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Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India

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Abstract. Tree species richness, tree density, basal area, population structure and distribution pattern were investigated in undisturbed, mildly disturbed, moderately disturbed and highly disturbed stands of tropical wet evergreen forests of Arunachal Pradesh. The forest stands were selected based on the disturbance index (the basal area of the cut trees measured at ground level expressed as a fraction of the total basal area of all trees including felled ones): (i) undisturbed stand (0% disturbance index), (ii) mildly disturbed (20% disturbance index), (iii) moderately disturbed (40% disturbance index), and (iv) highly disturbed stand (70% disturbance index). Tree species richness varied along the disturbance gradient in different stands. The mildly disturbed stand showed the highest species richness (54 of 51 genera). Species richness was lowest (16 of 16 genera) in the highly disturbed stand. In the undisturbed stand, 47 species of 42 genera were recorded while in the moderately disturbed stand 42 species of 36 genera were found. The Shannon–Wiener diversity index for tree species ranged from 0.7 to 2.02 in all the stands. The highest tree diversity was recorded in the undisturbed stand and the lowest in the highly disturbed stand. The stands differed with respect to the tree species composition at the family and generic level. Fagaceae, Dipterocarpaceae and Clusiaceae dominated over other families and contributed 53% in the undisturbed, 51% in the mildly disturbed, 42% in the moderately disturbed and 49% in the highly disturbed forest stands to the total density of the respective stand. Stand density was highest (5452 stems ha^{-1}) in the undisturbed stand, followed by the mildly disturbed stand (5014), intermediate (3656) in the moderately disturbed stand and lowest (338) in the highly disturbed stand. Dominance, calculated as the importance value index of different species, varied greatly across the stands. The highest stand density and species richness were represented in the medium girth class (51–110 cm) in all the stands. In the undisturbed stand, the highest density was found in the 111–140 cm girth class, while in the mildly disturbed stand the 51–80 cm girth range recorded the highest density. About 55, 68 and 52% species were found to be regenerating in the undisturbed, mildly disturbed and moderately disturbed stands, respectively. No regeneration was recorded in the highly disturbed stand. Variation in species richness, distribution pattern and regeneration potential is related to human interference and the need for forest conservation is emphasized.

Introduction

The world vegetation cover under natural forests has been depleting fast and a

significant portion of such areas is being converted to man-made plantation forests, mainly of timber trees (Pandey and Shukla 1999), to meet the growing need of the ever increasing human population. We now largely depend on managed forests for wild plant resources, as we do not have much natural forests left. The current pressure on the forest communities for large-scale collection of fuelwood and minor forest products, as well as the practices of grazing and trampling may alter the habitats of many species. As a result there is a lot of spatial and temporal variation in species richness, composition and productivity. A thorough understanding of the dynamics of the forests can help to increase the productivity, to maintain species composition, to limit financial inputs and to develop prescription for silvicultural operations (Oliver and Larson 1990; Bhat et al. 2000) and also to conserve the plant diversity (Murali et al. 1996).

Tropical forests occupy ca. 7% of the earth's area (Myers 1984). In India, they occupy ca. 84% of the total forest cover (637 293 km^2), which is 19.39% of the total geographical area (State of Forest Report 1999). Though the total geographical area of tropical wet evergreen forests is ca. 15 010 km^2 (10.7% of the tropical forest cover of India), phytogeographically these forests are rich in biological diversity (Chandrasekharan 1960). These forests face a serious threat, both natural as well as anthropogenic. Eventually, several species have become endangered. This implies a poor natural regeneration potential of the tree species. Thus, the need to set priorities for conservation of tree diversity has become inevitable. Identification of conservation areas ideally requires exhaustive knowledge of species and ecosystem diversity and distribution (Menon et al. 2001).

Tree regeneration can be predicted by the structure of their populations (Khan et al. 1987). The presence of sufficient numbers of seedlings, saplings and young trees in a given population indicates successful regeneration (Khan et al. 1987). A sustained regeneration and growth of all species in the presence of older plants is required for the growth of any plant community (Taylor and Zisheng 1988). Information on forest composition, effects of biotic and abiotic pressure, type of species surviving and the extent of biomass removal can help in rejuvenation of depleting forest through refinement of silvicultural practices, which must also be compatible with community involvement (Sundriyal et al. 1994; Murali and Setty 2001).

Pimm and Lawton (1998) have referred to the 'cruel twist of fate' whereby current rates of deforestation appear to be highest in the areas with the greatest biodiversity. This is particularly true in the tropics, which have been subject to widespread land-use changes. Remarkably, despite rampant land-use changes in the tropics, certain repositories of biodiversity, such as the northeastern region of India, especially the state of Arunachal Pradesh, have remained relatively untouched due to a variety of factors including ruggedness, remoteness, and inaccessibility. Arunachal Pradesh, by virtue of its geographical position, climatic conditions and altitudinal variations, is a biodiversity-rich region in northeast India with large tracts of tropical wet evergreen, subtropical, temperate, and alpine forests. The state is an abode of many rare, endemic, relic, primitive and endangered species. However, very little information exists on the extent and distribution of the state's biodiversi-

ty. In the absence of spatial data on the distribution and abundance of species, it is difficult to assess the prospect of conservation of biodiversity, both in the immediate future and over time. Unfortunately, due to increasing anthropogenic demands and technological development, the state is no longer immune to large-scale land-use change. The last few decades have seen a major transformation of once pristine landscapes (Menon et al. 2001).

The present study focuses on tree diversity, population status and community attributes of forest stands and the population structure of tree species in forests experiencing differing degrees of disturbance.

Materials and methods

Study area

The study was carried out in the wet evergreen *Dipterocarpus* forests (Kaul and Haridasan 1987) located in the Deomali Forest Division (27°3′–27°13′ N, 95°22′–95°37′ E; altitude 200 m), which correspond to Champion and Seth's (1968) IB/CI Assam Valley northern tropical evergreen forests and represent the climatic climax vegetation of the locality (Figure 1). These forests have been free from human interference over the centuries. This has been mainly due to the very limited human population in the area and the location of the villages on the inaccessible hill top. There is no record of any commercial exploitation of these forests prior to 1948. Some fellings in this area started as early as 1952, mostly for opening up roads. Extraction of timber was taken up in the late 1960s. During the Second World War the army carried out some exploitation of timber and firewood along the road. The first working plan for the introduction of scientific management in these forests was introduced in 1962 and the system of Compensatory Regeneration was adopted. As the all-round development started in the early 1970s, heavy pressure has been built up on these forests. Coffee plantations were developed by Arunachal Pradesh Forest Corporation Ltd. on a trial basis during 1978. *Coffea arabica* and *Coffea robusta* were planted after clearing subcanopy with the object to cultivate a suitable cash crop which can yield revenue during the intermediate period until the main timber species attain maturity and also to know whether there will be any effect on the growth of timber species from planting coffee. The present intensive demands for timber, fuel wood and other minor forest produce, combined with demand for forest land for cultivation, and setting up of industries are putting tremendous pressures on these forests. A large tract of the forests in this area has been disturbed to a great extent.

The four forest stands, having the same age and history, were classified on the basis of a disturbance index (the basal area of the cut trees measured at ground level expressed as a fraction of the total basal area of all trees including felled ones; Rao et al. 1990), into highly disturbed (disturbance index 70%), moderately disturbed (disturbance index 40%), mildly disturbed (disturbance index 20%), and undisturbed (disturbance index 0%). Each stand was located as one patch of the forest and

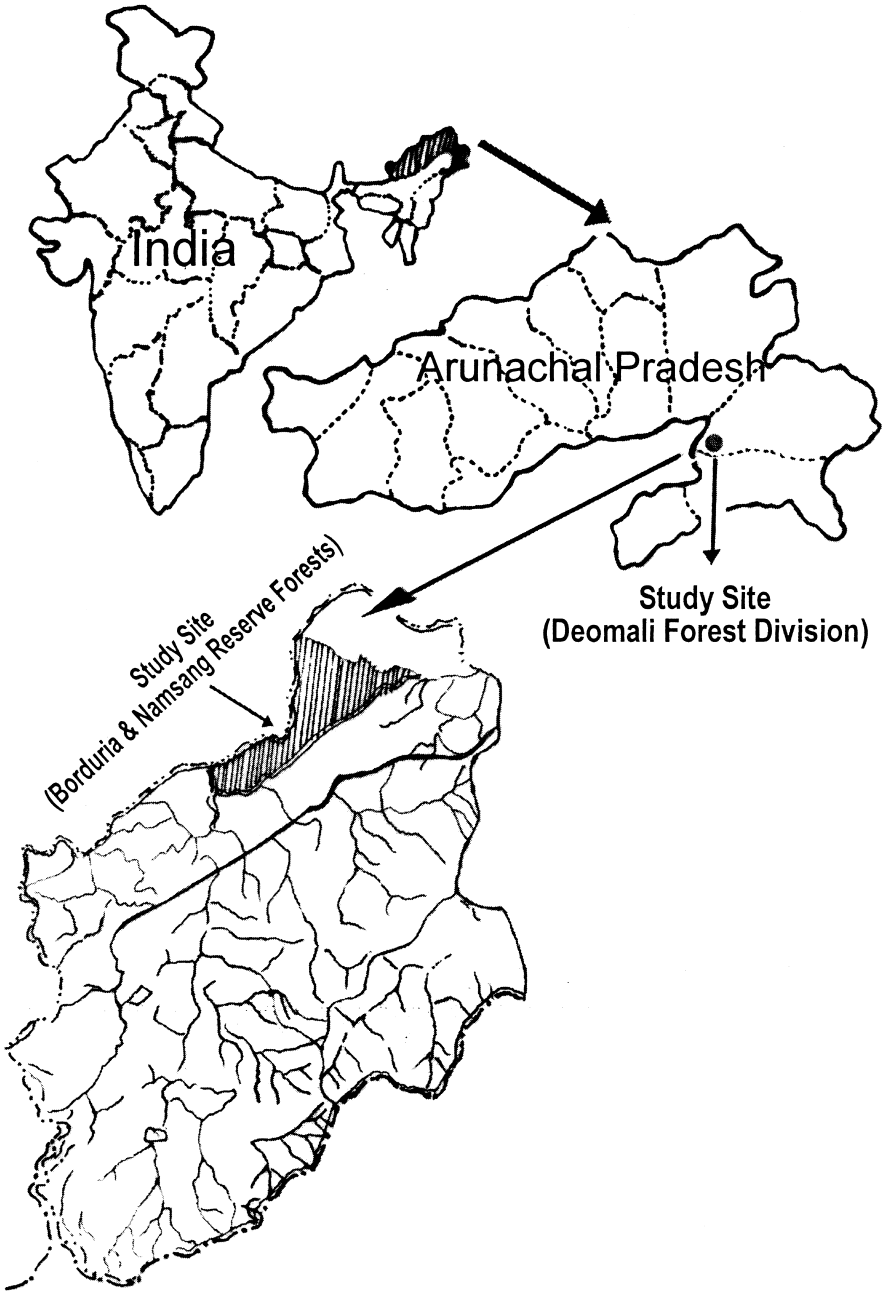

Figure 1. Map showing the location of the study site in the Deomali Forest Division of the State of Arunachal Pradesh, northeast India.

sampling was done within that patch. All the four stands are situated within a radius of 5 km on more or less flat land.

In all the four forest stands vegetation is dominated by an emergent strata of *Dipterocarpus macrocarpus* and *Shorea assamica* along with *Terminalia myriocarpa* and *Altingia excelsa*. The forests exhibit a multi-tiered stratification with an emergent layer occupied by the above species along with *Ailanthus grandis* and *Tetrameles nudiflora*. The main canopy contains *Mesua ferrea, Elaeocarpus ganitrus, E. rugosus, E. aristatus, Bischofia javanica, Turpinia nepalensis, Terminalia citrina, Endospermum chinensis, Aesculus assamicus, Trema cannabina, Talauma hodgsonii, Sapium baccatum, Chisocheton paniculata, Vatica lancifolia, Syzygium* sp., *Mangifera sylvatica, Chionanthus macrophylla*, and *Kydia calycina*. The subcanopy is often gregarious and consists of *Blastus cochinchinensis, Boehmeria glomerulata, Phlogacanthus thyrsiflorus, P. tubiflorus, Leea indica, Maesa indica, Calamus* sp., *Clerodendrum* sp. and *Laportea* sp. The herb layer has *Phrynium pubinerve, Musa* sp., *Impatiens* sp., and *Phegopteris* sp. The epiphytic flora is mainly composed of orchids such as *Dendrobium* spp., *Papilionanthe* sp., *Rhynchostylis* sp., *Agapetes* sp., *Hoya* sp. and *Dischidia* sp. A rare epiphytic pitcher plant, *Hoya rafflesiana*, is also found in these forests.

The climate of the study area is largely influenced by its terrain. The area falls within the tropical climate with well pronounced winter (December–February) and summer (May–September) seasons. Winter months are comparatively cool and dry, and the temperature may drop to 6 °C. However, fog, dew and condensation of moisture is a common phenomenon during winter. The periods October–November and March–April represent the autumn and spring seasons, respectively. During the pre-monsoon period from March onward occasional showers are common. About 85% of the annual rainfall is received during May–September. During this period humidity is very high (80–95%) and it gets warmer when it is not raining. There is hardly a completely dry month in a year. Rains are received by the southwest as well as the northeast monsoons, but maximum rainfall is received from the southwest monsoon (starting from April and continuing until October). During winter the rainfall is received from the northeast monsoon. The hottest months are July and August (max. temperature 36 °C). The mean annual values of climatic variables, which are more or less equal for all the four stands and were obtained from the meteorological station of Arunachal Pradesh Forest Corporation, Deomali Division, are: rainfall, 2500 mm; maximum and minimum temperatures, 27 and 19 °C; and relative humidity 83% (Figure 2).

The soil can be classified into two classes: old alluvial and new alluvial. The old alluvial soil occurs along the river Dihing and contains clay or sandy loam. The new alluvial soil is of recent origin and occurs along the bank of the Dihing river, and covers the older rock formation along the Namsang valley. The texture of soil at different parts varies from sandy loam to clay with 1–5% stone occupied by its volume and pH ranges from 5.5 to 7.5.

Methods

Phytosociological studies were carried out during 1998–1999 using the quadrat

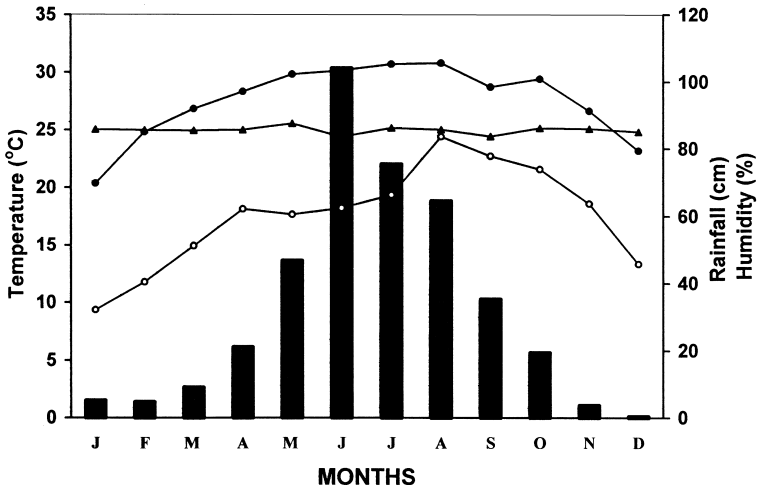

Figure 2. Rainfall, relative humidity and temperature data for the study area during January to December (mean of years 1997–2000); (■) average rainfall; (▲) relative humidity; (●) mean maximum temperature; (○) mean minimum temperature.

method (30×30 m^2 for trees and saplings, 10×10 m^2 for seedlings and shrubs and 1×1 m^2 for herbs within the same 30×30 m^2 quadrat). Ten quadrats were laid randomly in each forest stand for trees, saplings and seedlings. Tree species occurring in each of the quadrats were listed and their circumference was measured. The individuals in the case of tree species were separated into three categories, i.e. (a) seedlings ($\leq$10 cm collar circumference at the base), (b) saplings (10–20 cm collar circumference at the base), and (c) trees (>20 cm circumference at breast height (cbh), i.e. 1.37 m). Density (ha^{-1}) and basal area values were calculated for each tree species. The importance value index for each species was computed by summing up the relative density, relative frequency and relative dominance of the individual $\geq$20 cm cbh. Individuals of species with 10–20 cm collar circumference at the base were considered regenerating plants (Khan et al. 1987; Sundriyal et al. 1994). Regeneration was recorded for each stand to estimate the species status in different stands.

The similarity index (community coefficient) among different stands was calculated according to Jaccard (1912):

$$C_j = j/(a+b-j)$$

where j is the number of species common to both stands, a the number of species in stand A and b the number of species in stand B.

The Shannon–Wiener diversity index (Shannon and Wiener 1963) was calculated from the IVI values using the formula given by Magurran (1988):

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Table 1. Consolidated details of families, genera and species diversity index, concentration of dominance, stand density, basal area and regeneration status of tree species of four forest stands experiencing different degrees of disturbance.

Parameters	Forest stands				
	Undisturbed	Mildly disturbed	Moderately disturbed	Highly disturbed	Variance of means
Species richness	47	54	42	16	274.92*
Number of families	28	31	27	14	56.67*
Number of genera	42	51	36	16	220.25*
Shannon–Wiener diversity index	2.02	1.93	1.99	0.7	0.411^{ns}
Concentration of dominance	0.06	0.06	0.06	0.04	0.0001^{ns}
Similarity index	0.46	0.40	0.43	0.07	0.033^{ns}
Stand density (stems ha^{-1}) (tree + sapling + seedling)	5452	5014	3656	338	5357393*
Basal area (m^2 ha^{-1}) (tree + sapling + seedling)	104.60	51.75	18.60	43.23	1311.13*
Percentage of tree species regenerating	55	68	52	0.0	898.92*

* Significant at the 0.000 level; ^{ns} not significant.

where p_i is the proportion of the ith species and the number of individuals of all the species (n_i/N).

Simpson's index (Simpson 1949) measured the concentration of dominance (CD):

$$CD = -\sum_{i=1}^{s} (p_i)^2$$

where p_i is the same as for the Shannon–Wiener information function.

Results

Tree species richness, dominance, similarity index and basal area

Tree species richness varied according to the disturbance gradient in the different stands (Table 1). The mildly disturbed stand showed the highest species richness (54 of 51 genera). The species richness was the lowest (16 of 16 genera) in the highly disturbed stand. In the undisturbed stand 47 species of 42 genera were recorded, while in the moderately disturbed stand 42 species of 36 genera were found. The Shannon diversity index ranged from 0.7 to 2.02 in the four stands. The highest tree species diversity was recorded in the undisturbed stand and the lowest in the highly disturbed stand. The values of concentration of dominance were similar in the undisturbed, mildly disturbed and moderately disturbed stands, whereas it was lowest in the highly disturbed stand. The similarity index value was maximum in the undisturbed stand and minimum in the highly disturbed stand.

The highest forest stand density (5452 stems ha^{-1}) was recorded in the undis-

turbed stand and the lowest (338 stems ha^{-1}) in the highly disturbed stand. The basal area recorded was highest in the undisturbed stand (104.60 $m^2 ha^{-1}$) and lowest in the moderately disturbed stand (18.60 $m^2 ha^{-1}$) (Table 1).

Plant families, genera and species

Enumeration of plant families, genera and species in different stands showed the presence of 28 families with 42 genera in the undisturbed stand, 31 with 51 genera in the mildly disturbed stand, 27 with 36 genera in the moderately disturbed stand and 14 with 16 genera in the highly disturbed stand (Table 1). Out of the 28 families in the undisturbed stand, eight were represented by more than one genus and 20 by a single genus. Out of the 28 families in the undisturbed stand, 17 families consisted of a single species whereas 11 families had more than one species. Only four genera contained more than one species. Dipterocarpaceae, Clusiaceae, Theaceae and Combretaceae contributed more than 90% to the total stand density. In the mildly disturbed stand, out of 31 families, 13 were represented by more than one species and 18 had single species. Only three genera contained more than one species. In the moderately disturbed stand, out of 27 families 11 were represented by more than one species wherein species of Dipterocarpaceae and Clusiaceae were dominant. In the highly disturbed stand, out of 14 families only two were represented by more than one species. In this stand Dipterocarpaceae and Leguminosae dominated over the other families (Table 2).

Dominance and rarity

Dominance, calculated as the IVI of different species, varied greatly in different stands. *Shorea assamica, Dipterocarpus macrocarpus, Mesua ferrea, Castanopsis indica, Terminalia chebula* and *Vatica lanceaefolia* were dominant species in all the stands except the highly disturbed one. The emergent strata was occupied by *Dipterocarpus macrocarpus, Shorea assamica*, and *Terminalia chebula* in all the stands (Table 3).

Tree density and species richness in different girth classes

Tree stand density and species richness consistently decreased with increasing girth class of tree species from 20 to >200 cm girth (Figures 3 and 4). The highest tree stand density and species richness were recorded in the medium girth class (51–110 cm) in all stands. In the undisturbed stand the highest tree stand density was found in the 111–140 cm girth class, while in the mildly disturbed stand the 51–80 cm girth range recorded the highest stand density. In the highly disturbed stand no tree was recorded of more than 140 cm girth. The highest contribution of tree stand density per girth class to the total density in the undisturbed, mildly disturbed and moderately disturbed stands was recorded in the 51–80 cm girth class (47, 31 and

Table 2. Tree families, genera, species richness and density in four forest stands experiencing different degrees of disturbance.

Families	Undisturbed stand			Mildly disturbed stand			Moderately disturbed stand			Highly disturbed stand		
	Genera	Species	Density	Genera	Species	Density	Genera	Species	Density	Genera	Species	Density
Anacardiaceae	1	1	6	1	1	77	1	1	7	–	–	–
Apocynaceae	1	1	2	1	1	15	1	1	2	1	1	15
Araliaceae	1	1	102	2	2	7	–	–	–	–	–	–
Burseraceae	1	1	224	1	1	145	1	1	151	1	1	11
Chailletiaceae	1	1	4	–	–	–	–	–	–	–	–	–
Clusiaceae	2	2	745	2	2	784	2	2	421	1	1	20
Combretaceae	1	1	312	1	3	236	1	2	165	1	1	11
Dasticaceae	1	1	5	–	–	–	–	–	–	–	–	–
Dilleniaceae	1	1	2	–	–	–	1	1	7	–	–	–
Dipterocarpaceae	3	3	1760	3	3	1485	3	3	974	2	2	135
Elaeocarpaceae	1	2	110	1	2	48	1	1	57	1	1	7
Euphorbiaceae	3	3	93	3	3	243	3	4	241	–	–	–
Fabaceae	–	–	–	2	2	4	–	–	–	–	–	–
Fagaceae	1	1	386	1	1	332	1	1	164	–	–	–
Flacoutiaceae	–	–	–	1	1	12	–	–	–	1	1	9
Hamamelidaceae	1	1	2	1	1	9	1	1	153	–	–	–
Lauraceae	5	5	131	3	3	132	3	4	336	–	–	–
Leguminosae	–	–	–	2	2	2	1	1	64	2	2	75
Loranthaceae	1	1	2	–	–	–	–	–	–	–	–	–
Lythraceae	1	1	53	1	1	74	2	2	40	1	1	11
Magnoliaceae	3	3	285	3	4	303	1	2	186	1	1	4
Melastomataceae	1	1	4	1	1	4	–	–	–	–	–	–
Malvaceae	1	2	2	1	1	4	–	–	–	–	–	–
Meliaceae	2	3	324	3	3	453	1	2	283	1	1	13
Moraceae	–	–	–	2	2	5	1	1	4	1	1	7
Myrtaceae	1	1	73	1	1	39	1	2	3	–	–	–
Rosaceae	–	–	–	1	1	100	–	–	–	–	–	–
Rubiaceae	2	2	30	1	1	24	1	1	21	–	–	–
Sapindaceae	–	–	–	1	1	24	–	–	–	–	–	–
Sapotaceae	2	2	77	1	1	63	1	1	74	–	–	–
Simarubaceae	1	1	140	1	1	39	1	1	18	1	1	13
Sterculiaceae	1	1	7	1	1	7	1	2	100	1	1	7
Theaceae	1	1	461	1	1	122	1	1	152	–	–	–
Thymeleaceae	1	1	100	1	1	5	1	1	2	–	–	–
Urticaceae	–	–	–	–	–	–	1	1	4	–	–	–
Verbenaceae	–	–	–	3	3	126	2	2	23	–	–	–
Unknown	–	–	–	1	1	91	1	1	4	–	–	–
Total	42	47	5452	51	54	5014	36	42	3656	16	16	338

28%), while in the highly disturbed stand it was maximum (54%) in the 81–110 cm girth class. *Dipterocarpus macrocarpus*, *Shorea assamica*, *Mesua ferrea*, *Castanopsis indica*, C*anarium resiniferum*, and *Terminalia chebula* are the dominant species and represent at least one or two life stages in all the four forest stands (Figure 5).

Table 3. IVI of tree species (>20 cm cbh individuals) in four forest stands experiencing different degrees of disturbance.

Species	Undisturbed stand		Mildly disturbed stand		Moderately disturbed stand		Highly disturbed stand	
	Density	IVI	Density	IVI	Density	IVI	Density	IVI
Ailanthus exelsa Linn.	–	–	4	3.34	–	–	–	–
Ailanthus grandis Prain	140	6.11	24	5.12	18	9.83	13	8
Albizia lucida Benth.	–	–	2	1.98	–	–	–	–
Albizia procera Benth.		–	–	–	–	–	42	19.44
Alstonia scholaris Brown	2	1.26	–	–	–	–	–	–
Altingia exelsa Noronha.	2	1.15	9	4.42	27	12.03	–	–
Amoora wallichii King	–	–	9	3.62	–	–	–	–
Artocarpus heterophyllus Lamk	–	–	4	2.8	–	–	–	–
Barceaura sapida Murll.	73	4.11	126	6.76	57	9.57	7	9.41
Bischofia javanica Bl.	9	3.17	106	5.91	177	10.72	–	–
Bombax ceiba Linn.	2	.99	4	2.81	–	–	–	–
Camellia chinensis Linn.	461	22.45	122	10.53	152	4.92		–
Canarium resiniferum Linn.	224	11.91	145	8.74	151	14.30	11	19.43
Castanopsis indica A. DC.	318	18.65	278	16.31	164	18.37	–	–
Chukrasia tabularis Andr. Juss.	4	1.4	–	–	7	1.67	–	–
Chrysophyllum roxburghii G.Don	2	.97	–	–	–	–	–	–
Cinamommum tamala Nees	10	3.03	72	8.63	51	2.38	–	–
Cryptocarya amygdalina Nees	–	–	4	2.28	–	–	–	–
Dalbergia assamica Benth	–	–	4	2.5	–	–	–	–
Dalbergia sissoo Roxb. ex DC.	–	–	52	6.06	–	–	–	–
Dillenia indica Linn.	–	1.13	28	3.43	5.5	5.4	–	–
Dipterocarpus macrocarpus Veque	951	52.3	889	41.96	517	47.34	97	34.54
Duabanga grandiflora Roxb. ex DC		–	22	10.41	34	4	11	9.63
Dysoxylum binectariferum Hk. f. et. bedd.	7	3.35	20	8.41	25	8.53	13	8.53
Dysoxylum procera Hiern.	62	8	212	8	137	10	–	–
Elaeocarpus floribundus Roxb.	2	.97	7	2.77	22	5.05	–	–
Elaeocarpus ganitrus Roxb.	73	4.75	41	4.38	54	6	–	–
Elaeocarpus robustus Roxb	35	5.17	–	–	–	–	–	–
Eugenia praceox Roxb.	5	1.56	–	–	–	–	–	–
Ficus sp.	–	–	3	2.74	–	–	7	5.22
Flacourtia cataphracta Roxb.	–	–	12	5.56	–	–	–	–
Garcinia sp.	213	7.54	94	7.91	70	5.10	–	–
Glochidion arboreascens Bl.	4	1.59	11	4.13	7	2.64	–	–
Gmelina arborea Roxb	–	–	122	5.19	8.5	3.32	–	–
Gynocardea odorata R. Br.		–	–	–	–	–	9	7.43
Heteropanax fragrans (D. Don). Seem	51	1.59	7	–	29	3.48	–	–
Hodgsonia macrocarpa (Bl) Cogn.		–	112	3	101	7.42	–	–
Kydia calycina Roxb.	68	1.59	2	1.79	–	–	–	–
Lagerstroemia parviflora Roxb.	2	1.38	–	–	–	–	–	–
Lagerstroemia speciosa Roxb.	51	1.60	52	3.46	6.5	3.6	–	–
Litchi chinensis Sonnor	–	–	100	2.82	–	–	–	–
Litsea monopetela King.	51	1.68	156	5.13	153.5	3.95	–	–
Litsea salicifolia (Roxb.) ex Nees	60	2.19	–	–	–	–	–	–
Macropanax undulatus Seem.	51	1.92	–	–	–	–	–	–
Magnifera sylvatica Roxb.	5	2.59	77	2.10	7	4.04	–	–
Magnolia sp. Hk.	29	8.93	30	3.59	–	–	–	–

Table 3. (*continued*)

Species	Undisturbed stand		Mildly disturbed stand		Moderately disturbed stand		Highly disturbed stand	
	Density	IVI	Density	IVI	Density	IVI	Density	IVI
Melastoma malabathricum Linn.	4	8.02	4	2	–	–	–	–
Mesua ferrea Linn.	532	26.96	598	37.39	351	31.11	20	13.63
Michalia oblonga Wall. ex Hk. f.	–	–	55	3.52	–	–	–	–
Mimusops elengi Linn.	36	2.14	75	4.84	74	6.25	–	–
Persea bombycina Koster	4	3.33	–	–	34	3.14	–	–
Peterospermum acerifolium Wild	7	2.27	7	2.40	100	5.15	7	6.91
Phoebe goalparensis Hutch.	7	4.28	–	–	97	8.79	–	–
Premna bengalensis Cl.	–	–	4	2.28	115	7.18	–	–
Sapium baccatum Roxb.	7	4.33	–	–	–	–	–	–
Shorea assamica Dyer.	412	33.68	410	43.64	443	39.46	38	18.45
Skamoila[a]	41	4.09	91	11.15	13	9.62	–	–
Spondias mangifera Willd.	–	–	11	6.06	–	–	15	17.22
Syzygium cumini Linn.	68	2.46	39	4.07	33	2.47	33	10.72
Symplocos spicata Roxb	25	9	12	5.38	39	8.73	–	–
Talauma hodgsonii Hk. f. and Thoms.	256	9.82	218	10.78	186	15.14	4	4.41
Talauma procera King.	136	9.63	92	8.95	–	–	–	–
Terminalia chebula Retz	260	12.69	205	10.69	143	10.04	11	9.63
Terminalia myriocarpa Muell.	52	3.76	31	4.3	22	2.99	–	–
Tetrameles nudiflora R.Br.	5	3.90	–	–	–	–	–	–
Toona ciliata Roxb.	4	3.24	–	–	–	–	–	–
Vatica lanceaefolia Bl.	397	15.58	186	10.45	14.5	8.73	–	–
Vangueria spinosa Roxb.	2	1.13	12	4.9	10	7.69	–	–
Ziziphus apetala Hk. f.	30	2.16	–	–	–	–	–	–

[a]Local name.

Regeneration status

Out of the 47 tree species in the undisturbed stand only 26 were found to be regenerating. Thirteen species showed good regeneration (predominance of saplings + seedlings, which contributed more than 90% to the total density of a species), eight species had fair regeneration and five species showed poor regeneration. No regeneration was recorded for other species during our study period. In the mildly disturbed stand, out of 54 tree species 37 were found regenerating, of which 15 species had good regeneration, eight showed fair regeneration and 14 had poor regeneration. Out of 42 species in the moderately disturbed stand, 22 were found regenerating and good regeneration was recorded in nine species, seven species showed fair regeneration and six species had poor regeneration. No regeneration was recorded in the highly disturbed stand (Table 4).

Density of shrubs and herbs

Shrub and herb density are presented in Tables 5 and 6. The highest shrub density was recorded in the undisturbed stand, but the shrub species richness was maximum

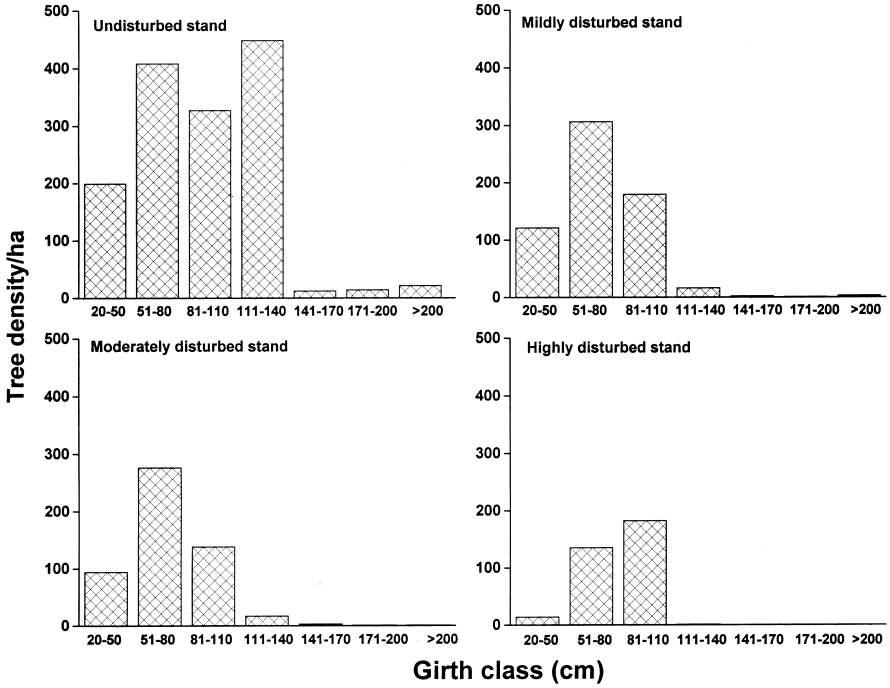

Figure 3. Density of tree species in various girth classes in four forest stands.

in the mildly disturbed stand. In all the stands *Blastus cochinchinensis* and *Litsea salicifolia* dominated over other species. No shrub was recorded in the highly disturbed stand due to collection for fuel wood and other purposes.

Herbs and vines covered the entire ground surface of the forest stands. The undisturbed stand recorded the highest herb and vine density, while the lowest density of these plants was recorded in the moderately disturbed stand. Herb and vine species such as *Cyperus rotundus, Forestia glabrata* and *Pteris quadrissmita* were common to all the stands.

Discussion

The overall structural pattern of the forest community revealed that all the study stands are dominated by *Dipterocarpus macrocarpus, Shorea assamica, Castanopsis indica, Terminalia chebula* and *Vatica lanceaefolia*, with a few exceptions in the highly disturbed stand. All the stands had a highly heterogeneous distribution of trees and can be considered as one of the highly diverse forests in the Eastern Himalaya (Singh and Singh 1987). The undisturbed stand had a high density of tree species due to restricted access of humans.

The emergent layer is occupied by *Dipterocarpus macrocarpus, Shorea as-*

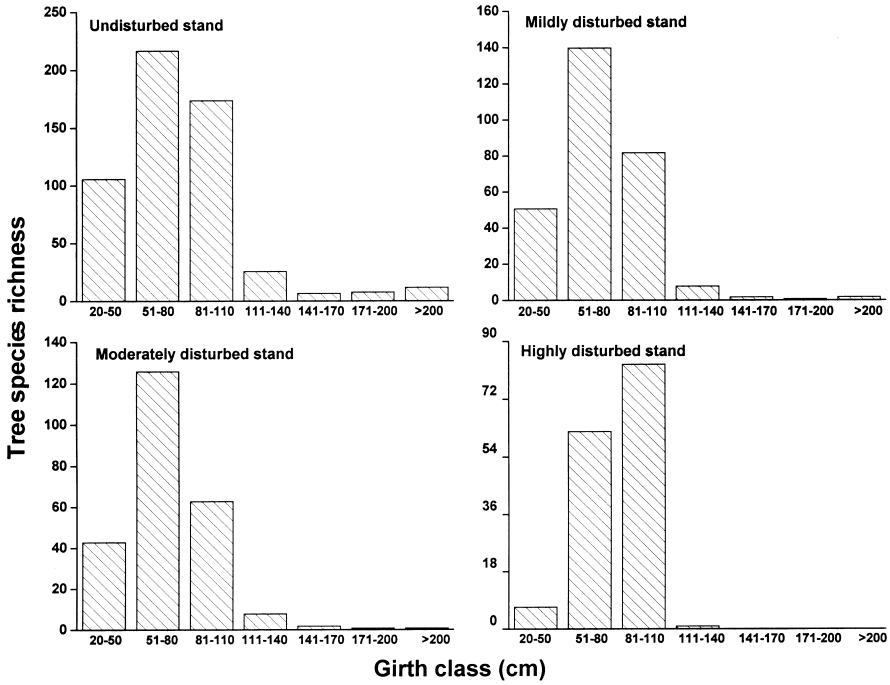

Figure 4. Species richness of tree species among various girth classes in four forest stands.

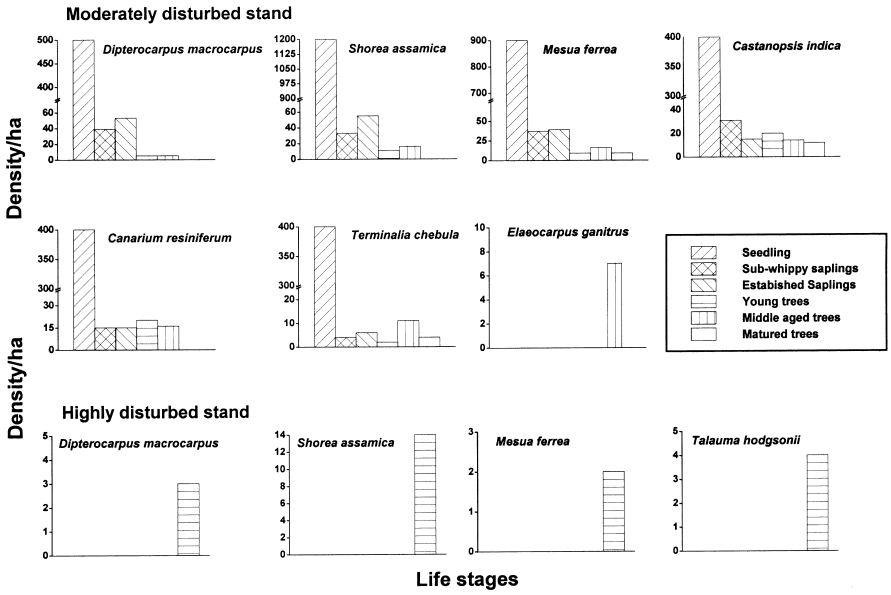

Figure 5. Population structure of some important tree species in four forest stands.

Table 4. Regeneration status of tree species in four forest stands experiencing different degrees of disturbance.

Species	Undisturbed stand				Mildly disturbed stand				Moderately disturbed stand				Highly disturbed stand			
	SE (ha^{-1})	SA (ha^{-1})	Prop. (%)[a]	Status	SE (ha^{-1})	SA (ha^{-1})	Prop. (%)[a]	Status	SE (ha^{-1})	SA (ha^{-1})	Prop. (%)[a]	Status	SE (ha^{-1})	SA (ha^{-1})	Prop. (%)[a]	Status
Ailanthus grandis Prain.	400	9	95	FR	100	6	91	GR	300	115	94	GR	–	–	–	–
Albizia lucida Benth.	–	–	–	–	–	2	#	FR	–	–	–	–	–	–	–	–
Alstonia scholaris Brown.	–	2	50	PR	–	–	–	–	–	–	–	–	–	–	–	–
Altingia exelsa Noronha	–	–	–	–	–	2	77	PR	–	–	–	–	–	–	–	–
Artocarpus heterophyllus Lamk.	–	–	–	–	200	4	#	PR	–	–	–	–	–	–	–	–
Barseaura sapida Murll.	200	9	#	FR	250	18	90	GR	–	–	–	–	–	–	–	–
Bischofia javanica Bl.	–	–	–	–	–	7	31	PR	500	4	97	FR	–	–	–	–
Camellia chinensis Linn.	1200	120	95	GR	600	33	57	PR	–	–	–	–	–	–	–	–
Canarium resiniferum Linn.	600	29	93	GR	700	115	96	GR	400	31	94	GR	–	–	–	–
Castanopsis indica Spach	800	78	92	GR	750	41	71	GR	400	49	91	GR	–	–	–	–
Cinnamomum tamala Nees.	–	15	78	FR	100	9	85	PR	100	–	98	PR	–	–	–	–
Cryptocarya amygdalina Nees	–	–	–	–	–	4	#	FR	–	–	–	–	–	–	–	–
Dalbergia sissoo Roxb. ex. DC.	–	–	–	–	100	–	#	PR	–	–	–	–	–	–	–	–
Dillenia indica Linn.	–	–	–	–	–	–	–	–	–	9	68	FR	–	–	–	–
Dipterocarpus macrocarpus Vesque	2500	120	91	GR	2500	70	96	GR	1400	93	96	GR	–	–	–	–
Dysoxylum procerum Hiern	–	–	–	–	–	–	–	–	200	–	95	PR	–	–	–	–
Elaeocarpus floribundus Bl.	–	–	–	–	–	7	#	FR	–	–	–	–	–	–	–	–
Elaeocarpus ganitrus Roxb.	200	2	92	FR	200	–	78	PR	–	–	–	–	–	–		–
Elaeocarpus robustrus Roxb.	–	35	#	FR	–	–	–	–	–	–	–	–	–	–	–	–
Ficus sp.	–	–	–	–	–	9	#	PR	–	–	–	–	–	–	–	–
Garcinia sp.	600	11	95	GR	300	9	90	FR	200	4	96	FR	–	–	–	–
Glochidion multiloculare Muell.	–	–	–	–	–	4	#	FR	–	7	#	PR	–	–	–	–
Gmelina arborea Linn.	–	–	–	–	250	8	88	PR	–	20	60	FR	–	–	–	–
Heteropanax fragrans D. Don	100	–	98	PR	–	–	–	–	–	–	–	–	–	–	–	–
Kydia calycina Roxb.	200	2	99	FR	–	–	–	–	–	–	–	–	–	–	–	–

Lagerstroemia speciosa (L.) pers	–	–	–	–	–	100	96	PR	–	4	30	FR	–	–	–	–
Litchi chimensis Sonnor	–	–	–	–	–	100	96	PR	–	–	–	–	–	–	–	–
Litsea lacta Benth.	–	2	28	PR	–	–	–	–	–	–	–	–	–	–	–	–
Litsea monopetala (Roxb.)	–	–	–	–	–	100	#	PR	–	–	–	–	–	–	–	–
Litsea salicifolia (Roxb.) ex Nees	100	20	#	FR	200	13	93	GR	–	13	#	PR	–	–	–	–
Magnolia sp.	100	–	77	PR	100	4	96	FR	–	–	–	–	–	–	–	–
Melastoma malabathricum Linn.	500	42	31	GR	–	–	–	–	–	–	–	–	–	–	–	–
Mesua ferrea Linn.	1400	115	94	GR	1650	91	97	GR	900	78	92	GR	–	–	–	–
Michelia oblonga Wall. ex Hk.	–	–	–	–	–	100	98	PR	–	–	–	–	–	–	–	–
Mimusops elengi Roxb.	100	2	93	FR	200	15	98	GR	–	15	68	FR	–	–	–	–
Premna bengalensis Cl.	–	–	–	–	–	11	#	FR	–	15	#	FR	–	–	–	–
Pterospermum acerifolium Willd.	–	–	–	–	–	9	#	PR	–	7	#	PR	–	–	–	–
Shorea assamica Dyer.	1000	153	93	GR	1600	135	84	GR	1200	89	93	GR	–	–	–	–
Sikamiola[b]	100	20	96	GR	200	46	90	GR	–	–	–	–	–	–	–	–
Syzigium cumuni Linn.	200	–	99	PR	150	5	94	GR	–	2	33	PR	–	–	–	–
Spondias magnifera Willd.	–	–	–	–	–	11	#	PR	–	–	–	–	–	–	–	–
Talauma hodgsonii Hk. f. and Thoms.	700	35	73	GR	600	21	96	GR	500	27	96	GR	–	–	–	–
Terminalia belerica Retz.	200	29	88	GR	–	–	–	–	–	–	–	–	–	–	–	–
Terminalia chebula Retz.	700	35	94	GR	250	18	90	GR	400	11	94	GR	–	–	–	–
Terminalia myriocarpa Heurck	–	–	–	–	100	7	#	FR	–	–	–	–	–	–	–	–
Vatica lanceaefolia Bl.	1100	51	96	GR	500	29	90	GR	200	11	95	GR	–	–	–	–

SE – seedlings, SA – saplings, GR – good regeneration, FR – fair regeneration, PR – poor regeneration; # – no mature trees present. [a]Proportion (%) of seedlings and saplings in total density of a particular tree species. [b]Local name.

Table 5. Density (10 m^{-2}) of shrubs in four forest stands experiencing different degrees of disturbance, ± SD values.

Species	Undisturbed stand	Mildly disturbed stand	Moderately disturbed stand	Highly disturbed stand
Abroma augusta Linn.	–	0.6 ± 08	0.2 ± 0.4	–
Baliospermum micranthum Muell. Arg.	–	0.2 ± 0.4	–	–
Begonia roxburghii (Miq) DC	–	0.2 ± 0.4	–	–
Beilschmiedia assamica Meissn.	–	0.2 ± 0.4	0.2 ± 0.4	–
Blastus cochichinensis Lour.	6.6 ± 2.6	3.8 ± 1.7	2 ± 0.4	–
Chasalia assamica Thw.	–	3.2 ± 1.1	–	–
Cinnamomum bejolghota Buch. Ham.	–	0.2 ± 0.4	1 ± 0.6	–
Cinnamomum sp.	0.6 ± 1.2	–	1.6 ± 1.2	
Clerodendrum infortunatum L.	1.2 ± 0.4	–	–	–
Clinogyne dichotoma Salisb.	–	0.2 ± 0.4	–	–
Coffea genkinsii Hk.	1.4 ± 0.4	0.2 ± 0.4	–	–
Datura stramonium Linn.	2 ± 1	–	–	–
Glycosmis pentaphylla Correa	–	0.4 ± 0.4	0.4 ± 0.8	–
Helicia nilagirica Bedd.	–	0.2 ± 0.4	–	–
Hymenodictyon sp.	–	0.2 ± 0.4	0.2 ± 0.4	–
Laportea crenulata Gaud.	3.8 ± 1.4	1.4 ± 1.01	–	–
Litsea elongata Wall.	–	0.6 ± 0.4	0.2 ± 0.4	–
Litsea salicifolia Roxb.	4.6 ± 3	4 ± 2.05	1.2 ± 0.4	–
Lycianthes subtruncata Hassl.	0.4 ± 0.4	0.2 ± 0.4	1 ± 0	–
Ophiorrhiza sp.	–	0.2 ± 0.4	–	–
Randia dumetorum Benth.	–	0.2 ± 0.4	–	–
Saprosma ternatum Hk.	8.8 ± 2.3	3.2 ± 2.6	0.2 ± 0.4	–
Solanum torvum Swartz	0.2 ± 0.4	–	–	–
Solanum spirale Roxb.	1.8 ± 1.7	0.4 ± 0.4	–	–
Sterculia villosa Roxb.	0.2 ± 0.4	–	–	–
Tetracera sarmentosa (Linn.) Vahl	4.4 ± 2.6	–	–	–
Viburnum foetidum Wall.	–	0.4 ± 0.4	–	–
Vitis bracteolata Wall.	–	1.6 ± 1.4	1 ± 0.6	–
Wendlandia sp.	1.4 ± 0.3	2.8 ± 1.2	1 ± 0.6	–

Table 6. Density (m^{-2}) of herbs and vines in four forest stands experiencing different degrees of disturbance, ± SD values.

Species	Undisturbed stand	Mildly disturbed stand	Moderately disturbed stand	Highly disturbed stand
Borreria articularis Linn.	4.4 ± 2.5	1.6 ± 0.48	1 ± 0	–
Buettneria aspera Colebr. ex Wall.	1 ± 0	1.2 ± 0.4	–	1.2 ± 0.4
Cardiospanum halicacabum Linn.	–	2 ± 1.67	1.2 ± 0.4	1.6 ± 0.4
Cerasus jenkinsii Hk. f. and Thoms.	–	0.87 ± 0.5	–	1.6 ± 0.8
Cyanotis cristata Linn.	–	2.4 ± 1.2	–	1 ± 0
Cyathula prostrata Blume.	3.1 ± 1.2	1.2 ± 0.4	–	–
Cynodon dactylon Pers.	9.4 ± 2.6	7.8 ± 4.22	2.6 ± 1.62	5.4 ± 3.8
Cyperus rotundus Linn.	4 ± 2.4	2.2 ± 0.54	–	1 ± 0
Forestia glabrata Linn.	10.6 ± 2.15	10 ± 3.78	1.8 ± 0.74	9.4 ± 3.92
Glycosmis sp.	–	0.6 ± 0.48	1.2 ± 0.4	–
Hedyotis scandens Roxb.	–	–	2.6 ± 1.35	–
Hypochaeris radicata Linn.	–	3.4 ± 1.62	–	0.4 ± 0.8
Hyptis suaveolens (Linn.) Poit.	1.2 ± 0.4	1 ± 0.4	–	3.2 ± 1.2
Myxopyrum smilacifolium Bl.	–	0.8 ± 0.6	1.2 ± 0.4	1.2 ± 0.4
Phrynium sp.	–	–	2.2 ± 0.4	–
Piper sp.	1 ± 0.63	–	7 ± 2.09	–
Pteris sp.	10.2 ± 3.31	4.2 ± 1.57	0.4 ± 0.8	3.4 ± 1.2
Selaginella sp.	3.2 ± 0.97	–	–	2.4 ± 0.97
Setaria glauca Beauv.	–	–	–	1.2 ± 0.4
Setaria palmifolia Stapf.	1.2 ± 0.7	1.2 ± 0.4	0.8 ± 0.4	–
Tinospora cordifolia Hiers.	–	0.2 ± 0.4	–	1.2 ± 0.82
Trachelopermum lucidum Hk. f.	–	–	–	–
Uncaria sessilifructus Roxb.	0.2 ± 0.4	–	–	0.2 ± 0.4

samica, Duabanga grandiflora and *Terminalia* spp. in all the stands. These dominant species restrict the light availability to the other species of main canopy and ground vegetation in the undisturbed and mildly disturbed stands. The presence of seedlings and saplings of these emergent species reveals that they are regenerating adequately in all the stands, in spite of competition from the subcanopy and herbaceous species. The data on regeneration status of tree species indicate that these species show continuous establishment of seedlings and saplings because of their widespread occurrence in the forest. However, in the moderately disturbed stand the additional microsites created due to man-made interference (felling of trees) favour the germination of other opportunist species (pioneer), improving their regeneration (Ohsawa et al. 1986). The reduced frequency of such opportunistic species in the forests can be attributed to the sporadic occurrence of periods of environmental conditions favorable for their regeneration (Wilson 1991). If such periods of opportunity are frequently available within the landscape, such species may show good germination and may even become dominant (Loucks 1970; Bormann and Likens 1979). However, some species still show poor regeneration due to problems in germination of seeds, even though favorable conditions prevailed in the forest. Apparently sporadic regeneration of Rudraksh (*Elaeocarpus ganitrus*) may be attributed to such problems.

Tropical forests are rich in species density (Richards 1952; Paijmans 1970) and many factors affect their diversity (Janzen 1970; Connell 1971; Hubbell 1979; Parthasarathy 1999). According to Whitmore (1984), in tropical rain forests the tree species number per hectare ranges from 20 to a maximum of 223. Species diversity is often correlated with rainfall, nutrient status (Hartshorn 1980) and disturbance level (Rao et al. 1990). Human-induced disturbance (such as mining, timber extraction, etc.) and livestock grazing also cause changes in species number, tree density and basal area (Rao et al. 1990). Unrestricted and open accessibility may cause enhanced utilization of the forest resource and this may eventually lead to a species-poor state (Vetaas 1993; Murali et al. 1996).

The role of gaps in the regeneration of forest trees is well recognized. Tree regeneration composition in the gaps has been shown to be dependent upon the history of the forest community, seed availability and the biology of the species (Hubbell and Froster 1992). Reduction of basal area in mildly, moderately and highly disturbed forest stands could be due to extraction of timber, debarking, rotting of damaged boles, etc. In spite of high disturbance, a greater basal area was observed in highly disturbed forest. Many tree species are also good coppicers and coppiced shoots display faster growth (Evans 1992); such shoots are abundant due to the extraction of trees from the highly disturbed forest stand. The greater basal area in highly disturbed stand is recorded due to the presence/non-removal of over-mature, mature, buttressed, bad form inferior tree species and abundance of coppiced shoots. Species composition is related to stand productivity and decrease in basal area reported due to deteriorating stand quality (Rai 1983). According to Smiet (1992), basal area values may be related to the stand disturbance index. So, in the heavily disturbed forest stand the basal area is lower than in the undisturbed and mildly disturbed stands. In the present study regeneration of Rudraksh (*Elaeocarpus*

ganitrus), the nuts of which are used as religious jewellery in the form of beads throughout India and southeast Asia, was found to be very poor. Though the adult trees were present in all the study stands, the density of saplings and seedlings was very poor except in the undisturbed and mildly disturbed stands. This could be attributed to the degree of disturbance. The undisturbed stand is protected and is not accessible to the wood collectors. Therefore, the seedlings and saplings of Rudraksh and other tree species had the chance to grow and establish. On the other hand, in the mildly disturbed stand the presence of gaps created by human interference facilitated light penetration to the ground. Hence, germination of seeds of Rudraksh and other species might have been facilitated.

Species composition of forest in the undisturbed, mildly disturbed and moderately disturbed stands is more or less similar, which may be attributed to the similar topography, soil and climatic conditions of the localities and to the shared original undisturbed community. However, the highly disturbed stand shows a different species composition especially at subcanopy level, due to enrichment by planting using the *taungya* system (personal observations). Coffee bushes grow luxuriantly in the subcanopy layer and no saplings of other species were recorded within the coffee plantings. The emergent layer still consists of *Dipterocarpus macrocarpus, Shorea assamica, Terminalia chebula, Duabanga grandiflora* etc. and regeneration of these species was abundant in the undisturbed, mildly disturbed and moderately disturbed stands. However, regeneration of Rudraksh was seen only in the undisturbed and mildly disturbed stands wherever small gaps were created in the canopy and the surface was occasionally burnt during winter with low intensity of surface fire.

All the forest stands, except the undisturbed one, were under increasing biotic pressure due to firewood, fodder and timber collection, and regeneration suffered because most tree species produce seeds concurrently with the peak period of collection from the forest. Seeds of many timber species are collected in huge quantities by the local contactors and are sold to private nursery owners, thus reducing the seed bank on the forest floor. Moreover, seeds of most of the forest timber species are susceptible to pests due to their thin seed coat, and are recalcitrant and lose their viability quickly (Sundriyal et al. 1994). The outbreak of a few insect pests has been a major cause of poor regeneration (personal observations). The proportions of different life stages (seedlings, saplings and mature) in a given species population may help in predicting its possible future status in the forest (Saxena and Singh 1984). Species with a nearly equal distribution of individuals in the three life stages are expected to remain dominant in the near future. The population size of species that lack either seedlings or saplings may decline in the coming years. The forest stands characterized by an abundance of only adults of the canopy and subcanopy species and absence or very low populations of seedlings and saplings are expected to face local extinction of some species in due course. The increasing biotic pressure may cause a drastic reduction in regeneration of several tree species. Indiscriminate tree cutting by local people, selective felling by the forest department and timber trade, the use of an enormous amount of wood in house construction, and plantations of tea and coffee are the major causes of forest

destruction in Arunachal Pradesh and adjoining areas. These biotic stresses also do not allow the degraded forests to regenerate.

However, Rudraksh (*Elaeocarpus ganitrus*) and a few associated species show good regeneration, even in the mildly disturbed forest stand, signifying the role of mild disturbance in tree regeneration. Harris and Farr (1974) and Boring et al. (1981) have also emphasized the positive role of mild disturbance in increasing the regeneration of trees. Khan et al. (1987), Barik et al. (1996) and Maram Kuba and Khan (1998) have also reported better regeneration of tree species in mildly disturbed forests of northeast India.

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