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Impact of Forest Fire on Biomass and Carbon Storage Pattern of Tropical Deciduous Forests in Bhoramdeo Wildlife Sanctuary, Chhattisgarh

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ABSTRACT

In developing countries, protected forests experience extensive anthropogenic disturbance due to fire, grazing, extraction of fuel wood and collection of non-wood forest products which contribute to the livelihood of forest dwelling populations. The present study includes the biomass and carbon storage pattern of Tropical Deciduous forests in fires affected areas of Bhoramdeo Wildlife Sanctuary. Delineation and identification of fire prone areas were done on the basis of historical ground fire data in conjunction with satellite remote sensing data provided by NRSA, based on the frequency of forest fire damage. The fire affected areas were divided into four fire zones *viz.,* high (HFZ), medium (MFZ), low (LFZ) and non fire zones (NFZ). Stratified random sampling was used by laying five quadrats (20m x 20m) for measuring trees and saplings. Within 20m x 20m quadrats, another 5m x 5m quadrats was laid for seedlings and shrubs, respectively. Total tree biomass recorded was maximum in LFZ and minimum in MFZ. The total sapling biomass was minimum in HFZ and maximum in NFZ. In case of seedling layer the maximum total biomass was accumulated in low fire zone whereas in shrub layer it was highest in HFZ. Carbon storage has same pattern as that biomass accumulation at all sites. It is evident that forest fires are driving factor in shaping forest vegetation, biomass accumulation and carbon storage. Efforts are needed to control on such type of fire which could allow the natural recovery processes to enhance biological diversity and sustainable development.

Key Words: Biomass; Carbon Storage; Vegetation; Tropical Deciduous Forest; Forest Fire

INTRODUCTION

Fire plays an important role in tropical deciduous forests across the globe. Most fires are deliberately or accidentally set by people. Forest fire has important effects on forest structure and diversity in deciduous forests. It is equally important to understand the role of fire in altering ecosystem functioning (Saha and Howe 2006). Forest fires are driving factor in shaping forest vegetation and the landscape in many parts of India (Hiremath 2007). In India, out of 67.5 million ha of forests, about 55% of the forest cover is annually subjected to fires (Gubbi 2003). Forest fires cause enormous loss to the forest ecosystem, diversity of flora and fauna and economic wealth. The shifts in species composition in natural forest occur slowly under normal conditions, but catastrophic disturbances like repeated fires can reduce structural and biological complexity in forests (Schindele et al. 1989). Interactions between the climatic regime, soil type and topography are all involved, as these features determine the vegetation type, the likelihood of fire and the probability of its spread. Fire enhances the productivity of ecosystems by releasing chemicals and nutrients locked up in the old herbage. The controlled fires enhance microbial activity and ameliorate the physico-chemical properties of forest soil. But the un-controlled fire is always harmful to both flora and fauna; it will arrest the progression of succession and lead to development of secondary forest communities of invasive and econo-mically unimportant fire hardy species. Tree species diversity in the tropics varies dramatically from place to place (Pitman et al. 2002). Much attention has been given to tropical forests due to their species richness (Whitmore 1984), high standing biomass (Bruenig 1983, Bargali and Singh 1997) and greater productivity (Jordan 1983, Bargali and Singh 1991, 1995, Bargali et al. 1992). Forest fire not only reduces diversity and abundance of vegetation but also reduces plant productivity and encou-rages invasion by non-palatable species and weeds (Miller and Kauffman 1998). With increased fragmen-tation of forested habitats and increasing human pressure on forest resources, the frequency and distribution of fire in tropical landscapes have increased several folds over what they were in the past (Cochrane 2003). Forest fire has increasingly become a frequent problem in India. Moreover, the losses from fire in respect of biodiversity, carbon sequestration capability, soil moisture and nutrients, are very significant from the point of view of ecological stability and environmental conservation.

STUDY AREA

The natural forest of Kawardha (Chhattisgarh) adjacent to Kanha National Park (M.P.) is one of the important natural heritage sites of Central India. It is well known for its rich, complex and diverse flora and fauna. Dry teak, sal, mixed and bamboo brakes are predominant vegetation types found in these forests. These forests acts as corridor and facilitate the movement and breeding of wild animals. The Baigas are the dominant tribe whose livelihood and economy depends maibly on these forests. Great harmony existed between tribals and valuable forests of this region in the past, such that the biodiversity of the region was well protected and conserved to cater the needs of future generations. However, during the past few decades, these forests were subjected to severe biotic disturbances. Forest fires have became major threat in certain pockets due to illegal and crude methods of extractions of NTFPs. The fire season ranges from March to May. Majority of these forest fires are surface fires, linked to deliberate human activities and are closely related to their socio-economic conditions as well. Presently there is a dearth of both qualitative and quantitative information on the impacts of forest fire on vegetation status in this region. Therefore, this study was conducted for the assessment of biomass and carbon storage pattern of vegetation across the fire gradient of this tropical ecosystem.

The present study was carried out in and around Bhoramdeo Wildlife Sanctuary located in Kabirdham district (21° 23' to 22° 00' N latitudes and 80° 58' to 82° 34' E longitudes). The Sanctuary, covering 163.80 sq. km, was notified by the forest department of Chhattis-garh (notification no. F/7/18/FC/ Raipur og 7 August 2001) to conserve the rich endemic flora and fauna. It is named after famous Bhoramdeo temples, known as 'Khajuraho of Chhattisgarh' built by King Ramchandra of Nag dynasty in 11th century AD. that are significant in terms of archaeology and history. Bhoramdeo wildlife sanctuary is ecologically fragile and sensitive zone as it connects the best protected tiger reserves of Kanha (M.P) and Achanakmar (C.G.). The corridor is arguably the most important for migration and breeding tiger populations, and key to their survival in Central India.

The topography of Bhoramdeo Wildlife Sanctuary is hilly, which falls in the Maikal Range of the Satpura hills belongs to Chilphi group formation of Archean age class. The altitude ranges from 600 to 900 m from the sea level. The climate of the study area is dry tropical with an average annual rainfall ranges from 1250 mm to 1380 mm. The mean monthly annual temperature ranges from 16.5 °C in December to 40.8 °C in May. The mean annual maximum and minimum temperature of study area is 43.4 °C in May and 7.9 °C in December, respec-tively. Soils of the study area are grouped into two classes viz. Entisols and Ultisols. Different types of forest vegetation occur in the study area (see Jhariya et al. 2012). Northern and eastern sides are covered with luxuriant forests, whereas teak plantations occupy a major area in the south. In the west, a large area is covered by degraded and mixed forest and also with bamboo brakes occasionally found as patches in this direction.

According to Champion and Seth (1968), the forests of the study area are classified into four major forest types viz., (1) Southern Tropical Dry Deciduous Teak Forest (5A/C1b), (2) Northern Tropical Dry Peninsular Deciduous Sal Forest (5B/C1c), (3) Northern Tropical Dry Mixed Deciduous Sal Forest (5B/c2) and (4) Dry Bamboo Brakes (5/E9). The major tree species found in these forests are *Adina cordifolia* Hook.f., *Anogeissus latifolia* Wall ex Bedd., *Buchanania lanzan* Spreng., *Cassia fistula* Linn., *Dendrocalamus strictus* Roxb., *Diospyros melanoxylon* Roxb., *Lagerstroemia parviflora* Roxb., *Lannea coromandelica* (Houtt.) Merr., *Madhuca longifolia* Roxb., *Ougeinia oojeinensis* (Roxb.) Hochr., *Emblica officinalis* Gaertn, *Schleichera oleosa* (Lour.) Oken, *Shorea robusta* Gaertn.f., *Sterculia urens* Roxb., *Terminalia tomentosa* Wight & Arn.., *Terminalia chebula* Retz. etc. Similarly shrubs species like *Bauhinia racemosa* Lam., *Bauhinia vahlii* (W.) A., *Butea superba* Roxb. ex Willd., *Carissa spinarum* D.C., *Dioscaria alata* Roxb., *Mallotus phillippinensis* Muell., *Mimusops hexandra* Roxb., *Ventilago cayculata* Tul., *Zizyphus xylopyra* (Retz.) Wild., etc. are abundant. *Achyranthus aspera* inn., *Apluda mutica* Hack*., Crotalaria calycina* Schrank., *Desmodium pulchellum* (L) Benth., *Eragrostis tenella* Linn., *Ischaemum pilosum* Klein ex Willd*., Paspalidium flavidum* (Retz.) A.Camus, *Tridax procumbens* Linn., etc. are most widely found herbs in the ground layer in these forests. The sanctuary also harbours important wild animals like tiger, leopard, hyena, fox, bear, cheetal, wild buffalo, nilgai etc. The river Sakari flows through the Sanctuary, which is life line for the entire region as it provides drinking water in lean periods. Man-made and accidental fires are very common in the sanctuary area as it influences the spatial and temporal distribution of vegetation

METHODOLOGY

Forest fire hazards are very frequent in Bhoramdeo sanctuary, affecting both the structure and functioning of natural forest ecosystem leading to large scale degradation. More than 90% of forest fires in the sanctuary are caused by humans and usually set intentionally either to promote the growth of fodder for grazing livestock or to facilitate the collection of non-timber forest products (NTFP) like collection of Tendu leaves, Sal seeds, Mahua flowers, honey, gums etc. especially in summer (March-May). The livelihood and economy of inhabitants are intricately linked to these activities.

Historical ground fire data in conjunction with satellite remote sensing data was used for delineation and identification of fire affected areas. The data on fire prone areas (with latitudes and longitudes) in sanctuary and adjoining areas were collected from Chhattisgarh State Forest Fire Management Information System in conjunction with data from Indian Remote sensing Satellite (IRS-P6) and TERRA/AQUA Moderate resolution Imaging Spectroradiometer (MODIS) provided by NRSC, Hyderabad. Based on the 6 years data (2005-2010) and ground survey, the frequency and intensity of fire incidences in different compartments were recognized. We have made extensive ground surveys in different compartments of Sanctuary and adjoining forests with GPS during February to May in 2010 to locate the fire affected compartments. The survey revealed that most of forest fire is surface fires and affected more than 70% of the sanctuary area. The fire affected areas were first located on compartment map on 1:50,000 Survey of India topo maps and identified in the field with the help of GPS for laying sample plots. Based on the frequency, intensity and spatial extent of the damage, the fire affected areas were divided into four fire regimes *viz.,* high, medium, low and non-fire zones. In general southern and western aspects of sanctuary were more affected by fire hazards as compared to northern and eastern aspects. Two compartments 126 P and 102 P in south west direction were identified as high fire regime category, where the frequency of fire incidences was 100% occurring every year and spread in >70%% of the compartment. The compartments, 127 and 75 represented medium fire zone, where the fire hazards were reported in alternate years (50% frequency) damaging about 40-70% area of the compartment. Similarly, the compartments 128 and 94 fall under the category of low fire regime, where the fire incidences occurred once in 5 years and affecting < 40% of the area. The historical data revealed that the compartments 123 and 82 were not affected by any fire damage during 2005-2010.

The trees and saplings were analyzed by randomly laying five 20 x 20 m quadrats in two compartments for each of the fire regime. The girth at breast height (i.e., 1.37 m above the ground) of all the trees and saplings in each quadrat was measured and recorded individually. In each of this quadrat, a 5 x 5 m sub quadrat was laid randomly for measuring seedlings and shrubs. The seedlings (<10 cm GBH) and shrubs are measured at the collar height. The details of the floristic study have been given by Jhariya et al. (2012). Species specific allometric equations relating tree circumference to their component (bole, branch, foliage and root) biomass developed earlier by Singh and Misra (1979) and Singh and Singh (1991) for the deciduous forest species were used for the estimation of biomass (Table 1). Authors reported that

$$ln\ Y = a + b\ lnX$$

is the best fit model, where Y corresponds to component biomass (kg) , X to girth of trunk at breast height (cm) and 'a' and 'b' were regression constantans varied for each component. The wood density values for each species were accounted while constructing allometric equations by Singh and Mishra (1979).

The tree individuals in each quadrat were categorized into different girth classes. The mean GBH (Girth at breast height) value for each species for a girth

Table 1. Allometric relationship between GBH, X (cm) and biomass of different components Y (kg tree^{-1}) for various species according to ln Y = a + b ln X. (from Singh and Misra 1979)

Species	**Bole**	Branch	**Root**	**Leaves**
Tree species				
Acacia catechu	-2.0973+2.3131x log X	-3.1626+2.9565x log X	-2.1735+2.0756x log X	-2.2882+1.6889 x log X
Emblica officinalis	-2.2675+2.3175 x log X	-3.1576+2.8571 x log X	-2.1898+2.0283 x log X	-2.2645+1.7667 x log X
Lagerstroemia parviflora	-2.227762.2908 x log X	-2.9451+2.6849 x log X	-3.0475+2.5876 x log X	-2.7657+2.0988 x log X
Diospyros melanoxylon	-2.3639+2.4012 x log X	-3.7528+3.1466 x log X	-2.5208+2.4420 x log X	-2.7088+1.9090 x log X
Tree species pool	-2.1725+2.2880 x log X	-3.2888+2.9420 x log X	-2.6045+2.2913 x log X	-2.6977+2.0403 x log X
Shrub species				
Zizyphus glaberrima	-3.0740+2.8055 x log X	-3.4728+2.970 x log X	-3.1395+2.5270 x log X	-2.8830+2.0780 x log X
Nyctanthes arbortristis	-2.7727+2.5251 x log X	-2.4477+1.9890 x log X	-3.0406+2.3875 x log X	-2.6580+1.8924 x log X
Shrub species pool	-2.9407+2.6727 x log X	-3.0225+2.5422 x log X	-3.0849+2.4481 x log X	-2.7795+1.9953 x log X

class was used in the regression equation to get an estimate of biomass (by component) for that girth class. Then this value was multiplied by the density of trees in that girth class. The girth class values were summed to obtain the biomass estimate for each of the quadrats in each site. Shrub biomass was calculated using the computation protocol given by Singh and Misra (1979) and Singh and Singh (1991). Carbon concentration was calculated by assuming that the carbon content is 50% of the total biomass (Brown and Lugo 1982, Cannell 1995, Dixon et al. 1994, Ravindranath et al. 1997, Richter et al. 1995, Schroeder 1992). The values for carbon storage in different components were summed to obtain total carbon storage in the vegetation.

RESULTS AND DISCUSSION

The density of trees across the various forest fire zones ranged from 255 to 630 trees ha^{-1} (Table 2). Maximum density of tree layer was recorded under non-fire zone followed by medium fire, low fire and high fire zones. In the high fire zone and non-fire zone *Shorea robusta* and *Ougeinia oojeinensis* were recognized as predominant plant community. The greater tree population in the non-fire zone was the direct consequence of fire protection. In the tree layer maximum number of tree species (20) were recorded in non-fire zone having maximum tree density (630 individuals ha^{-1}) and basal area (15.71 m^2 ha^{-1}) followed by medium fire zone (15 species with 360 individuals ha^{-1} density and 10.21 m^2 ha^{-1} basal area), low fire zone (12 species with 340 individuals ha^{-1} density and 14.54 m^2 ha^{-1} basal area) and high fire zone (10 species with 255 individuals ha^{-1} density and 10.11 m^2 ha^{-1} basal area).

For the sapling layer maximum number of species i.e., 18 species with the density of 990 individuals ha^{-1} having 3.18 m^2 ha^{-1} basal area were recorded for non-fire zone. High fire zone recorded 14 species with 305 individuals ha^{-1} density and 0.86 m^2 ha^{-1} basal area, whereas medium fire zone had only 13 species with more number of individuals i.e., 590 individuals ha^{-1} having 1.60 m^2 ha^{-1} basal area. The low fire zone recorded 17 species with 650 individuals ha^{-1} and 1.65 m^2 ha^{-1} basal area. In low and non-fire zone similar number of seedling species (7 species) were recorded but the density was slightly higher (13680 individuals ha^{-1}) in low fire zone as compared to non-fire zone (12720 individuals ha^{-1}). The basal area also showed the similar trend. High fire zone recorded the lowest number of species (7) having the density of 10400 individuals ha^{-1}, whereas the medium fire zone showed a slight increase in species number (9) and density (10960 individuals ha^{-1}) as compared to high fire zone. In contrast to tree layer the number of shrub species was maximum in the high fire zone (i.e., 10 species) and minimum in the non-fire zone (6 species). The medium and low fire zone recorded similar number of species (7). Maximum density of shrub layer (2480 individuals' ha^{-1}) was recorded in the medium fire zone and minimum (1120 individuals ha^{-1})

Table 2. Community characteristics of different forest fire zones of Bhoramdeo Wildlife Sanctuary

Vegetation Layer	Characters	High Fire Zone	Medium Fire Zone	Low Fire Zone	Non-Fire Zone
Tree Layer	Number of Species	10	15	12	20
	Density (individuals ha^{-1})	255	360	340	630
	Basal Area (m^2h^{-1})	10.11	10.21	14.54	15.71
	Shannon Index (H')	2.57	3.49	2.40	2.68
	Simpson's Index (Cd)	0.24	0.10	0.32	0.32
	Species richness (d)	1.62	2.37	1.88	2.94
	Equitability (e)	1.11	1.28	0.96	0.89
	Beta diversity (βd)	2.7	1.8	2.25	1.35
Sapling Layer	Number of Species	14	13	17	18
	Density (individuals ha^{-1})	305	590	650	990
	Basal Area (m^2h^{-1})	0.86	1.60	1.65	3.18
	Shannon Index (H')	3.22	3.09	3.26	2.88
	Simpson's Index (Cd)	0.14	0.14	0.15	0.25
	Species richness (d)	2.27	1.88	2.47	2.46
	Equitability (e)	1.22	1.20	1.15	0.99
	Beta diversity (βd)	1.78	1.92	1.47	1.38
Seedling Layer	Number of Species	7	9	13	13
	Density (individuals ha^{-1})	10400	10960	13680	12720
	Basal Area (m^2h^{-1})	0.48	1.81	2.25	1.86
	Shannon Index (H')	2.10	2.80	2.70	2.47
	Simpson's Index (Cd)	0.29	0.17	0.22	0.25
	Species richness (d)	0.64	0.86	1.26	1.26
	Equitability (e)	1.08	1.27	1.05	0.96
	Beta diversity (βd)	2.71	2.11	1.46	1.46
Shrub Layer	Number of Species	10	7	7	6
	Density (individuals ha^{-1})	2080	2480	1840	1120
	Basal Area (m^2h^{-1})	0.59	0.65	0.67	1.11
	Shannon Index (H')	3.13	2.67	2.50	2.35
	Simpson's Index (Cd)	0.12	0.16	0.20	0.22
	Species richness (d)	1.17	0.76	0.79	0.71
	Equitability (e)	1.36	1.37	1.28	1.31
	Beta diversity (βd)	1.10	1.57	1.57	1.83
Herb Layer	Number of Species	5	10	7	6
	Density (individuals ha^{-1})	136000	668000	138000	112000
	Shannon Index (H')	1.69	2.71	2.50	2.39
	Simpson's Index (Cd)	0.36	0.20	0.21	0.20
	Species richness (d)	0.33	0.67	0.50	0.43
	Equitability (e)	1.05	1.17	1.28	1.33
	Beta diversity (βd)	3.8	1.9	2.71	3.16

in the non-fire zone. The high and low fire zones had 2080 and 1840 individuals ha^{-1}, respectively. Maximum basal area (1.11 $m^2 ha^{-1}$) was recorded for non-fire zone and minimum (0.59 $m^2 ha^{-1}$) for high fire zone.

The total biomass (aboveground and belowground) of tree layer (Table 3) across different forest fire zones ranged from 101.43 Mg ha^{-1} to 192.36 Mg ha^{-1} for medium and low fire zones. The total aboveground biomass was 139.34, 88.24, 169.73 and 111.00 Mg ha^{-1} for high fire, medium fire, low fire and non-fire zone, respectively. The total belowground biomass were varied from 13.18 to 22.63 Mg ha^{-1} for medium fire and low fire zone, whereas it was 18.47 and 17.36 Mg ha^{-1} for high fire and non-fire zone. In the high fire zone the distribution of biomass in different components was 48.97 Mg ha^{-1} in bole, 85.80 Mg ha^{-1} in branch, 4.57 Mg ha^{-1} in leaf and 18.47 Mg ha^{-1} in root. The bole, branch, leaf and root constituted 31.03, 54.36, 2.89 and 11.70 per cent, respectively of the total biomass. Among the individual species *Shorea robusta* constituted the highest biomass in the high fire zone. The medium fire zone showed the distribution of biomass in different component were 32.80 Mg ha^{-1} in bole, 51.99 Mg ha^{-1} in branch, 3.46 Mg ha^{-1} in leaf and 13.18 Mg ha^{-1} in root. The bole, branch, leaf and root constituted 32.33, 51.25, 3.41 and 12.99 per cent, respectively of the total biomass. In the low fire zone the distribution of biomass in different components .was 59.33 Mg ha^{-1} in bole, 104.85 Mg ha^{-1} in branch, 5.55 Mg ha^{-1} in leaf and 22.63 Mg ha^{-1} in root. The bole, branch, leaf and root constituted 30.84, 54.50, 2.88 and 11.76 per cent, respectively of the total biomass. The non-fire zone showed the biomass of different components was 43.18 Mg ha^{-1} in bole, 62.89 Mg ha^{-1} in branch, 4.93 Mg ha^{-1} in leaf and 17.36 Mg ha^{-1} in root. The bole, branch, leaf and root constituted 33.63, 48.99, 3.84 and 13.52 per cent, respectively of the total biomass. Among the individual species *Shorea robusta* constituted the highest biomass whereas lowest by *Lagerstroemia parviflora* in the non-fire zone.

The total aboveground biomass of sapling layer (Table 4) across the different forest fire zones ranged from 3.43 Mg ha^{-1} to 11.46 Mg ha^{-1} for high fire zone and non-fire zone. The total biomass (aboveground and belowground) was 4.21, 7.42, 6.68 and 13.97 Mg ha^{-1} for high fire, medium fire, low fire and non-fire zone, respectively. The total belowground biomass was varied from 0.78 to 2.52 Mg ha^{-1} for high fire and non-fire zone. In the high fire zone the bole, branch, leaf and root constituted 44.33, 30.0, 6.54 and 18.52%, respectively of the total biomass. The medium fire zone showed the distribution of biomass in different components was 3.38 Mg ha^{-1} in bole, 2.21 Mg ha^{-1} in branch, 0.48 Mg ha^{-1} in leaf and 1.36 Mg ha^{-1} in root. Among the individual species *Casearia graveolens* constituted the highest biomass followed by *Lagerstroemia parviflora* and *Anogeissus latifolia* in the medium fire zone. In case of low fire zone the bole, branch, leaf and root constituted 48.22, 25.97, 7.27 and 18.53 per cent, respectively of the total biomass. The non-fire zone has highest biomass in terms of total biomass (aboveground as well as belowground) and the biomass of different component wise among the all fire zones.

The total biomass (above aground and belowground) of seedling layer (Table 5) across the different forest fire zones ranged from 4.62 Mg ha^{-1} to 6.47 Mg ha^{-1} for high fire zone and low fire zone. The total belowground biomass was 1.04, 1.06, 1.37 and 1.31 Mg ha^{-1} for high, medium, low and non-fire zone, respectively. In the high fire zone among the all species *Shorea robusta* constituted the highest biomass whereas lowest by *Buchanania lanzan* and *Syzygium cumini*. In the medium fire zone the bole, branch, leaf and root constituted 54.02, 14.84, 10.55 and 20.50 per cent, respectively of the total biomass. In the low fire zone the distribution of biomass in different components was 3.54 Mg ha^{-1} in bole, 0.83 Mg ha^{-1} in branch, 0.72 Mg ha^{-1} in leaf and 1.37 Mg ha^{-1} in root. The non-fire zone showed the biomass of the bole, branch, leaf and root constituted 54.95, 12.44, 10.65 and 21.94 per cent of the total biomass. Among the individual species *Shorea robusta* constituted the highest biomass whereas lowest by *Lagerstroemia parviflora* and *Saccopetalum tomentosum* in the non-fire zone.

The total biomass of shrub layer (Table 6) across the forest fire zones ranged from 2.48 Mg ha^{-1} to 5.88 Mg ha^{-1} for low fire zone and high fire zone. The total belowground biomass was varied from 1.71 to 3.98 Mg $ha^{-}1$ among the different fire zone. In the high fire zone the bole, branch, leaf and root constituted 18.04, 10.11, 4.12 and 67.66 per cent, respectively of the total biomass. The medium fire zone showed the distribution of biomass in different components was 0.98 Mg ha^{-1} in bole, 0.55 Mg ha^{-1} in branch, 0.24 Mg ha^{-1} in leaf and 3.72 Mg ha^{-1} in root. Among the individual species *Zizyphus xylopyra* constituted the highest biomass followed by *Carissa spinarum* and *Ventilago cayculata* in the medium fire zone. In case of low fire zone the bole, branch, leaf and root constituted 16.39, 9.83, 5.14 and 68.82 per cent, respectively of the total biomass. The non-fire zone has lowest biomass as compare to high fire zone and medium fire zone but higher than the low fire zone.

The present estimates values of biomass are comparable with the estimates made by many workers. Navar-Chaidez (2011) studied the stand biomass in tropical forests of Mexico and found that the above-ground biomass varies from 116.37 Mg ha^{-1} to 167.43

Mg ha^{-1} which is comparable with the present study (88.24 to 169.73 Mg ha^{-1}). Total belowground biomass of present study was between 13.18 Mg ha^{-1} and 22.63 Mg ha^{-1}, respectively which resembled with belowground biomass of tropical deciduous forest estimated by Singh et al. (2009). Singh and Singh (1991) have reported similar findings in tropical forest in India and stated that the total biomass of tree layer and shrub layer were ranged from 24.4 Mg ha^{-1} to 73.2 Mg ha^{-1} and 7.13 Mg ha^{-1} to 20.98 Mg ha^{-1}. Pande (2005) have stated the aboveground plant biomass in the tree layers of different sites ranged from 25.69 to 82.91 Mg ha^{-1} and also reported that the total shrub biomass was varied from 0.69 to 3.77 Mg ha^{-1} which is closer to present findings. A compilation by Murphy and Lugo (1986) showed that the total biomass ranged from 78 to 320 Mg ha^{-1} for a variety of tropical dry forest. Aboveground biomass of present study (88.24-169.73 Mg ha^{-1}) comparable with the global pattern of aboveground biomass in tropical dry forests was 30-273 Mg ha^{-1} (Murphy and Lugo 1986). The value range of 153-221 Mg ha^{-1} reported from Sri Lankan tropical rain forests (Brown and Lugo 1982). Terakunpisut et al. (2007) reported an AGB value of 275 Mg ha^{-1} for the tropical rain forests of Thailand which is double than the present study. The AGB values of 170 Mg ha^{-1} for the broadleaved forests of tropical America, 260 Mg ha^{-1} for tropical Africa, 215 Mg ha^{-1} for tropical Asia and 150 Mg ha^{-1} for total tropics were reported by Brown and Lugo (1984). Cairns et al. (2003) have reported near to similar findings in tropical forest of Mexico and stated that the total aboveground biomass was 225 Mg ha^{-1}. Delaney et al. (1997) estimated aboveground biomass up to 285 Mg ha^{-1} for Venezuela Tropical forest which is more than the present work. The present study aboveground biomass is very similar to the aboveground biomass reported by Cairns et al. (2000) for the semi-evergreen tall/medium forest in the three states of the Yucatan Peninsula (111.2 Mg ha^{-1}), but less than the aboveground biomass for the state of Veracruz (225.8 Mg ha^{-1}). Hall and Uhling (1991) estimated the biomass of forests in South and South East Asia using the volume estimates and biomass expansion factors derived from Brown et al. (1989). Their biomass estimates for India ranged from 116 Mg ha^{-1} for forest undisturbed and 35, 66 and 84 Mg ha^{-1} for logged, unproductive and managed forests, respectively. Tiwari (1994) reported average total aboveground biomass in different forest types of Rajaji National Park, Dehradun, India between 52.36 Mg ha^{-1} (Plantations) and 371.08 Mg ha^{-1} (Sal forest).

The total carbon estimated for tree layer was varied from 50.71 Mg C ha^{-1} to 96.18 Mg C ha^{-1} for medium fire and low fire zone (Table 7). In the high fire zone the distribution of carbon in the different components was 24.49 Mg C ha^{-1} in bole, 42.90 Mg C ha^{-1} in branch, 2.29 Mg C ha^{-1} in leaf and 9.23 Mg C ha^{-1} in root. The bole, branch, leaf and root constituted 31.03, 54.37, 2.89 and 11.70 per cent, respectively of the total carbon. The medium fire zone showed that the higher amount of carbon present in the *Boswellia serrata* and *Lannea coromandelica* among the all recorded species in this fire zone. The low fire zone showed highest amount of total carbon constitution across the study site. Among the all species present in this zone *Shorea robusta* alone contribute 79.50% of the total carbon. The non-fire zone showed the carbon concentration of different components was 21.59 Mg C ha^{-1} in bole, 31.45 Mg C ha^{-1} in branch, 2.46 Mg C ha^{-1} in leaf and 8.68 Mg C ha^{-1} in root. The total aboveground carbon estimated for this zone was 55.50 Mg C ha^{-1}.

The total carbon estimated for sapling layer (Table 8) across the different forest fire zones ranged from 2.11 Mg C ha^{-1} to 6.99 Mg C ha^{-1} for high fire zone and non-fire zone. The high fire zone showed that the highest amount of carbon recorded by the *Shorea robusta* among the all species found in this fire zone. In the medium fire zone the bole, branch, leaf and root constituted 45.50, 29.74, 6.40 and 18.30 per cent, respectively of the total carbon. In the low fire zone the distribution of carbon concentration in different components was 1.61 Mg C ha^{-1} in bole, 0.87 Mg C ha^{-1} in branch, 0.24 Mg C ha^{-1} in leaf and 0.62 Mg C ha^{-1} in root. The non-fire zone showed the highest carbon estimates of the bole, branch, leaf and root as compare to other study sites. Among the individual species *Shorea robusta* had the highest carbon concentration (51.78%) among all recorded species.

The total carbon of seedling layer (Table 9) across the different forest fire zones ranged from 2.31 Mg C ha^{-1} to 3.23 Mg C ha^{-1} for high fire zone and low fire zone. In the high fire zone the bole, branch, leaf and root constituted 54.93, 10.92, 11.49 and 22.58%, respectively of the total carbon concentration. The medium fire zone showed the highest carbon estimated by the *Lagerstroemia parviflora* among the all species found in this zone. The low fire zone recorded maximum carbon concentration across the study site. The non-fire zone has 2.33 Mg C ha^{-1} of total aboveground carbon estimates. Among the all species found in this zone the *Shorea robusta* alone has the value of carbon concentration of 43.47% of the total.

Table 3. Biomass (Mg ha^{-1}) of different component of tree layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Adina cordifolia Hook.f.	1.19	1.50	0.12	0.45	3.26	3.45	7.15	0.30	1.30	12.19	0.70	0.73	0.08	0.26	1.78	0.32	0.34	0.04	0.12	0.82
Aegle marmelos Linn.	-	-	-	-	-	-	-	-	-	-	0.66	0.84	0.07	0.25	1.81	-	-	-	-	-
Anogeissus latifolia Wall ex Bedd.	0.32	0.70	0.05	0.20	1.26	2.42	6.01	0.41	1.56	10.40	-	-	-	-	-	3.49	12.53	0.75	2.55	19.32
Boswellia serrata Roxb. ex Colebr.	-	-	-	-	-	9.42	17.93	0.84	3.54	31.72	-	-	-	-	-	-	-	-	-	-
Bridelia retusa (Linn.) Spreng.	0.87	1.22	0.09	0.33	2.51	-	-	-	-	-	-	-	-	-	-	1.36	1.58	0.15	0.51	3.59
Buchanania lanzan Spreng.	0.10	0.04	0.01	0.03	0.18	0.60	0.49	0.09	0.18	1.36	0.19	0.09	0.03	0.06	0.37	0.37	0.19	0.05	0.11	0.73
Careya arborea Roxb.	-	-	-	-	-	1.13	1.40	0.12	0.42	3.07	-	-	-	-	-	-	-	-	-	-
Casearia graveolens Dalz.	-	-	-	-	-	0.75	0.64	0.09	0.28	1.77	-	-	-	-	-	0.34	0.27	0.04	0.13	0.78
Cassia fistula Linn.	-	-	-	-	-	-	-	-	-	-	0.98	1.18	0.10	0.37	2.63	0.59	0.64	0.06	0.22	1.52
Dalbergia paniculata Roxb.	-	-	-	-	-	0.64	0.62	0.07	0.24	1.57	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	-	-	-	-	-	0.31	0.20	0.03	0.12	0.67	-	-	-	-	-	-	-	-	-	-
Emblica officinalis Gaertn	-	-	-	-	-	0.29	0.33	0.03	0.11	0.76	0.18	0.18	0.02	0.07	0.46	-	-	-	-	-
Garuga pinnata Roxb.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.20	0.19	0.02	0.08	0.49
Grewia tiliaefolia Vahl.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.11	0.02	0.04	0.28
Kydia calycina Roxb.	-	-	-	-	-	0.23	0.18	0.03	0.09	0.52	-	-	-	-	-	0.47	0.55	0.05	0.18	1.25
Lagerstroemia parviflora Roxb.	-	-	-	-	-	1.67	1.71	0.22	0.89	4.49	1.96	2.10	0.25	1.08	5.39	0.10	0.08	0.01	0.04	0.24
Lannea coromandelica (Houtt.) Merr.	1.09	1.27	0.12	0.41	2.89	7.07	10.15	0.70	2.65	20.56	0.11	0.09	0.01	0.04	0.26	2.05	2.83	0.21	0.77	5.86
Madhuca longifolia Roxb.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.09	0.01	0.04	0.26
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.52	0.47	0.06	0.20	1.24
Ougeinia oojeinensis (Roxb.) Hochr.	4.24	5.48	0.44	1.59	11.75	3.59	3.90	0.40	1.34	9.23	5.49	7.94	0.54	2.06	16.03	4.47	5.30	0.48	1.68	11.92
Saccopetalum tomentosum (H F.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.72	0.45	0.07	0.22	1.46
Schleichera oleosa (Lour.) Oken	1.65	2.22	0.17	0.62	4.66	-	-	-	-	-	0.20	0.19	0.02	0.08	0.49	0.11	0.09	0.01	0.04	0.26
Semecarpus anacardium L.	-	-	-	-	-	0.34	0.27	0.04	0.13	0.78	2.79	4.54	0.26	1.05	8.63	-	-	-	-	-
Shorea robusta Gaertn.f.	36.94	70.47	3.30	13.88	124.59	-	-	-	-	-	45.43	86.34	4.09	17.07	152.93	23.08	30.19	2.42	8.65	64.34
Sterculia urens Roxb.	0.20	0.19	0.02	0.08	0.49	0.88	1.02	0.10	0.33	2.34	-	-	-	-	-	0.11	0.09	0.01	0.04	0.26
Terminalia alata Heyne ex Roth.	2.36	2.70	0.26	0.89	6.21	-	-	-	-	-	0.64	0.62	0.07	0.25	1.57	3.39	5.12	0.33	1.27	10.11
Terminalia chebula Retz.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.24	1.78	0.12	0.47	3.61
Total				157.81					101.43					192.36					128.36	

Table 4. Biomass (Mg ha^{-1}) of different component of sapling layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Adina cordifolia Hook.f.	-	-	-	-	-	-	-	-	-	-	0.07	0.04	0.01	0.03	0.15	-	-	-	-	-
Anogeissus latifolia Wall ex Bedd.	0.20	0.31	0.03	0.11	0.64	0.40	0.57	0.05	0.21	1.23	0.12	0.17	0.01	0.06	0.37	0.36	0.48	0.04	0.19	1.07
Bombax ceiba Linn.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	0.03	0.007	0.02	0.11
Boswellia serrata Roxb. ex Colebr.	-	-	-	-	-	0.02	0.007	0.003	0.006	0.03	-	-	-	-	-	-	-	-	-	-
Buchanania lanzan Spreng.	0.07	0.017	0.01	0.02	0.12	.	.	.	.	.	0.51	0.12	0.08	0.17	0.88	0.45	0.10	0.07	0.15	0.78
Butea monosperma (Lamk) Taub.	0.016	0.007	0.003	0.006	0.03	.	.	.	.	.	0.03	0.01	0.005	0.01	0.07	-	-	-	-	-
Casearia graveolens Dalz.	-	-	-	-	-	0.69	0.36	0.10	0.26	1.41	0.07	0.04	0.01	0.03	0.15	0.27	0.15	0.04	0.10	0.57
Cassia fistula Linn.	-	-	-	-	-	0.02	0.007	0.003	0.006	0.03	0.03	0.01	0.005	0.01	0.07	-	-	-	-	-
Dalbergia paniculata Roxb.	-	-	-	-	-	0.16	0.09	0.02	0.06	0.32	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	0.19	0.07	0.03	0.09	0.37	0.51	0.21	0.06	0.22	1.00	0.17	0.05	0.026	0.08	0.33	0.25	0.08	0.04	0.11	0.48
Emblica officinalis Gaertn	0.22	0.15	0.04	0.10	0.51	0.05	0.03	0.008	0.02	0.11	0.06	0.03	0.01	0.03	0.13	0.14	0.10	0.02	0.07	0.33
Grewia tiliaefolia Vahl.	0.014	0.01	0.003	0.006	0.03	-	-	-	-	-	-	-	-	-	-	0.10	0.09	0.02	0.04	0.24
Kydia calycina Roxb.	-	-	-	-	-	0.19	0.10	0.03	0.07	0.39	0.08	0.04	0.01	0.03	0.16	0.07	0.03	0.01	0.02	0.13
Lagerstroemia parviflora Roxb.	0.11	0.07	0.017	0.04	0.24	0.57	0.36	0.09	0.21	1.24	0.46	0.28	0.07	0.17	0.98	0.50	0.34	0.08	0.20	1.11
Lannea coromandelica (Houtt.) Merr.	-	-	-	-	0.00	0.18	0.11	0.02	0.07	0.37	0.11	0.07	0.01	0.04	0.23	0.11	0.07	0.01	0.04	0.23
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.23	0.14	0.03	0.09	0.49
Ougeinia oojeinensis (Roxb.) Hochr.	0.11	0.066	0.01	0.04	0.23	0.36	0.21	0.05	0.14	0.76	0.12	0.07	0.017	0.046	0.26	0.19	0.11	0.026	0.07	0.41
Saccopetalum tomentosum (HF.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.009	0.005	0.009	0.06
Schleichera oleosa (Lour.) Oken	0.11	0.067	0.014	0.04	0.23	-	-	-	-	-	0.02	0.007	0.003	0.006	0.03	0.106	0.07	0.01	0.04	0.23
Semecarpus anacardium L.	-	-	-	-	-	0.12	0.07	0.017	0.046	0.26	-	-	-	-	-	-	-	-	-	-
Shorea robusta Gaertn.f.	0.66	0.39	0.09	0.25	1.39	-	-	-	-	-	1.09	0.61	0.15	0.41	2.26	3.44	2.04	0.47	1.28	7.23
Sterculia urens Roxb.	0.07	0.03	0.01	0.02	0.13	0.12	0.06	0.017	0.04	0.24	-	-	-	-	-	0.05	0.03	0.007	0.02	0.11
Syzygium cumini (Linn.) Skeels.	0.01	0.007	0.003	0.008	0.03	-	-	-	-	-	0.17	0.11	0.03	0.08	0.39	-	-	-	-	-
Terminalia alata Heyne ex Roth.	0.09	0.05	0.01	0.03	0.18	-	-	-	-	-	0.05	0.02	0.007	0.018	0.10	0.07	0.03	0.01	0.02	0.13
Terminalia chebula Retz.	0.03	0.01	0.005	0.01	0.07	-	-	-	-	-	0.07	0.04	0.009	0.03	0.14	0.12	0.07	0.016	0.05	0.26
Total				4.21					7.42					6.68					13.97	

Table 5. Biomass (Mg ha^{-1}) of different component of seedling layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Anogeissus latifolia Wall ex Bedd.	-	-	-	-	-	0.31	0.18	0.021	0.119	0.62	0.17	0.099	0.011	0.066	0.35	0.27	0.16	0.018	0.106	0.56
Buchanania lanzan Spreng.	0.067	0.002	0.012	0.024	0.11	-	-	-	-	-	0.13	0.005	0.02	0.048	0.21	0.17	0.006	0.03	0.06	0.26
Casearia graveolens Dalz.	0.19	0.04	0.039	0.07	0.34	0.38	0.08	0.077	0.14	0.69	0.71	0.15	0.14	0.26	1.26	0.49	0.11	0.098	0.18	0.88
Cassia fistula Linn.	-	-	-	-	-	0.24	0.05	0.047	0.087	0.42	-	-	-	-	-	0.02	0.005	0.004	0.008	0.04
Chloroxylon swietenia D.C.	-	-	-	-	-	0.09	0.02	0.017	0.03	0.15	-	-	-	-	-	-	-	-	-	-
Dalbergia paniculata Roxb.	-	-	-	-	-	0.06	0.01	0.01	0.02	0.11	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	0.69	0.09	0.16	0.38	1.32	0.58	0.08	0.13	0.31	1.10	0.30	0.04	0.07	0.16	0.57	0.54	0.07	0.13	0.29	1.04
Emblica officinalis Gaertn	-	-	-	-	-	-	-	-	-	-	0.09	0.03	0.04	0.07	0.22	-	-	-	-	-
Kydia calycina Roxb.	-	-	-	-	-	0.21	0.047	0.04	0.08	0.38	0.15	0.033	0.030	0.056	0.27	-	-	-	-	-
Lagerstroemia parviflora Roxb.	0.13	0.05	0.028	0.032	0.24	0.64	0.23	0.14	0.16	1.17	0.25	0.09	0.05	0.06	0.45	0.02	0.007	0.004	0.005	0.03
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13	0.03	0.026	0.048	0.23
Ougeinia oojeinensis (Roxb.) Hochr.	-	-	-	-	-	0.28	0.06	0.056	0.10	0.50	0.02	0.005	0.004	0.008	0.04	0.021	0.005	0.004	0.008	0.04
Saccopetalum tomentosum (HF.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.017	0.002	0.004	0.004	0.03
Schleichera oleosa (Lour.) Oken	-	-	-	-	-	-	-	-	-	-	0.021	0.005	0.004	0.008	0.04	0.11	0.023	0.02	0.04	0.19
Shorea robusta Gaertn.f.	1.18	0.26	0.24	0.44	2.11	-	-	-	-	-	1.50	0.33	0.30	0.56	2.68	1.45	0.32	0.29	0.54	2.60
Sterculia urens Roxb.	-	-	-	-	-	-	-	-	-	-	0.02	0.005	0.004	0.008	0.04	-	-	-	-	-
Syzygium cumini (Linn.) Skeels.	0.21	0.047	0.04	0.08	0.38	-	-	-	-	-	0.13	0.028	0.026	0.05	0.23	-	-	-	-	-
Terminalia alata Heyne ex Roth.	0.06	0.014	0.013	0.024	0.11	-	-	-	-	-	-	-	-	-	-	0.021	0.005	0.004	0.008	0.04
Terminalia chebula Retz.	-	-	-	-	-	-	-	-	-	-	0.064	0.014	0.013	0.024	0.11	0.021	0.005	0.004	0.008	0.04
Total				4.62					5.16				6.47					5.98		

Table 6. Biomass (Mg ha^{-1}) of different component of shrub layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Bauhinia racemosa Lam.	0.02	0.01	0.10	0.010	0.15	-	-	-	-	-	0.01	0.009	0.068	0.007	0.10	-	-	-	-	-
Bauhinia vahlii (W.) A.	0.03	0.02	0.17	0.02	0.24	0.03	0.02	0.14	0.01	0.19	0.01	0.009	0.068	0.007	0.10	-	-	-	-	-
Butea superba Roxb. ex Willd.	0.53	0.28	1.81	0.09	2.71	0.02	0.01	0.10	0.010	0.15	0.02	0.01	0.10	0.009	0.14	0.52	0.27	1.74	0.08	2.61
Carissa spinarum D.C.	0.014	0.009	0.07	0.007	0.10	0.15	0.09	0.60	0.04	0.88	0.13	0.07	0.50	0.03	0.73	-	-	-	-	-
Dioscaria spp Roxb.	0.02	0.01	0.10	0.009	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Embelia robusta Roxb.	0.007	0.005	0.03	0.003	0.05	0.03	0.02	0.17	0.016	0.24	0.014	0.009	0.068	0.007	0.10	0.02	0.014	0.10	0.009	0.14
Mallotus phillippinensis Muell.	0.007	0.005	0.034	0.003	0.05	0.014	0.009	0.068	0.007	0.10	-	-	-	-	-	-	-	-	-	-
Mimusops hexandra Roxb.	-	-	-	-	-	-	-	-	-	-	0.034	0.023	0.17	0.016	0.24	0.034	0.02	0.169	0.016	0.24
Spatholobus roxburgii Benth.	0.007	0.005	0.034	0.003	0.05	-	-	-	-	-	-	-	-	-	-	0.014	0.009	0.068	0.007	0.10
Ventilago cayculata Tul.	0.15	0.09	0.60	0.04	0.88	0.04	0.03	0.20	0.02	0.29	0.18	0.11	0.74	0.05	1.07	0.014	0.009	0.068	0.007	0.10
Zizyphus xylopyra (Retz.)Willd.	0.27	0.15	1.03	0.062	1.51	0.69	0.37	2.44	0.13	3.63	-	-	-	-	-	0.13	0.07	0.50	0.03	0.73
Total				5.88					5.48					2.48					3.92	

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Table 7. Carbon (Mg ha^{-1}) storage pattern of different component of tree layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Adina cordifolia Hook.f.	0.60	0.75	0.06	0.22	1.63	1.73	3.57	0.15	0.65	6.10	0.35	0.37	0.04	0.13	0.89	0.16	0.17	0.02	0.06	0.41
Aegle marmelos Linn.	-	-	-	-	-	-	-	-	-	-	0.33	0.42	0.03	0.12	0.91	-	-	-	-	-
Anogeissus latifolia Wall ex Bedd.	0.16	0.35	0.03	0.10	0.63	1.21	3.00	0.21	0.78	5.20	-	-	-	-	-	1.75	6.26	0.37	1.27	9.66
Boswellia serrata Roxb. ex Colebr.	-	-	-	-	-	4.71	8.97	0.42	1.77	15.86	-	-	-	-	-	-	-	-	-	-
Bridelia retusa (Linn.) Spreng.	0.44	0.61	0.04	0.16	1.25	-	-	-	-	-	-	-	-	-	-	0.68	0.79	0.07	0.25	1.80
Buchanania lanzan Spreng.	0.05	0.02	0.01	0.02	0.09	0.30	0.24	0.04	0.09	0.68	0.10	0.04	0.01	0.03	0.18	0.18	0.10	0.03	0.06	0.36
Careya arborea Roxb.	-	-	-	-	-	0.56	0.70	0.06	0.21	1.53	-	-	-	-	-	-	-	-	-	-
Casearia graveolens Dalz.	-	-	-	-	-	0.38	0.32	0.04	0.14	0.88	-	-	-	-	-	0.17	0.13	0.02	0.06	0.39
Cassia fistula Linn.	-	-	-	-	-	-	-	-	-	-	0.49	0.59	0.05	0.18	1.32	0.29	0.32	0.03	0.11	0.76
Dalbergia paniculata Roxb.	-	-	-	-	-	0.32	0.31	0.04	0.12	0.79	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	-	-	-	-	-	0.16	0.10	0.02	0.06	0.33	-	-	-	-	-	-	-	-	-	-
Emblica officinalis Gaertn	-	-	-	-	-	0.15	0.16	0.02	0.05	0.38	0.09	0.09	0.01	0.04	0.23	-	-	-	-	-
Garuga pinnata Roxb.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.09	0.01	0.04	0.25
Grewia tiliaefolia Vahl.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.05	0.01	0.02	0.14
Kydia calycina Roxb.	-	-	-	-	-	0.11	0.09	0.01	0.04	0.26	-	-	-	-	-	0.24	0.28	0.03	0.09	0.63
Lagerstroemia parviflora Roxb.	-	-	-	-	-	0.84	0.85	0.11	0.45	2.24	0.98	1.05	0.12	0.54	2.69	0.05	0.04	0.01	0.02	0.12
Lannea coromandelica (Houtt.) Merr.	0.55	0.64	0.06	0.20	1.45	3.53	5.07	0.35	1.33	10.28	0.06	0.04	0.01	0.02	0.13	1.03	1.41	0.10	0.39	2.93
Madhuca longifolia Roxb.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.04	0.01	0.02	0.13
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.26	0.23	0.03	0.10	0.62
Ougeinia oojeinensis (Roxb.) Hochr.	2.12	2.74	0.22	0.80	5.88	1.79	1.95	0.20	0.67	4.61	2.74	3.97	0.27	1.03	8.01	2.24	2.65	0.24	0.84	5.96
Saccopetalum tomentosum (HF.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36	0.22	0.04	0.11	0.73
Schleichera oleosa (Lour.) Oken	0.83	1.11	0.08	0.31	2.33	-	-	-	-	-	0.10	0.09	0.01	0.04	0.25	0.06	0.04	0.01	0.02	0.13
Semecarpus anacardium L.	-	-	-	-	-	0.17	0.13	0.02	0.06	0.39	1.39	2.27	0.13	0.52	4.32	-	-	-	-	-
Shorea robusta Gaertn.f.	18.47	35.23	1.65	6.94	62.30	-	-	-	-	-	22.72	43.17	2.04	8.54	76.47	11.54	15.10	1.21	4.33	32.17
Sterculia urens Roxb.	0.10	0.09	0.01	0.04	0.25	0.44	0.51	0.05	0.17	1.17	-	-	-	-	-	0.06	0.04	0.01	0.02	0.13
Terminalia alata Heyne ex Roth.	1.18	1.35	0.13	0.44	3.10	-	-	-	-	-	0.32	0.31	0.04	0.12	0.79	1.69	2.56	0.16	0.64	5.06
Terminalia chebula Retz.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.89	0.06	0.23	1.81
Total				78.90					50.71					96.18					64.18	

Table 8. Carbon (Mg ha^{-1}) storage pattern of different component of sapling layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Adina cordifolia Hook.f.	-	-	-	-	-	-	-	-	-	-	0.03	0.02	0.00	0.01	0.07	-	-	-	-	-
Anogeissus latifolia Wall ex Bedd.	0.10	0.16	0.01	0.05	0.32	0.20	0.29	0.02	0.11	0.62	0.06	0.08	0.01	0.03	0.18	0.18	0.24	0.02	0.09	0.54
Bombax ceiba Linn.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.02	0.00	0.01	0.06
Boswellia serrata Roxb. ex Colebr.	-	-	-	-	-	0.01	0.00	0.00	0.00	0.02	-	-	-	-	-	-	-	-	-	-
Buchanania lanzan Spreng.	0.04	0.01	0.01	0.01	0.06	.	.	.	.	.	0.26	0.06	0.04	0.08	0.44	0.23	0.05	0.04	0.07	0.39
Butea monosperma (Lamk) Taub.	0.01	0.00	0.00	0.00	0.02	.	.	.	.	.	0.02	0.01	0.00	0.01	0.03	-	-	-	-	-
Casearia graveolens Dalz.	-	-	-	-	-	0.35	0.18	0.05	0.13	0.71	0.03	0.02	0.00	0.01	0.07	0.14	0.08	0.02	0.05	0.28
Cassia fistula Linn.	-	-	-	-	-	0.01	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.01	0.03	-	-	-	-	-
Dalbergia paniculata Roxb.	-	-	-	-	-	0.08	0.04	0.01	0.03	0.16	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	0.10	0.03	0.01	0.04	0.19	0.25	0.11	0.03	0.11	0.50	0.09	0.03	0.01	0.04	0.17	0.13	0.04	0.02	0.06	0.24
Emblica officinalis Gaertn	0.11	0.08	0.02	0.05	0.26	0.02	0.02	0.00	0.01	0.06	0.03	0.02	0.01	0.02	0.07	0.07	0.05	0.01	0.03	0.17
Grewia tiliaefolia Vahl.	0.01	0.01	0.00	0.00	0.02	-	-	-	-	-	-	-	-	-	-	0.05	0.04	0.01	0.02	0.12
Kydia calycina Roxb.	-	-	-	-	-	0.09	0.05	0.01	0.04	0.19	0.04	0.02	0.01	0.02	0.08	0.03	0.01	0.01	0.01	0.07
Lagerstroemia parviflora Roxb.	0.05	0.04	0.01	0.02	0.12	0.28	0.18	0.05	0.11	0.62	0.23	0.14	0.04	0.08	0.49	0.25	0.17	0.04	0.10	0.56
Lannea coromandelica (Houtt.) Merr.	-	-	-	-		0.09	0.05	0.01	0.03	0.19	0.05	0.03	0.01	0.02	0.11	0.05	0.03	0.01	0.02	0.11
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.07	0.02	0.04	0.24
Ougeinia oojeinensis (Roxb.) Hochr.	0.05	0.03	0.01	0.02	0.11	0.18	0.11	0.03	0.07	0.38	0.06	0.04	0.01	0.02	0.13	0.10	0.06	0.01	0.04	0.20
Saccopetalum tomentosum (HF.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.00	0.00	0.00	0.03
Schleichera oleosa (Lour.) Oken	0.05	0.03	0.01	0.02	0.11	-	-	-	-	-	0.01	0.00	0.00	0.00	0.02	0.05	0.03	0.01	0.02	0.11
Semecarpus anacardium L.	-	-	-	-	-	0.06	0.04	0.01	0.02	0.13	-	-	-	-	-	-	-	-	-	-
Shorea robusta Gaertn.f.	0.33	0.20	0.05	0.12	0.70	-	-	-	-	-	0.54	0.31	0.08	0.20	1.13	1.72	1.02	0.24	0.64	3.62
Sterculia urens Roxb.	0.03	0.01	0.01	0.01	0.07	0.06	0.03	0.01	0.02	0.12	-	-	-	-	-	0.03	0.02	0.00	0.01	0.06
Syzygium cumini (Linn.) Skeels.	0.01	0.00	0.00	0.00	0.02	-	-	-	-	-	0.08	0.05	0.02	0.04	0.20	-	-	-	-	-
Terminalia alata Heyne ex Roth.	0.04	0.02	0.01	0.02	0.09	-	-	-	-	-	0.02	0.01	0.00	0.01	0.05	0.03	0.01	0.01	0.01	0.07
Terminalia chebula Retz.	0.02	0.01	0.00	0.01	0.03	-	-	-	-	-	0.03	0.02	0.00	0.01	0.07	0.06	0.04	0.01	0.02	0.13
Total				2.11					3.71					3.34					6.99	

Table 9. Carbon (Mg ha^{-1}) storage pattern of different component of seedling layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Anogeissus latifolia Wall ex Bedd.	-	-	-	-	-	0.153	0.089	0.010	0.060	0.31	0.085	0.050	0.006	0.033	0.17	0.136	0.079	0.009	0.053	0.28
Buchanania lanzan Spreng.	0.034	0.001	0.006	0.012	0.05	-	-	-	-	-	0.067	0.002	0.012	0.024	0.11	0.084	0.003	0.015	0.030	0.13
Casearia graveolens Dalz.	0.096	0.021	0.019	0.036	0.17	0.192	0.042	0.039	0.072	0.34	0.353	0.077	0.071	0.131	0.63	0.246	0.054	0.049	0.091	0.44
Cassia fistula Linn.	-	-	-	-	-	0.118	0.026	0.024	0.044	0.21	-	-	-	-	-	0.011	0.002	0.002	0.004	0.02
Chloroxylon swietenia D.C.	-	-	-	-	-	0.043	0.009	0.009	0.016	0.08	-	-	-	-	-	-	-	-	-	-
Dalbergia paniculata Roxb.	-	-	-	-	-	0.032	0.007	0.006	0.012	0.06	-	-	-	-	-	-	-	-	-	-
Diospyros melanoxylon Roxb.	0.347	0.047	0.081	0.188	0.66	0.289	0.039	0.067	0.156	0.55	0.149	0.020	0.035	0.080	0.28	0.272	0.037	0.063	0.147	0.52
Emblica officinalis Gaertn	-	-	-	-	-	-	-	-	-	-	0.045	0.014	0.019	0.034	0.11	-	-	-	-	-
Kydia calycina Roxb.	-	-	-	-	-	0.107	0.023	0.021	0.040	0.19	0.075	0.016	0.015	0.028	0.13	-	-	-	-	-
Lagerstroemia parviflora Roxb.	0.066	0.024	0.014	0.016	0.12	0.321	0.116	0.068	0.078	0.58	0.123	0.044	0.026	0.030	0.22	0.009	0.003	0.002	0.002	0.02
Mitragyna parviflora (Roxb.) Korth.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.064	0.014	0.013	0.024	0.11
Ougeinia oojeinensis (Roxb.) Hochr.	-	-	-	-	-	0.139	0.030	0.028	0.052	0.25	0.011	0.002	0.002	0.004	0.02	0.011	0.002	0.002	0.004	0.02
Saccopetalum tomentosum (HF.) Thoms	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.009	0.001	0.002	0.002	0.01
Schleichera oleosa (Lour.) Oken	-	-	-	-	-	-	-	-	-	-	0.011	0.002	0.002	0.004	0.02	0.053	0.012	0.011	0.020	0.10
Shorea robusta Gaertn.f.	0.588	0.129	0.118	0.219	1.05	-	-	-	-	-	0.748	0.164	0.150	0.278	1.34	0.727	0.159	0.146	0.270	1.30
Sterculia urens Roxb.	-	-	-	-	-	-	-	-	-	-	0.011	0.002	0.002	0.004	0.02	-	-	-	-	-
Syzygium cumini (Linn.) Skeels.	0.107	0.023	0.021	0.040	0.19	-	-	-	-	-	0.064	0.014	0.013	0.024	0.11	-	-	-	-	-
Terminalia alata Heyne ex Roth.	0.032	0.007	0.006	0.012	0.06	-	-	-	-	-	-	-	-	-	-	0.011	0.002	0.002	0.004	0.02
Terminalia chebula Retz.	-	-	-	-	-	-	-	-	-	-	0.032	0.007	0.006	0.012	0.06	0.011	0.002	0.002	0.004	0.02
Total				2.31					2.58					3.23					2.99	

Table 10. Carbon (Mg ha^{-1}) storage pattern of different component of shrub layer in different fire zones of Bhoramdeo Wildlife Sanctuary

Species	High Fire Zone					Medium Fire Zone					Low Fire Zone					Non Fire Zone				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Bauhinia racemosa Lam.	0.01	0.01	0.05	0.005	0.07	-	-	-	-	-	0.01	0.005	0.03	0.003	0.05	-	-	-	-	-
Bauhinia vahlii (W.) A.	0.02	0.01	0.08	0.008	0.12	0.01	0.01	0.07	0.007	0.10	0.01	0.005	0.03	0.003	0.05	-	-	-	-	-
Butea superba Roxb. ex Willd.	0.26	0.14	0.90	0.044	1.35	0.01	0.01	0.05	0.005	0.07	0.01	0.01	0.05	0.005	0.07	0.26	0.136	0.87	0.041	1.30
Carissa spinarum D.C.	0.01	0.005	0.03	0.003	0.05	0.08	0.04	0.30	0.020	0.44	0.07	0.04	0.25	0.015	0.37	-	-	-	-	-
Dioscaria spp Roxb.	0.01	0.01	0.05	0.005	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Embelia robusta Roxb.	0.003	0.002	0.02	0.002	0.02	0.02	0.01	0.08	0.008	0.12	0.01	0.005	0.03	0.003	0.05	0.01	0.007	0.05	0.005	0.07
Mallotus phillippinensis Muell.	0.003	0.002	0.02	0.002	0.02	0.01	0.005	0.03	0.003	0.05	-	-	-	-	-	-	-	-	-	-
Mimusops hexandra Roxb.	-	-	-	-	-	-	-	-	-	-	0.02	0.01	0.08	0.008	0.12	0.02	0.011	0.08	0.008	0.12
Spatholobus roxburgii Benth.	0.003	0.002	0.02	0.002	0.02	-	-	-	-	-	-	-	-	-	-	0.01	0.005	0.03	0.003	0.05
Ventilago cayculata Tul.	0.08	0.04	0.30	0.020	0.44	0.02	0.01	0.10	0.010	0.15	0.09	0.05	0.37	0.026	0.54	0.01	0.005	0.03	0.003	0.05
Zizyphus xylopyra (Retz.)Willd.	0.13	0.08	0.52	0.031	0.76	0.34	0.19	1.22	0.066	1.82	-	-	-	-	-	0.07	0.037	0.25	0.015	0.37
Total				2.94					2.74					1.24					1.96	

In the shrub layer the total carbon estimates were ranged from 1.24 to 2.94 Mg C ha^{-1} across the all study site (Table 10). The total belowground carbon concentration was 1.99, 1.86, 0.85 and 1.32 Mg C ha^{-1} in high, medium, low and non-fire zone, respectively. In the high fire zone the *Butea superba* constitute maximum amount (45.91%) of total carbon followed by *Zizyphus xylopyra* and *Ventilago cayculata* among the all recorded species. The medium fire zone showed the distribution of carbon concentration in different components was 0.49 Mg C ha^{-1} in bole, 0.28 Mg C ha^{-1} in branch, 0.12 Mg C ha^{-1} in leaf and 1.86 Mg C ha^{-1} in root. In case of low fire zone the bole, branch, leaf and root constituted 16.39, 9.83, 5.14 and 68.82 per cent, respectively of the total biomass. The non-fire zone has lowest biomass as compare to high fire zone and medium fire zone but higher than the low fire zone. Among all species, *Butea superba* and *Zizyphus xylopyra* contribute about 85.20% of total carbon in this layer of non-fire zone. Distribution pattern of carbon across the girth classes also followed the similar pattern as was the case with biomass distribution. It was negligible in young individuals belonging to seedlings and saplings classes and highest storage was observed in higher girth class.

The potential of forests to sequester carbon depends on the forest type, age of forest and size class of trees (Terakunpisut et al. 2007). The amount of carbon stored in the tropical forest of the present study (50.71-96.18 Mg C ha^{-1}) was similar to the disturbed tropical forests of Sri Lanka (77 Mg C ha^{-1}), but lower than the relatively undisturbed matured tropical rain forest of Malaysia (223 Mg C ha^{-1}) reported by Brown and Lugo (1982). Ogawa et al. (1965) reported a carbon stock of 60 to 179 Mg C ha^{-1} in different tropical forest types of Thailand. Flint and Richards (1996) estimated carbon sequestration in Southeast Asia including India, Thailand, Cambodia, Malaysia and Indonesia, and reported the value range of 17 Mg C ha^{-1} in severely degraded tropical dry forest to 350 Mg C ha^{-1} in the undisturbed matured tropical rain forests. The value range of 153-221 Mg ha^{-1} reported from tropical rain forests (Brown and Lugo 1982, Swamy et al. 2010) is higher than the values found in the present study.

A higher proportion of aboveground biomass (AGB) in the higher diameter classes in natural forest does indicate the important role of large trees in carbon storage, but does not undermine the role of small trees (<60 cm dbh) which would enhance the future carbon stock because of their high carbon sequestration potential. It is well established that young trees sequester carbon till maturity that varies from 25 to 75 years depending upon the forest type. Beyond the maturity, the trees generally have marginal carbon sequestration capability (Lal and Singh 2000). Wide variation in stand structure and tree growth in these forests resulted in lower aboveground biomass. Other factors responsible for such low total AGB are different stages of forest growth cycle, habitat and species variability and varying tree density (Terakunpisut et al. 2007). Many workers have reported that in natural forests, there is a net addition to standing biomass leading to carbon storage if most trees are yet to be matured. Such scenarios are applicable to the forests where disturbance events are sporadic and concurrent. On the other hand, the matured forests do not add up any further biomass because most part of the gross primary productivity is either used up in respiration or returned to soil as litter with no net addition to the aboveground biomass density. Such matured natural forests thus do not significantly contribute towards carbon uptake, though they are important for regeneration and sustaining biodiversity. However, plantation forests with higher annual productivity were reported to be ideal for carbon storage and sequestration (Lal and Singh 2000). Thus, creation of new plantation on degraded lands as affected by fire is a better option for carbon storage when these are planted and harvested periodically and used as a long-term source of timber.

CONCLUSION

The tropical forests are characterized by high species richness, standing biomass and productivity and their diversity has attracted much attention in recent year. In most developing countries, including India, even protected forests experience extensive anthropogenic disturbance due to fire, grazing, extraction of fuel wood and collection of non-wood forest products which contribute to the livelihood of forest dwelling populations. In the present study the conversion rate of seedlings into older girth class is less in high zone as compared to non-fire zone. The present study reveals that the forest fire had significantly influenced the regeneration, species composition, diversity, biomass and carbon storage status of tropics. The increasing biotic interferences in greater amount are degrading these forests and resulting in poor quality of the stand. Prescribed burning can be applied to reduce the high intensity of wild fires. Prescribed burning especially under tropical ecosystem could be pursued to reduce the fuel loads and create a spatial mosaic of fuel load distribution. Remote sensing and GIS methods are very useful to assess spatial and temporal characteristics of fire regimes and must become an integral part of fire management. The study recommends to apply such novel techniques for fire detection and monitoring systems for fire prediction.

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