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Post-fire regeneration dynamics of tree species in a tropical dry deciduous forest, Western Ghats, India

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ABSTRACT

This study was aimed to understand the effect of repeated fire on tropical dry deciduous forest in Mudumalai Tiger Reserve (MTR), Western Ghats. Tropical dry deciduous forests are prone to forest fire owing to high fuel load and long dry season. Fire frequency map of the study area was prepared for 15 years from 1999 to 2013 using annual burn maps. Study area was stratified as B1 to B6 (one to six times burned) and compared to control (B0 – unburned during 1999–2013). Three plots were randomly laid in each stratum and seedlings; saplings and trees present in each plot were recorded. Species diversity indices showed increase in dominance and decrease in diversity with increasing fire frequency. Results showed that overall stem density (>1 cm DBH) ranged from 576 (SD 112.69) (B1) to 236 (SD 20) individual ha^{-1} (B6). The basal area ranged from 36.8 (SD 2.19) m^2 ha^{-1} (B0) to 12.12 (SD 2.69) m^2 ha^{-1} (B5). Fire promoted seedling density from B0 to B2 and after that it started decreasing whereas sapling density was poor in all classes and recorded least in B6. Stem density of trees did not vary much up to B3 and started decreasing after that. Number of species decreased linearly with increasing fire frequency. In the analysis of dominant species, *Tectona grandis* showed a very significant mean difference in seedling, sapling and tree population whereas *Terminalia cranulata* did not show significant difference in mean densities of seedling, sapling or trees. It is found that fire with long interval can promote seedlings density but species diversity decreases with increasing fire frequency.

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1. Introduction

There is a long-standing interest in studying post-fire dynamics of plant communities (Hodgkins, 1958; Ahlgren, 1960; Swan, 1970). The important role played by fire in shaping global vegetation has been recognized (Bond and Keeley, 2005; Turner et al., 1997; Archibald et al., 2005; Tessler et al., 2014; Nyamai et al., 2014). Post-fire dynamics of plant communities depends on several factors. Plants can be adapted to a particular fire regime, which includes fire frequency, fire intensity and pattern of fuel consumption or can be lost when that regime changes (Keeley et al., 2011; Christopoulou et al., 2014). Fire frequency is one of the most important factors affecting regeneration, dominance and diversity of woody species. Increased short-interval fires may bring a change in the ecosystem and it does not allow recovering to its pre-disturbance level (Tessler et al., 2014; Díaz-Delgado et al., 2002). On the other hand, decreasing fire frequency may also affect ecosystem structure.

Forest fires affect forest regeneration directly by killing stem tissues of seedlings and saplings, heating the soil sufficiently to kill seeds and roots near the soil surface (Kennard et al., 2002) and also indirectly influence regeneration patterns by killing reproductive trees with thin bark (Balch et al., 2013; Pinard et al., 1999). Immediate effect of fire depends on its intensity. Varying intensities of fires are well-known to affect soil properties and below-ground processes, plant species demography and plant community structure but long-term effects depend also on fire frequency and seasonality (Gill, 1975). Short-interval fire frequency can alter stand structure by greatly reducing the density of saplings and also by moderate reductions in the density of midstory trees (Hutchinson et al., 2012). The fire frequency limits to woody plant regeneration are unknown for most tropical species (Balch et al., 2013).

The majority of fires occur in India are in tropical dry deciduous forests, which account for >40% of all forest in India (Hiremath and Sundaram, 2005; Wikramanayake et al., 1998; Rodgers et al., 2002; Krishna and Reddy, 2012). In Western Ghats, fire return interval was reduced from 10 years (1909–1921) to 3.3 year (1989–2002) due to land-cover transformations in the surrounding landscape and forest fragmentation (Kodandapani et al., 2004). These

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frequent fires could lead to an increase in dominance of few fire tolerant species and a decrease in diversity in this forest even on short time scales.

Knowledge on the causes of fires, about their extent, their effect on forest ecosystems, and their link to the goods and services that people derive from forests is scant in India (Bahuguna and Singh, 2002; Krishna and Reddy, 2012). There are very few studies in India on post fire ecological dynamics of trees in tropical deciduous forest (Saha and Howe, 2003; Kodandapani et al., 2008, 2009). Impact of fire frequencies on regeneration of woody species has also not been much studied in India. Hence, the main purpose of this study is to examine fire effects on species diversity, stand characteristics (density, basal area) and compare regeneration of tree species across burns.

2. Materials and methods

2.1. Study site

This study was conducted in MTR. MTR is located in the state of Tamilnadu and is a part of the Nilgiri Biosphere Reserve (NBR) (Fig. 1). Spread over an area of 321 Km^2 with an average altitude of 1000 m and a rainfall gradient of 50–200 cm per annum from east to west has resulted in different forest types. Average maximum temperature in MTR varied from 25.4 ± 0.5 °C in August to 31.0 ± 0.3 °C in April, and average minimum temperature from 13.9 ± 0.5 °C in January to 18.1 ± 0.6 °C in April (Dattaraja et al., 2013).

Based on the climate of the area, there are three distinct seasons recognized. January–May is a dry summer season; southwest monsoon brings rains to a large part of the sanctuary during June–September while the retreating monsoon (winter or northeast monsoon) also brings rain to the eastern part during October–November (Suresh et al., 2010).

The vegetation types found in MTR are classified into southern tropical dry thorn forest, southern tropical dry deciduous forest, southern tropical moist deciduous forest, southern tropical semi-evergreen forest, moist bamboo brakes and riparian forest (Champion and Seth, 1968). Most of the area of reserve is covered by tropical dry deciduous forest.

There are 21 tiny hamlets located within the park. People living in these settlements include Mountain Chetties and tribes. Mountain Chetties main occupation is to perform agricultural practices in swamp vayal habitats and rear cattle. Few tribes work in agriculture fields of Chetties and they also collect tuber, honey, and perform fishing operations in the reserve for their sustenance. These people work as fire watchers, tourist guides and anti-poaching watchers.

2.2. Fire frequency mapping

Fire frequency maps were prepared by using fire maps of each year from 1999 to 2013. For the period between 2001 and 2012,

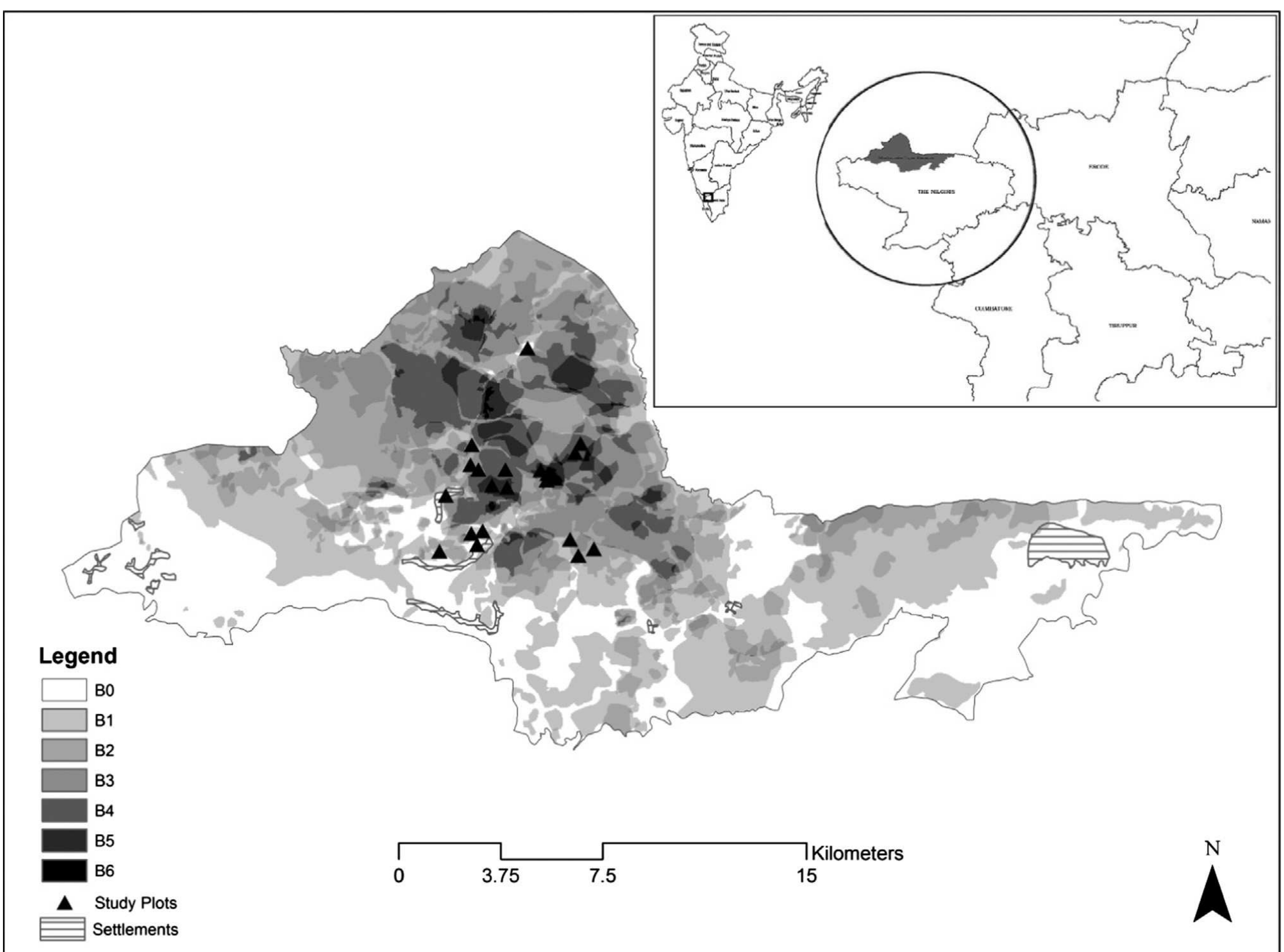

Fig. 1. Study area location, study plots and forest fire frequency map for 15 years (1999–2013).

fire maps available in the Tamilnadu forest department were obtained. Fire maps for the year 1999, 2000 and 2013 were prepared using satellite images of Landsat 5 Thematic Mapper acquired on 02, February 1999 and 07, April 1999, Landsat 7 ETM+ acquired on 28 January 2000, 01 April 2000, 17 April 2000, 03 May 2000, 31 January 2013 and Landsat 8 OLI-TIRS acquired on 13 April 2013. Satellite images for the study area were extracted, geo-corrected and classified into burned and unburned areas using supervised classification. We used ERDAS Imagine 2011 to analyze the satellite images. All the raster data were converted to vector form and assigned a unique identity value for burned and unburned areas. After assigning the unique value all the data were converted to raster again. These raster data were combined to obtain a single fire frequency composite map using spatial analyst in ArcGIS 10.

2.3. Field sampling

The study was carried out only in the deciduous forest in MTR. For each class (Control (B0) and fire frequency, B1–B6) three 0.1 ha ($n = 21$) square plots were laid randomly. All woody stems $\geqslant$1 cm gbh inside the plots were enumerated.

For seedlings, four 5 $\times$ 5 meter subplots were laid on four corners of the 0.1 hectare plot. Plot size was constant across all samples. Vegetation data was collected in the month of November and December 2013. All the trees were identified using checklists and flora of Mudumalai (Sharma et al., 1979). Measurements such as collar girth (CG), girth at breast height (GBH) and height (H) were recorded for all the woody plants for both living and dead. For seedlings only number was counted. Seedling was defined as height less than 50 cm and collar girth less than 1 cm whereas sapling was defined as height 50–150 cm and collar girth 1 to $\leqslant$10 cm. Trees were defined as >10 cm GBH.

2.4. Data analysis

The total number of species among plots within each fire frequency class and species in different growth forms (seedlings, saplings and trees) were calculated. For each growth form stem density and basal area data were calculated and subjected to

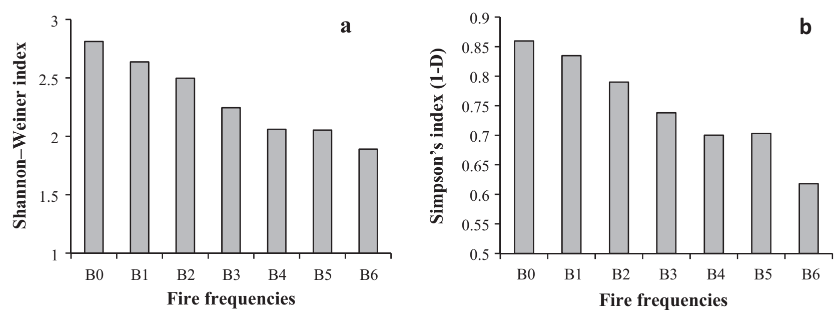

Fig. 2. Shannon–Weiner index (a) and Simpson's dominance index (b) for the stems present in different Burn frequencies and control class.

Table 1
Description of site characteristics; fire frequency, fire return interval (FRI), year of burn, area burned and tree stem density.

Class code	Fire frequency class	Year of occurrence	No. of plots	FRI (year)	Area (dry deciduous forest) (%)	Basal area (SD) ($m^2\ ha^{-1}$)	Tree density (SD) (ha^{-1})
B0	Unburned (control)	Never burned in past 15 year	3	0	11.76	36.81 (2.19)	407 (41.63)
B1	Burned once	2009	3	15	24.21	29.70 (7.21)	463 (32.15)
B2	Burned twice	2002, 2010	3	7.5	24.99	36.53 (10.09)	430 (60.00)
B3	Thrice burned	2002, 2007, 2012	3	5	21.40	25.48 (0.90)	427 (25.17)
B4	Four time burned	2000, 2002, 2007, 2012	3	3.75	13.38	18.04 (8.59)	387 (85.05)
B5	Five time burned	2000, 2002, 2007, 2010, 2012	3	3	3.86	12.12 (2.69)	280 (34.64)
B6	Six time burned	2000, 2002, 2004, 2007, 2010, 2012	3	2.5	0.40	14.20 (2.35)	210 (10.00)

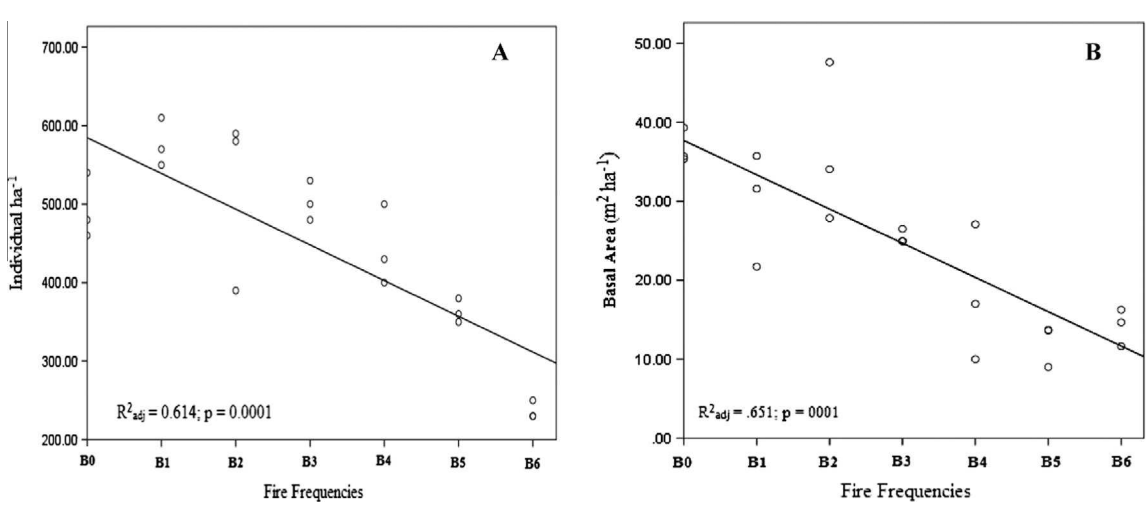

Fig. 3. Relationships of forest fire frequencies with (A). Stem density (DBH > 1 cm) and (B) basal area.

one-way ANOVA to examine significant differences in these variables among fire frequency classes. Means that exhibited differences were compared using Tukey's test with a 5% probability significance threshold. Diversity of all living stems was estimated by using the Shannon–Wiener index (H') and Simpson's dominance index (1-D). GBH was converted to DBH. Regression analysis was performed to examine the relationship of stem density and basal area for the trees dbh >1 cm and total number of species regenerating with fire frequencies. Stem size distribution was also analyzed as the total count per size class within fire frequency class to see stand structure. The effect of fire frequency on regeneration of some dominant species of MTR was analyzed by examining the density of seedlings and saplings. This was also repeated for trees. Friedman's two-way analysis of variance by rank was conducted to see the significant differences in distribution of seedlings, sapling and tree densities of dominant species. Fire return interval was calculated for MTR using fire frequencies. All statistical analyses were performed using IBM SPSS Statistics 20. The significance threshold was set at 0.05.

3. Results

3.1. Species diversity and stand structure

We found 45 species representing 38 genera and 28 families in six fire frequency classes and control plots of which only five species; *Anogeissus latifolia*, *Cassia fistula*, *Terminalia cranulata*, *Tectona grandis*, *Phyllanthus emblica* were present in the all classes and 23 species were present in only one class. The species present in control and burned classes were 24 (B0), 20 (B1), 23 (B2), 20 (B3), 13 (B4), 12 (B5), 10 (B6). Of the 45 species, seedlings and saplings were represented by 30 species and 17 species respectively and 15 species were present only in tree stage. Shannon–Weiner (H') and Simpson dominance index (1-D) showed linier decline in species diversity and incline in dominance with increasing fire frequency (Fig. 2).

The stem density (DBH > 1 cm) in the fire classes ranged from 236 (SD 20.82) (B6) to 576 (SD 112.69) (B1) individual ha^{-1}. In control plot (B0) stem density (DBH > 1 cm) was 493 (SD 41.63). The

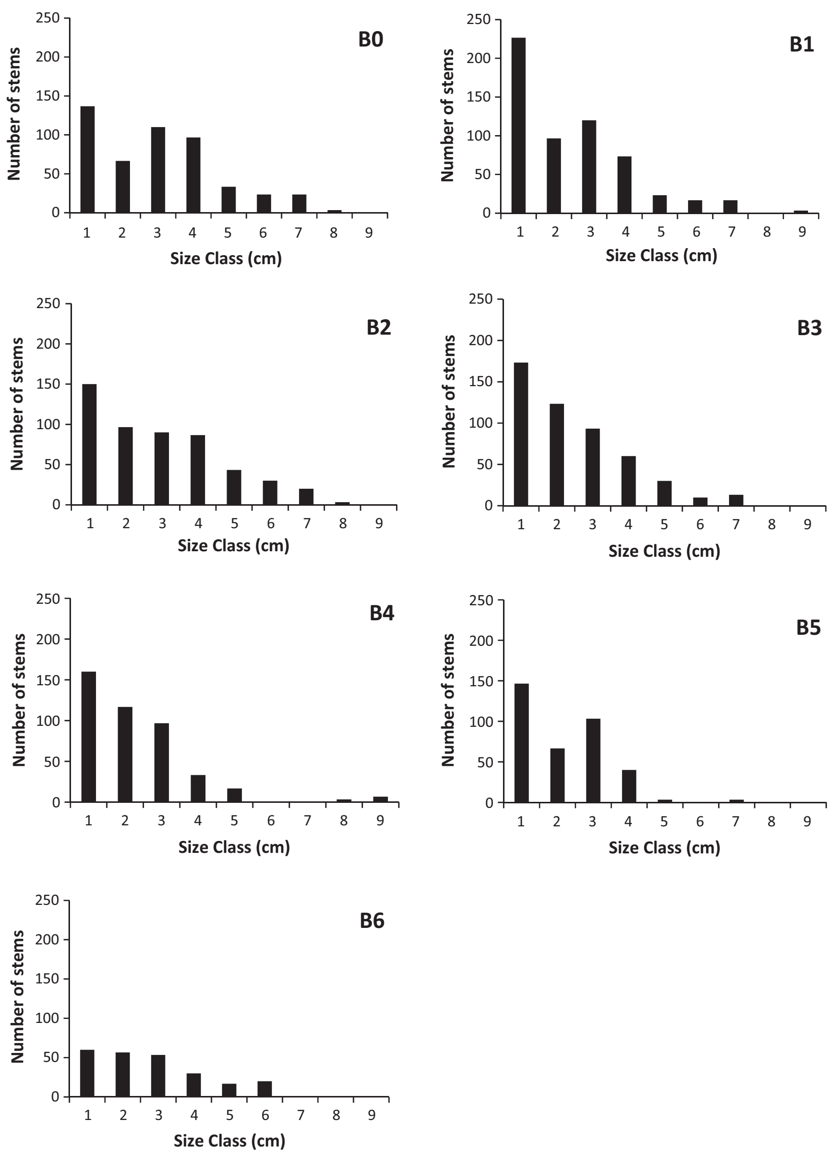

Fig. 4. Stem diameter distribution in unburned and burned classes. The minimum diameter class is 1–10 cm and increased by 10 cm interval.

basal area ranged from 36.53 (SD 10.09) $m^2 ha^{-1}$ in B2 to 12.12 (SD 2.69) m^2 ha^{-1} in five times burned (B5) compared to 36.81 (SD 2.19) m^2 ha^{-1} in control (Table 1). The Basal area showed significant mean differences among the fire frequency classes. While comparing with control plots, only B4 ($p = 0.022$), B5 ($p = 0.002$) and B6 ($p = 0.005$) showed significant mean difference but were not significantly different from one another. Regression analysis revealed that the density of trees and basal area linearly declined across the fire gradients (Fig. 3A and B).

Stem diameter distribution in the smaller stem size stage showed significant differences between control and burned plots (B1–B6). Stems with 1–10 and 10–20 cm DBH were higher in all burned classes compared to control (B0) except in B6. In the 20–30 cm DBH class, the number of stems in B2, B3, B4 and B5 were similar. In the larger size class (>50 cm), the number of stems in control, B1, B2 and B3 were similar (Fig. 4).

3.2. Regeneration

Significant differences in the mean stem density of seedlings, trees and total population were observed among fire frequencies. While comparing seedling and tree population density in burn classes with control plot, B5 and B6 showed significant mean differences. Seedling density showed an initial rapid increase in B1 and B2 plots, followed by a steep decrease (Fig. 5A). Whereas, tree population did not change much in B1, B2 and B3, but after that with increasing fire frequency, it started decreasing (Fig. 5C). Saplings did not show substantial variation among the fire frequencies. Sapling density was very low in all burn frequencies. B1 and B2 had relatively higher sapling densities compared to B0, which did not show much difference until B5. But, B6 had least sapling density (Fig. 5B). Forest area with highest fire frequencies had significantly lower seedling, saplings and tree densities. Total number of seedling species in each fire frequency class had a strong negative linear relationship ($R^2 = 0.966$, $p = 0.001$) with fire frequencies (Fig. 5D).

Regeneration pattern of three dominant species; *A. latifolia*, *T. cranulata*, *T. grandis*, which represent 62% of the tree population, was also studied. Friedman's two-way analysis of variance by rank suggested that distributions of seedling density of *A. latifolia*, *T. cranulata*, *T. grandis* were significantly different ($p = 0.011$) among fire frequency classes but sapling ($p = 0.502$) and tree density ($p = 0.095$) were not significantly different. *T. grandis* showed a very significant mean difference in seedling, sapling and tree densities among fire frequency classes. Stem density of *T. grandis* went up in B1 then start decreasing. Highest stem density of *T. grandis* was found in B1, which received fire once in 15 years (FRI = 15).

A. latifolia showed significant difference in mean densities of seedling and tree but sapling was not significantly different among the fire groups. *T. cranulata* did not show significant difference in mean densities of seedling, sapling and tree among fire frequency classes. Seedling density of *T. cranulata* was less only in B5 and B6 compared to control (Fig. 6).

4. Discussion

This analysis of forest fires in the MTR demonstrates the significance of forest fires as frequent disturbance events. In the study area, the fire season lasts from January to May but most of these

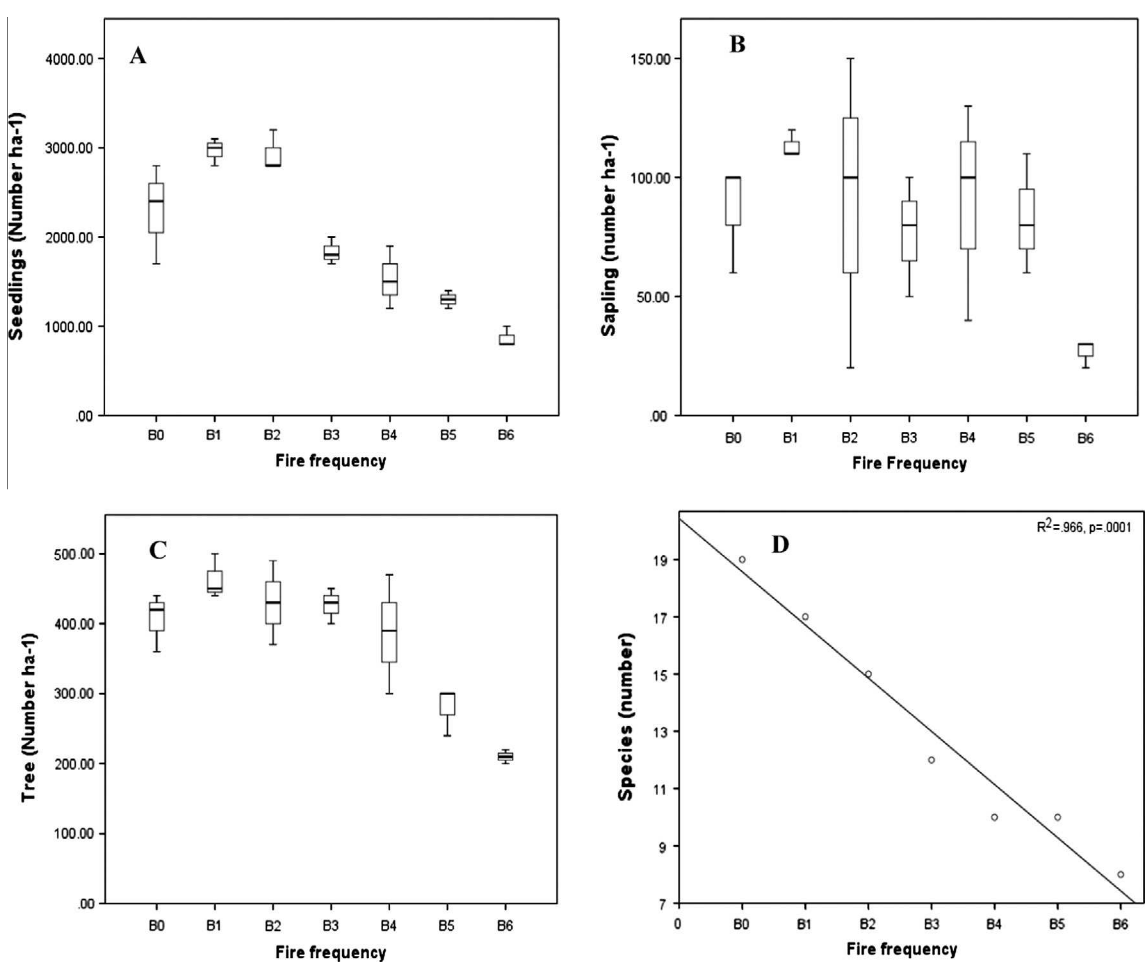

Fig. 5. Box plot of (A) seedlings, (B) saplings, (C) trees and (D) relationship between total species in seedling stage and fire frequency.

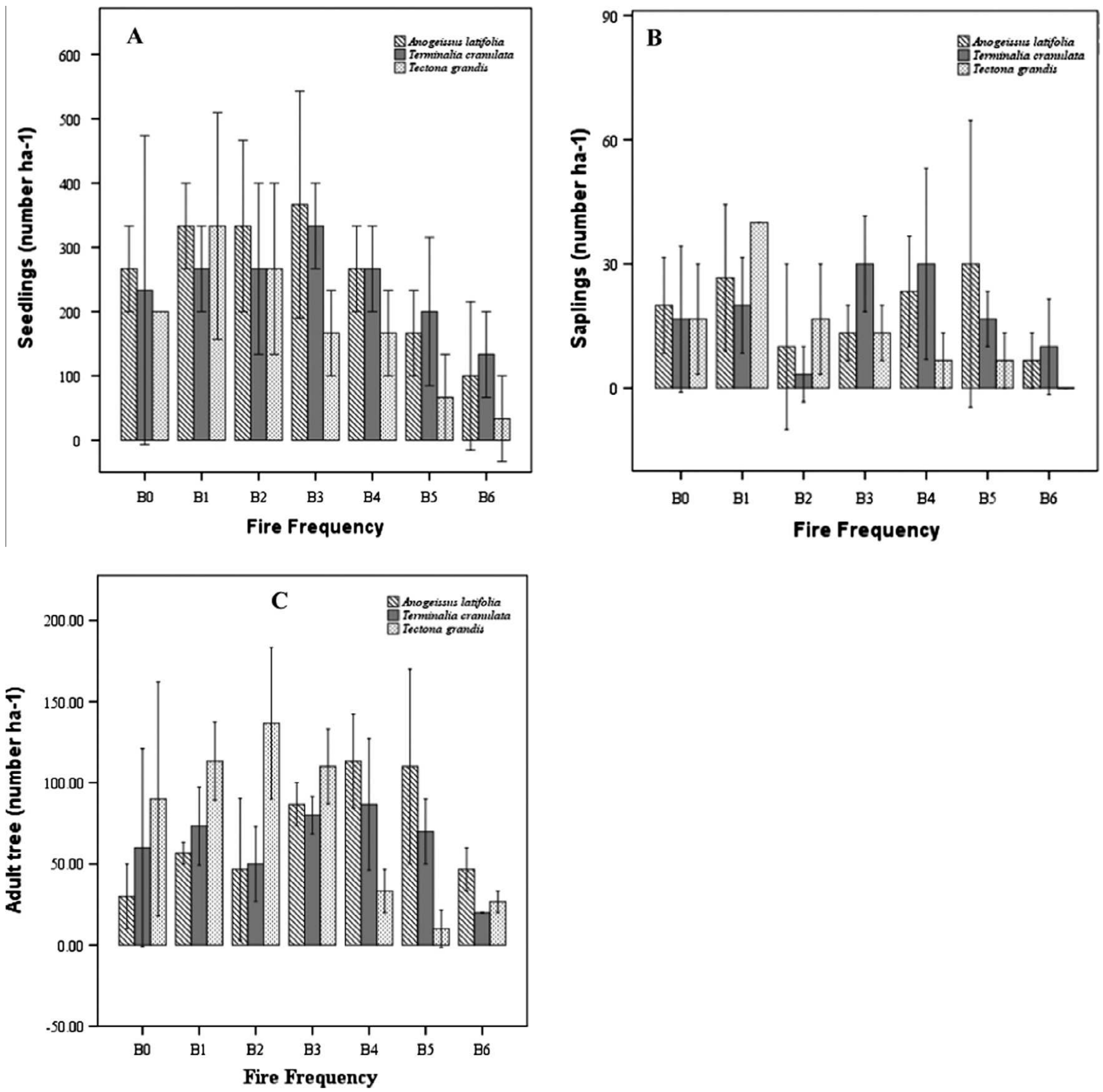

Fig. 6. Comparison of three dominant species of dry deciduous forest of MTR in different stages (A) seedlings; (B) saplings and (C) trees.

fires occur in the month of February and March. The variation in the vegetation types is very prominent. There is variability in the vulnerability to fires across different vegetation types. Fuel load from both grasses and leaf litter is significantly higher in the tropical dry deciduous forests compared with all other vegetation types. Mean fire return interval for the whole reserve increased significantly to 9.28 years (1999–2013) while it was 3.3 years (1989–2002) as reported by Kodandapani et al. (2004). MTR was dominated by *Dalbergia latifolia*, *Pterocarpus marsupium* and *Lagerstroemia microcarpa* 150 years ago (Cleghorn, 1861) and at present dominated by *A. latifolia* and *T. cranulata*. This clearly indicates the dynamics of species dominance in MTR. Based on the present study, fire may also have a role to play in the process of species dynamics by enhancing the opportunities of regeneration of certain fire tolerant species with thick bark and re-sprouting mechanisms. If these dry tropical deciduous forests had been protected from annual anthropogenic fire throughout Asia, their species composition would have been quite different (Saha and Hiremath, 2003). Because it is to be anticipated that fewer species will be able to persist and recurrent fires may also contribute to the rapid invasion of the reserve by exotic fire-adapted species.

Although there were not environmental differences (soil, topography and climate) among the control and burned classes, the results showed significant variation in species diversity in MTR. Species diversity decreases and dominance of fewer species increases with increasing fire frequency. Basal area, tree density, and diameter distribution for the control were similar to those reported by previous studies in the MTR (Reddy et al., 2008). Fire showed a negative relationship with stem density (>1 cm DBH) and basal area. Number of individual was little higher in B1 and B2 compared to control due to presence of stems of smaller size class (1–10 and 10–20 DBH).

Results suggest that one or two fires in 15 years (FRI > 7.5 year) can be good for regeneration of the tree species, and it does not have any noteworthy impact on trees. Seedlings and tree density showed significant mean difference among fire classes. B1 and B2 showed highest density of seedlings, which are higher than control, and it starts decreasing thereafter. Whereas, the tree population did not change much up to B4 and decreased subsequently. It is inferred that after one or two fires in 15 years having equal time interval, plants get enough time and more available soil nutrients for regeneration but the species diversity decreases with the

Table 2
Ten most abundant species of woody plants in seedling, sapling and tree classes present in Burned (B1–B6) and control (B0). Most abundant species in the group is highlighted.

Species	Family	% Abundance						
		B0	B1	B2	B3	B4	B5	B6
Seedling								
Anogeissus latifolia	Combretaceae	**11.6**	**11.2**	11.4	**20**	17.4	12.8	11.5
Terminalia cranulata	Combretaceae	10.1	9	9.1	18.2	17.4	15.4	15.4
Phyllanthus emblica	Euphorbiaceae	5.7	4.4	4.4	10.9	13	**20.8**	**34.6**
Cassia fistula	Caesalpiniaceae	1.3	7.8	4.4	12.5	**19.6**	**20.8**	8.1
Tectona grandis	Verbenaceae	8.7	11.1	9.2	9.3	11.1	5.4	3.5
Lagerstroemia microcarpa	Lythraceae	7.4	6.7	**22.8**	1.6	N/P	N/P	N/P
Grewia tiliifolia	Tiliaceae	8.7	9.1	4.4	7.1	4.6	2.3	N/P
Randia dumetorum	Rubiaceae	7.4	9.1	6.8	3.8	2	5.4	N/P
Kydia calycina	Malvaceae	3	9.1	6.8	7.1	4.6	N/P	N/P
Dalbergia latifolia	Fabaceae	N/P	2.4	2.4	1.6	6.5	10	N/P
Sapling								
Anogeissus latifolia	Combretaceae	**24.0**	29.4	11.1	17.4	25.9	**36.0**	25.0
Terminalia cranulata	Combretaceae	20.0	17.6	3.7	**39.1**	**33.3**	20.0	37.5
Tectona grandis	Verbenaceae	16.0	**35.3**	**18.5**	17.4	7.4	8.0	N/P
Cassia fistula	Caesalpiniaceae	N/P	2.9	**18.5**	21.7	22.2	20.0	25.0
Phyllanthus emblica	Euphorbiaceae	8.0	N/P	3.7	4.3	11.1	8.0	12.5
Grewia tiliifolia	Tiliaceae	12.0	N/P	14.8	N/P	N/P	4.0	N/P
Lagerstroemia microcarpa	Lythraceae	N/P	2.9	7.4	N/P	N/P	N/P	N/P
Randia dumetorum	Rubiaceae	4.0	N/P	3.7	N/P	N/P	N/P	N/P
Syzygium cumini	Myrtaceae	N/P	2.9	3.7	N/P	N/P	N/P	N/P
Kydia calycina	Malvaceae	N/P	N/P	3.7	N/P	N/P	4.0	N/P
Tree								
Anogeissus latifolia	Combretaceae	12.2	20.2	12.8	23.8	**33.8**	**45.0**	23.6
Terminalia cranulata	Combretaceae	17.0	19.1	10.9	**25.8**	28.5	25.7	13.9
Tectona grandis	Verbenaceae	**22.4**	**28.3**	**29.5**	**25.8**	9.2	4.6	11.1
Phyllanthus emblica	Euphorbiaceae	5.4	3.5	1.9	2.6	3.8	7.3	**36.1**
Cassia fistula	Caesalpiniaceae	1.4	6.4	5.8	11.9	18.5	11.9	2.8
Lagerstroemia microcarpa	Lythraceae	9.5	4.0	17.3	1.3	N/P	N/P	N/P
Grewia tiliifolia	Tiliaceae	2.7	2.9	5.1	1.3	0.8	0.9	N/P
Randia dumetorum	Rubiaceae	6.1	2.3	0.6	N/P	0.8	N/P	N/P
Dalbergia latifolia	Fabaceae	2.7	2.3	0.6	0.7	0.8	1.8	N/P
Radermachera xylocarpa	Bignoniaceae	2.7	2.9	5.1	1.3	0.8	0.9	N/P

N/P = Not Present.

increasing fire, and it promotes fire- resistant species and root-sprouters like *T. cranulata*, *A. latifolia*, *P. emblica* and *Kydia calycina*.

Results suggest that less frequent fires (B1 and B2) support regeneration of *T. grandis* whereas B3 and B4 support regeneration of *A. latifolia* and *T. cranulata.* High fire frequency classes (B5 and B6) support regeneration of *T. cranulata*, *P. emblica*, *C. fistula* and *A. latifolia* (Table 2). It suggests that all kinds of fire whether high or low frequency, will have an impact on vegetation. But fires with low frequencies (FRI > 7.5 year) will provide good regeneration opportunities and maintain more number of species.

5. Conclusions

It is concluded from this study that fire has varying degree of impact on tree species of dry deciduous forest. Low frequency of fire (FRI > 7.5) has enhanced seedling and sapling densities of tree species. Mid frequency of fire (FRI < 7.5 and >3.75) has affected seedlings but not trees. High frequency of fire (FRI < 3.75) has significantly affected stem density and regeneration negatively at the same time it has supported few fire-resistant species. All fire frequencies (B1–B6) have shown a negative impact on the diversity of tree species. Any kind of fire regime will have some impact on vegetation either beneficial or detrimental but decline in tree diversity in all fire classes suggests that fire is a matter of serious concern. MTR may sustain the current fire regime, but it will have long-term consequences on vegetation dynamics. Further research on fire should continue to test various ecological effects of fire, as well as intensity, pattern, etc. Research should also be conducted on impact of fire on soil nutrient dynamics and soil microorganisms because they regulate plant regeneration as well.

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