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Effect of Forest Fire on Tree Species Diversity in the Tropical Dry Deciduous Forest of Nauradehi Wildlife Sanctuary, Madhya Pradesh, Central India

DINESH MALASIYA[1], TAPAS RAY[1], SATYAM VERMA[2], RADHA RAJPOOT[1], DEVANAND MAURYA[1], TINKU KUMAR[1], PRAMOD KUMAR KHARE[1], AND MOHAMMED LATIF KHAN[1*]

[1]Forest Ecology and Eco-Genomics Lab, Department of Botany, Dr. Hari Singh Gour Vishwavidyalaya (A Central University), Sagar - 470003, Madhya Pradesh, India

[2]School of Environmental and Forest Sciences, University of Washington, Seattle, Washington, USA

E-mail: dineshmalasiya@gmail.com, tapasray1892@gmail.com, satyamverma69@gmail.com, rajpootradha86@gmail.com, devanandpch@gmail.com, tinkurajput658@gmail.com, p.k.khare@gmail.com, khanml61@gmail.com

***Corresponding author**

ABSTRACT

A study was conducted to analyze the tree species composition and diversity in the Central Indian dry deciduous forest of Nauradehi Wildlife Sanctuary, Madhya Pradesh. The objective of the current study was to understand the impact of forest fire on the tree species diversity in the Central Indian tropical dry deciduous forest. Identification of fire-affected areas was done based on satellite remote sensing data of Landsat 5,7 and 8 satellite images, and different fire zones were classified in the study area into five fire frequency classes i.e., F1 to F4 and one unburned class i.e., F0. Five plots were laid within each fire class including the unburned class. A total of 3128 trees belonging to 49 plant species, 39 genera, and 14 families were recorded in all the fire frequency classes. *Tectona grandis* is the dominant tree species in the unburned, low fire, moderate fire, and in high fire zones where *Terminalia tomentosa* dominated in the severe burn areas. The results show that with the increased in fire frequency the tree species diversity, basal area and IVI increased from low, medium and high fire zones. However, these parameters decreased and again increased in the severe fire zones. The results of different indices indicate that tree diversity fluctuates with the increase in fire frequency.

Key words: Forest fire frequency; Tree Diversity; Importance Value Index; Basal area; Tropical dry deciduous forest; Central India.

INTRODUCTION

Forests are the source of livelihood to most rural communities especially in developing countries, satisfying local demands for fuel wood, construction material, herbs for medicinal uses including socioeconomic functions alongside their cycles, water table stabilization, water retention and filtration, prevention of bank erosion and also serving as a habitat for fauna (Dybala et al. 2019, Egbe et al. 2019, Krzeminska et al. 2019). Anthropogenic activities like tree logging for construction of houses and canoes, fuel wood collection and forest conservation to agricultural farmlands by locals have imposed a huge threat to the ecosystem (Egbe et al. 2021, Whelan 1995). Forest fires are the natural ecological disturbance agent creating a variety of effects on ecosystem composition, structure, and function at both the landscape and regional levels depending on type of fire, fire intensity, fire frequency, and fire behavior (Keane et al. 2002). Fire is an ecological and evolutionary factor maintaining ecosystem diversity and services and thus, it may be considered as the good or bad guy, some ecosystems are resilient to fire and usually need fire to maintain their diversity and ecosystem services (Fidelis 2020). Forest fires have been a part of the ecosystems for many thousands of years (Gadgil 1992), and it is an integral component of many temperate and tropical ecosystems (Bond and Keeley 2005). Forest fires are a major issue in the tropics during the dry season (Kodandapani et al. 2004), and tropical dry deciduous forests (Champion and Seth 1968) are especially fire-prone due to high total and dead fuel load, dry seedling and understory litter (Verma et al. 2015). Certain plant species have adapted to these fires by maintaining characteristics such as thick bark and altered timing of sprout germination for the post-fire reestablishment of forest ecosystem (Khan and Tripathi 1989). Fires in Indian context have been used

in the past as a management regime to stimulate germination of important timber species such as Teak (*Tectona grandis*) and Sal (*Shorea robusta*). However, our understanding on the impacts of dry season fire is limited (Hebbalalu et al. 2016). Forest fire has a different level of effects on the recovery of tree species in the dry deciduous forest of Central India (Ray et al. 2021). Annual, low-intensity fires in the forest of central India reduce diversity of tree seedling and shift juvenile composition by favoring proliferation of root-sporters (Saha 2002). The stress caused by the fire in central Indian dry tropical forest results into reduction in area and losing the species and becoming least diverse (Jhariya et al. 2012) . These fires affect the species diversity, nutrient dynamics, regeneration potential, as well as emitting greenhouse gases that have negative consequences on the global climate (Amiro 2001, Ray et al. 2019). The objective of present study was to understand the impact of forest fire on the tree diversity in the Central Indian dry deciduous forest of Nauradehi Wildlife Sanctuary Madhya Pradesh.

MATERIAL AND METHODS

Study area

This study was carried out in tropical dry deciduous forest in Nauradehi Wildlife Sanctuary (NWS) in Madhya Pradesh state of India during the year 2018-19. The study area lies in Sagar, Damoh and Narsinghpur districts of Madhya Pradesh state (Fig.1). It is located between 23° 5' to 23°43' North and 79° 5' to 79° 25' East. The entire area of NWS is located in the Vindhyan range situated at a height of 400 to 600 m from the sea level. The average annual rainfall in the area varies from 732-1691 mm, with the rainy season from early July to mid-September. Average annual temperature ranges from 19.5 to 31.18°C, with the lowest temperature in the month of December and January and highest occurring during the month of May and June.

Fire mapping

Toposheets (F44 B2 – B12) were collected from the survey of India in 1: 50000 scale. Burned area maps for 1997 to 2017 were prepared using Landsat images downloaded from USGS website. Fire location data was downloaded from NASA FIRMS from January 2002 to December 2017 and used to compute the number of fires and their proximity to the road, footpath and settlements. All the images were geometrically corrected based on survey of India topographic maps using ERDAS imagine 11.0. Forest fire frequency maps were prepared using Landsat 5, 7 and 8 images from 1997 to 2017. Geometrically corrected satellite images of NWS were classified into unburned (F0 unburned zone), and burned, i.e., from F1 to F4 fire zones were F0 fire class indicates the unburned zone, F1- low fire zone, F2-Medium fire zone or moderately burn area, F3-Highly burn area or high fire zone and F4 fire class indicates the severely burn area or very high fire zone.

Field data collection

Field vegetation data in the NWS were collected from 25 plots (0.5 ha each). 125 X 40 m^2 plots were randomly established in each fire frequency class (F1 – F4) including the unburned class (F0). The floristic data were collected during the period of September and October 2018. Global Positioning System (GPS) was used to distinguish the field sample plots. All individual trees with diameter at breast height (dbh) ≥30 cm were counted and identified within each plot. The dbh (at 1.3 m above the ground) of the species were measured using a diameter tape. In the case of buttresses, the measurement was made above buttresses, following standard forestry techniques. Trees were identified using scientific identification keys in the Flora of Madhya Pradesh and available literature, herbarium in the Department of Botany, Dr. Harisingh Gour Vishwavidyalaya Sagar, Madhya Pradesh.

Data analysis

Ecological measurements

The floristic data were quantitatively analyzed for basal area, relative density, relative frequency and relative dominance. Importance Value Index (IVI) for the tree species was determined as the sum of the relative density, relative frequency and relative dominance.

Basal area (m^2) = $\pi(1/2\ dbh)^2$

Relative density = (Total number of individuals of species / Total number of individuals of all species) ×100

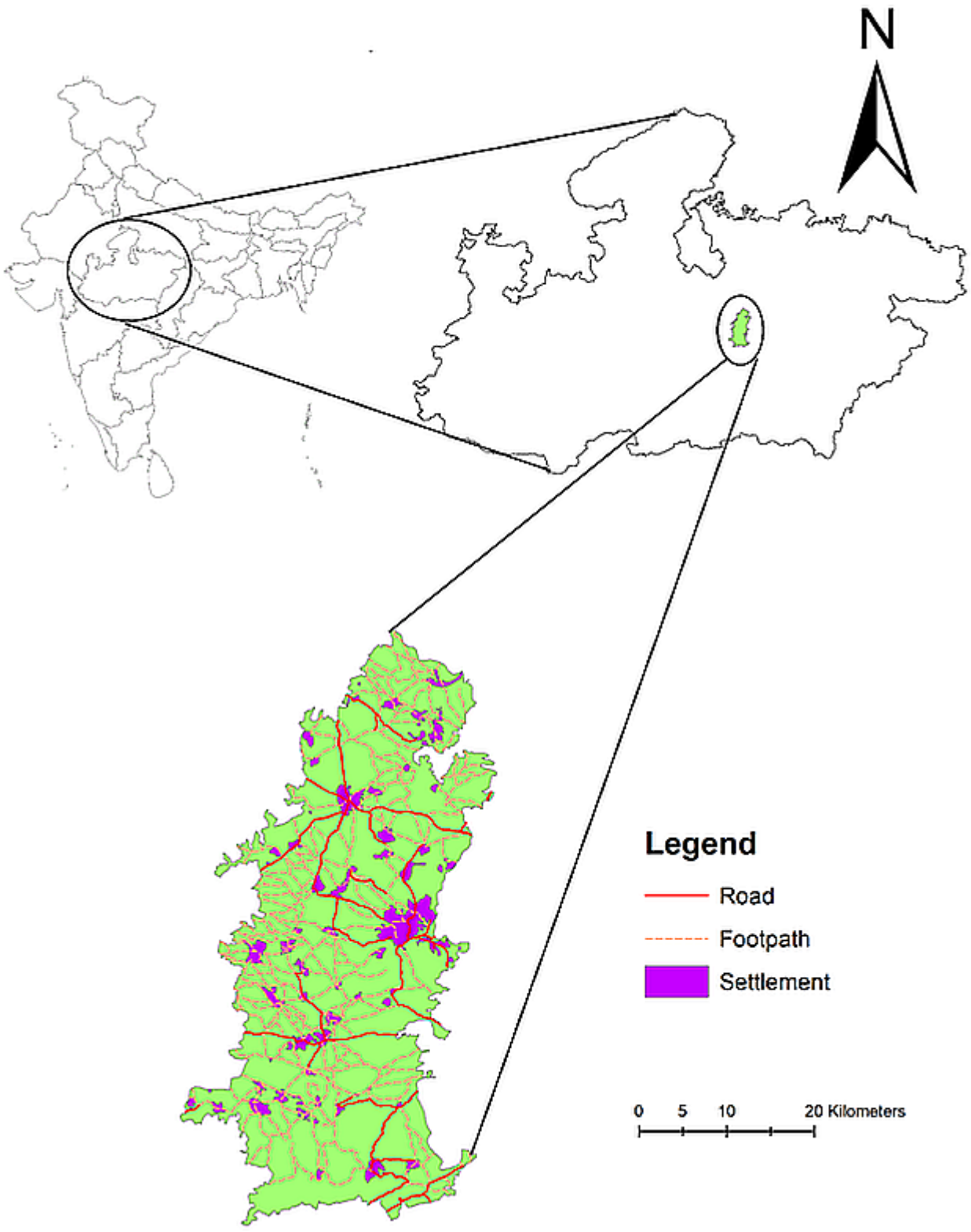

Figure 1. Location map of the study area

Relative frequency = (Total number of quadrats in which species occurred/ Total number of quadrats studies) ×100

Relative dominance = (Total basal area of species/ Total basal area of all species) ×100

Importance Value Index (IVI) = " relative density + relative frequency + relative dominance

Diversity indices

Shannon-Wiener Index was used to determine the tree diversity, calculated as follows

$H^{`} = \sum(ni/N) \ln(ni/N)$

Where H = Index of species diversity, pi = Proportion of total sample belonging to i-th species, n = number of species, ln = natural log.

Dominance was calculated by Simpson's index

$D = 1-\sum n(n-1)/N(N-1)$

Where n is the number of individuals of one species, N = the total number of all individuals (Shannon and Weiner, 1963; Simpson, 1949).

RESULTS

Forest structure and species composition

A total of 3128 individual trees were enumerated in the floristic survey. These trees belong to 49 species, 39 genera and 21 plant families. The highest number of tree species was recorded in F4 fire class with 32 species from 30 genera and 19 families and the least number of species was recorded in F3 fire class having 23 species from 20 genera and 14 families. In F0 un-burnt class, a total of 26 species from 24 genera and 16 families were recorded. In F1 fire class, a total of 28 tree species from 21 genera and 16 plant families were recorded, while in F2 fire class, a total of 31 tree species from 29 genera and 17 plant families were recorded. The Shannon – Wiener diversity differed across the different sites, with the highest diversity recorded in F4 fire class and the least in F1 fire class, while the Simpson's dominance index recorded highest in F3 fire class and minimum in F4 fire class (Table 1).

Abundance data showed that the *Tectona grandis* (Verbenaceae) dominated in all fire classes followed by *Terminalia tomentosa* (Combretaceae), *Lagerstroemia parviflora* (Lythraceae) and *Anogeissus latifolia* (Combretaceae). *Tectona grandis* is the dominant tree species in the fire classes F1, F2, F3 and F0 where in F4 fire class dominance showed by *Terminalia tomentosa* (Table 2).

Basal area

In the F0 fire class, tree basal area ranged from 8.55 to 0.024 m^2ha^{-1}, the top five tree species with the largest basal area including *Tectona grandis* (8.55 m^2ha^{-1}), *Butea monosperma* (8.00 m^2ha^{-1}), *Anogeissus latifolia* (6.80 m^2ha^{-1}), *Terminalia tomentosa* (5.88 m^2ha^{-1}) and *Aegle marmelos* (4.19 m^2ha^{-1}). In F1 fire class, tree basal area ranged from 9.50 to 0.041 m^2ha^{-1}. In this class *Tectona grandis* (9.50 m^2ha^{-1}), *Lagerstroemia parviflora* (8.55 m^2ha^{-1}), *Terminalia tomentosa* (5.02 m^2ha^{-1}), *Anogeissus latifolia* (3.53 m^2ha^{-1}), and *Wrightia tinctoria* (2.12 m^2ha^{-1}) are the top five tree species in terms of basal area. In F2 fire class, tree basal area ranges from 7.60 to 0.019 $m^2ha^{-1}$and the top five tree species with largest basal area in this class are *Tectona grandis* (7.60 m^2ha^{-1}), *Terminalia tomentosa* (5.25 m^2ha^{-1}), *Aegle marmelos* (4.61 m^2ha^{-1}), *Chloroxylon swietenia*

Table 1. Some ecological parameters of different burned and unburned classes in NWS

Parameters	F0	F1	F2	F3	F4
Number of species	26	28	31	23	32
Number of genera	24	21	29	20	30
Number of families	16	16	17	14	19
Shannon-Wiener Index	2.54253	2.13928	2.78021	2.43841	2.8513
Simpson Index	0.19334	0.22724	0.161858	0.237146	0.107366

Table 2. Top ten abundant tree species in different burned and unburned classes of NWS

Species Name	Family	F0	F1	F2	F3	F4
Tectona grandis	Verbenaceae	149	173	156	161	54
Terminalia tomentosa	Combretaceae	61	68	59	53	103
Lagerstroemia parviflora	Lythraceae	39	171	36	37	54
Anogeissus latifolia	Combretaceae	100	45	51	50	58
Aegle marmelos	Rutaceae	59	23	49	9	46
Diospyros melanoxylon	Ebenaceae	12	39	35	36	29
Chloroxylon swietenia	Rutaceae	4	3	55	21	51
Miliusa tomentosa	Annonaceae	—	1	26	66	15
Lannea coromandelica	Anacardiaceae	19	18	20	14	29
Wrightia tinctoria	Apocynaceae	25	28	3	23	3

(4.21 m^2ha^{-1}), and *Anogeissus latifolia* (3.86 m^2ha^{-1}). While in F3 fire class, tree basal area ranges from 7.34 to 0.04 m^2ha^{-1} and the top five tree species with highest basal area are *Tectona grandis* (7.34 m^2ha^{-1}), *Terminalia tomentosa* (5.70 m^2ha^{-1}), *Anogeissus latifolia* (3.55 m^2ha^{-1}), *Miliusa tomentosa* (2.45 m^2ha^{-1}) and *Chloroxylon swietenia* (2.43 m^2ha^{-1}). Where in F4 fire class, tree basal area ranges from 8.23 to 0.03 m^2ha^{-1} and the top five tree species with highest basal area in this class are *Terminalia tomentosa* (8.23 m^2ha^{-1}), *Chloroxylon swietenia* (5.39 m^2ha^{-1}), *Dalbergia latifolia* (4.20 m^2ha^{-1}), *Anogeissus latifolia* (3.43 m^2ha^{-1}) and *Lannea coromandelica* (3.34 m^2ha^{-1}). In all fire classes the highest basal area of any tree species was reported in F1 fire class in *Tectona grandis* (9.50 m^2ha^{-1}) and the lowest basal area of any species is of *Gymnosporia spinosa* (0.019 m^2ha^{-1}) in F2 fire class (Table 3).

Importance Value Index (IVI)

In the different fire classes, trees in different plots differed in terms of IVI. In F0 unburned class, IVI ranges from 2.24 to 31.18, the top five tree species with the highest IVI are *Tectona grandis* (31.18), *Flacourtia indica* (23.69), *Anogeissus latifolia* (22.54), *Diospyros melanoxylon* (19.77), and *Butea monosperma* (17.95). Whereas the *Gymnosporia spinosa* shows the minimum value (2.24) in terms of IVI. In F1 fire class IVI ranges from 3.09 to 37.81, the top five tree species with the highest IVI in this class are *Tectona grandis* (37.81), *Lagerstroemia parviflora* (37.32), *Albizia procera* (24.28), *Terminalia tomentosa* (21.59), and *Anogeissus latifolia* (16.41), where the minimum IVI express by the *Gymnosporia spinosa* (3.09). In F2 fire class IVI ranges from 2.40 to 32.16, the top five tree species in terms of IVI are *Tectona grandis* (32.16), *Terminalia tomentosa* (19.68), *Aegle marmelos* (18.44), *Anogeissus latifolia* (17.83) and *Chloroxylon swietenia* (15.83), where the *Gymnosporia spinosa* shows the minimum value (2.40). In F3 fire class IVI ranged from 2.11 to 39.47, the top five tree species with highest IVI are *Tectona grandis* (39.47), *Madhuka indica* (23.92), *Terminalia tomentosa* (20.87), *Anogeissus latifoloa* (18.66) and *Miliusa tomentosa* (8.50), whereas the *Terminalia arjuna* shows the minimum (2.11). In F4 fire class IVI ranged from 2.45 to 26.28, the top five tree species with highest IVI are *Terminalia tomentosa* (26.28), *Chloroxylon swietenia* (18.98), *Anogeissus latifolia* (17.97), *Dalbergia paniculate* (17.07) and *Tectona grandis* (16.38) where *Schrebera swietenioides* shows the minimum IVI (2.45) (Table 3).

DISCUSSION

In recent decades, tropical forest fires occur more frequently and at large scale than they used to be earlier. Anthropogenic fires in dry forests of India are a regular event (Hebbalalu et al. 2016). These forests have experienced the fire for thousands of years (Gadgil 1992). The main cause of anthropogenic fires is poaching, antler collection, grazing, tourism, estates and settlements in and around the reserves (Verma et al. 2015). Results showed that different indices of tree species in the

Table 3. Basal area and Importance Value Index of tree species in burned and unburned classes of NWS

Species Name	F0		F1		F2		F3		F4	
	BA	IVI	BA	IVI	BA	IVI	BA	IVI	BA	IVI
Acacia catechu (L. f.) Willd.	-	-	0.05	3.42	0.03	3.05	-	-	-	-
Aegle marmelos (L.) Correa.	4.20	14.9	1.58	10.9	4.62	18.4	0.61	9.43	2.95	15.09
Albizia lebbeck (L.) Benth.	0.30	3.98	0.06	3.66	0.07	5.14	0.28	8.3	0.19	10.25
Albizia odoroatissima (L. f.) Benth.	0.10	3.76	-	-	-	-	-	-	-	-
Albizia procera (Roxb.) Benth.	-	-	0.67	24.3	-	-	-	-	-	-
Anogeissus latifolia (Roxb. ex DC.) Wall.ex Bedd.	6.80	22.5	3.53	16.4	3.87	17.8	3.55	18.7	3.44	17.97
Anogeissus pendula Edgew.	0.07	2.67	-	-	-	-	-	-	-	-
Bauhinia recemosa Lamk.	-	-	-	-	0.45	6.59	-	-	0.31	4.354
Bauhinia retusa Roxb.	-	-	0.13	5.82	-	-	-	-	-	-
Bauhinia variegate L.	0.47	2.66	-	-	-	-	-	-	-	-
Bombax ceiba L.	-	-	0.55	12.8	-	-	-	-	0.05	3.629
Bridelia retusa (L.) A. Juss	-	-	0.05	3.61	0.63	8.09	-	-	0.09	3.63
Buchanania lanzan Spreng.	-	-	0.08	4.6	1.29	10.1	0.7	11.7	1.1	10.41
Butea monosperma (Lam.) Taub.	8.00	18	-	-	-	-	-	-	-	-
Careya arborea Roxb.	-	-	-	-	-	-	-	-	0.05	3.547
Casearia elliptica Willd.	0.80	17.2	0.1	3.2	-	-	-	-	-	-
Cassia fistula L.	0.16	9.05	0.29	9.62	0.24	7.87	0.3	7.83	0.17	6.848
Chloroxylon swietenia DC.	0.5	11.1	0.37	7.91	4.22	15.9	2.44	15.4	5.4	18.99
Dalbergia sissoo Roxb.	-	-	-	-	-	-	0.26	5.87	0.98	0.01
Dalbergia latifolia Roxb.	-	-	-	-	-	-	-	-	4.21	6.599
Dalbergia paniculate Roxb.	-	-	0.65	9.38	0.53	7.36	0.42	4.82	-	17.08
Diospyros melanoxylon Roxb.	0.6	19.8	1.5	15.7	2.08	14.6	2.25	15.7	1.32	12.6
Elaeodendron glaucum (Rottb.) Pers.	-	-	-	-	0.1	5.33	-	-	0.07	2.99
Emblica officinalis Gaertn.	0.3	9.43	0.19	6.78	0.74	11	2.36	15.9	0.9	10.04
Flacourtia indica (Burm.f.) Merr.	0.8	23.7	0.06	3.78	0.95	9.22	1.19	9.76	0.51	7.479
Gardenia latifolia Ait.	3.3	10.8	0.28	5.28	0.28	5.63	-	-	0.29	4.642
Garuga pinnata Roxb.	0.3	7.67	-	-	-	-	-	-	-	-
Gymnosporia spinosa (Blanco) Merr. & Rolfe	0.02	2.24	0.07	3.09	0.02	2.41	-	-	-	-
Holarrhena antidysentrica (L,) Wall.ex A. DC.	-	-	-	-	-	-	-	-	0.38	6.115
Ixora parviflora Vahl.	-	-	-	-	-	-	0.05	4.54	-	-
Kydia calycina Roxb.	-	-	-	-	0.06	2.99	-	-	-	-
Lagerstroemia parviflora Roxb.	1.5	14.7	8.55	37.3	1.93	11.9	2.01	17.1	1.63	15.97
Lannea coromandelica (Houtt.) Merr.	2.7	12.1	1.88	13	1.88	12.8	2.03	15.4	3.34	15.83
Madhuca indica Gmel.	1.7	7.99	0.29	6.88	2.85	11.8	1.85	23.9	1.79	13.39
Miliusa tomentosa (Roxb.) Sinclair	-	-	0.06	3.9	1.53	10.7	2.46	18.5	0.84	10.8
Mitragyna parvifolia (Roxb.) Korth.	3.7	12.5	1.42	8.87	0.36	6.92	-	-	0.34	5.895
Nyctenthus arbor-tristis L.	-	-	-	-	-	-	-	-	0.04	3.159
Pterocarpus marsupium Roxb.	1	5.04	-	-	-	-	0.65	12	0.17	9.149
Schleichera oleosa (Lour.) Oken.	-	-	-	-	1.35	8.02	0.72	7.52	0.46	8.283
Schrebera swietenioides Roxb.	-	-	-	-	0.34	4.54	-	-	0.05	2.457
Semecarpus anacardium L. f.	-	-	-	-	0.15	3.82	-	-	-	-
Soymida febrifuga (Roxb.) A. Juss.	0.2	6.03	-	-	-	-	-	-	-	-
Tectona grandis L. f.	8.6	31.2	9.5	37.8	7.6	32.2	7.35	39.5	2.11	16.39
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	-	-	-	-	—-	-	0.31	2.11	-	-
Terminalia bellirica (Gaertn.) Roxb.	-	-	-	-	1.5	11.3	0.08	5.31	0.04	3.272
Terminalia tomentosa (Roxb. ex DC.) Wight & Arn.	5.9	17.3	5.03	21.6	5.26	19.7	5.71	20.9	8.23	26.28
Wrightia tinctoria R. Br.	0.6	9.04	2.12	12	0.12	3.67	0.55	10	0.08	2.821
Ziziphus jujuba Lamk.	-	-	0.04	3.19	0.11	6.79	-	-	-	-
Ziziphus xylopyrus (Retz.) Willd.	0.5	4.66	0.46	5.18	0.23	4.34	-	-	0.28	4.058
Total	**53**	**300**	**39.6**	**300**	**45.4**	**300**	**38.1**	**300**	**41.8**	**300**

different fire classes in tropical dry deciduous forest differed largely. The maximum number of tree species is found in the moderately burn class (F2) and severely burn class (F4), whereas the least number of tree species is reported in highly burn class (F3) followed by unburned (F0) and low fire class (F1). The Shannon-wiener diversity index value is higher in severely burn fire class F4 and Simpsons dominance index showed the highest value in lowest burning fire class F2. Our results are in conformity with the studies of Ray et al. (2021) on forest fires in Central India and argued that fire decreases the tree diversity. The results of the basal area show that with the increase of fire frequencies there is an increase in the diversity and basal area, then it decreases in medium and high fire zone but it increases in the very high fire zone where the IVI shows the same parameters. Hence the results show that as the fire frequency increased the tree species diversity, basal area and IVI values increased in low fire zones, and then decreased in medium fire zones and in high fire zones and then again increased in the severe burning zones. Sagar and Singh (2006) also reported that the species diversity increased linearly with increase in total basal area. The results of different diversity parameters showed that tree diversity fluctuates with increasing the fire intensity in the different fire classes.

CONCLUSION

This study estimates the tree species composition and diversity in the fire affected areas in the Central Indian dry deciduous forest of Nauradehi Wildlife Sanctuary. The tree species diversity increased in F1 fire zone and decreased in F2 and F3 fire zone and again increased in F4 fire zone. It indicates that the tree diversity fluctuates with the increase in the fire frequency in different fire affected areas.

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Authors' contributions: DM and MLK designed and drafted the manuscript. DM, TR, RR, Dev M, TK and SV did the fieldwork and data collection. MLK and PKK contribute to revised manuscript.

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