*

Table 5: Girth class analysis of trees in Highly Disturbed (HD), Moderately Disturbed (MD) and Undisturbed (UD) stands in tropical moist deciduous forests.

Girth class (cm)	Species richness			Density (Stem ha^{-1})			Basal Area (m2 ha^{-1})		
	HD	MD	UD	HD	MD	UD	HD	MD	UD
30-60 cm	59	64	67	105.750	276.000	402.000	1.458	4.189	6.324
61-90 cm	28	38	48	21.000	59.500	181.250	0.950	2.618	8.029
91-120 cm	13	18	34	17.000	30.500	80.750	1.509	2.733	6.990
121-150 cm	14	16	26	20.500	36.500	52.750	3.012	5.295	7.437
$\geq$151 cm	9	10	18	21.250	31.750	27.250	5.614	8.457	8.169

similarity of 63.79 (Fig. 2). Though maximum number of tree species (77) were recorded from UD stands; more shrub, climber and herb species were found to occur in UD forests compared to HD and MD forest stands. A total of 187 herbaceous species representing 31 families were also collected from the study area; the lowest number of herb species (70) being reported from UD stands.

The diversity indices of trees *viz*. Shannon, Simpson, Evenness Fisher's alpha and Margaleff's indices varied greatly across the three study areas (Table 3). While Shannon's Index varied from 3.20 to 3.42, Simpson Index ranged between 0.09-0.12, Evenness index from 0.75 to 0.79, Fisher's alpha from 14.45 to 16.10 and Margaleff's index for species richness varied between 29.65 and 34.83. The values of Shannon index and Simpson Index are indicative of the facts that UD forests are most diverse in terms of species richness, density and girth class distribution as compared to MD and HD forest stands.

Importance Value Index (IVI)

The IVI of ten dominant tree species of sample plots laid along three disturbance gradients is given in table 4. Being located in tropical moist deciduous forest belts of Eastern India, the single species *Shorea robusta* (Sal) dominated the community with highest IVI in all three human impacted forest stands. In HD forests, *Shorea robusta* recorded highest IVI of 93.85 followed by that of *Lannea coromandelica* (17.39), *Diospyros melanoxylon* (12.20), *Semecarpus anacardium* (9.70) and *Cleistanthus collinus* (8.91). In MD stands, highest IVI was reported for *Shorea robusta* (99.74) followed by *Lannea coromandelica* (14.755) and *Terminalia tomentosa* (14.579). Similarly, *Shorea robusta, Protium serratum*, *Cleistanthus collinus* and *Lannea coromandelica* were quantitatively important in UD forests with IVI of 83.290, 13.227, 12.326 and 10.212 respectively (Table 5).

Stand Density and Basal Area

In the present tree enumeration, 2976, 1733 and 742 stems were counted from HD, MD and UD forest stands respectively. The stand density (744 stems ha^{-1}) was the highest in UD and lowest (185.50 stems ha^{-1}) in HD forest patches. The stand basal area varied from 12.54 m^2 ha^{-1} in HD to 23.27m^2 ha^{-1} in MD and 36.95m^2 ha^{-1} in UD forest stands. The most predominant species *Shorea robusta* (Sal) occupied total basal area of 58.38m^2, 43.34m^2 and 31.84m^2 in UD, MD and HD forests respectively. The stem density was positively and linearly correlated with total tree basal area. The greater the basal area, the lower the coefficient of variation and this relationship implies a more uniform distribution of tree individuals in the study area (Fig. 3).

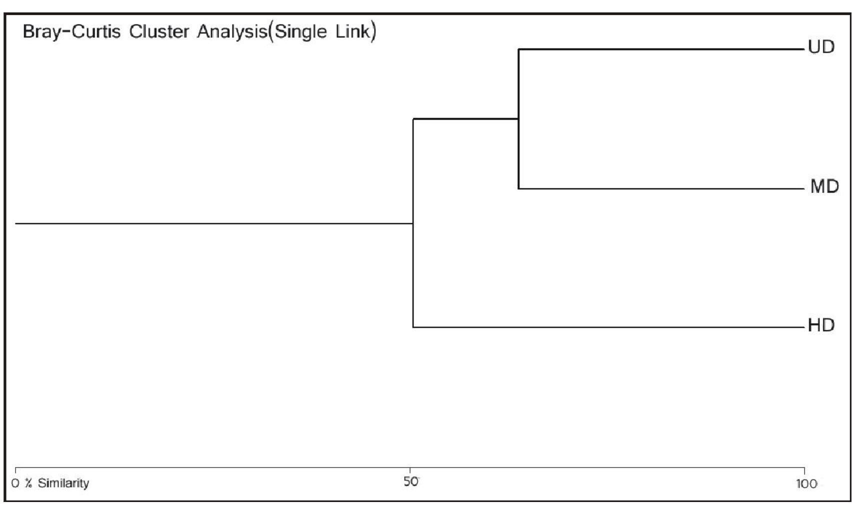

Fig. 2: Bray-Curtis cluster analysis (single link) based on abundance of tree species in the tropical moist deciduous forests of Eastern Ghats of Odisha.

Variation in tree girth

With increasing girth class, the species richness of trees decreased in all the forest stands located along three disturbance gradients (Table 5). In UD forests, maximum of 67 tree species were represented by individuals having lowest girth class (30-60cm); 48 species under GBH range of 61-90 cm and only 18 species with GBH of $\geq$150 cm. In all the three categories of forests, individuals of low girth class (GBH=30-60 cm) were predominant.

The tree density also decreased with increasing girth class in all the study sites.

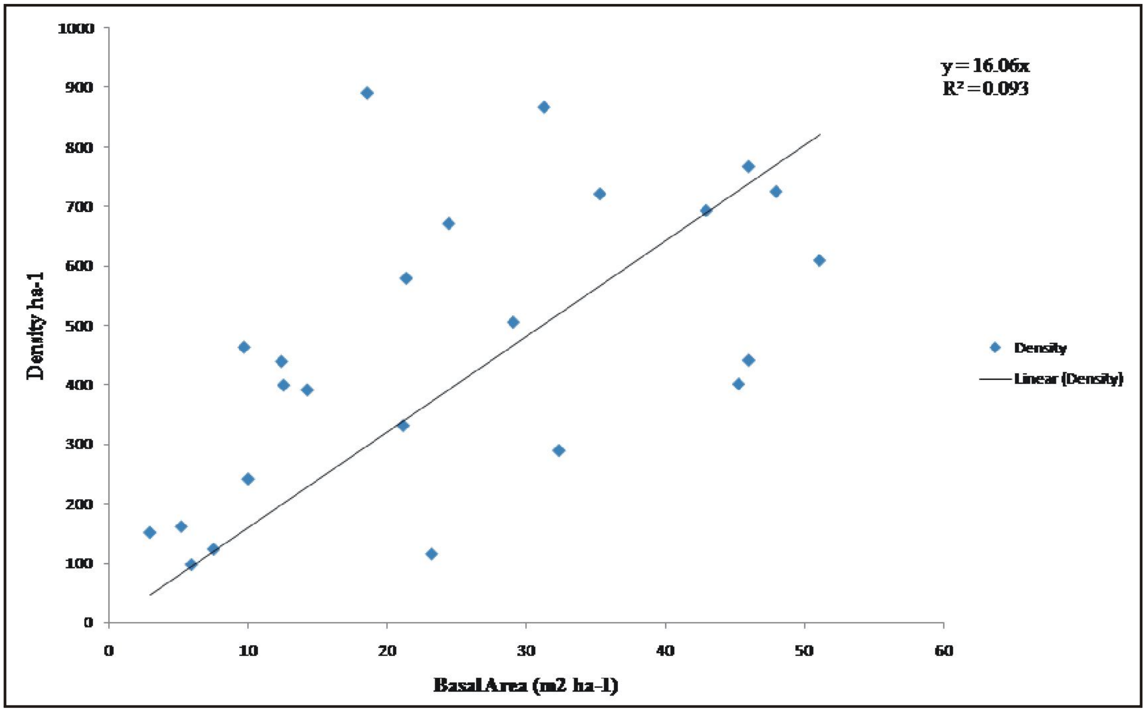

Fig. 3: Relationship between basal area and density in the tropical moist deciduous forests of Eastern Ghats of Odisha.

Maximum density of trees (402 stems ha^{-1}) was observed in the girth class of 30-60cm in UD forests followed by MD (276 stems ha^{-1}) and minimum (105.75 stems ha^{-1}) in HD stands. The number of tree stems having GBH $\geq$150 cm was more (31.75 stems ha^{-1}) in MD and the least (21.25 stems ha^{-1}) in HD forest stands.

The total basal area was the maximum in Undisturbed (UD) forests as compared to MD and HD stands under all five girth classes (30-60, 61-90, 91-120, 121-150 and $\geq$150 cm). Lowest basal area (0.950 m^2ha^{-1}) was recorded under GBH category of 61-90 cm and highest (5.614m^2ha^{-1}) under girth class of more than 150 cm. In MD and UD forests, trees of $\geq$150 cm GBH contributed to maximum basal area of 8.457 m^2 ha^{-1} and 8.169 m^2 ha^{-1} respectively. In spite of low stem density, maximum total basal area was recorded for trees of higher girth classes (121-150 cm and $\geq$151 cm GBH) in all the forest patches experiencing different degrees of human-induced disturbances.

Discussion

The structure and composition of tropical forests are largely altered by human-induced disturbances (Kumar and Ram, 2005; Zhu *et al.*, 2007) but the extent of impact depends on the intensity and nature of such disturbance (Chown, 2010). Species diversity of any particular forest stand is modified by disturbances (Grubb, 1977; Huston, 1979) and is generally low in forests experiencing intense human activities (Peltzer *et al.*, 2000). In the present study, a maximum of 272 species was recorded from MD forests, which is in agreement with the intermediate disturbance hypothesis of Connell, (1978), which advocates the fact that mild and moderate disturbances create conditions that provide opportunities for establishment and growth of fast-colonizing species. In the present study, higher species diversity in MD stands can be attributed to colonization of herbaceous ephemerals (83 species) during monsoon and post-monsoon seasons due to open canopy and consequent availability of adequate sunlight for germination, establishment and growth of herbs.

Several workers are of the opinion that, in general, trees are dominant in the undisturbed forests, shrubs in the moderately disturbed and herbs in the highly disturbed forests. In this particular study, UD forest stands harboured maximum number of tree species (77 species), which corroborates the findings of Behera *et al.*, (2005); Sagar and Singh, (2005) and Sapkota *et al.*, (2009). Further, our observation on the predominance of shrubs (35 species) and climbers/ lianas (43 species) in MD stands compared to UD and HD forests, is in agreement with that of Bhuyan *et al.*, (2003).

Under monsoon climates, the understory vegetation composition varies considerably in different forest types/ sub-types and seasons. Several factors are responsible for this variation, including the composition of over-story vegetation (Sangar *et al.*, 2008), availability of nutrients and moisture in the forest floors (Newbery *et al.*, 1996), successional history of the forest stand (La Frankie *et al.*, 2006) and management strategies adopted (Hart and Chen 2008). Raizada *et al.*, (1998) observed that disturbance favours the growth of annual herbs and/ or short-lived perennials. Out of the 187 species of herbs collected in the present study, 138 species were found to occur in HD forests followed by MD (122 species) and UD forests (70 species). Poaceae, Fabaceae, Acanthaceae and and Asteraceae were the dominant plant families in terms of herb species diversity. Selective removal of trees for timer and firewood by local people results in opening of canopies, which favours the germination and growth of light-demanding short-lived herbs thus, leading to their increased diversity and density. Annual forest fire, grazing and scrapping of forest floors also provide ideal conditions for seed germination and establishment of herbaceous weeds.

It is interesting to note that in the studied sites, tree species such as *Alangium salvifolium*, *Antidesma ghaesembilla*, *Bauhinia purpurea*, *Bauhinia variegata*, *Cordia dichotoma*, *Dillenia pentagyna*, *Flacourtia jangomas*, *Garuga pinnata*, *Mangifera indica*, *Spondias pinnata*, *Terminalia chebula* etc. which produce edible fruits and are used in traditional medicine are absent in HD forests due to selective removal and poor regeneration over the years.

The progressive reduction in density (744/ha to 185.52/ha) and basal area (36.95 m^2/ha to 12.54m^2/ha) of trees from the UD to HD forests was observed in the present study, a finding supported by several other forest inventories from Asia (Bhuyan *et al.,* 2003; Ramirez-Marcial *et al.,* 2001; Smiet, 1992). The decline in stem density along the disturbance gradients may be due to the increased intensity of extraction of timber and fuel wood from forests adjacent to village clusters compared to relatively undisturbed forests away from human habitation. The low basal area of trees in HD forests may be due to selective felling of trees belonging to larger girth class. The reduction in basal area due to human-induced disturbances has also been reported by several workers (Chittibabu and Parthasarathy, 2000; Nath *et al.,* 2005; Anitha *et al.,* 2009).

Both species richness and stem density of trees decreased with increasing girth class except for the larger girth classes (121-150 cm and >150 cm) in MD sites (Table 5). The stem density of trees in the low girth classes (30-60, 61-90, 91-120 cm) was highest in UD stands and gradually decreased with increase in GBH. The decline in stem density with increasing DBH classes has been reported by Ganesh *et al.,* (1996) for evergreen forests of Kalakad - Mundanthurai Tiger Reserve of Western Ghats of India. More pronounced decline in stem density in the low DBH classes compared to the high girth classes, as recorded in the present study is in agreement with the findings of Muthuramkumar *et al.,* (2006) and Sapkota *et al.,* (2009). This may be due to the fact that trees of low girth classes are illegally felled by locals for use as construction materials, fencing and firewood and the ease at which it can be transported out of the forests escaping the notice of forest officials.

It is generally conceived that the dominance of few tree species in any particular forest could be due to adverse habitat conditions, past disturbance or anthropogenic intervention during successional stages of development, which gives advantage to few species selectively (Parthasarathy and Karthikeyan, 1997). As in several other forest inventories, Importance Value Index (IVI) is the most important parameter to understand the community composition and the competitive ability of species in the forest ecosystem. In the present study, the IVI of the top ten tree species across sites located under three disturbance gradients is given in table 4. The predominant species *Shorea robusta* (Sal) scored highest IVI in all the forest stands, which points at the fact that the species has adapted to disturbance by developing certain coping mechanisms in due course of time (Sapkota *et al.,* 2009). Of the other dominant tree species, *Lannea coromandelica* and *Diospyros melanoxylon* scored high IVI of 17.393 and 12.204 respectively in HD forests but species such as *Lannea coromandelica* (14.755), *Terminalia tomentosa* (IVI=14.579), *Cleistanthus collinus* (IVI=14.071) had high IVI in MD stands. The general observations of Visalakshi, (1995) and Kadavul and Parthasarathy, (1999) based on their studies of the forests of Peninsular India that IVIs of the dominant species increase from the undisturbed to the highly disturbed stands was not supported in the present investigation.

The values of diversity indices such as Shannon-Weiner Index, Simpson index and Evenness Index did not follow a definite pattern as per the intensities of disturbance. Shannon Index (3.42) and Evenness Index (0.79) were highest for UD forests and Simpson Index was recorded highest (0.12) for MD forest stands. This is not in conformity with the results of Peltzer *et al.,* (2000), who found an increase in Shannon diversity and evenness index with increasing disturbance. Highest Simpson index value in MD forests and low in HD stands implies that disturbance resulted in low equitability and high dominance because of the selective exploitation of few species. Sapkota *et al.,* (2009) attributed this phenomenon to the heavy dominance of disturbance-tolerant dominant over-storey species in heavily disturbed sites.

In the present study, the diversity, distribution and composition of plant species were found to vary considerably in response to varying levels of human-induced disturbances. The total number of plant species including trees, shrubs, climbers and herbs were maximum in MD forests and minimum in UD forest stands. Maximum number of tree species in UD; shrubs and climbers in MD and herbs in HD forests are reported in the present study. Tree density and basal area declined with increase in intensity of disturbance. Most of the tree species were represented by individuals of low girth classes. Diversity indices also varied considerably along disturbance gradient. The present study revealed that human induced disturbances are responsible for reduction in biological diversity of plants and cause of alternation in structure and composition of forests in Eastern Ghats of India. The results of the study will help in understanding the impact of disturbance on forest vegetation and to formulate appropriate forest conservation and management strategies.

Conclusion

Though tropical forests are rich in terms of vegetation composition and plant species diversity, they are subject to varying levels of human-induced disturbances. As a result, the species diversity, pattern of distribution, composition and structure of tropical forests have been substantially altered during the last few decades. In the present study involving Sal-dominated tropical moist deciduous forests of Eastern Ghats of India, maximum tree species diversity in undisturbed forests and abundance of herbs in undisturbed habitats was recorded. Most of the tree species are represented by individuals of low girth classes and the density and basal area of trees declined with increase in intensity of disturbance. Selective removal of timber and fuelwood species, NTFP collection, grazing and developmental activities in the adjacent areas are responsible for degradation of forests. The findings of the present study will be useful for forest managers in understanding the negative impact of human-induced disturbances on forest biodiversity and shall provide base-level data for formulation of site-specific forest management action plans.

Authors' contribution

TS conducted fieldwork, collected and analysed data and prepared the draft manuscript. LKA helped in statistical analysis and manuscript preparation. PCP identified the plants, guided fieldwork and finalized preparation of manuscript.

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