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Research Article

Regeneration status and plant biomass under different fire regimes in the tropical forest of Chhattisgarh

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Abstract

The regeneration status and species interactions reflect the health and sustainability of forests under given site conditions. The tropical forest faces several challenges for its sustenance in terms of regeneration, biodiversity, and natural balance due to various abiotic and biotic factors. Numerous factors influence the admixture and stratification of forests, with forest fires appearing to be one of the more challenging and common biotic factors. The present study explores the forest fire influence on regeneration, species interaction, and population dynamics in a protected area, Bhoramdeo Wildlife Sanctuary, (BWS) of Chhattisgarh state of India. The entire area was divided into four distinct sites, i.e., no fire zone (NFZ), low fire zones (LFZ), medium fire (MFZ) and high fire zones (HFZ) depending upon geo-referenced data and ground truth verification A total of 41 tree species (23 families) was recorded in the BWS. The dominant family was Rubiaceae followed by Leguminosae and Combretaceae. The density and girth relationship showed that the 86.37 −91.71% of individuals had ≤10 cm girth i.e. low girth class structure and 8.29−13.63% were in girth classes exceeding 10 cm GBH. The population structure revealed that tree, (> 10 cm, dbh) sapling (> 30 cm, height), and seedling (height up to 30 cm) species show a consistent decrease in number from the seedling to sapling stage and also from the sapling to trees stage. Among different fire regimes, *Anogeissus latifolia*, *Buchanania lanzan*, *Diospyrous melanoxylon*, *Lannea coromandelica*, *Shorea robusta*, and *Syzygium cumini* exhibited good regeneration potential. The total biomass under different fire regimes varied from 116.03-358.36 Mg ha^{-1}, being highest under NFZ and lowest in HFZ, respectively. It is evident that keeping the forest fire under control will maintain its biodiversity and overall ecology, including nutrient cycling, regeneration, and ecosystem services, all of which contribute to its improved sustainability. Moreover, the species having good regeneration potential should be planted where the stocking is not up to the mark and where the incidence of fire is more common and frequent.

Keywords: Biomass, Forest fire, Fire regimes, Population structure, Regeneration.

INTRODUCTION

Forest fire is a common and mostly a human-made phenomenon in India as well as in most of tropical countries across the world (Neeraja et al., 2021; De Andrade et al., 2020; Chandra and Bhardwaj, 2015; Kittur et al., 2014; Jhariya et al., 2012, 2014). A forest fire may be beneficial or devastating depending upon the severity, intensity, fire

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return interval, fuel load as well as the current environmental and site conditions (Dhar et al., 2023; Jhariya and Singh, 2021a, 2021b). Repeated and highly intense fire is the most devastating and consumes all the organic material and it volatilizes important macronutrients, while the low severity of fire makes nutrients available and supports the growth of the understory and post-fire community (Thonicke et al., 2001). Hence fire management may help in improving soil properties that affect vegetation, its regeneration, and development (Bargali et al., 2023; Schafer and Mack, 2010; Certini, 2005).

Forest regeneration, species richness, and composition are the important indicators that reflect and determine the biodiversity and overall health of the forest ecosystem and are vulnerable to biotic and abiotic environmental gradients both natural and anthropogenic (Barlow et al., 2016). Forest fire is one of the important disturbances that later altered the forest ecosystem significantly (De Andrade et al., 2020). However, the impact of forest fires is not uniform or equal and is dependent upon various components of the environment (Mina et al., 2023). Every year, millions of hectares of forest globally are burned by forest fires causing incalculable social, economic, and environmental loss.

In India, forest fire is a very common phenomenon and this event takes place every year, especially in the deciduous forest. As per the report of (Gubbi 2003), approximately 55% of the Indian forest is prone to fire annually, which causes enormous loss and alteration in the forest stand and its dynamics (Saha and Howe, 2006). Although, changes and alterations in the vegetation naturally take place slowly, disturbances like forest fires can accelerate and have a significant impact on floristic structure and composition. Controlled fire may be beneficial from regeneration, nutrient cycling, forest weed, and plantation management points of view but uncontrolled fire has a detrimental influence on the biota of the region. Therefore, a forest fire is regarded as "*a good servant but a bad master"*(FRI, 2018). Moreover, it arrests the successional process as well as leads to the growth and development of secondary, unwanted, and fire-hardy species in the region (Gosper et al., 2012; Jhariya et al., 2014; Verma and Jayakumar, 2015; Neeraja et al., 2021).

The state of Chhattisgarh is bestowed with rich forest cover and biodiversity. However, rapid population growth, urbanization, developmental activity, and exploitation of bio-resources have put pressure on the valuable tropical forest and its biota. Land use changes, deforestation, grazing, and forest fires become the major threats that alter the forest structure, diversity, and future stand dynamics (Devi et al., 2023). Forest fire is one of the serious concerns, and has become a major threat and concern for forest management due to its incidence and frequent occurrence in certain pockets of the state. Therefore, the present research investigation was carried out to evaluate the following: (1) the effects of forest fires on floristic and population structure under varying fire regimes; (2) the effects of forest fires on the state of regeneration at the species and site levels; and (3) the aboveground biomass of trees under different fire regimes.

MATERIALS AND METHODS

Study site

Chhattisgarh state in India is bestowed with abundant natural resources and retains approximately 44% of the geographical area under the forests. The agroecological conditions of the state support the vast floral and faunal diversity in the state. The study site (Bhoramdeo Wildlife Sanctuary, BWS) is an important protected site in Chhattisgarh, Central India. The natural forest of the study site is reflected by rich, diverse, and complex floral and faunal biodiversity (Jhariya and Singh 2021a, 2021b). The BWS is situated in the dry tropical forest of the Maikla Range of the Satpura Hills and was established in 2001. The BWS sanctuary is situated between 21° 23′ to 22° 00′ N, 80° 58′ to 82° 34′ E., and at 677 msl.

Physiographically, the area is undulating with varying hillocks. The rocks of the region are granite and cysts. Entisols and Ultisols are the major soil types in the study area. The soil is nutrient-limited, alkaline, and spatially less variable (Baboo et al., 2017). The sanctuary area is characterized by a dry tropical climate. Monthly average temperature varies between 16.9^{0}C (January) and 36.0^{0}C (May). Mean annual temperature and rainfall average 26.4^{0}C and 976 mm, respectively (Jhariya, 2017a, 2017b).

Diverse types of vegetation occur in the BWS. The luxuriant forest occurs in the north and eastern parts of the BWS while the human-made forest of teak is common in the southern parts of BWS. Bamboo brakes and degraded mixed vegetation are mainly found in the western part of the study area (Champion and Seth, 1968). Accidental and intentional forest fires are most common in the BWS which influence the temporal and spatial distribution of flora.

Experimental design and analysis

The repeated reconnaissance along with monitoring of the field condition of the sanctuary were performed on four sites i.e., high fire zone (HFZ), medium fire zone (MFZ), low fire zone (LFZ), and no-fire zone (NFZ) in terms of tree species composition and fire disturbance regimes. On the basis of different fire regimes, the sites were categorized into HFZ, MFZ, LFZ, and NFZ. The fire regimes were categorized on the basis of historical statistics obtained from the National Remote Sensing Agency (NRSA), Hyderabad and the state forest department followed by local inquiry in the study area (Kittur et al., 2014; Jhariya et al., 2012, 2014). After the demarcation of fire regimes, the one-hectare permanent plot in each site was marked and observations were recorded.

The floristic structure and composition of trees in different fire regimes were analysed through stratified random sampling using quadrats of 10 m x 10 m size. Tree GBH (Girth at breast height) was measured and recorded at quadrat as well as species level, within each of these quadrats sub-quadrats of 2 m x 2 m were placed for enumeration of saplings and seedlings. Vegetation data were quantitatively analysed following (Curtis and McIntosh, 1950). The frequency of species occurrence was analyzed following (Raunkiaer,1934) and (Hewit and Kellman, 2002). Population structure was determined following (Saxena and Singh,1984). The computation method of (Khan et al., 1987) was used for determining the regeneration of species under different fire regimes. For measuring the biomass, allometric equations developed by (Singh and Misra, 1979) and (Singh and Singh, 1991) were used for the tropical dry deciduous forests.

RESULTS

Floristic structure

The species composition of the sanctuary area reflects substantial variation in different vegetation storey as well as under different fire regimes. A sum of 41 tree species distributed into 23 families was recorded in the BWS. The dominant family was Rubiaceae followed by Leguminosae and Combretaceae (Table 1). In different vegetation layers, the species showed their higher frequency of occurrence in frequency class-A i.e., rare category, and occurred singly in different fire regimes. The Raunkiaer's frequency classes revealed that higher presence of rare class (47-72%) followed by low frequency, intermediate class, moderately high frequency, and least representation in high frequency or common class (Table 2). The highest density in all the vegetation layers in different fire regimes was mostly measured for *Shorea robusta* and *Diospyros melanoxylon* (Table 3).

Table 1: Family wise distribution of the species in the Bhoramdeo Wildlife Sanctuary.

Species	Family	Ditribution*
Adina cordifolia Hook.f.	Rubiaceae	Southern Asia
Aegle marmelos Linn.	Acanthaceae	India, Bangladesh, Sri Lanka, and Nepal
Anogeissus latifolia Wall ex Bedd.	Combretaceae	India, Nepal, Myanmar, and Sri Lanka
Boswellia serrata Roxb.	Burseraceae	India, Pakistan
Bridelia retusa (Linn.) Spreng.	Euphorbiaceae	Bangladesh, Nepal, India, Sri Lanka, Southern China, Indochina, Thailand and Sumatra
Buchanania lanzan Spreng.	Anacardiaceae	The Indian subcontinent, Southeast Asia, and adjacent parts of China
Careya arborea Roxb.	Lecythidaceae	The Indian subcontinent, Afghanistan, and Indochina
Casearia graveolens Dalz.	Salicaceae	Asia from Thailand to South Central China to Pakistan
Cassia fistula Linn.	Leguminosae	Indian subcontinent, Southeast Asia, from Southern Pakistan through India and Sri Lanka to Bangladesh, Myanmar and Thailand
Catunaregam spinosa Thunb.	Rubiaceae	South Asia and other Asian countries
Choloroxylon swietenia DC.	Rutaceae	India, Sri Lanka, and Madagascar
Dalbergia paniculata Roxb.	Leguminosae	India, Sri Lanka, Nepal, Burma and Indo-China
Dillenia pentagyna Roxb.	Dilleniaceae	Sulawesi to South-Central China to India and Sri Lanka
Diospyros melanoxylon Roxb.	Ebenaceae	India and Sri Lanka
Diospyrous montana Roxb.	Ebenaceae	India, Sri Lanka, Indo-China to Australia
Emblica officinalis Gaertn	Euphorbiaceae	India
Gardenia latifolia (Aiton) Hortus Kew.	Rubiaceae	India to Bangladesh
Gardenia lucida Roxb	Rubiaceae	India, Africa, Asia
Gardenia resinifera Roth.	Rubiaceae	India
Garuga pinnata Roxb.	Burseraceae	India, China, Vietnam
Grewia tiliaefolia,Vahl.	Tiliaceae	India, Sri Lanka
Kydia calycina Roxb.	Malvaceae	The Indian subcontinent, southern China, and Southeast Asia
Lagerstroemia parviflora Roxb.	Lythraceae	Tropical southern Asia
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	South and Southeast Asia, ranging from Sri Lanka to Southern China
Madhuca latifolia, Roxb.	Sapotaceae	India, Nepal, Myanmar and Sri Lanka
Mitragyna parviflora Roxb.	Rubiaceae	India and Sri Lanka
Ougeinia oojeinensis (Roxb.) Hochr.	Leguminosae	India and Nepal
Pterocarpus marsupium Roxb.	Leguminosae	India, Nepal, Sri Lanka

Saccopetalum tomentosum H.F.&Thoms.	Anonaceae	India
Schleichera oleosa (Lour.) Oken	Sapindaceae	South East Asia, India
Schrebera swietenioides Roxb.	Oleaceae	India, Bangladesh, Myanmar, Thailand, Cambodia and Laos
Semecarpus anacardium L.f.	Anacardiaceae	India
Shorea robusta Gaertn.f.	Dipterocarpaceae	The Indian subcontinent, Myanmar, Nepal, Bangladesh
Sterculia urens Roxb.	Malvaceae	India
Stereospermum chelenoides DC.	Bignoniaceae	South Asia
Syzygium cumini (Linn.) Skeels.	Myrtaceae	India, Asian country
Tectona grandis Linn. f.	Lamiaceae	Bangladesh, India, Indonesia, Malaysia, Myanmar, Thailand, Sri Lanka
Terminalia belerica Roxb.	Combretaceae	Tropical Asia, from India to Indonesia
Terminalia chebula Retz.	Combretaceae	South Asia, India, Nepal, China, Sri Lanka, Malaysia, Vietnam
Terminalia tomentosa W&A.	Combretaceae	India, Nepal, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam
Zizyphus mouritiana Lamk.	Rhamnaceae	Indo-Malaysian region of South-East Asia

Based on Hooker, (1978)

Table 2: Raunkiaer's classification of vegetation under different fire regimes in Bhoramdeo Wildlife Sanctuary.

Layer	Fire regimes	Number of species in different frequency class				
		A	B	C	D	E
Tree	HFZ	8	2	0	0	1
	MFZ	7	6	1	1	0
	LFZ	12	4	1	1	0
	NFZ	16	6	5	1	0
Sapling	HFZ	2	0	0	0	0
	MFZ	3	0	0	0	0
	LFZ	5	0	0	0	0
	NFZ	7	0	0	0	0
Seedling	HFZ	9	1	0	1	1
	MFZ	10	3	0	2	0
	LFZ	14	2	0	1	1
	NFZ	18	3	1	1	0

Table 3: Regeneration of tree species under different fire regimes in Bhoramdeo Wildlife Sanctuary.

Species	High Fire Zone (HFZ)				Medium Fire Zone (MFZ)				Low Fire Zone (LFZ)					Non-Fire Zone (NFZ)					
	S	Sap	Tree	RS	S	Sap	Tree	RS	S	Sap	Tree	RS	S		Sap	Tree	RS		
Adina cordifolia	--	--	20	NR	--	--	--	--	--	--	20	NR	--		--	40	NR		
Aegle marmelos	--	--	--	--	--	--	--	--	--	--	--		250		--	10	FR		
Anogeissus latifolia	--	--	30	NR	1500	250	30	GR	500	--	40	FR	500		250	60	GR		
Boswellia serrata	--	--	--	--	--	--	--	--	--	--	--	--	--		--	10	NR		
Bridelia retusa	--	--	--	--	--	--	--	--	250	--	--	FR	250		--	20	FR		
Buchanania lanzan	250	--	10	FR	250		30	FR	1250	250	50	GR	--		250	30	PR		
Careya arborea	--	--	--	--	--	--	--	--	--	--	10	NR	250		--	--	FR		
Casearia graveolens	250	--	--	FR	1000	--	--	FR	1250	--	40	FR	2000		--	10	FR		
Cassia fistula	500	--	--	FR	500	--	10	FR		--	--	--	1250		--	--	FR		
Catunaregam spinosa	--	--	--	--	--	--	--	--	500	--	--	FR	--		--	--	--		
Choloroxylon swietenia	--	--	--	--	--	--	--	--	500	--	--	FR	--		--	--	--		
Dalbergia paniculata	--	--	--	--	--	--	10	NR	--	--	--		--		--	20	NR		
Dillenia pentagyna	--	--	--	--	--	--	--	--	500	--	--	FR	--		--	--		--	
Diospyros melanoxylon	4750	250	10	GR	4250	500	50	GR	6500	500	--	GR	2500		250	30		GR	
Diospyrous montana	500	--	--	FR	500	--	--	FR	--	--	--	--	250		--	--		FR	
Emblica officinalis	--	--	--	--	--	--	30	NR	--	--	10	NR	-		--	10		NR	
Gardenia latifolia	--	--	--	--	--	--	--	--	500	--	--	FR	250		--	10		FR	

Gardenia lucida	--	--	--	--	--	--	--	--	--	--	--	--	--		--	10		NR	
Gardenia resinifera	250	--	--	FR	--	--	20	NR	--	--	--	--	--		--	--		--	
Garuga pinnata	250	--	--	FR	--	--	--	--	750	--	--	FR	250		--	--		FR	
Grewia tiliaefoli	--	--	--	--	--	--	30	NR	--	--	10	NR	250		--	30		FR	
Kydia calycina	--	--	--	--	--	--	--	--	--	--	--	--	--		--	30		NR	
Lagerstroemia parviflora	1000	--	20	FR	--	--	50	NR	--	--	10	NR	1000		--	20		FR	
Lannea coromandelica	--	--	20	NR	--	--	30	NR	--	--	40	NR	250		250	40		GR	
Madhuca latifolia	--	--	20	NR	--	--	--	--	--	--	10	NR	250			60		FR	
Mitragyna parviflora	--	--	--	--	--	--	--	--	--	--	--	--	--		--	20		NR	
Ougeinia oojeinensis	--	--	20	NR	--	--	40	NR	--	250	90	PR	--		500	80		PR	
Pterocarpus marsupium	--	--	--	--	--	--	--	--	750	--	10	FR	--	--		20			NR
Saccopetalum tomentosum	--	--	--	--	--	--	--	--	--	--	--		250	--		50			FR
Schleichera oleosa	--	--	--	--	--	--	10	NR	250	--	10	FR	1000	--		10			FR
Schrebera swietenioides	500	--	--	FR	--	--	--	--	--	--	--	--	--	--		--			--
Semecarpus anacardium	--	--	--	--	--	--	--	--	--	--	20	NR	--	--		--			--
Shorea robusta	3500	500	180	GR	2500	250	120	GR	4500	250	110	GR	4250	250		100			GR
Sterculia urens	--	--	--	--	--	--	--	--	--	--	--	--	250	--		30			FR
Stereospermum chelenoides	--	--	--	--	--	--	--	--	250	--	20	FR	--	--		--			--
Syzygium cumini.	500	--		FR	250			FR	250	--	--	FR	1500	250		20			GR
Tectona grandis	--	--	--	--	--	--	--	--	--	--	--	--	--	--		30			NR
Terminalia belerica	--	--	--	--	--	--	--	--	--	--	10	NR	250	--		--			FR
Terminalia chebula	--	--	30	NR	--	--	20	NR	250	--	20	FR	250	--		20			FR
Terminalia tomentosa	250	--	20	FR	750	--	10	FR	1000	250	80	GR	750	--		60			FR
Zizyphus mouritiana	--	--	--	--	250	--	--	FR	500	--	--	FR	250	--		--			FR

Note: S= seedling, Sap= saplings, RS= regeneration status, GR= good regeneration, FR= fair regeneration, PR= poor regeneration, NR= not regenerating.

Stand density-GBH relationship

Density and GBH relationship showed exponential model [Y = exp (a – bx)] under different fire regimes. About 86.37−91.71% of vegetation reflects ≤10 cm girth, whereas 8.29−13.63% individuals had a >10 cm GBH (Figure 1) and 1.58–2.18% of individuals exceeded > 50 cm GBH. The pooled species density as per the GBH reflects the following equation:

Y= exp [10113-1.03x] for HFZ (r^2=0.899 p <5%) (1)

Y= exp [9326-0.92x] for MFZ (r^2=0.837 p <5%) (2)

Y= exp [12164-0.91x] for LFZ (r^2=0.820 p <5%) (3)

Y= exp [11485-0.82x] for NFZ (r^2=0.803 p <5%) (4)

Population structure

The population structure represents the size and age class gradation of the individuals under different fire regimes which are demonstrated in Figure 2-5.

In HFZ (Figure 2), class (A) was dominant except for *Adina cordifolia*, *Anogeissus latifolia*, *Lannea coromandelica*, *Madhuca latifolia*, *Terminalia chebula* and *Ougeinia oojeinensis*. The seedling class was found to be dominated in *Diospyros melanoxylon* and *Shorea robusta*, both together contributed 66% in this class. Class (B) revealed a higher presence of *Shorea robusta*. Class (C) and D showed dominancy of *A. latifolia, M. latifolia*, *S. robusta*, *L. coromandelica*, *O. oojeinensis*, and *T. chebula*. The older class (E) is represented as negligible or nil, and *S. robusta* was the only species represented by class E. The proportion of seedlings to the higher class (D) decreased steadily (e.g. *Buchanania lanzan*, *D. melanoxylon*, and *S. robusta*).

The population structure in MFZ (Figure 3) showed higher contribution by seedling class (A) and dominancy of *D. melanoxylon* and *S. robusta* which contribute 54% of the total population. Class (B) was negligible and only represented by *A. latifolia*, *D. melanoxylon*, and *S. robusta*. Intermediate-size class (C) was abundant on this site and represented by *B. lanzan*, *D. melanoxylon*, *Lagerstroemia parviflora*, *O. oojeinensis*, *Phyllanthus emblica*, and *S.*

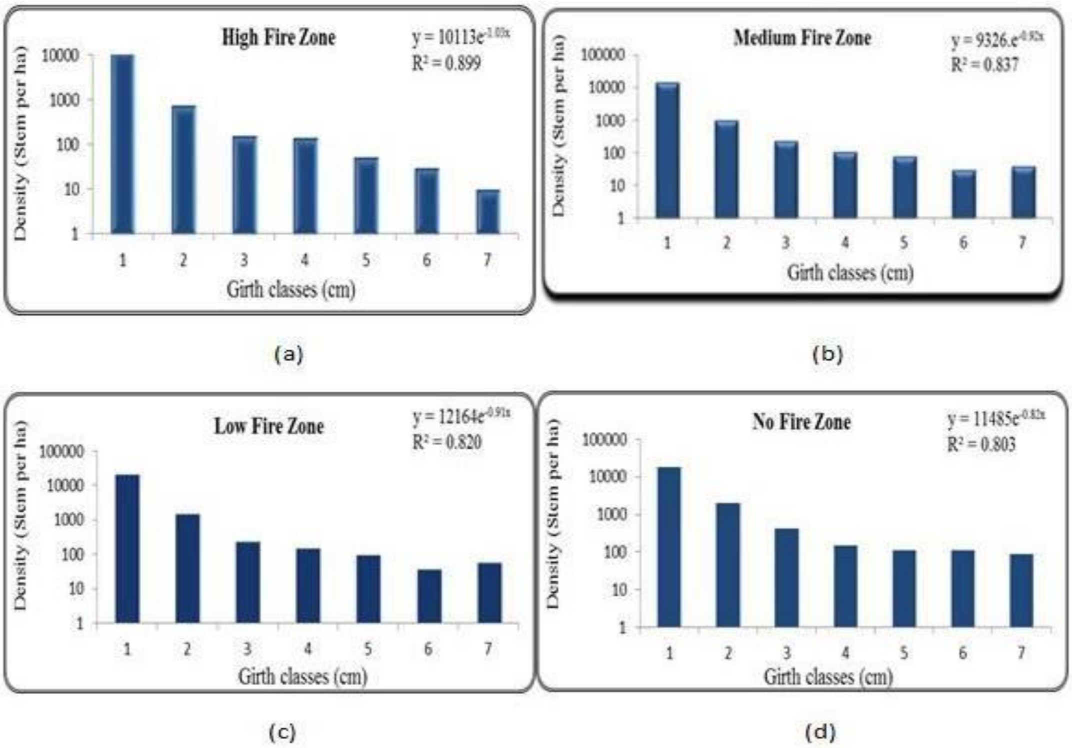

Figure 1: Relationship between density of seedling, sapling and trees with mean girth class (cm) are: 1 = ≤10; 2 = > 10 - ≤ 30; 3 = > 30 - ≤ 50; 4 = > 50 - ≤ 70; 5 = > 70 - ≤ 90; 6 = > 90 - ≤ 110; 7 = > 110.Where 1, 2 and 3, respectively are seedling, sapling and tree.

robusta. Class (D) and (E) were mostly negligible or nil except for *D. melanoxylon*, *L. coromandelica,* and *S. robusta*.

In LFZ, *S. robusta* represents all classes, whereas *B. lanzan* and *T. tomentosa* represent all size classes except class (E). In class (A), *D. melanoxylon* and *S. robusta* contribute 88% of the total population. The size class (C) is the dominant class over (D) and class (E). Class (E) was found in *A. cordifolia*, *M. latifolia*, *O. oojeinensis*, *Pterocarpus marsupium* and *S. robusta* (Figure 4).

In NFZ, *S. robusta* revealed all classes in population structure. *A. latifolia* and *D. melanoxylon* were found in all classes except class (E). *Careya arborea*, *D. melanoxylon*, *Garuga pinnata*, *Terminalia belarica*, and *Zizyphus mauritiana* were represented only by seedling size class (A). Class (B) and (C) revealed the dominancy of *O. oojeinensis* (Figure 5).

Wildfire and regeneration status

The seedlings and saplings proportion in the vegetation stand is regarded as the regeneration potential of the species. In HFZ, only *D. melanoxylon* and *S. robusta* species showed good regeneration potential. In MFZ, *A. latifolia*, *D. melanoxylon*, and *S. robusta* have good regeneration. In LFZ, *B. lanzan*, *D. melanoxylon*, and *S. robusta* have good generation potential. In NFZ, *A. latifolia*, *D. melanoxylon*, *L. coromandelica*, *S. robusta*, and *S. cumini* showed good regeneration potential (Table 3). The regeneration status revealed that in HFZ only 11.11% of species were showing good regeneration potential and 33.33% were not regenerating while in the MFZ 15.79% showed good regeneration and 47.37% of species were not regenerating. In LFZ 14.29% of species showed good regeneration potential while 32.14% of species not regenerating. In NFZ 14.71% of species showed good regeneration, 52.94% had fair regeneration, and 26.47% of species were not regenerating well (Table 4).

Forest biomasss

The biomass of the tree species in different fire regimes is given in (Table 5). The total biomass under different fire regimes varied from 116.03-358.36 Mg ha^{-1}, being highest under NFZ and lowest in HFZ, respectively. In HFZ, bole, branch, leaf, and root biomass were 36.87 Mg ha^{-1}, 59.89 Mg ha^{-1}, 4.13 Mg ha^{-1}, and 15.15 Mg ha^{-1}, respectively. In MFZ, bole, branch, leaf, and root biomass were 52.60 Mg ha^{-1}, 76.26 Mg ha^{-1}, 5.31 Mg ha^{-1}, and 20.66 Mg ha^{-1}, respectively. In LFZ, bole, branch, leaf, and root biomass were 76.60 Mg ha^{-1}, 120.40 Mg ha^{-1}, 7.62 Mg ha^{-1}, and 28.83 Mg ha^{-1}, respectively. In NFZ, bole, branch, leaf, and root biomass were 118.7 Mg ha^{-1}, 182.72 Mg ha^{-1}, 12.22 Mg ha^{-1}, and 44.72 Mg ha^{-1}, respectively. Among the different species, *S. robusta* was found to be the dominant species and contributed the highest biomass in all the studied sites.

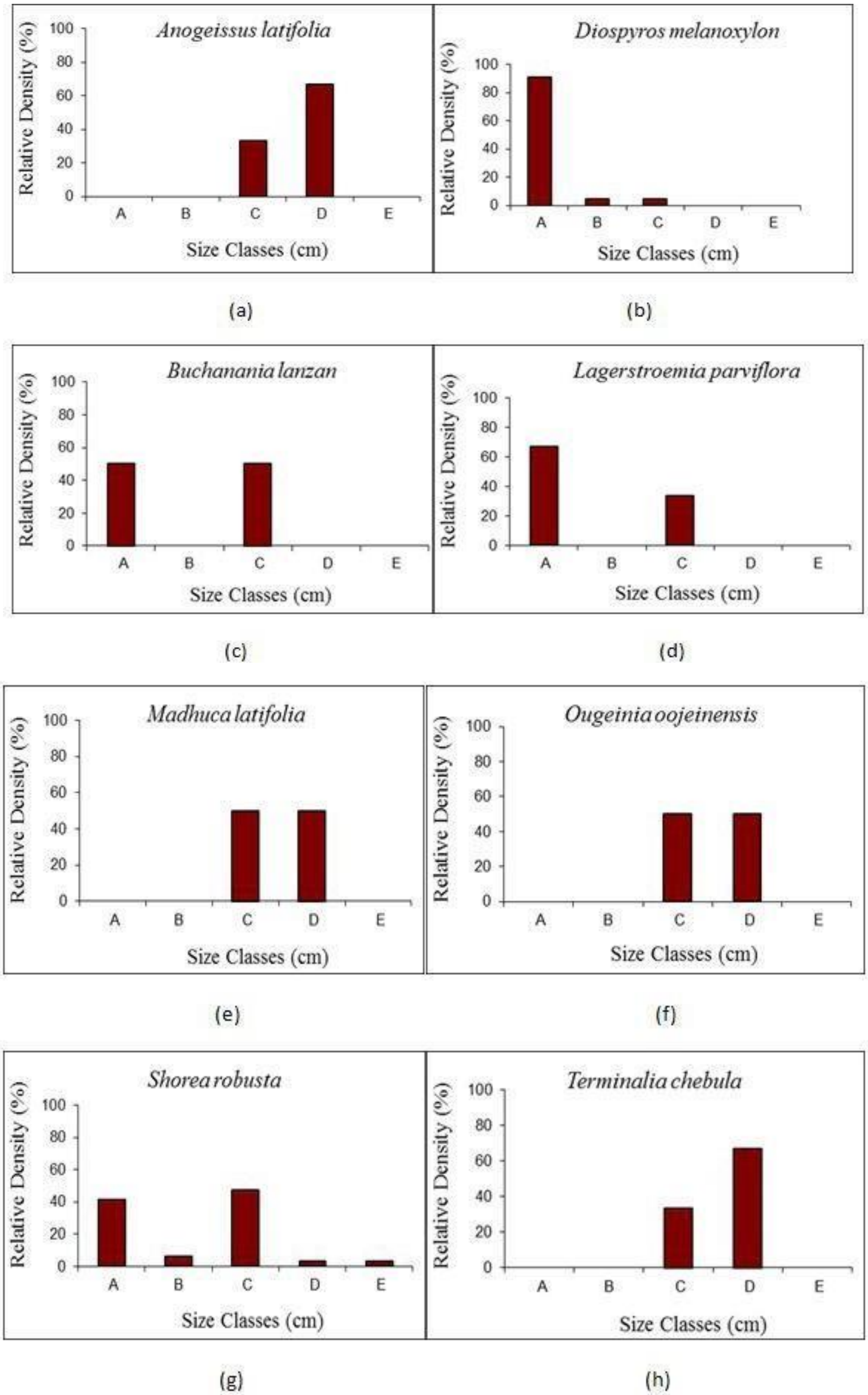

Figure 2: Population structures of major tree species of high fire zone of Bhoramdeo Wildlife Sanctuary. Size classes are made on the basis of GBH.

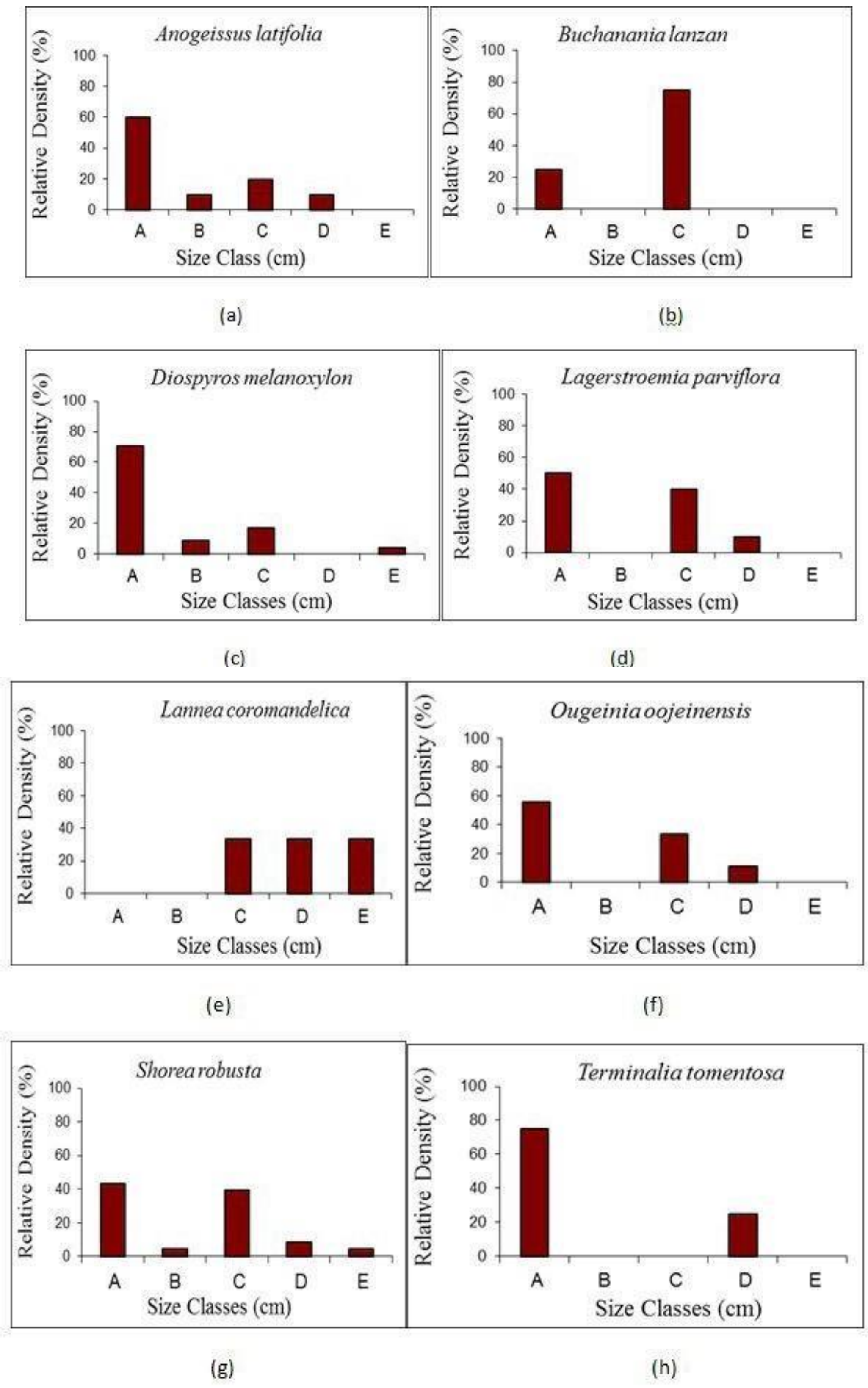

Figure 3: Population structures of major tree species of medium fire zone of Bhoramdeo Wildlife Sanctuary. Size classes are made on the basis of GBH.

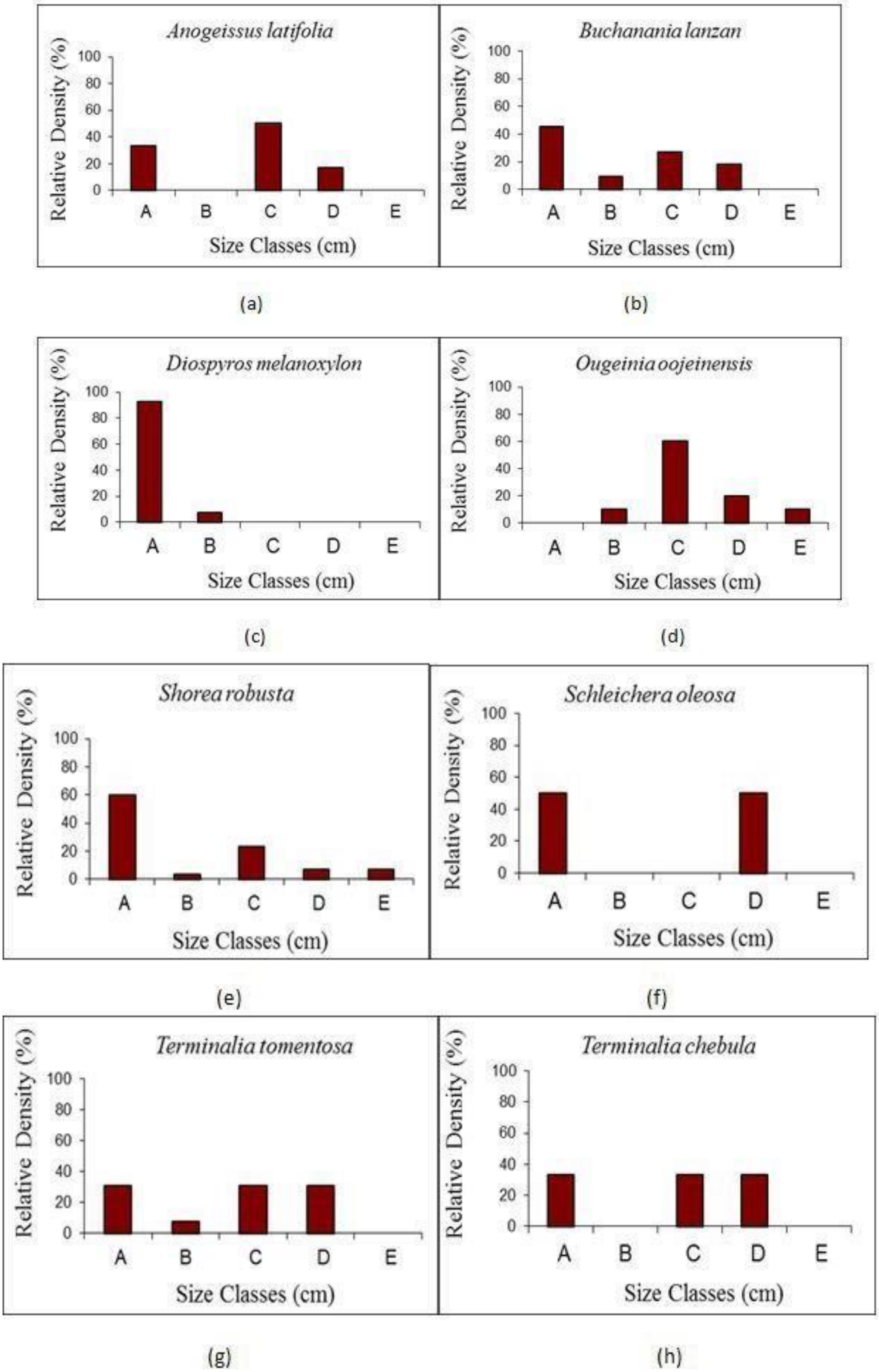

Figure 4: Population structures of major tree species of low fire zone of Bhoramdeo Wildlife Sanctuary. Size classes are made on the basis of GBH.

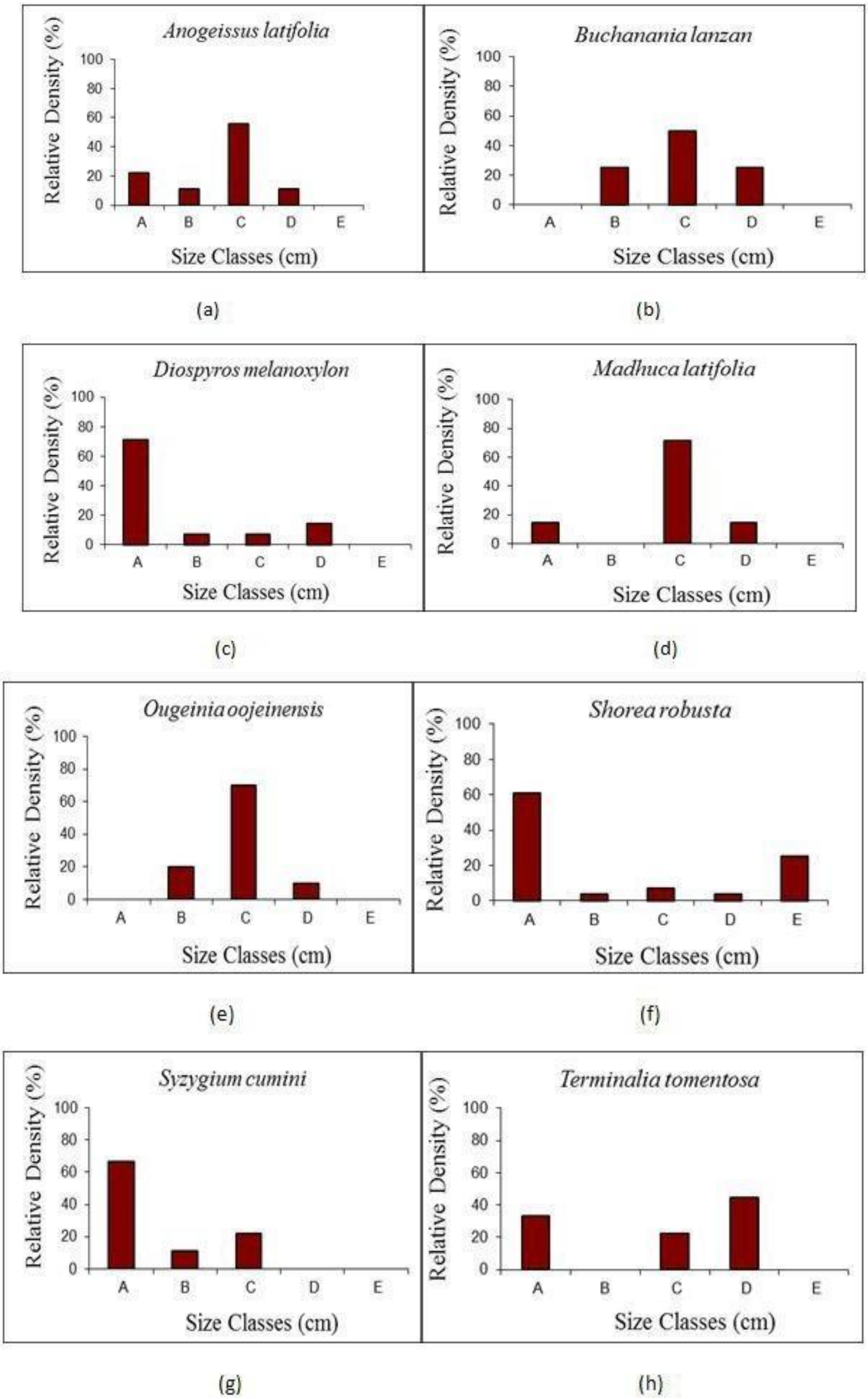

Figure 5: Population structures of major tree species of no fire zone of Bhoramdeo Wildlife Sanctuary. Size classes are made on the basis of GBH.

Table 4: Regeneration status (%) of species under different fire regimes in Bhoramdeo Wildlife Sanctuary.

Fire Zones	Good regeneration	Fair regeneration	Poor regeneration	Not regenerating
HFZ	11.11	55.56	0.00	33.33
MFZ	15.79	36.84	0.00	47.37
LFZ	14.29	50.00	3.57	32.14
NFZ	14.71	52.94	5.88	26.47

Table 5: Stand biomass (Mg ha^{-1}) under different fire regimes in Bhoramdeo Wildlife Sanctuary.

Species	HFZ					MFZ					LFZ					NFZ				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Adina cardifolia	1.05	1.05	0.12	0.39	2.62	--	--	--	--	--	5.53	9.28	0.52	2.08	17.40	5.75	8.27	0.57	2.16	16.75
Aegle marmelos	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.64	0.68	0.07	0.24	1.64
Anogeissus latifolia	3.55	12.66	0.76	2.59	19.56	2.25	6.42	0.42	1.52	10.60	2.54	7.73	0.49	1.75	12.51	4.07	12.51	0.79	2.81	20.19
Boswellia serrata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.25	3.39	0.22	0.85	6.70
Bridelia retiosa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.06	4.13	0.31	1.15	8.64
Buchanania lanzan	0.19	0.09	0.03	0.06	0.37	1.20	0.97	0.17	0.36	2.71	3.63	3.99	0.52	1.08	9.22	3.05	4.83	0.42	0.89	9.19
Careya arborea	--	--	--	--	--	--	--	--	--	--	0.23	0.18	0.03	0.09	0.52	--	--	--	--	--
Casearia graveolens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.23	0.18	0.03	0.09	0.52
Casearia graveolens	--	--	--	--	--	--	--	--	--	--	1.10	0.91	0.13	0.41	2.55	--	--	--	--	--
Cassia fistula	--	--	--	--	--	0.41	0.38	0.05	0.15	0.98	--	--	--	--	--	--	--	--	--	--
Dalbergia paniculata	--	--	--	--	--	2.25	3.39	0.22	0.85	6.70	--	--	--	--	--	3.72	6.12	0.35	1.40	11.58
Diospyrous melanoxylon	1.00	0.90	0.08	0.37	2.36	6.20	8.00	0.44	2.12	16.77	--	--	--	--	--	4.05	4.49	0.30	1.42	10.26
Gardenia latifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.95	1.11	0.10	0.35	2.51
Gardenia lucida	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.95	1.11	0.10	0.35	2.51
Gardenia resinifera	--	--	--	--	--	0.46	0.36	0.06	0.17	1.05	--	--	--	--	--	--	--	--	--	--
Grwia tiliaefolia	--	--	--	--	--	4.80	5.28	0.40	1.64	12.13	1.05	1.12	0.10	0.37	2.64	4.32	4.76	0.36	1.47	10.92
Kydia calycina	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.00	2.16	0.22	0.75	5.13
Lagerstroemia parviflora	0.78	0.69	0.11	0.37	1.95	4.26	4.46	0.54	2.31	11.58	0.57	0.53	0.08	0.29	1.47	2.37	2.63	0.29	1.35	6.64
Lannea coromandelica	3.48	5.22	0.34	1.30	10.34	6.48	10.39	0.62	2.43	19.91	1.93	1.91	0.22	0.72	4.78	2.26	2.36	0.25	0.85	5.72
Madhuca latifolia	2.90	4.06	0.29	1.09	8.34	--	--	--	--	--	10.35	24.06	0.85	3.89	39.14	4.16	5.64	0.43	1.56	11.78
Mitragyna parviflora	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.72	2.06	0.18	0.64	4.61

Ougeinia oojeinensis	2.15	2.82	0.22	0.81	6.00	2.43	2.98	0.26	0.91	6.58	11.44	16.38	1.14	4.29	33.25	4.46	4.96	0.49	1.67	11.57
Phyllanthus emblica	--	--	--	--	--	1.61	1.94	0.17	0.59	4.31	0.20	0.18	0.03	0.09	0.50	0.20	0.18	0.03	0.09	0.50
Pterocarpus marsupium	--	--	--	--	--	--	--	--	--	--	4.69	6.16	0.21	1.31	12.37	4.16	4.58	0.22	1.13	10.09
Saccopetalum tomentosum	--	--	--	--	--	--	--	--	--	--	0.57	0.28	0.06	0.17	1.08	2.77	1.71	0.27	0.84	5.59
Schleichera oleosa	--	--	--	--	--	0.23	0.18	0.03	0.09	0.52	1.75	2.44	0.17	0.66	5.02	0.23	0.18	0.03	0.09	0.52
Semecarpus anacardium	--	--	--	--	--	--	--	--	--	--	0.87	0.86	0.10	0.33	2.16	--	--	--	--	--
Shorea robusta	16.88	26.29	1.67	6.34	51.19	18.07	29.26	1.73	6.79	55.85	18.27	28.41	1.77	6.86	55.31	43.86	85.45	3.86	16.49	149.66
Sterculia urens	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.87	0.73	0.10	0.32	2.03
Syzygium cumini	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.56	0.43	0.07	0.21	1.27
Tectona grandis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.16	2.47	1.08	1.48	10.18
Terminalia belerica	--	--	--	--	--	--	--	--	--	--	0.64	0.68	0.07	0.24	1.64	--	--	--	--	--
Terminalia chebula	4.00	5.24	0.41	1.50	11.15	0.64	0.56	0.08	0.24	1.51	2.66	3.76	0.26	1.00	7.68	1.17	1.29	0.13	0.44	3.03
Terminalia tomentoso	0.87	0.86	0.10	0.33	2.16	1.31	1.69	0.13	0.49	3.63	8.58	11.54	0.87	3.22	24.21	9.72	14.31	0.95	3.65	28.63
Total	**36.87**	**59.89**	**4.13**	**15.15**	**116.03**	**52.60**	**76.26**	**5.31**	**20.66**	**154.83**	**76.60**	**120.40**	**7.62**	**28.83**	**233.45**	**118.70**	**182.72**	**12.22**	**44.72**	**358.36**

DISCUSSION

Floristic structure

Floristic analysis is the key to assessing and understanding the stands' ecological condition. Forest fire intensity and return interval in addition to abiotic and biotic factors accelerate the alteration process of the vegetation mix, structure, and diversity in due course of time (Hassan et al., 2007; Kumar et al., 2017). The higher species of seedlings, saplings, and trees were found in NFZ as compared to the rest of the sites (HFZ, MFZ, LFZ). Similarly, (Kafle, 2006) also reported that the protected area possesses a higher tree population and species richness than the fire-affected areas which supports the present findings. A similar trend was also revealed by (Kodandapani, 2008) in his study comprising ecological characteristics of forest fires in a tropical forest of the Western Ghats. The frequent fire incidents do not provide the time for natural recovery and selected or fire-hardy species can only withstand or survive. This in turn alters the overall floristic structure and dynamics of the forest stands as revealed by the HFZ (Bargali et al., 2023; Jhariya et al., 2012; Kittur et al., 2014).

Stand density-GBH relationship

The exponential relationship between population and GBH reflects a young forest structure this could be due to quicker turnover, low biomass accumulation, and anthropogenic removal in the dry tropical forest. (Singh and Singh, 1991) found that 3-5% of the vegetation population exceeded 50 cm GBH in the tropical forest of Uttar Pradesh and (Chaturvedi et al., 2011) mentioned these trends for similar forest types. Similarly, (Jhariya and Yadav, 2018) found 72.66% and 73.87% of individuals, respectively in natural and teak stands of northern Chhattisgarh have ≤10 cm girth and 1.27-6.22% population have ＞50 cm girth class. (Murphy and Lugo, 1986) reported that 2-3% of individuals exceeded 10 cm GBH in the Puerto Rican sub-tropical dry forest which corroborates with present findings. (Longhi et al., 1999) have reported 42% of individuals with 15-25 CBH and only 2.2% with CBH > 65 for fragments of the deciduous seasonal forest in Brazil. (Kujur et al., 2021) found 66.05–73.04% of individuals have ≤10 cm girth and 1.62–3.48% of individuals were distributed in girth class ＞50 cm.

Population structure

The representation of seedling, sapling, and tree stages reflects the health and future status of the forest. The distribution of trees as per size class entails the stand's population structure (Dhaulkhndi et al., 2008; Khan et al., 1987; Saxena and Singh, 1984). The forest fire (Murthi et al., 2002), grazing pressure, light availability (Teketay, 1997), soil factors, and anthropogenic pressure were reported to affect the regeneration of the forest. This is dependent and regulated through various internal processes in addition to external causes (Barker and Patrick, 1994). The number of tree, sapling, and seedling showed consistent reduction from seedling to sapling and sapling to tree stage. This revealed good natural regeneration but the subsequent conversion from seedling to sapling and tree class were very low or dramatic. This could be related to more fire interference on sapling and intermediate classes towards utilization as poles, fodder, fuelwood, etc.

Across the fire regimes, class A was found to be dominant which reflects frequent reproduction (Kittur et al., 2014; Jhariya et al., 2012; Knight, 1975; West et al., 1981). This trend shows substantial utilization of older size classes as well as heavy mortality in lower size classes. In class (A), *D. melanoxylon* was dominant in all the sites except NFZ and unable to reach succeeding classes as a dominant species. This is because humans set fires to burn the ground litter and for good sprouts of various species and grasses. The heavy stress arrests the growth and limits the species from reaching the next stage of the life cycle. The hump in intermediate classes reflects the faster growth and least mortality of individuals (West et al., 1981). Once the species exceed the class B and enters into the initial class of the tree such as *A. latifolia*, *B. lanzan, L. parviflora*, *M. latifolia* and *O. oojeinensis* in HFZ, *A. latifolia, B. lanzan*, *L. parviflora*, *L. coromandelica* and *O. oojeinensis* in MFZ, *A. latifolia, B. lanzan*, *O. oojeinensis*, *T. chebula* in LFZ and in NFZ *A. latifolia, B. lanzan, M. latifolia* and *O. oojeinensis*. In the different fire regimes, NFZ and LFZ were regenerating well due to the presence of higher trees that supply the seeds for natural regeneration. However, MFZ showed comparatively better regeneration than the HFZ which did not show good regeneration. Khurana has concluded that biotic interference leads to eroding the soil and making it nutrient-poor which could not favour natural regeneration (Khurana, 2007).

Wildfire and regeneration status

Anthropogenic interferences alter the qualitative and quantitative traits of the forest ecosystem (Shankar, 2001). The species with rare occurrences that contribute substantial diversity are at risk of extinction due to various pressures and least natural regeneration. Among them, human interference is more disturbing to the biota of the ecosystem. Forest fires do not provide enough time for natural recovery or balance in the regeneration dynamics of the ecosystem. The presence of a mother tree or large trees influences the overall population of the seedlings (Rao et al., 1990). Change in seedling and sapling density shows that anthropogenic disturbances were degrading forests with the passing of time without possibilities of rejuvenation under the influence of forest fire. The good regeneration potential of the species revealed the compatibility of species with the site conditions (Dhaulkhndi et al., 2008).

The regeneration potential of the species is altered by climatic perturbation and anthropogenic disturbances. The density of the succeeding phase from seedlings to saplings and trees gets reduced due to the forest fire and competition for similar resources. The regeneration success depends upon the seedling initiation ability, ability to survive, and growth traits under a given environmental setup (Good and Good, 1972). Fire events also determine the floristic composition by selection of species that will retained in the particular stand. Fire-sensitive species are eliminated by the fire where the interval is regular, in the early phase of succession or establishment phase (Chandler et al., 1983). Two tactics determine the species' response to fire frequency viz., species that are capable of sprouting can resist or withstand different fire regimes whereas those that maintain their population, and seed production or favored under sporadic fire (Keeley, 1981). Besides these some functional traits such as sprouting ability and thickness of bark allow the species to resist or tolerate the fire (Saha and Howe, 2003) while the non-sprouting and species having thin bark are more sensitive and vulnerable to fire (Gosper et al., 2012; Hoffmann et al., 2012). This mechanism alters the regeneration potential of the species under different fire regimes.

Forest biomass

The Forest fire has a significant impact on the vegetation, its development and biomass as well as its accumulation pattern (Sannigrahi et al., 2020) depending upon the severity, frequency and fire return intervals. Among different fire regimes, HFZ showed a severe reduction in the tree biomass. As compared to NFZ, fire caused a reduction in the 68.94% bole, 67.22% branch, 66.20% leaf, 66.12% root, and 67.62% total biomass in HFZ. In MFZ, the reduction in the biomass as compared to NFZ was 55.69% bole, 58.26% branch, 56.55% leaf, 53.80% root, and 56.79% total biomass. LFZ showed a 35.47% reduction of biomass in bole, 34.11% in branch, 37.64% in leaf, 35.53% in root, and 34.86% total biomass as compared to the NFZ. This might be due to the stress condition and limiting environment (de Meira Junior et al., 2020) developed by the fire events that would arrest the growth and functional traits as compared to the control or NFZ (Raj and Jhariya, 2021a, 2021b). High and frequent fire alters the plant density and diversity (Bargali et al., 2022) and suppresses the growth and dry matter production which in turn causes the loss in biomass and productivity of the forest ecosystem (Zhang et al., 2015).

CONCLUSION

Forest fire has a substantial impact on forest regeneration, population structure, and forest biomass. There is wider floral variation in different fire regimes. The higher number of plant species, families, regeneration, and biomass were recorded in the NFZ and lowest at the HFZ. The relationship between plant density and girth class showed the small structure of the forest as a majority of the contribution (86.37–91.71%) of the individuals belongs to the ≤10 cm girth class. The population structure revealed that tree, sapling, and seedling showed a consistent decrease from the seedling to sapling stage and also from the sapling to trees stage. Among different fire regimes, *Anogeissus latifolia*, *Buchanania lanzan*, *Diospyrous melanoxylon*, *Lannea coromandelica*, *Shorea robusta*, and *Syzygium cumini* showed good regeneration potential. The total biomass was higher under NFZ and lowest in HFZ. The fire causes the reduction of bole biomass from 35.47-68.97%, 34.11-67.22% in branch biomass, 37.64-66.20% reduction in leaf biomass, 35.53-66.12% in root biomass, and 34.86-67.62% reduction in total biomass. The reduction was higher in HFZ followed by MFZ and LFZ, respectively. Thus, the forest should be protected from fire followed by proper management strategies for conservation of the intact forest. Further, *Anogeissus latifolia*, *Buchanania lanzan*, *Diospyrous melanoxylon*, *Lannea coromandelica*, *Shorea robusta,* and *Syzygium cumini* should be promoted for the plantation for proper stocking and where the fire incidence is common.

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DECLARATION

ETHICS APPROVAL

Not applicable.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

MKJ: Conducted the experiments, data curation, analysed the data, wrote, reviewed, and edited the MS.

ST: Literature, reviewed and framed the MS.

LS: Provided technical guidance, conceptualization, supervision, and review of MS.

JSS: Editing and reviewing the MS

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REFERENCES

Baboo, B., Sagar, R., Bargali, S.S., Verma, H., (2017). Tree species composition, regeneration and diversity of an Indian dry tropical forest protected area. Trop Ecol. 58(2), 409–423.

Bargali, H., Bhatt, D., Sundriyal, R.C., Uniyal, V.P., Pandey, A., et al., (2023). Effect of forest fire on tree diversity and regeneration in the forests of Uttarakhand, Western Himalaya, India. Front For Glob Change 6, 1198143.

Bargali, H., Calderon, L.P.P., Sundriyal, R.C., Bhatt, D., (2022). Impact of forest fire frequency on floristic diversity in the forests of Uttarakhand, western Himalaya. Trees Forests People. 9, 100300.

Barker, P.C.J., Kirk Patrick, J.B., (1994). *Phyllocladus asplenifolius*: variability in the population structure of the regeneration niche and dispersion pattern in Tasmanian forest. Aust J Bot. 42, 163-190.

Barlow, J., Lennox, G.D., Ferreira, J., Berenguer, E., Lees, A.C., et al., (2016). Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature. 535, 144–147.

Certini, G., (2005). Effect of fire on properties of soil - A review. Oecologia. 143, 1-10.

Champion, H.G., Seth, S.K., (1968). A revised Survey of the Forest Types of India. Government of India Publication, New Delhi. 404 pages.

Chandler, C., Philip, C., Philip, T., Louis, T., Dave, W., (1983). Ecological Principles and Their Relationship to Fire in Forestry. In: Forest Fire Behaviour and Effects: Vol 1. A Wiley-Interscience Publicaiton, John Wiley & Sons.

Chandra, K.K., Bhardwaj, A.K., (2015). Incidence of Forest Fire in India and Its Effect on Terrestrial Ecosystem Dynamics, Nutrient and Microbial Status of Soil. Int J Agric For. 5(2), 69-78.

Chaturvedi, R.K., Raghubanshi, A.S., Singh, J.S., (2011). Carbon density and accumulation in woody species of tropical dry forest in India. For Ecol Manag. 262, 1576-1588.

Curtis, J.T., McIntosh, R.P., (1950). The interrelations of certain analytic and synthetic hytosociological characters. Ecol. 31, 434-455.

De Andrade, D.F.C., Roberto, A., Schwartz, G., Olegário, J., et al., (2020). Forest resilience to fire in eastern Amazon depends on the intensity of pre-fire disturbance. For Ecol Manag. 472, 118258.

de Meira Junior, M.S., Pinto, J.R.R., Ramos, et al., (2020). The impact of long dry periods on the aboveground biomass in a tropical forest: 20 years of monitoring. Carbon Balance Manage. 15, 12.

Devi, A., Jhariya, M.K., Yadav, D.K., Banerjee, A., (2023). Understory diversity and forest soil properties in different forest stands in Northern Chhattisgarh, India. S Afr J Bot. 162, 171-182.

Dhar, T., Bhatta, B., Aravindan, S., (2023). Forest fire occurrence, distribution and risk mapping using geoinformation technology: A case study in the sub-tropical forest of the Meghalaya, India. Remote Sensing Application: Society and Environment. 29, 100883.

Dhaulkhandi, M., Dobhal, A., Bhatt, S., Kumar, M.,(2008). Community structure and regeneration potential of natural forest site in Gangotri, India. j basic appl sci. 4(1), 49-52.

FRI,(2018). Forest fires in India.Forest Research Institute, ICFRE, Dehradun, 53 p.

Good, N.F., Good, R.E., (1972). Population dynamics of tree seedlings and saplings in mature Eastern hardwood forest. Bull Torrey Bot. Club. 99(4), 172-178.

Gosper, C.R., Yates, C.J., Prober, S.M., Parsons, B.C., (2012). Contrasting changes in vegetation structure and diversity with time since fire in two Australian Mediterranean-climate plant communities. Austral Ecol. 37, 164–174.

Gubbi, S., (2003). Fire, fire burning. Deccan Herald, 05-01-2003, Bangalore, India.

Hassan, A., Wahab, R., Alias, M.A., Salim, R.M., (2007). Growth performance of 9-year-old selected 5 indigenous wood species planted on degraded forest land. Int J Agric Res. 2, 302–306.

Hewit, N., Kellman, M., (2002). True seed dispersal among forest fragments: dispersal ability and biogeographical controls. J Biogeogr. 29(3), 351–363.

Hoffmann, W.A., Geiger, E.L., Gotsch, S.G., Rossatto, D.R., Silva, L.C., et al.,(2012). Ecological thresholds at the savanna-forest boundary: How plant traits, resources and fire govern the distribution of tropical biomes. Ecology Letters. 15, 759–768.

Hooker, J.D., C.B., K.C.S.I., (1978).The Flora of British India.Bishen Singh Mahendra Pal Singh, Dehradun, India.

Jhariya, M.K., Bargali, S.S., Swamy, S.L., Kittur, B., (2012). Vegetational Structure, Diversity and Fuel Load in Fire Affected Areas of Tropical Dry Deciduous Forests in Chhattisgarh. Vegetos. 25(1), 210-224.

Jhariya, M.K., Bargali, S.S., Swamy, S.L., Kittur, B., Bargali, K., et al., (2014). Impact of forest fire on biomass and carbon storage pattern of tropical deciduous forests in Bhoramdeo Wildlife Sanctuary, Chhattisgarh. Int J Ecol Environ Sci. 40(1), 57-74.

Jhariya, M.K., (2017a). Vegetation ecology and carbon sequestration potential of shrubs in tropics of Chhattisgarh, India. Environ Monit Assess. 189(10), 518,

Jhariya, M.K., (2017b). Influences of forest fire on forest floor and litterfall dynamics in Bhoramdeo Wildlife Sanctuary (C.G.), India. J For Environ Sci. 33(4), 330-341.

Jhariya, M.K., Yadav, D.K., (2018). Biomass and carbon storage pattern in natural and plantation forest ecosystem of Chhattisgarh, India. J For Environ Sci. 34(1), 1-11.

Jhariya, M.K., Singh, L., (2021a). Herbaceous diversity and biomass under different fire regimes in a seasonally dry forest ecosystem. Environ Dev Sustain. 23(5), 6800-6818.

Jhariya, M.K., Singh, L., (2021b). Effect of fire severity on soil properties in a seasonally dry forest ecosystem of Central India. Int J Environ Sci Technol. 18(12), 3967-3978.

Kafle, S.K., (2006). Effect of forest fire protection on plant diversity in a tropical deciduous dipterocarp-oak forest Thailand. General Technical Report PSW- GTR-208.

Keeley, J.E., (1981). Reproductive cycles and fire regimes. In: Fire Regimes and Ecosystem Properties. Gen. Tech. Rep. WO-26, Washington, D.C. USDA, Forest Service, pp. 231-277.

Khan, M.L., Rai, J.P.N., Tripathi, R.S., (1987). Population structure of some tree species in disturbed and protected sub-tropical forests of north-east India. Acta Oecologia. 8, 247-255.

Kittur, B., Swamy, S.L., Bargali, S.S., Jhariya, M.K., (2014). Wildland Fires and Moist Deciduous Forests of Chhattisgarh, India: Divergent Component Assessment. . For Res. 25(4), 857-866.

Knight, D.H., (1975). A phytosociological analysis of species-rich-tropical forest on Barro Colorado Island; Panama. Ecol Monogr. 45, 259-284.

Kodandapani, N., Cochrane, M., Sukumar, R., (2008). A comparative analysis of spatial, temporal and ecological characteristics of forest fires in seasonally dry tropical ecosystems in the Western Ghats, India. For Ecol Manag. 256, 607-617.

Kujur, E., Jhariya, M.K., Yadav, D.K., Banerjee, A., (2021). Biomass, carbon storage and CO_2 mitigation potential of two riparian sites of Northern Chhattisgarh, India. Environ Earth Sci. 80, 723.

Kumar, A., Jhariya, M.K., Yadav, D.K., Banerjee, A., (2017). Vegetation dynamics in Bishrampur collieries of northern Chhattisgarh, India: eco-restoration and management perspectives. Environ Monit Assess. 189, 371.

Khurana, P., (2007). Tree layer analysis and regeneration in tropical dry deciduous forest of Hastinapur. Indian For. 16(1), 43-50.

Longhi, S.J., Nascimento, A.R.T., Fieig, F.D., Della Flora, J.B., Freitas, et al., (1999). Floristic composition and community structure of a forest fragment in Santa Maria, Brazil. Ciencia Florestal. 9(1), 115-133.

Mina, U., Dimri, A.P., Farswan, S., (2023). Forest fires and climate attributes interact in central Himalayas: an overview and assessment. Fire Ecol. 19, 14.

Murphy, P.G., Lugo, A.E., (1986). Ecology of tropical dry forests. Annu Rev Ecol Evol Syst. 17, 67-88.

Murthi, I.K., Murali, K.S., Hedge, G.T., Bhat, P.R., Ravindranath, N.H., (2002). A comparative analysis of regeneration in natural forest and joint forest management plantations in Uttara Kannada Dist, Western Ghats. Curr Sci. 83, 1358-1364.

Neeraja, U.V., Rajendrakumar, S., Saneesh, C.S., Dyda, V., Knight, T.M., (2021). Fire alters diversity, composition, and structure of dry tropical forests in the Eastern Ghats. Ecol Evol.11, 6593–6603.

Raj, A., Jhariya, M.K., (2021a). Site quality and vegetation biomass in the tropical Sal mixed deciduous forest of Central India. Landsc Ecol Eng. 17(3), 387-399.

Raj, A., Jhariya, M.K., (2021b). Carbon storage, flux and mitigation potential of tropical Sal mixed deciduous forest ecosystem in Chhattisgarh, India. J Environ Manage. 293(1), 112829.

Rao, P., Barik, S.K., Pandey, H.N., Tripathi, R.S., (1990). Community composition and population structure in a sub-tropical broad leaved forest along a disturbance gradient. Vegetatio. 88, 151-162.

Raunkiaer, C., (1934). The Life Form of Plants and Statistical Plant Geography. Claredon Press ISBN 9978–40–943-2, Oxford.

Saha, S., Howe, H.F., (2006). Stature of juvenile trees in response to anthropogenic fires in a tropical deciduous forest of Central India. Conserv Soc. 4(4), 619-627.

Saha, S., Howe, H.F., (2003). Species composition and fire in a dry deciduous forest. Ecol. 84(12), 3118–3123.

Sannigrahi, S., Pilla, F., Basu, B., Basu, A.S., Zhang, Q., et al., (2020). Identification of conservation priority zones using spatially explicit valued ecosystem services: A case from the Indian Sundarbans. Integr. Environ. Assess. Manag. 16, 773-787.

Saxena, A.K., Singh, J.S., (1984). Tree population structure of central Himalayan forest associations and implications concerning their future composition. Vegetatio. 54, 61-69.

Schafer, J.L., Mack, M.C., (2010). Short-term effects of fire on soil and plant nutrients. Plant Soil. 334, 433-447.

Shankar, U., (2001). A case of high tree diversity in a sal (*Shorea robusta*) dominated lowland forest of eastern Himalaya: Floristic composition, regeneration and conservation. Curr Sci. 81(7), 776-786.

Singh, K.P., Misra, R., (1979). Structure and Functioning of Natural, Modified and Silvicultural Ecosystems of Eastern Uttar Pradesh. Final Technical Report (1975-1978). MAB research project, 1979, Banaras Hindu University, India.

Singh, L., Singh, J.S., (1991). Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. Ann Bot. 68, 263-273.

Teketay, D., (1997). Seedling population and regeneration of woody species in dry Afromontane forests of Ethiopia. For Ecol Manag. 98, 149-165.

Thonicke, K., Venevsky, S., Sitch, S., (2001). The role of fire disturbance for global vegetation dynamics: coupling fire into a dynamic global vegetation model. Glob Ecol Biogeogr. 10(6), 661-677.

Verma, S., Jayakumar, S., (2015). Post-fire regeneration dynamics of tree species in a tropical dry deciduous forest, Western Ghats, India. For Ecol Manag. 341, 75–82.

West, D.C., Shugart, Jr. H.H., Ranney, J.W., (1981). Population structure of forest cover of a large area. For Sci. 27, 701-710.

Zhang, C., Ju, W., Chen, J., Wang, X., Yang, L., et al., (2015). Disturbance-induced reduction of biomass carbon sinks of China’s forests in recent years. Environ Res Lett. 10, 114021.