Tropical Ecology **46**(2): 229– 239, 2005 ISSN 0564– 3295

Biomass and productivity in some disturbed tropical dry deciduous teak forests of Satpura plateau, Madhya Pradesh

P. K. PANDE*

Wood Anatomy Discipline, Botany Division, Forest Research Institute, Dehradun 248006

Abstract: Biomass and productivity in some tropical dry deciduous disturbed teak (*Tectona grandis*) forests of Satpura plateau were estimated in three communities identified as *Tectona grandis– Lagerstroemia parviflora–Sterculia urens* (site I); *T. grandis–Lannea coromandalica–Diospyros melanoxylon–Butea monosperma* (site II); *T. grandis–Chloroxylon swietenia–L. parviflora–D. melanoxylon* (site III) and a young plantation of *T. grandis* (site IV). Disturbance magnitude was determined by estimating density–diameter relationship and site quality parameters viz. soil nutrients and stand density. Site I and III (also IV) were most and least disturbed sites, respectively. Height and biomass, and gbh and biomass showed exponential relationships, thus can used for the estimation of biomass of the region. Trees contributed maximum towards total biomass followed by herbs and shrubs. Mature sites showed higher biomass than the younger sites. Photosynthetic:non–photosynthetic ratio was higher for younger and less disturbed sites and can be attributed to their higher photosynthetic demand at early developmental stages and protection of foliage by less disturbances from lopping and grazing. Younger stands showed higher values for root:shoot ratios. Invariably, the NPP_{tree} and NPP_{total} were higher for mature stands (reflection of the lesser tree density and higher mean basal area). NPP_{tree} and NPP_{total} under present study were lower than in other tropical dry forests. This may be the reflection of disturbance on the forests, lower soil depth and poor soil quality. NPP_{teak} and NEP_{teak} were highest for least (IV) and lowest for most disturbed site (I), indicating the negative effect of disturbance. This study suggested that plantation of target species in the blanks inside the forest created by disturbances improves the productivity, and balances the structure of forest ecosystem due to invasion of local species in due course of time.

Resumen: Se hicieron estimaciones de la biomasa y la productividad en algunos bosques tropicales secos caducifolios perturbados de teca (*Tectona grandis*) de la meseta Satpura, en tres comunidades identificadas como *Tectona grandis – Lagerstroemia parviflora–Sterculia urens* (sitio I); *T. grandis – Lannea coromandalica – Diospyros melanoxylon – Butea monosperma* (sitio II) y *T. grandis – Chloroxylon swietenia – L. parviflora – D. melanoxylon* (sitio III), y una plantación joven *T. grandis* (sitio IV). La magnitud de la perturbación fue determinada a través de la estimación de la relación entre la densidad y el diámetro, y de parámetros de la calidad de sitio como los nutrientes del suelo y la densidad del rodal. El sitio I fue el más perturbado y los sitios III y IV fueron los más perturbados. La altura y la biomasa, y el perímetro a la altura del pecho y la biomasa mostraron relaciones exponenciales; por lo tanto, pueden ser utilizadas para hacer estimaciones regionales de la biomasa. Los árboles mostraron la máxima contribución a la biomasa total, seguidos por las hierbas y los arbustos. Los sitios maduros tuvieron mayor biomasa que los jóvenes. El cociente biomasa fotosintética:biomasa no fotosintética fue mayor para los sitios jóvenes y menos perturbados, lo que puede ser atribuido a una mayor demanda fotosintética en etapas tempranas de desarrollo y a una mejor protección del follaje debido a un menor daño físico y forrajeo del mismo. Los rodales más jóvenes mostraron valores mayores para los cocientes raíz–vástago. Invariablemente, la $PPN_{arbórea}$ y la PPN_{total} fueron mayores en los rodales maduros (reflejo de una menor densidad arbórea y una mayor área basal promedio). En el presente estudio, tanto la la $PPN_{arbórea}$ como la PPN_{total} tuvieron valores menores que en otros bosques tropicales secos. Esto puede estar reflejando el disturbio al que estuvieron sometidos los bosques, una menor profundidad de suelo y una pobre calidad del suelo. La PPN_{teca} y la PNE_{teca} fueron mayores en el sitio menos perturbado (IV) y menores en el más perturbado (I), mostrando así el efecto negativo del disturbio. Este estudio sugiere que la plantación de especies blanco en claros dentro del bosque mejora la productividad y balancea la estructura del ecosistema forestal debido a una invasión oportuna en el tiempo por parte de especies locales.

Corresponding Author; e–mail: pandep123@rediffmail.com

Resumo: A biomassa e a produtividade em algumas florestas tropicais secas decíduas disturbadas de teca (*Tectona grandis*) do planalto de Saptura foram estimadas em três comunidades identificadas como *Tectona grandis-Lagerstroemia parviflora-Sterculia urens* (estação – I); *T. grandis-Lannea coromandalica-Diospyros melanoxylon-Butea monosperma* (estação - II) e *T. grandis-Clhloroxylon swieteia-L. parviflora-D. melanoxylon* (estação – III) e uma plantação jovem (estação IV). A dimensão das perturbações foi determinada estimando a relação entre distribuição dos diâmetros e os parâmetros de qualidade da estação como os nutrientes do solo e a densidade das parcelas. A estação I e III foram a mais e menos perturbadas, respectivamente. A altura e a biomassa, e o PAP e a biomassa mostraram uma relação exponencial que pode ser utilizada para estimação da biomassa da região. As árvores são as principais contribuintes para a biomassa total a que se seguem as ervas e arbustos. As estações adultas evidenciaram valores de biomassa mais elevados do que as estações jovens. O rácio fotossintético : não-fotossintético foi mais elevado para as estações mais jovens e menos disturbadas e este facto pode ser atribuído à sua mais elevada procura fotossintética nos estágios iniciais de desenvolvimento e protecção da folhagem por perturbações menores por podas de copa e pastagem. As parcelas mais novas mostraram os valores mais altos para os rácios raízes : lançamentos. Invariavelmente, os valores da $PPL_{árvore}$ e PPL_{total} foram maiores para as parcelas adultas (reflexo de menor densidade arbórea e maior área basal média). No presente estudo a $PPL_{árvore}$ e a PPL_{total} era menor do que noutras florestas tropicais secas. Este facto pode bem ser o reflexo das perturbações nas florestas, menor espessura e inferior qualidade do solo. A PPL_{teca} e a PLE_{teca} foi a maior para a estação menos perturbada (IV) e a mais baixa para a estação mais perturbada (I), indicando o efeito negativo da perturbação. Este estudo sugere que a plantação de espécies determinadas nas clareiras florestais resultantes de perturbações aumenta a produtividade, e equilibra ao longo do tempo a estrutura do ecossistema devido à invasão de espécies locais.

Key words: Above and belowground biomass, decomposition, disturbances, litter, non– photosynthetic, photosynthetic.

Introduction

Tropical dry forests represent the major biome in India covering 46% of the total forest cover (Singh & Singh 1988). Generally, tropical dry forests are smaller in structure and floristically less complex than wet forests. Mature dry forest converts into altered dry forest following grazing, fuel wood harvesting, selective logging and other anthropogenic activities. Also, on further degradation by clear cutting for timber, cultivation, pastures, etc., they are converted into grass– and scrub–lands and finally to barren lands. However, these forests may convert into mature dry forest on the availability of seed pool, favorable site conditions and proper management (Murphy & Lugo 1986). The teak forests of Satpura plateau, mostly categorized under tropical dry forests (Champion & Seth 1968), are well known for their floral diversity. The major tree associates of teak are *Madhuca indica, Diospyros melanoxylon, Buchanania lanzen, Lagerstroemia parviflora, Terminalia* spp., etc. These species are important for tribals for their daily needs. Major part (50%) of these forests is surrounded by villages, which are mainly inhabited by tribals. Their dependency on the forests is very high, resulting into great disturbances in the forests.

Some studies have been carried out on biomass estimation and productivity in different forest ecosystems in India (George *et al.* 1990; Negi *et al.* 1990, 1995; Ranawat & Vyas 1975; Singh 1975; Singh & Singh 1981). Understanding the patterns of storage and production of organic matter in forests in relation to the disturbances is critical for management purposes. The arrangement of populations by size class distribution has been generally used to quantify the magnitude of the disturbance due to stem removal by any means like mortality, illicit felling, faulty silvicutural practices, etc. in the past (Robertson *et al.* 1978; Schmelz & Lindsey 1965). Likewise, disturbance magnitude in the present study has been quantified using density–diameter relationship for different sites (Pande 2001; Robertson *et al.*1978).

Considering the above, the objectives of the present investigation were: (i) to understand the allocation of biomass in different life forms and their components at different sites as per the disturbance magnitude, (ii) to compare the standing biomass and productivity of selected sites as per their disturbance magnitude, and (iii) to develop regression models for predicting tree biomass using gbh and height. An attempt has also been made to compare the biomass and current productivity of the study sites with other forests of India.

Table 1. Characteristics of site (soil depth: 0–20 cm).

Site	Density (tree ha^{-1})	TBA[(a)] (m^2 ha^{-1})	K [(b)] (yr^{-1})	Litter Production [(c)] (t $h^{-1}yr^{-1}$)	Soil pH	N (t ha^{-1})	P (t ha^{-1})	Organic C (%)
I	690	155 (0.225)	2.26	3.30 (1.26)	7.9	0.07	0.005	0.2
II	950	148 (0.157)	3.33	4.53 (1.24)	8.0	0.41	0.006	1.5
III	1630	93 (0.059)	2.57	3.27 (1.00)	8.0	0.41	0.019	1.5
IV	2500	132 (0.053)	2.26	3.30 (1.26)	7.9	0.41	0.009	1.5

Note: [(a)] TBA, total basal area, values in parentheses is mean basal area; [(b)] Decomposition constant (k). The values of 'k' are calculated using l/x_{ss}, where, l is litter production and x_{ss} litter accumulation (Olson 1963); [(c)] Litter stocks (kg ha^{-1}).

Materials and methods

The site

The study sites were located in south Chhindwara forest division, Sillevani range and Khutama beat (Site I, Amla–55 L, compartment N 348; Site II, Amla–6, compartment N 345–B; Site III, Amla–45 compartment N 346–A and Site IV a 16 yr old plantation of *T. grandis* in the large gap inside the forest of site I) of Madhya Pradesh (India). The study area (20° 28' to 22° 49' N– lat and 78° 40' to 79° 24' E long) covers at an elevation of 410–457 m asl. The forests of the area are categorized under group 5A /(1_b) as 'tropical dry deciduous forest' (Champion & Seth 1968). As per the records of Forest Department, the site represents undulating rock of Decan trap. The soil is sandy loam and alluvium occurs along the 'nalas', Further, available soil phosphorus was more at site III followed by IV, II, and I. (Table 1) Available nitrogen and organic carbon was equal at site II, III, and IV and lowest at site I (Table 1). N/P ratio followed the order: II (73.75)> IV (46.93) > III (21.52) > I (14.79). As per the stand density for tree species, site IV showed highest density values followed by III, II and I.

Floristic composition

Three communities were identified as *Tectona grandis–Lagerstroemia parviflora–Sterculia urens* (site I); *T. grandis–Lannea coromandalica–Diospyros melanoxylon–Butea monosperma* (site II) and *T. grandis–Chloroxylon swietenia–L. parviflora–D. melanoxylon* (site III) at different sites. Site IV is a *T. grandis* plantation inside the forest (Table 2). It was considered as a measure for the enhancement in tree productivity by gap filling plantation of dominant tree species (teak). The mean basal area (MBA) indicated that site I is highly mature site (highest MBA) among the studied sites followed by II, III and IV. It also reflected to total basal area. The disturbed and mature sites (I & II) showed less tree density than of the undisturbed and younger sites (III & IV) for teak and all tree species. Most of the shrub layer composed of saplings of *T. grandis, D. melanoxylon, L. parviflora, C. swietenia* and *B. monosperma* at all the sites. Besides, *Lantana camara, Zizyphus jujuba* were recorded from site I; *Flacourtia indica* from site II, and *Diospyros melanoxylon* as small bushes from site III. In all, 20 herb species are found at site I; 22 species at site II and 18 species at site III. *Triumfetta rhombifolia, Indigofera trifoliate, Oplismenus burmanii, Cyperus kyllingia, Sida rhombifolia, S. acuta* were the common herb species at all the sites. *Hemidesmus indicus, Achyranthes aspera, Hyptis suaveolens, Ageratum conzoides,* well known medicinal plants, were recorded from these sites.

Climate

The climate of the area is monsoonal with seasonal rainfall. Total precipitation was 1247 mm with a monthly maximum of 235 mm during September (1998). The annual mean maximum and minimum temperatures were 29°C and 20°C, respectively, with an average mean temperature of 25°C.

Table 2. Vegetation analysis of tree species at different sites (D=density, tree ha^{-1}; TBA = total basal area, m^{-2} ha^{-1}; IVI = Importance Value Index).

Species / Site	I			II			III			IV		
	D	TBA	IVI	D	TBA	IVI	D	TBA	IVI	D	TBA	IVI
Tectona grandis	470	81.35	157	360	82.75	118	960	68.72	156	2500	131.89	299
Lagerstroemia parviflora	120	9.94	50	020	0.189	07	210	4.96	39	0020	0.192	1
Ougeinia oojeiensis	020	9.81	16	–	–	–	–	–	–	–	–	–
Soymida febrifuga	010	9.46	11	–	–	–	–	–	–	–	–	–
Chloroxylon swietinia	020	4.22	13	020	19.08	17	220	11.33	43	–	–	–
Sterculia urens	010	20.38	19	010	0.46	4	010	0.15	3			
Cassia fistula	020	0.27	10	–	–	–	–	–	–	–	–	–
Terminalia chebula	010	15.58	15	–	–	–	–	–	–	–	–	–
Greiwia tiliaefolia	010	4.48	08	010	0.50	4						
Diospyros melanoxylon	–	–	–	180	4.47	36	140	3.96	28	–	–	–
Miliusa tomentosa	–	–	–	080	1.36	19	030	3.33	10	–	–	–
Butea monosperma	–	–	–	130	8.83	32	050	1.32	15	–	–	–
Ixora aerborera	–	–	–	040	1.00	10	–	–	–	–	–	–
Annona squamosa	–	–	–	030	0.22	11	–	–	–	–	–	–
Buchanania lanzen	–	–	–	040	3.46	14	–	–	–	–	–	–
Terminalia alata	–	–	–	010	20.38	17	–	–	–	–	–	–
Lannea coromandalica	–	–	–	010	5.35	78	–	–	–	–	–	–
Zizyphus xylopyra	–	–	–	010	0.76	4	–	–	–	–	–	–
Aegle marmelos	–	–	–	–	–	–	010	0.15	3	–	–	–
Total	690	155.48	300	950	148.8	300	1630	93.93	300	2520	132.08	300

Magnitude of disturbance

The degree of past disturbances was estimated by calculating coefficient of determiner (R^2) between density diameter relationship (Robertson *et al.* 1978; Schmelz & Lindsey 1965). The magnitude in R^2 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 (Robertson *et al.* 1978). Examination of R^2 values for all tree species, the degree of disturbance followed the order: 0.58 (III)<0.18(II)< 0.05(I). No site is near to one and indicate different degree of disturbances at Satpura forests. These R^2 values are non–significant for both negative power and negative exponential function. However, the site I is most and III is the least disturbed site. The more details in this regard are given in Pande (2001). The trend for disturbance magnitude as per the site characteristics viz. soil characters (in terms of soil available N, P, and organic carbon) and tree density analyzed in this study also supports the trend of disturbance magnitude analyzed by size class distribution using density–diameter relationship (Table 1).

Biomass studies

Biomass studies were conducted during 1998 using Harvest method of stratified tree technique, following Peterken & Newbould (1966) in Sellaveni range of Chhindwara forest division, Madhya Pradesh (India). In the study, 'multiple random quadrat method' is used. The advantages of multiple random quadrat method over single plot method are: firstly, it samples optimum area and secondly, it avoids homogeneity of the samples. Twenty quadrats (size 10×10 m for trees, 3 × 3 m for shrubs and 1×1 m for herbs) were laid randomly along the transect on each site to sample the maximum representative area. The size of quadrat was determined by plotting species area curve and number of quadrats was determined by plotting increasing number of quadrats against the number of species (Misra 1968). The girth at breast height (gbh) and height of each tree was measured individually. In order to have better distribution of sample trees over the population, the whole number of trees was divided into different girth classes. Sample trees for each girth class were selected as being nearest to the average of each class (Ovington *et al.* 1967). Twelve trees for teak and sixteen for others were selected for felling for all the sites. These sample trees were felled and roots were excavated for underground biomass. The whole tree biomass was recorded for different components viz. leaves, twigs, branches, bole and roots and presented on oven dry weight basis. The tree biomass was calculated as total biomass of standing crop minus leaf biomass plus litter stock. Shrub biomass was estimated using mean tree technique (Ovington *et al.* 1967). The mean girth was also calculated for estimating shrub biomass for each species. One plant of near to mean girth of each species was selected for felling. In all, 10 plants of different shrub species were felled and roots were excavated. The 'harvest method' was also used for estimating herb biomass. Five quadrats (1×1m) were laid randomly at each site for estimating herb biomass. Biomass was harvested and separated into different species as far as possible. Unidentified material is grouped as 'miscellaneous'. The herb biomass was divided into shoot and root and weighed and presented on oven dry weight basis. The biomass of all herbs pooled to get total herb biomass.

The calculated biomass of each sample tree leaving leaf biomass of each girth class was divided by age. The 12 girth classes ranged from 1–15.7 cm to 172.7–188.4 cm having the class interval of 15.7 were formed. Age was determined by volume tables and further confirmed by counting growth rings. The growth rings were counted manually after smoothing the cross surfaces mechanically and applying glycerin on the smooth surface of the basal disc of each sample (Ramesh Rao 1966). The density of that diameter class was multiplied by this value. This exercise was done for each species. Finally, all the values were summed and value of litter production was added to get net primary productivity (NPP). (NEP) Net Ecosystem Productivity was calculated as bole production of trees (Turner *et al.* 1995). NPP_{tree} is derived from bole, bark, twigs, roots and litter production, while NEP is bole production of trees.

Litter studies

Five permanent litter plots (size, 5×5 m) were randomly placed in each site. All the plots initially cleared and swept clean of any deposited debris. This deposited debris was separated in to leaves and twigs and measured as the litter status (stock) of the forest floor. Collecting the litter from these plots made monthly estimation of litter fall and sorting it into leaves, twigs and 'miscellaneous' consisting of litter of other than main species and other unidentified organic matter (Sharma & Pande 1989). All the results are expressed on oven dry weight basis. Annual decomposition constants (k) are calculated using 'l/x_{ss},' where 'l' is annual litter production and x_{ss} is litter accumulation (Olson 1963).

Results and discussion

Allocation of biomass in different life forms

Table 3 shows allocation of above and below ground biomass in different life forms at different sites. Trees contributed highest magnitude towards total biomass. It is about 96% for sites I, II and IV and 85% for site III, whereas, the contribution of herb biomass ranked second i.e. about 2.5% (II), 2.3% (IV) and 2.3% (I) except for site III, where the contribution of shrub biomass ranked second (10.2%). The shrub biomass followed the order: site III> I> II>IV. The higher contribution of saplings (3874 plant ha^{-1}) towards shrub biomass at site III as compared to site I (1771 plant ha^{-1}) may be the reason of higher shrub biomass at site III (Pande 2001).

The percent allocation of above ground biomass (trees) followed the order: 86.4 (II) > 85.8 (I) > 80.8 (III) > 78.7 (IV) while for shrubs (%) it follows: 47.7 (II) > 41.9 (I) > 40 (III) > 37.5 (IV), and for the herbs, the order of importance was 92.2 (IV) > 73.1 (II) >66.6 (I)> 64.8 (III). Site I and II

Table 3. Allocation of above–and below ground–biomass (t ha^{-1}) in different life forms at different sites.

Life–forms	Biomass				NPP
	Aboveground	Belowground	Total	% of total	(t $ha^{-1}yr^{-1}$)
Site I					
Trees	82.91	13.73	96.64	95.8	6.39
Shrubs	0.81	1.12	1.93	1.9	0.48
Herbs	1.54	0.77	2.31	2.3	2.31
Total	85.26	15.62	100.88	100.0	9.18
Site II					
Trees	73.33	11.49	84.81	95.8	6.33
Shrubs	0.72	0.79	1.51	1.7	0.38
Herbs	1.59	0.58	2.17	2.5	2.17
Total	75.64	12.86	88.49	100.0	8.88
Site III					
Trees	25.59	6.07	31.65	85.3	4.76
Shrubs	1.43	2.34	3.77	10.1	0.94
Herbs	1.10	0.60	1.70	4.5	1.70
Total	28.12	9.01	37.12	100.0	7.4
Site IV					
Trees	35.68	9.70	45.35	96.2	5.94
Shrubs	0.26	0.43	0.69	1.5	0.17
Herbs	1.00	0.09	1.09	2.3	1.09
Total	36.94	10.22	47.13	100.0	7.20

produced the relative higher biomass than of sites III and IV. It simply reflects the maturity of the stand.

The contribution of root biomass was higher for younger sites (III, 24.3 & IV, 21.6%) as compared with mature and disturbed sites (I, 15.0 & II, 13.5). It indicates that teak allocates more resources to root system at the early stages of its growth to optimize the nutrient uptake. The higher allocation of root biomass at initial phase of growth in teak forest was also reported by Prasad & Mishra (1984) who attributed it to die back of shoots.

The root: shoot ratio was higher for younger and less disturbed sites (III, 0.24 and IV, 0.27) as compared to mature and disturbed sites (I, 0.17 and II, 0.16). The mean root: shoot biomass ratio was reported as 0.24±0.14 for tropical forests (Cairns *et al.* 1997). The percent values of root: shoot ratio for the younger and less disturbed sites are well within the reported range for tropical forests. However, the values for disturbed and mature sites are lower as compared to other tropical forests (Cairns *et al.* 1997).

The allocation of biomass in different components in tropical and subtropical forest is given in Table 4. Total biomass ranged between 38.6–239.8 t ha^{-1}. The ranges for the present study for above–ground (28.1–85.3), below–ground (9.1–15.6) and total biomass (39.1–100.9 t ha^{-1}) are on the lower side of range reported for tropical/subtropical forest of India (Table 4). It probably may be related to the lower soil depth and poor soil of Satpura plateau.

Allocation of biomass in different tree species at different sites is presented in Table 5. Teak contributed highest biomass at site IV followed by III, II and I. This suggests that disturbance effects adversely to the biomass and productivity of teak. The other significant contributors to the total tree biomass were *L. parviflora,* and *Cassia fistula* at site I; *B. monosperma*, *D. melanoxylon* and *B. lanzen* at site II and *C. swietenia, L. parviflora* and *D. melanoxylon* at site III.

Differential values of standing biomass at various sites may be due to selective removal of forest products during different periods. As such, the higher total tree biomass at mature and disturbed sites may be related to the presence of more trees at larger girth classes, which is indicated by higher MBA as compared to younger and less disturbed stands. The higher MBA increased TBA in spite of the lower density, which in turn increased the biomass at disturbed sites. More herb and shrub biomass produced by disturbed sites is indicative of the fact that the

Table 4. Dry phytomass (t ha^{-1}) of tropical dry forests of India.

Locality	Phytomass				Authority
	AG	BG	Total	BG/AG	
Varanasi	–	7.6	–	–	Bandhu (1970)
Varanasi	205.5	34.3	239.8	0.17	Singh (1975)
Varanasi	64.3	9.5	73.8	0.15	Singh & Singh (1981)
Chandraprabha	95.0	–	–	–	Singh (1989)
Udaipur	28.2	–	–	–	Ranawat & Vyas (1975)
Haldwani	74 .6–164.0	15.4–17.9	90.0–19	0.21–0.11	Negi *et al.* (1995)
Tripura	114	24.40	138.40	0.21	Negi *et al.* (1990)
Coimbatore	27.6	11.1	38.6	0.4	George *et al.* (1990)
Dehra Dun	129.6	–	–	–	Kaul *et al.* (1979)
Chhindwara	28.1–85.3	9.1–15.6	37.1–100.9	0.32–0.18	Present study

space/resource created by disturbances are efficiently utilized by herbs due to their smaller niche size. The higher shrub biomass at younger site (III) than of the disturbed sites (I and II) may be due to the higher regeneration potential of different tree species at this site as indicated by higher number of seedling (Pande 2001). Consequently saplings contributed more towards shrub biomass at site III as compares to disturbed and mature sites.

Photosynthetic and non–photosynthetic biomass

Allocation of biomass in photosynthetic and non–photosynthetic components at different sites is tabulated in Table 6. Photosynthetic/non–photosynthetic component ratio follows the order: 0.137 (IV) > 0.120 (III) > 0.04 (II) > 0.039 (I). Younger and less disturbed stands (III & IV) showed higher values for this ratio. It may be explained as: firstly, the photosynthetic demand is higher at early developmental stages of stand growth thus form higher foliage and, secondly, the less disturbances protect the foliage from the lopping and grazing at site III and IV.

Net primary productivity

NPP_{tree} was highest for site I (6.39) followed by II (6.33), IV (5.94) and III (4.76). NPP_{shrub} followed the order: 0.94 (III) > 0.48(I) > 0.38 (II) > 0.17 (IV), while for NPP_{herb}, the order of importance was: 2.31 (I) > 2.17> (II), 1.70 (III) > 1.09 (IV). NPP_{total} was highest for mature stands than of the younger ones. NPP_{tree} and NPP_{total} was higher for disturbed sites (I & II) than of the less disturbed sites (III & IV). Similar is the case for NPP_{herb}. Herbs utilized newly created space/resources resulting gap created by felling/lopping of trees (disturbances).

The percent NPP contribution of *Tectona grandis* is highest for site IV (49.2) and lowest for site I (17.8). The values of NPP_{tree} in present study (4.8–6.4 t ha^{-1}) were lower than of the reported range (6.42–25.39 t ha^{-1}) for tropical forests (Karmacharya & Singh 1992; Negi *et al.* 1995). However, the values are near to George *et al.* (1990) and Kaul *et al.* (1979). This is the reflection of lower soil depth and low soil fertility of the plateau forests as suggested by George et al (1990). Net primary productivity on per tree basis was higher for mature and disturbed sites than of the younger sites. This is due to less density and higher mean basal area of trees of mature sites (Table 7).

Net ecosystem productivity

NEP_{teak} and NEP_{tree} showed higher values for the mature stands (Table 7) due to their less tree density and higher per tree biomass. Plantation inside the forest also showed higher values of bole production in both the cases (NEP_{teak} and NEP_{tree}). As compared to reported stem wood biomass production (4–18 t ha^{-1} yr^{-1}) in tropical dry regions (Murphy & Lugo 1986) the present values (0.8 - 1.35) were much lower. This can be attributed to the disturbances in the forests, lower soil depth and nutrient poor soil of the investigation sites.

Regression analysis

Figs. 1 and 2 show the exponential regression models alongwith their R^2 values developed for gbh and biomass, and height and biomass relations. This is based on basic data of sampled trees of teak. The regression models developed for the prediction of biomass for regional basis to avoid the necessity of repeated destructive sampling. Height and gbh are considered as independent variable in developed exponential regression

Table 5. Allocation of biomass (t ha^{-1}) in different components of different tree species.

Species	Leaf	Twig	Bole	Bark	Root	Total
Site I						
Tectona grandis	0.93	2.78	44.89	3.13	8.82	60.55
Lagerstroemia parviflora	0.47	0.84	1.45	0.30	0.72	3.78
Cassia fistula	0.01	0.02	0.10	0.01	0.04	0.18
Miscellaneous*	0.48	4.00	20.46	3.05	4.15	32.14
Litter stock	–	–	–	–	–	1.27
Total	1.89	7.64	66.90	6.49	13.73	97.92
Site II						
Tectona grandis	1.11	3.10	45.59	3.40	8.22	61.42
Diospyros melanoxylon	0.05	0.07	0.56	0.11	0.19	0.97
Lagerstroemia parviflora	0.003	0.01	0.03	–	0.01	0.05
Miliusa tomentosa	0.10	0.02	0.06	0.02	0.03	0.24
Butea monosperma	0.07	0.36	0.35	0.05	0.31	1.14
Annona sequamosa	0.01	0.02	0.04	0.01	0.02	0.10
Buchanania lanzen	0.04	0.08	0.52	0.13	0.12	0.89
Ziziphus xylocarpa	0.01	0.03	0.15	0.03	0.06	0.28
Sterculia urens	0.002	0.01	0.06	–	0.02	0.09
Ixora aerborea	0.01	0.06	0.20	0.03	0.07	0.37
Miscellaneous*	0.24	1.16	14.41	1.03	2.44	19.27
Litter stock	–	–	–	–	–	1.25
Total	1.65	4.92	61.97	4.81	11.49	86.06
Site III						
Tectona grandis	1.87	2.15	13.74	3.50	5.21	26.47
Lagerstroemia parviflora	0.05	0.19	0.40	–	0.13	0.76
Chloroxylon swietenia	0.09	0.16	1.77	–	0.33	2.34
Diospyros melanoxylon	0.04	0.05	0.44	0.08	0.15	0.76
Butea monosperma	0.02	0.09	0.08	0.013	0.07	0.27
Sterculia urens	0.002	0.01	0.03	–	0.01	0.07
Ziziphus xylocarpa	0.03	0.04	0.25	0.05	0.07	0.44
Miliusa tomentosa	0.09	0.02	0.34	–	0.10	0.55
Litter stock	–	–	–	–	–	1.00
Total	2.20	2.71	17.05	3.64	5.98	32.78
Site IV						
Tectona grandis	4.56	4.41	20.91	5.77	9.66	45.31
Lagerstroemia parviflora	0.003	0.001	0.03	–	0.01	0.04
Litter stock	–	–	–	–	–	1.27
Total	4.56	4.41	20.94	5.77	9.67	46.62

*Miscellaneous indicates sum of biomass of few and scattered trees.

models against dependent variables like leaf, bole, twig, bark and root biomass. Coefficient of determiner (R^2) shows that there are much variations among the height and biomass, and gbh and biomass relations. However, gbh biomass relationship showed relatively higher R^2 values therefore, gbh alone can safely be used for prediction of biomass for the region under study.

Table 6. Allocation of biomass (t ha^{-1}) in photosynthetic and non–photosynthetic compo–nents at different sites.

Site	Photosynthetic	Non-Photosyn-thetic	Total
I	3.77 (4)	97.17 (96)	100.89
II	3.52 (4)	84.97 (96)	88.50
III	3.98 (11)	33.14 (89)	37.12
IV	5.70 (12)	41.42 (88)	47.12

Note: Values in parenthesis are percent values

Table 7. NPP and NEP (Net Ecosystem Productivity) on per tree basis at different sites (t $ha^{-1}yr^{-1}$).

Site	I	II	III	IV
NPP_{Teak}	0.0024	0.0031	0.0014	0.0012
NPP_{Tree}	0.0093	0.0067	0.0029	2.279
NEP_{Teak}	0.0017 (0.7823)	0.0022 (0.7851)	0.0007 (0.6705)	0.0005 (1.351)
NEP_{Tree}	0.0019 (1.3158)	0.0013 (1.2450)	0.0005 (0.8510)	0.00054 (1.3543)

Note : Values in parenthesis are total value

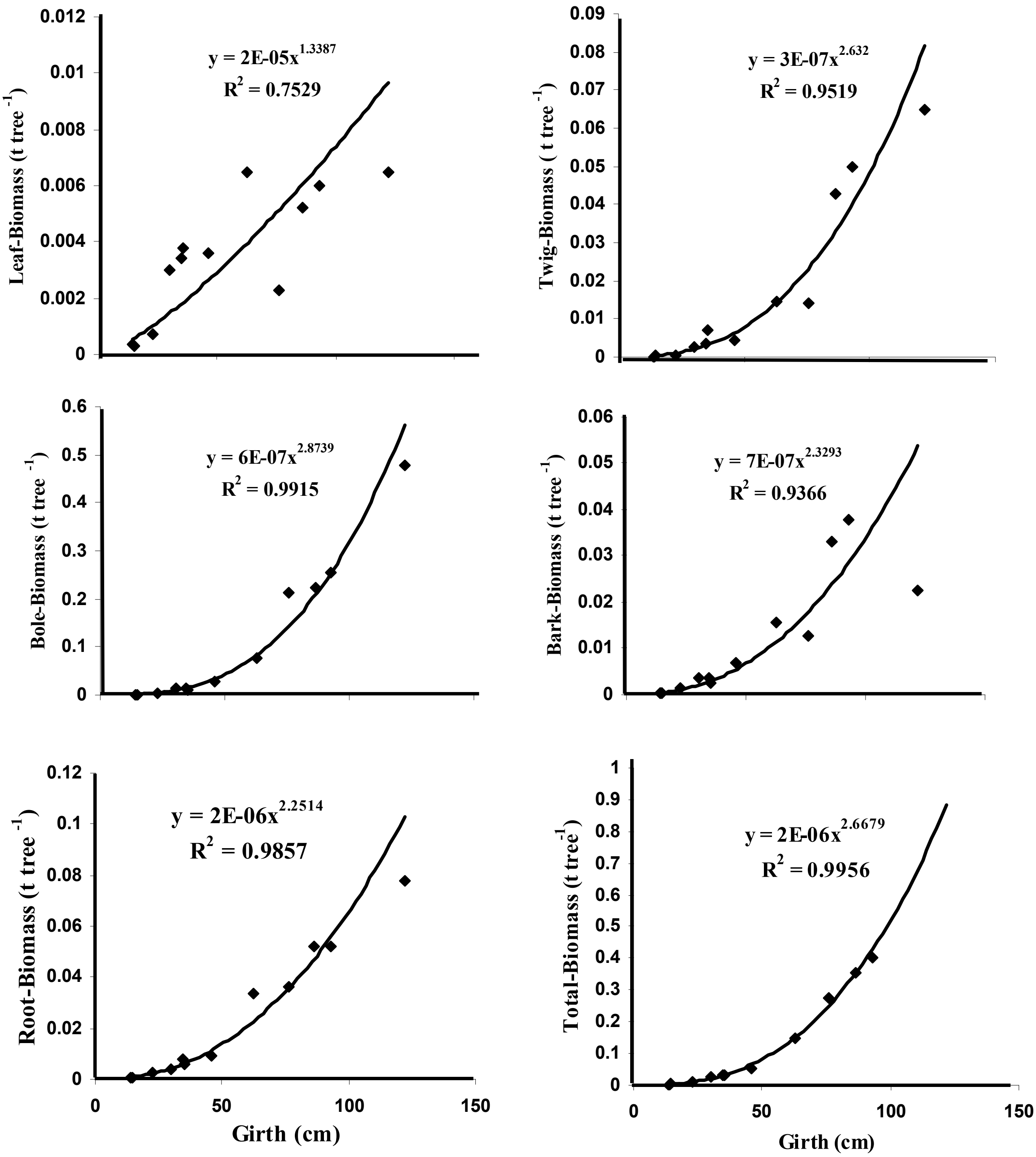

Fig 1. Relationship between girth at breast height (gbh) and different components of tree (teak) biomass

In conclusion, it may be stated that disturbances not only reduced biomass of dominant tree species (teak) but also lowered the productivity. It is evident from the minor contribution of saplings to the shrub biomass at disturbed sites as compared to less disturbed site III. Further, the NEP $_{teak}$ was 72.7% higher at site IV (plantation inside the forest, site I) than of site I. It clearly indicated that, for target species productivity of disturbed site I increased substantially by gap filling plantation. It also improved the site quality. The forest managers can use these evidences for planning to fill the blanks in side the forest by target species so that

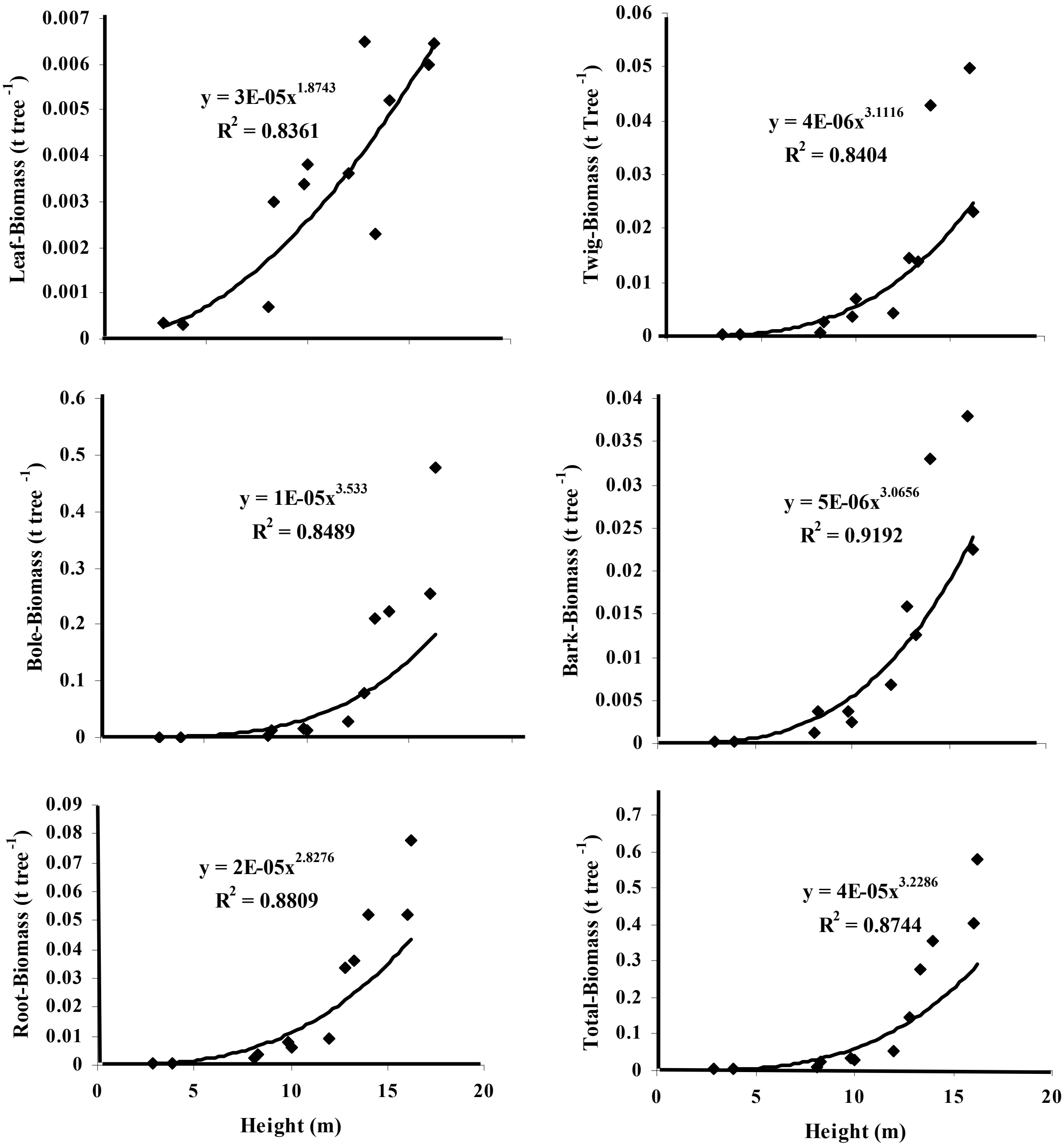

Fig 2. Relationship between height and different components of tree (teak) biomass.

tree productivity would be maintained. This will also help in maintaining the tree composition of the forest during the stand development.

Acknowledgements

The author is thankful to Mr. H.K. Verma, Conservator of Forest, Chhindwara, for providing necessary facilities during the field work. The author is also thankful to Head, Center for Forestry Research and Human Resource Development, Chhindwara, for providing necessary facilities. Acknowledgement is also due to Mr. D.P. Jharia, T.A.I. of the Center, for helping in laboratory and field.

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