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STRUCTURES OF THE TROPICAL DRY DECIDUOUS TEAK (*TECTONA GRANDIS*) FORESTS OF SATPURA PLATEAU (INDIA) WITH SPECIAL EMPHASIS ON REGENERATION AND DISTURBANCE

P. K. Pande

Centre for Forestry Research and Human Resource Development, Chhindwara - 480 001, India

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PANDE, P. K. 2001. Structures of the tropical dry deciduous teak (*Tectona grandis*) forest of Satpura Plateau (INDIA) with special emphasis on regeneration and disturbance. Comparative quantitative structures and regeneration behaviours of important tree species of three sites in the tropical dry deciduous teak forest of South Chhindwara Division (Sillevani Range) of Satpura Plateau (Central India) were analysed. Sites III and I were the least and highly disturbed sites respectively. Three communities were identified, namely, *Tectona grandis-Lagerstroemia parviflora-Sterculia urens* (site I), *T. grandis-Diospyros melanoxylon-Butea monosperma-Miliusa tomentosa* (site II) and *T. grandis-Chloroxylon swietenia-L. parviflora-D. melanoxylon* (site III). The mean stand density (plants 100 m^{-2}) ranged between 6.9 (site I) and 16.30 (site III) for trees; 19.99 (site I) and 38.87 (site III) for shrubs; and 13 816 (site II) and 25 600 (site I) for herbaceous layer, whereas the total basal cover (cm^2 100 m^{-2}) ranged between 956 (site III) and 1555 (site I) for trees; 21 (site II) and 54 (site III) for shrubs; and 561 (site II) and 2803 (site I) for herbs. Shannon-Weiner index ranged between 1.485 (site III) and 2.064 (site II). Minimum tree diversity was recorded at the least disturbed site. The same was true for herb and shrubs diversity. Concentration of dominance showed a reverse trend to diversity index. The disturbance magnitude had an adverse effect on teak regeneration.

Key words : Density - diversity index - distribution patterns - population structure

PANDE, P. K. 2001. Struktur hutan jati (*Tectona grandis*) daun luruh kering tropika di Dataran Tinggi Satpura (India) dan penekanan khusus terhadap pemulihan dan kerosakan. Struktur kuantitatif bandingan dan tingkah laku pemulihan spesies pokok penting di tiga tapak hutan jati daun luruh kering tropika di Bahagian Chhindwara Selatan (Banjaran Sillevani), Dataran Tinggi Satpura (India Tengah) dianalisis. Tapak III merupakan tapak yang paling kurang rosak sementara tapak I merupakan yang paling teruk terganggu. Tiga komuniti dikenal pasti iaitu *Tectona grandis-Lagerstroemia parviflora-Sterculia urens* (tapak I), *T. grandis-Diospyros melanoxylon-Butea monosperma-Miliusa tomentosa* (tapak II) dan *T. grandis-Chloroxylon swietenia-L. parviflora-D. melanoxylon* (tapak III). Kepadatan dirian min (tumbuhan 100 m^{-2}) berjulat antara 6.9 (tapak I) dan 16.30 (tapak III) bagi pokok; 19.99 (tapak I) dan 38.87 (tapak III) bagi pokok renek; dan 13 816 (tapak II) dan 25 600 (tapak I) bagi lapisan herba, manakala jumlah luas pangkal (cm^2 100 m^{-2}) berjulat antara 956 (tapak III) dan 1555 (tapak I) bagi pokok; 21 (tapak II) dan 54 (tapak III) bagi pokok renek; dan 561 (tapak II) dan 2803 (tapak I) untuk pokok herba. Indeks Shannon-Weiner berjulat antara 1.485 (tapak III) dan 2.064 (tapak II). Kepelbagaian pokok minimum dicatatkan di tapak yang paling kurang rosak, begitu juga untuk kepelbagaian pokok herba dan pokok renek. Tumpuan dominans menunjukkan trend yang bertentangan dengan indeks kepelbagaian. Magnitud kerosakan mempunyai kesan yang buruk terhadap pemulihan pokok jati.

Introduction

Tropical dry forests form a major biome in India covering about 46% of the total forest cover of the country (Singh & Singh 1988). Most of the forests cover diversified communities, land-forms and land-relief, which support the tribal population of the area. These forests are largely threatened by various anthropogenic disturbances like lopping, burning, over-grazing and clearing for cultivation. Local species extinction rates appear to be very high for tropical species (Farworth & Golley 1974). Various factors, *viz.* climate, season, time of canopy gap creation, shapes, sizes of disturbance patches, etc., govern the dynamics of these forests, which influence the regeneration of woody species (Sukumar *et al.* 1992). Consequently, these forests are being depleted faster, thus disturbing the ecosystem in terms of their structure and function.

Some studies have been undertaken on vegetation analysis of natural forests of different climatic zones of India (Ralhan *et al.* 1982, Saxena & Singh 1982, Jha & Singh 1990, Parthasarthy *et al.* 1992, Visalakshi 1995). However, little information is available on the structure of tropical dry deciduous forests. Hence, the objectives of the present study were to compare the: (1) vegetation composition, structure and diversity of three teak forests, (2) species turnover among these sites and (3) regeneration behaviour of different tree species at different sites due to disturbances with special emphasis on the maintenance of teak.

Materials and methods

Site

The study sites were in South Chhindwara Forest Division, Sillavani Range and Khutama Beat (site I, Amla-55 L, compartment no. 348; site II, Amla-6, compartment no. 345-B; site III, Amla-45, compartment no. 346-A) of Chhindwara districts (Madhya Pradesh) situated between latitudes 20° 28'–22° 49' N and longitudes 78° 40'–79° 24' E at an elevation of 410–457 m asl. The forests of the area are categorised under group 5A/C_{1b} as "tropical dry deciduous forest" (Champion & Seth 1968). As per the records of the State Forest Department, Chhindwara, the site is an undulating rock of decan trap. The soil which is fairly deep sandy loam and alluvium, occurs along the "nalas". Some of the important features of the site are given in Table 1.

Table 1. Vegetational and soil characteristics of study sites

Site	Density (tree ha^{-1})	Total basal cover (cm^2 ha^{-1})	Productivity (kg ha^{-1} y^{-1})	Soil pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})
I	690	155 487 (225)	1159	7.95	71	19.80
II	950	148 823 (157)	1340	7.99	413	18.20
III	1630	95 643 (59)	1304	7.99	413	19.20

Values in brackets are mean basal area (cm^2 $tree^{-1}$)

Climate

The climate of the area is monsoonal with seasonal rainfall. The total precipitation recorded in 1998 was 1247 mm with a maximum of 235 mm in September. The annual mean maximum and minimum temperature were 29 °C and 20 °C respectively, with a mean temperature of 25 °C. June (34 ± 4.77 °C) and December (17 ± 3.98 °C) were the hottest and coldest months of the year respectively.

Methods

The whole area was divided into three sites. Phytosociological studies were conducted in 1998 using quadrat method (size of quadrat, 10 × 10 m for trees; 5 × 5 m for shrubs and 1 × 1 m for herbs). The size of the quadrat was determined by plotting species-area curve. The number of quadrats was determined by plotting increasing number of quadrats against the number of species (Misra 1968). Twenty quadrats were placed separately at each site for tree, shrub and herb. Girth at breast height (gbh) at 1.37 m above ground level of each tree (> 10 cm gbh) was measured and recorded in each quadrat, individually. The seedlings were considered as herbs while saplings as shrubs. Quantitative analysis of vegetation for frequency, density and dominance was conducted following Misra (1968). Their relative values were calculated and summed to get an Importance Value Index (IVI) of individual species. The abundance to frequency ratio (A/F) for different tree species was determined to elicit their distribution patterns. This ratio indicates regular (< 0.025), random (0.025–0.05) and contagious (> 0.05) distributions (Curtis & Cottam 1956). β diversity was estimated following Whittaker (1972):

$$\beta_w = (S/\alpha) - 1$$

where S = total number of species at both sites, α = the mean species richness of both sites and β_w = β diversity.

Following Jaccard (1912), similarity index (community coefficient) among different sites was calculated as:

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

where j is the number of common species to both the sites; a is the number of species in site A and b is the number of species in site B.

Shannon-Wiener diversity index (Shannon & Wiener 1963) was calculated from the IVI values using the formulae as given in Magurran (1988):

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

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

Concentration of dominance (Cd) was measured by Simpson's Index (Simpson 1949):

$$Cd = \sum_{i=1}^{s} (p_i)$$

where p_i is the same as for Shannon-Wiener information function. Equitability index (J') was calculated following Pielou (1966):

$$J' = H'/\log S$$

where H' is diversity index and S is number of species.

To ascertain the resource apportionment among the various species at various sites, dominance-diversity (D-D) curves were drawn. The relative importance value is an expressive measure of the realised niche of species, thus treated as an expression of the relative niche size.

Results

Vegetation analysis

The different parameters of vegetation analysis for trees, shrubs and herbs are tabulated in Tables 2, 3 and 4. Three communities were identified on IVI basis as *Tectona grandis-Lagerstromia parviflora-Sterculia urens* (site I), *T. grandis-Lannea coromandelica-Diospyros melanoxylon-Butea monosperma-Miliusa tomentosa* (site II) and *T. grandis-Chloroxylon swietenia-L. parviflora-D. melanoxylon* (site III). Most of the shrub layer was composed of saplings of *T. grandis, D. melanoxylon, L. parviflora* and *B. monosperma* at all the sites. *Triumfetta rhomboidea, Indigofera trifoliata, Oplismenus burmannii, Cyperus kyllingia, Sida rhombifolia, S. acuta* were the common herb species for all the sites. *Hemidesmus indicus, Achyranthes aspera, Hyptis suaveolens, Ageratum conyzoides* are well-known medicinal plants recorded from these sites.

Total density for tree layer ranged between 6.9 (I) and 16.30 (III) trees 100 m^{-2}; 19.99 (I) and 38.87 (III) saplings for shrubs 100 m^{-2} and 13 816 (II) and 25 600 (I) plants 100 m^{-2} for herb layer, whereas the range for total basal cover (cm^2 100 m^{-2}) was 956 (III) and 1555(I) for trees; 21(II) and 54(III) for shrubs and 561(II) and 2803(I) for herbs. Abundance to frequency (A/F) ratio for tree species ranged between 0.03 and 0.1 (I); 0.03 and 0.2 (II) and 0.03 and 0.1 (III).

Species richness, diversity index (H') and concentration of dominance (Cd)

Species richness (SR), diversity index (H') and concentration of dominance (Cd) for all the sites are given in Table 5. Site II showed highest species richness followed by I and III. Diversity index values also followed the similar trend. However, concentration of dominance followed the reverse trend of species diversity.

Similarity index (community coefficient)

Sites II and III were more similar as far as tree and shrub composition were concerned, whereas site I and II showed more similarity when considering herbs as the measure (Table 6).

Table 2. Vegetation analysis of tree layer

Species	Density (tree 100 m^{-2})	Frequency (F) (%)	Abundance (A) (trees 100 m^{-2})	A/F	Total basal area (cm^2 100 m^{-2})	Relative density	Relative frequency	Relative dominance	Importance value index (IVI)
Site I									
Tectona grandis	4.7	100	4.7	0.05	813.5	68.1	37.03	52.32	157.5
Lagerstroemia parviflora	1.2	70	1.83	0.02	99.40	17.39	25.92	6666	49.69
Ougeinia oojeinensis	0.2	20	1	0.05	98.08	2.89	7.40	6.30	16.59
Soymida febrifuga	0.1	10	1	0.1	94.57	1.45	3.70	6.08	11.23
Chloroxylon swietenia	0.2	20	2	0.05	42.20	2.89	7.40	2.71	13.00
Sterculia urens	0.1	10	1	0.1	203.8	1.45	3.70	13.10	18.75
Cassia fistula	0.2	20	1	0.05	2.67	2.89	7.40	0.17	10.46
Terminalia chebula	0.1	10	1	0.1	155.86	1.45	3.70	10.02	15.17
Grewia tiliaefolia	0.1	10	1	0.1	44.76	1.45	3.70	2.88	8.03
Total	**6.9**	-	-	-	**1554.8**	**100**	**100**	**100**	**300**
Site II									
Tectona grandis	3.6	100	3.6	0.04	827.5	37.89	24.39	55.61	117.8
Diospyros melanoxylon	1.8	60	3	0.05	44.73	18.95	14.63	3.01	36.50
L. parviflora	0.2	20	1	0.05	1.89	2.12	4.88	0.13	7.13
G. tiliaefolia	0.1	10	1	0.1	4.97	1.05	2.45	0.34	3.84
Miliusa tomentosa	0.8	40	2	0.05	13.60	8.42	9.75	0.91	19.08
Butea monosperma	1.3	50	2.6	0.05	88.35	13.68	12.19	5.95	31.82
C. swietenia	0.2	10	2	0.2	190.8	2.10	2.44	12.83	17.37
Ixora arborea	0.4	20	2	0.1	10.01	4.21	4.88	0.67	9.76
Annona squamosa	0.3	30	1	0.03	2.21	3.15	7.32	0.15	10.62
Buchanania lanzen	0.4	30	1.33	0.04	34.57	4.21	7.31	2.32	13.84
Terminalia alata	0.1	10	1	0.1	203.8	1.05	2.44	13.69	17.18
Lannea coromandelica	0.1	10	1	0.1	53.51	1.05	2.44	3.59	78.08
Zizyphus xylopyra	0.1	10	1	0.1	7.64	1.05	2.44	0.51	4
S. urens	0.1	10	1	0.1	4.58	1.05	2.44	0.31	3.80
Total	**9.5**	**410**	-	-	**1488**	**100**	**100**	**100**	**300**
Site III									
Tectona grandis	9.6	100	9.6	0.09	687.2	58.89	25.64	71.85	156.4
L. parviflora	2.1	80	2.63	0.03	49.61	12.88	20.51	5.29	38.68
C. swietenia	2.2	70	3.14	0.04	113.3	13.49	17.95	11.85	43.28
D. melanoxylon	1.4	60	2.33	0.04	39.56	8.59	15.38	4.25	28.22
Butea monosperma	0.5	40	1.25	0.03	13.16	3.07	10.25	1.37	14.70
S. urens	0.1	10	0.1	0.1	1.55	0.62	2.56	0.16	3.34
Aegle marmelos	0.1	10	1	0.1	1.55	0.62	2.56	0.16	3.34
M. tomentosa	0.3	20	1.5	0.07	33.32	1.84	5.14	3.47	10.45
Total	**16.30**	**390**	-	-	**956.43**	**100**	**100**	**100**	**300**

Table 3. Vegetation analysis of shrub layer

Species	Density (tree 100 m^{-2})	Frequency (F) (%)	Abundance (A) plants 100 m^{-2})	Total basal area (cm^2 100 m^{-2})	Relative density	Relative frequency	Relative dominance	Importance value index (IVI)
Site I								
Tectona grandis	13.33	100	13.33	25.59	66.68	66.67	52.94	186.28
Lantana camara	1.11	10	11.11	0.08	5.55	6.67	0.18	12.40
Chloroxylon swietenia	1.11	10	11.11	3.18	5.55	6.67	6.58	18.80
Lagerstroemia parviflora	2.22	10	22.22	7.47	11.12	6.67	15.45	33.24
Zizyphus jujuba	1.11	10	11.11	8.83	5.55	6.67	18.27	30.48
Miliusa tomentosa	1.11	10	11.11	3.18	5.55	6.67	6.58	18.80
Total	**19.99**	-	-	**48.34**	**100**	**100**	**100**	**300**
Site II								
T. grandis	7.78	60	12.96	5.51	30.44	35.29	26.14	91.87
Diospyros melanoxylon	6.67	40	16.67	6.68	26.09	23.53	31.69	81.31
L. parviflora	1.11	10	11.11	0.79	4.34	5.88	3.75	13.97
Butea monosperma	6.67	40	16.67	3.43	26.09	23.53	16.27	65.89
Flacourtia indica	2.22	10	22.22	2.47	8.68	5.88	11.72	26.23
Annona squamosa	1.11	10	11.11	2.20	4.35	5.88	10.44	20.67
Total	**25.56**	**170**	-	**21.08**	**100**	**100**	**100**	**300**
Site III								
T. grandis	28.88	100	28.88	40.08	74.30	55.55	74	203.86
C. swietenia	3.33	30	16.66	8.47	8.57	16.67	15.63	40.87
D. melanoxylon	5.55	40	13.88	5.27	14.27	22.22	9.72	46.21
B. monosperma	1.11	10	11.11	0.346	2.86	5.56	0.65	9.06
Total	**38.87**	-	**160.5**	**54.17**	**100**	**100**	**100**	**300**

Table 4. Vegetation analysis of herbaceous layer

Species	Density (tree 100 m^{-2})	Frequency (F) (%)	Abundance (A) plants 100 m^{-2})	Total basal area (cm^2 100 m^{-2})	Relative density	Relative frequency	Relative dominance	Importance value index (IVI)
Site I								
Hyptis suaveolens	11680	100	11680	1390	45.6	7.58	49.59	102.7
Sida rhombifolia	240	40	600	16.94	0.94	3.03	0.60	4.57
Triumfetta rhomboidea	560	80	700	36.96	2.19	6.06	1.32	9.57
Abutilon indicum	360	80	450	28.80	1.41	6.06	1.03	8.5
Cassia tora	6020	100	6020	725.5	23.5	7.58	25.88	56.98
Oplismenus burmani	1000	80	1250	70.0	3.91	6.06	2.49	12.46
Vernonia cinerea	340	60	566.6	16.66	1.33	4.54	0.59	6.46
Ageratum conyzoides	320	80	400	40.19	1.25	6.06	1.43	8.74
Mimosa pudica	360	60	600	1.15	1.40	4.54	0.04	5.98
Euphorbia hirta	440	80	550	26.84	1.72	6.06	0.96	8.74
Indigofera trifoliata	80	20	400	2.48	0.31	1.52	0.09	1.92
Cyperus kyllingia	900	80	1125	113.04	3.51	6.06	4.03	13.6
S. acuta	260	80	325	24.96	1.17	6.06	0.89	8.12
Alloteropsis cimicina	300	40	750	22.50	1.17	3.03	0.80	5.0
Dactyloctenium aegyptium	420	60	700	40.32	1.64	4.54	1.43	7.61
Heteropogon contortus	300	40	750	35.7	1.17	3.03	1.27	5.47
Setaria tomentosa	300	40	750	41.40	1.17	3.03	1.47	5.67
S. glauca	680	80	850	85	2.65	6.06	3.03	11.74
Tridax procumbens	100	20	500	18	0.39	1.52	0.64	2.55
Cynodon dactylon	940	100	940	66.36	3.67	7.58	2.36	13.61
Total	**25 600**	**1320**	-	**2802.7**	**100**	**100**	**100**	**300**
Site II								
Triumfetta rhomboidea	600	100	600	18.84	4.34	11.4	3.35	19.10
Cyperus kyllingia	1117	100	1116.7	78.89	8.08	11.4	14.05	33.56
Oplesmenus burmanni	1783	8	2140	31.49	12.9	0.94	5.62	19.46
Indigofera trfoliata	2650	83.33	3975	29.95	19.2	9.53	5.35	34.06
Sida acuta	66.7	50	133	2.31	0.48	5.72	0.41	6.61
Cassia tora	5150	100	5150	273.3	37.3	11.4	48.72	97.42
Euphorbia hirta	33.3	16.66	200	0.59	0.24	1.90	0.04	2.18
C. semilacifolia	16.66	16.66	100	1.18	0.12	1.90	0.21	2.23
Achyranthes aspera	233	50	467	16.46	1.68	5.72	2.94	10.34
Vitis trifolia	33.33	16.66	200	2.68	0.24	1.90	0.48	2.62
Hemidesmus indicus	83.33	33.33	250	1.41	0.61	3.81	0.25	4.66
Butea monosperma	50	16.66	150	10.59	0.36	1.90	1.89	4.15
Trigonella acculta	100	16.66	600	3.14	0.72	1.90	0.56	3.18
Ageratum conyzoides	167	33.33	350	11.80	1.12	3.81	2.12	7.14
S. rhombifolia	50	50	100	1.73	0.36	5.72	0.31	6.39
Commellina bengalensis	50	33.33	150	3.50	0.36	3.81	0.62	4.79
D. melanoxylon	33.33	16.66	200	3.20	0.24	1.90	0.57	2.71
Dioscoria bulbifera	100	33.33	300	7	0.72	3.81	1.24	5.77
Heteropogon contortus	667	33.33	2000	20.94	4.83	3.81	3.73	12.37
Setaria tomentosa	667	33.33	2000	32.72	4.83	3.81	5.83	14.47
Vernonia cinerea	133	16.66	800	7.06	0.96	1.90	1.26	4.12
Tridax procumbens	33	16.66	200	2.33	0.24	1.90	0.42	2.56
Total	**13 816**	**874.6**	-	**561.1**	**100**	**100**	**99.99**	**299.97**

(continued)

(Table 4 - continued)

Species	Density (tree 100 m^{-2})	Frequency (F) (%)	Abundance (A) plants 100 m^{-2})	Total basal area (cm^2 100 m^{-2})	Relative density	Relative frequency	Relative dominance	Importance value index (IVI)
Site III								
Lathyrus aphaca	9100	100	9100	737.1	45.5	11.1	40.83	97.5
M. pudica	760	60	1266	2.66	3.80	6.67	0.147	10.62
Hemidesmus indicus	60	40	150	1.20	0.30	4.44	0.07	4.81
Dioscorea bulbifera	280	60	466	20.72	1.40	6.67	1.46	9.53
Triumfetta rhomboidea	320	60	533	22.40	1.60	6.67	1.29	9.56
Cassia tora	1800	100	1800	234.0	9.01	11.1	12.96	33.09
Hyptis suaveolens	260	40	650	25.74	1.30	4.44	1.48	7.32
Sida acuta	20	20	100	0.76	0.1	2.22	0.04	2.36
Indigofera trifoliata	60	20	300	4.08	0.30	2.22	0.23	2.75
Oplesmenus burmanni	1920	100	1920	130.56	9.61	11.1	7.26	27.98
Bothriochloa pertusa	4600	60	7666	538.2	23.0	6.67	29.81	59.50
Cyperus kyllingia	480	80	600	62.40	2.40	8.89	3.86	15.14
Echinocarpus sp.	20	20	100	1.26	0.1	2.22	0.07	2.39
V. cinerea	20	20	100	1.20	0.1	2.22	0.07	2.39
Euphorbia hirta	20	20	100	1.44	0.1	2.22	0.07	2.39
Achyranthes aspera	160	40	400	12.32	0.20	4.44	0.14	4.78
Tectona grandis	40	40	100	8.40	0.20	4.44	0.14	4.78
Ageratum conyzoides	60	20	300	0.78	0.10	2.22	0.07	2.39
Total	**19 980**	**900**	-	**1805.2**	**100**	**100**	**100**	**300**

Table 5. Species richness (SR), concentration of dominance (Cd), diversity index (H') and equitability (J') of different layers (T = trees; S = shrub and H = herb) at different sites

Site	SR			Cd			H' & J'		
	T	S	H	T	S	H	T	S	H
I	9	6	20	0.315	0.41	0.167	1.585 (1.661)	1.245 (1.599)	2.424 (1.863)
II	14	6	22	0.20	0.23	0.151	2.064 (1.80)	1.584 (2.035)	2.439 (1.857)
III	8	4	18	0.321	0.50	0.172	1.485 (1.664)	0.927 (1.539)	2.116 (1.685)

Values in parentheses are equitability (J')

Table 6. Similarity index (C_j) among the different study sites

Sites		II			III		
		T	S	H	T	S	H
I	T	0.28	-	-	0.31	-	-
	S	-	0.20	-	-	0.25	-
	H	-	-	0.61	-	-	0.58
II	T	-	-	-	0.61	-	-
	S	-	-	-	-	0.46	-
	H	-	-	-	-	-	0.25

Discussion

Most of the species exhibited random or contagious pattern of distribution. Regular distribution was rarely reported for all the sites. Random pattern of distribution was reported for temperate Himalayan forests (Saxena & Singh 1982, Singhal *et al.* 1986, Pande *et al.* 1996) and also for some tropical forests (Pande *et al.* 1988, Visalakshi 1995, Pande 1999), whereas contagious/clumped distribution was reported for Garhwal Himalaya and some tropical forests of the Indian subcontinent (Joshi & Tewari 1990, Parthasarthy *et al.* 1992, Visalakshi 1995, Bhandari *et al.* 1997).

The data on the vegetation of the present study were compared with those of the other tropical forests. In several tropical forests, total basal cover and density range from 0.10 to 1.07 m^2 100 m^{-2} and from 5.5 to 18 trees respectively (Visalakshi 1995). Singh and Singh (1981) reported the density of trees and shrubs in the fenced (11.74 trees and 132 plants 100 m^{-2}) and unfenced (9.36 trees and 554 plants 100 m^{-2}) stands of the tropical dry deciduous forests. In the chalked forest reserve of Tamil Nadu, Parthasarthy *et al.* (1992) reported that stand density range from 3.20 to 12.60 trees 100 m^{-2} and total basal area from 0.18 to 1.07 m^2 100 m^{-2}. Tree density and total basal area in an equatorial forest ecosystem in Kongolo Island, Zaire range from 4.40 to 5.53 trees 100 m^{-2} and from 0.10 to 0.45 m^2 100 m^{-2} respectively (Mosango 1991). Values of tree stand density in the present study were within the reported range for tropical forests while the values of total basal cover were lower than those of Parthasarthy *et al.* (1992) and fell within the range reported by Mosango (1991). Pande *et al.* (1988) reported a range for density (plant 100 m^{-2}) from 18 to 70 for shrub layer in old growth tropical plantations. Density for shrub layer in the present study was within the reported range.

The Shannon-Wiener diversity indices are generally high for tropical forests which range from 0.81–4.1 for the Indian subcontinent (Singh *et al.* 1984, Parthasarthy *et al.* 1992, Visalakshi 1995). The values of diversity index in the present study (0.927–2.424) could be compared with the values reported by Visalakshi (1995), which range between 0.83 and 2.43 for the Marakkanam forest reserves in south India. The values reported by Rajathinam (1992) and Parthasarthy *et al.* (1992) for tropical evergreen forests are relatively higher than those of the present study.

The values of concentration of dominance (Cd) for tropical forests in India lie within the range of 0.21 to 0.92 (Bisht 1989, Parthasarthy *et al.* 1992, Visalakshi 1995). The values of concentration of dominance in this study (0.167–0.500) showed a reverse trend to those of the diversity index from tree to herb layers and except for the herb layer, were and within the reported range for the Indian tropical forests. In general, the equitability indices followed the similar trend as the diversity indices. Equitability index was higher for herbs compared to shrubs and trees except in site II which was more equitable for shrub species. Site III, the least disturbed one, had the lowest species richness.

β_w diversity was calculated to ascertain the degree of species turnover among the various sites for tree, shrub and herb species (Table 7). Maximum turnover of species for tree layer was recorded between sites I and III (0.65) and lowest between sites II and III (0.27). The range for turnover of species for shrub layer was 0.35 (sites II & III) to 0.67 (sites I & II). It was between 0.33 (sites I & II) and 0.47 (sites II & III) for herb species.

Table 7. β_w diversity among the different sites

Sites		II			III		
		T	S	H	T	S	H
	T	0.56	-	-	0.65	-	-
I	S	-	0.67	-	-	0.60	-
	H	-	-	0.35	-	-	0.35
	T	-	-	-	0.27	-	-
II	S	-	-	-	-	0.35	-
	H	-	-	-	-	-	0.47

The log transformed IVI values for tree, shrub and herb species were ordinated against the species sequence to draw the dominance-diversity (D-D) curves for interpreting community organisation in terms of resource share and niche space partitioning (Figure 1). D-D curves for tree species showed log normal series for sites I and II and log series for site III. However, for shrub and herb species, these curves

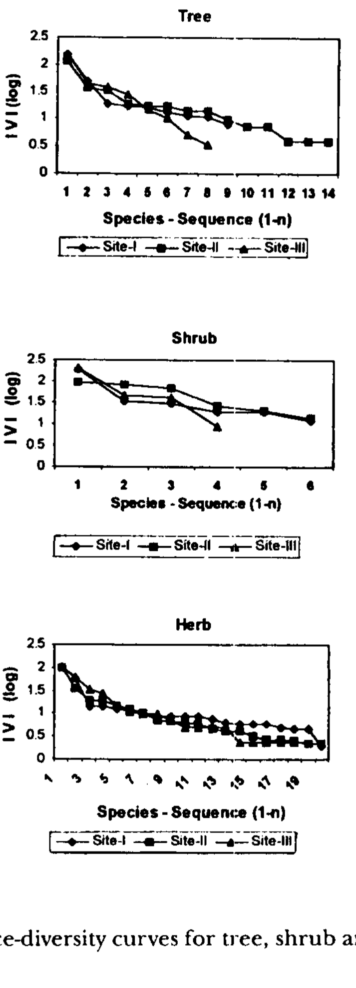

Figure 1. Dominance-diversity curves for tree, shrub and herbaceous layer

followed log normal series for all the sites except site III for shrubs, which followed geometric series, confirming the niche pre-emption hypothesis of Whittaker (1975). Referring to Table 5 and Figure 1, it is obvious that site II was more diverse and log normal. In this case, habitats are differentiated by many factors. Consequently, species of equal abundance are not in direct competition for resources. It also reflects relatively greater equitable share distribution of resources among the various species. The log normal distribution is assumed to apply to those large number of species which are not clearly related to resource use (Whittaker & Woodwell 1969, Whittaker 1975). This is true for sites I and II for shrubs and all sites for herb species. Site III was, relatively, less diverse and followed log series. In this case, the intervals between the arrival of these species are random rather than regular (Boswell & Patil 1971). Further, it is applicable in those situation where one or a few factors dominate the ecology of the community.

The arrangement of population structure by size class distribution has been used to understand regeneration, disturbances and future stability of tree species populations in forest communities (Schmelz & Lindsey 1965, Robertson 1978). The degree of past disturbances can be estimated by calculating the coefficient of determinants, r^2, between density and diameter relationship (Robertson *et al.* 1978). The magnitude of coefficient indicates the degree to which a stand approximates a balanced structure. The values of r^2 closer to 1 means the system is more balanced. Examination of r^2 values for individual species (*T. grandis*) revealed the degree of disturbance in the following order: III(0.76) < II(0.14) < I(0.09). Considering the density of all species, the r^2 values were in the order: 0.58(III) > 0.18(II) > 0.05(I). The lower values of r^2 for the stands in the present investigation were due to the unbalanced distribution of many species as a result of disturbances. However, in both cases, sites III and I were the least disturbed and most disturbed sites respectively. In all the three sites, *T. grandis*, the main canopy species, did not follow the inversed J-shaped curve. Inversed J-shaped curve is typical of well-developed forests with a broad range of tree sizes (Mayer 1953). Moreover, none of the stands followed a sigmoid pattern. Site III followed a rotated sigmoid pattern (Figure 2). The stable or equilibrium population structure of an undisturbed forest stand is, to a small extent, of a rotated sigmoid type (Schmelz & Lindsey 1965, Goff & West 1975). Further, this was reported predominantly for deciduous forests (Goff & West 1975, West *et al.* 1981).

Invariably, all the three sites of the present study showed a remarkable degree of dissimilarity in their structure and composition (Table 6), which may reflect various degrees of disturbance in those sites. This comparative phytosociological study of three tropical dry teak forests suggests that these forests are governed by a complex array of microclimatic factors originated from biotic and anthropogenic disturbances.

The greater contribution of seedlings, saplings and individuals in the lower girth classes for sites III and II showed an 'extending population structure', which is indicative of better regeneration on these sites. However, in site I, which was highly disturbed, the proportion of individuals was greater in the larger girth classes compared to smaller girth classes. This is indicative of a 'declining population structure'. It reflects species that reproduced well previously but showed poor reproduction and establishment in the present.

In the present study the following patterns of population structure were recognised on the basis of distribution of individuals in different size classes (Table 8):

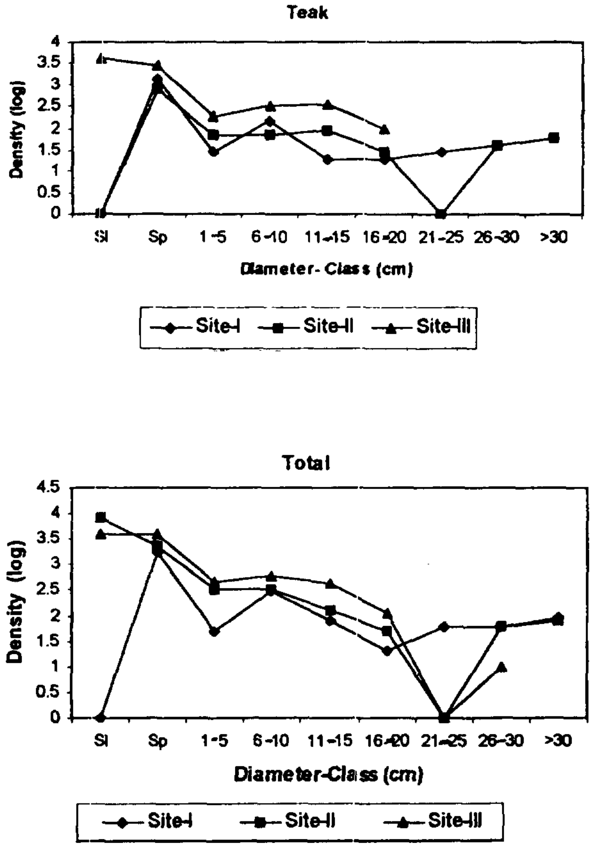

Figure 2. Density-diameter relationship at different sites (x-axis: 1-seedlings, 2-saplings and 3 - n, represents increasing diameter classes as given in Table 8)

(1) The absence of established seedlings and presence of saplings for all the species of sites I and II (except for *D. melanoxylon* and *B. monosperma*), and site III (except *T. grandis*) suggests that these species can be called as fair reproducers as they reproduced well in the immediate past.
(2) The presence of both seedlings and saplings of *B. monosperma, D. melanoxylon* (site II) and *T. grandis* (site III) is indicative of their present good regeneration.
(3) Occurrence of saplings alone indicate that these species can be recent invaders and may become subcanopy species later on.
(4) Certain species were present only in larger girth classes, namely, *Soymida febrifuga, Terminalia chebula, Sterculia urens* (site I), *T. alata* and *Lannea coromandelica* (site II) and *Aegle marmelos* (site III). These species are therefore either relic or nomads.

The absence of seedlings and saplings of, for example, *Ougeinia oojeinesis, Cassia fistula* (site I), *Buchanania lanzen, Ixora arborea, Miliusa tomentosa, S. urens* (site II), and *Lagerstroemia parviflora, M. tomentosa* (site III) in their respective sites indicate that these

Table 8. Distribution of tree species (tree ha^{-1}) by diameter class (cm)

Species	Seedlings	Saplings	1–5	6–10	11–15	16–20	21–25	26–30	> 30	Total
	(1)	(2)	(3)	(4)	(5)	20 (6)	(7)	30 (8)	(9)	(10)
Site I										
Tectona grandis	-	1333	30	270	20	20	30	40	60	1803
Legerstroemia parviflora	-	222	10	60	40	-	-	10	-	342
Ougenia oojeinensis	-	-	-	-	-	-	10	10	-	20
Cassia fistula	-	-	10	-	10	-	-	-	-	20
Soymida febrifuga	-	-	-	-	-	-	-	-	10	10
Terminalia chebula	-	-	-	-	-	-	-	-	10	10
Chloroxylon swietinia	-	111	-	-	10	-	10	-	-	131
Grewia tiliaefolia	-	-	-	-	-	-	10	-	-	10
Sterculia urens	-	-	-	-	-	-		-	10	10
Miliusa tomentosa	-	111	-	-	-	-	-	-	-	111
Total	**-**	**1777**	**50**	**310**	**80**	**20**	**60**	**60**	**90**	**2467**
Site II										
Tectona grandis	-	780	70	70	90	30	-	40	60	1140
Diospyros melanoxylon	3333	670	70	110	-	-	-	-	-	4183
Legerstroemia parviflora	-	110	20	-	-	-	-	-	-	130
Ixora arborea	-	-	20	20	-	-	-	-	-	40
Chloroxylon swietenia	-	-	-	-	-	10	-	-	10	20
Butea monosperma	50 000	667	50	40	30	-	-	-	10	5797
M. tomentosa	-	-	50	30	-	-	-	-	-	80
G. tiliaefolia	-	-	-	10	-	-	-	-	-	10
Annona squamosa	-	110	30	-	-	-	-	-	-	140
Buchanania lanzen	-	-	10	10	10	10	-	-	-	40
Terminalia alata	-	-	-	-	-	-	-	10	-	10
Zizyphus xylopyrus	-	-	10	-	-	-	-	-	-	10
S. urens	-	-	-	10	-	-	-	-	-	10
Lannea coromandelica	-	-	-	-	-	-	-	10	-	10
Total	**8333**	**2337**	**330**	**300**	**130**	**50**	**-**	**60**	**80**	**11 620**
Site III										
T. grandis	4000	2880	190	330	340	100	-	-	-	7840
Lagerstroemia parviflora	-	-	100	100	10	-	-	-	-	210
C. swietenia	-	333	60	90	60	10	-	-	-	553
D. melanoxylon	-	550	50	90	-	-	-	-	-	690
M. tomentosa	-	-	20	-	-	-	-	10	-	30
Aegle marmelos	-	-	-	-	10	-	-	-	-	10
Butea monosperma	-	111	30	10	10	-	-	-	-	161
S. urens	-	-	10	-	-	-	-	-	-	10
Total	**4000**	**3874**	**460**	**620**	**430**	**110**	**-**	**10**	**-**	**9504**

species would be completely replaced by other species in the near future. The dominant species, namely, *T. grandis*, will remain in the near future at site III. However, its importance may decline at other sites as indicated by the absence of its seedlings. However, *M. tomentosa* may become a subcanopy species in the near future at site I.

On the basis of the above population structure, it may be concluded that site III, the least disturbed one, exhibited excellent regeneration potential of *T. grandis* and its other associate species. Site II, which showed a 'declining population structure' had moderate regeneration of associate species; however, teak regenerated fairly well in the immediate past. The poor regeneration of different tree species at site I may be due to various biotic disturbances like grazing, illicit felling, lopping, etc., at this site in the past. It is obvious from the preceding discussion that disturbances adversely affect the regeneration of teak. In addition, the stand age also affected teak regeneration as indicated by the mean basal area (Table 1). Younger stands showed better regeneration of teak. Hence, planting of teak is advisable at sites II and III as artificial regeneration is necessary for the improvement of teak regeneration and maintenance of vegetation composition. Otherwise these sites will be dominated by other species such as *B. monosperma*, *D. melanoxylon* and *L. parviflora*.

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