Anthropogenic fire regime in a deciduous forest of central India

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Components of anthropogenic fire regime are described in a central Indian deciduous forest managed by the Gond tribals of Mendha in Gadchirolli District of Maharashtra. Characteristics such as fire intensity, flame height and fire residence time were used to describe the anthropogenic fire regime. The study was conducted over three consecutive years – 1999, 2000 and 2001. The study plots were established in 4 ha of a forest patch in the reserve forests managed by the Gond tribals. Fires occurred in March each year, though the exact dates varied during different years. Leaf litter formed an important component of the fuel-load, which increased from February until April; 75% of leaf shedding completed by late March. Fuel-load showed a significant increase with time during 1999 and 2000. In 2001, leaf litter was completely shed by March and fires occurred earlier due to early retreat of monsoons and lower-than-average rainfall in 2000. Spatial variation in the soil surface temperatures was attained during the fires, with coefficient of variation equalling, 19, 13.38 and 20% in March 1999, 2000 and 2001 respectively. The sample points attained temperatures ranging from 45 to 510°C. The mean flame height ranged from 55 to 60 cm. The median fire residence time experienced by a tree juvenile (< 1.5 m height) was 12 s, ranging from no exposure to 35 s exposure. The fire-return interval was one year. The fire regime can be summarized as low intensity ground fires affecting tree juveniles < 75 cm in height.

ANTHROPOGENIC fires date back to 50,000 years ago when hunter-gatherers first colonized India[1]. Since then the accidental fires occur in the dry season because of human use of the forests, and intentional fires are set for shifting cultivation, to enhance both fodder production and the collection of non-timber forest produce. If lightning strikes ignited natural fires in pre-human times, their intensity and behaviour are not known. The current anthropogenic fire regime in deciduous forests is of interest because its spatial distribution and intensity influence recruitment of trees, forest stature, tree growth and soil properties[2–4]. Recent studies have used satellite data to monitor fire intensity in coal-mining areas[5], or used remotely sensed data to predict fire-hazards[6]. While these studies are important and have high resolution, they cover areas that have high conservation priority such as National Parks, and areas that are of economic importance. Less than 4.5% of India's forests have the protected-area status[7]. The unprotected forests have high conservation and economic value, but get disproportionate research attention.

The natural fire regime in the dry deciduous forests of India is unknown, but it is suggested that the deciduous forest communities did not evolve with fires as selection pressure[8,9]. Anthropogenic fires cause savannization of forests, opening of canopy and reduction of forest stature[1,10,11]. To evaluate the response of plants to fire and the effects of fire on the dynamics of the deciduous forests, it is important to understand the fire regime affecting a region. I initiated a project in 1999 to monitor the anthropogenic fire regime, (reported in this study) and effects of fire and fire-protection on juvenile tree growth, diversity (reported elsewhere) in a tropical deciduous forest of central India.

The objective of this study is to examine fire intensity, fire-return interval, and fire residence time (components of a fire regime[12]) in central India. Fire intensity is the severity of fire in terms of heat released per unit area[13] and is determined by the quality and quantity of fuel (fuel load)[14,15]. It affects nutrient cycling, and response of plants to fire[16–18]. The total time an individual plant or individual unit of study is exposed to fire is the fire residence time. Fire-return interval is the time between two fires in a unit area[19]. Greater the residence time, greater is the impact on the stems; some plants are charred completely, while some are superficially burnt depending upon the fire residence time[20]. The experimental approach and detailed observations of fire regime at one site make this study unique among those of fire on forests and grasslands in India[16,17,21].

The study was carried out in dry deciduous forests of the lower plateau region in Mendha village of Gadchirolli District (18°40′ and 20°48′N; 79°58′ and 80°44′E), Maharashtra. The state has 54,030 km^2 of land under forest, of which approximately 30% is in Gadchirolli District. The area receives a mean annual rainfall of 1600 mm from June to November. Rainfall is concentrated between June and October sometimes extending to November, with occasional showers in February and April. Topography is gentle to moderately sloping and ranges between 150 and 300 m above sea level. Soils are moderately deep; they are well-drained vertisols with high water-holding capacity[22].

Dry deciduous and moist deciduous forests are the chief vegetation types in the study area. The study plots were established in the dry deciduous forest dominated by *Terminalia alata* (Combretaceae), *Pterocarpus marsupium* (Fabaceae) and *Anogeissus latifolia* (Combretaceae). The canopy is 18–20 m high and two other strata, middle-storey dominated by 10–12 m tall trees and understorey consisting of herbs and shrubs, are present. The forests were selectively logged for timber until 1980.

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Presently no logging is permitted on a commercial basis, except bamboo-cutting. The indigenous Gond tribals living in villages adjoining the forest area manage the forests. Ground fires occur once in a year between February and April, which is the fire season in that region. The fires are not necessarily set by the people of Mendha, but approach from other directions and sweep past Mendha forests also. Leaf litter is the main component of fuel-load. Fires are anthropogenic in origin, because burning facilitates collection of *Madhuca longifolia* var. latifolia (Mahua) flowers and *Diospyros* leaves. There is a strong belief that fire enhances the growth and yield of *Diospyros* leaves. This produce is an important part of the tribal economy.

Twenty-four plots, each of 9 m^2, were established in a 4 ha forest patch which was less than 10% of the total village forest area. All individuals in plots < 1.5 m height were tagged and classified as juveniles (> 10 cm and < 1.5 m height) and seedlings (< 10 cm in height). In 1999, eight plots each were assigned to March burns, April burns, and control (no fire). Two fire treatment levels were established to test if the leaf litter accumulating after March produces a significantly greater fire intensity, causing stronger negative effects on juvenile and seedling mortality and die-back. In 2000, the two fire treatment levels were amalgamated into one level, and the study plots were burned in March only. This was done because no difference was found in the response of juvenile growth between March and April burn fires in 1999. To compensate for this increase in plot number in burned treatments, more control plots were established in February 2000. I use the terms, anthropogenic and experimental for describing the fires initiated by people and those imposed by me, respectively, but they are not compared or differentiated statistically. A plot was either burnt under the influence of anthropogenic fires that occurred in March, or burnt by me if patchy anthropogenic fires escaped a plot. Three March-burn plots and all of the April-burn plots in 1999 were burnt experimentally; four plots each in 2000 and 2001 had to be burnt experimentally because they escaped burning in the anthropogenic fires. Escape from fire was due to very small discontinuities in the fuel-load. The experimental burns were imposed in late morning on three different days immediately after the anthropogenic fires swept past the area.

To estimate fuel-load without compromising the fire intensity in the plots, ten additional plots of 0.25 m^2 were set close to the main study plots and used to collect fuel-load. Fire-resistant flagging marked the fuel-load collection plots, which made them easy to locate. The sampling was done biweekly starting February–May in 1999, 2000, and in February and March, 2001. Leaf litter was the main component of fuel-load, with a small proportion of dried grass and standing dead-plant matter. The fuel-load was collected in a paper bag and fresh weight was measured. Two-way analysis of variance was done to compare the fuel-loads in February–May in 1999 and 2000. Analysis did not include fuel-loads from 2001 because no data were collected after March. Biweekly counts within a month were added to give one data point for that month, and those data were used in the analysis of variance.

Fire temperature is used as a surrogate measure of fire intensity[18]. Tempil, temperature-sensitive tablets[23] were used to record the soil surface temperature and below-ground soil temperature (2 cm beneath the soil surface). I used the tablets sensitive to 45, 79, 150, 316, 399, 510 and 650°C. The wide range in temperature was used to monitor the variability in fire intensity. Before the actual burning took place, a trial was done to monitor the maximum temperature reached by burning of leaf litter. The maximum temperature attained was 650°C and hence was used as the upper limit of the range. The temperature-sensitive tablets were placed in the main study plots. Four tablets corresponding to each temperature were placed in four randomly chosen points in 12 plots (six in March and six in April fire in 1999). Coefficient of variation was computed to monitor the spatial variation in fire intensity among the sampling points.

I assessed the flame height from outside the plot and collected two samples at two opposite sides of the main study plot. The time taken for a plot to burn was recorded and total exposure time of a juvenile to fire was monitored in a plot for 5–6 plants per plot.

Fire-return interval in the Mendha forests and in those around Mendha was recorded. The fire initiation day was considered as the first day when hills within 15 km radius of the area around the village were seen on fire. The forests within the area with 15 km radius were approached by bus when public transportation was available, or on the bicycle to assess the extent of burning. Fire-return interval was estimated for a site as difference in time between two successive burns.

Fuel-load increased from February until April and stabilized in mid-April, showing hardly any increase in May (Table 1). The analysis of variance showed a significant effect of the month on fuel-loads ($F_{3,72} = 13.98$, $P < 0.0001$), but the year and month interaction effects were non-significant. The fuel-load collected in March 2001 was greater than those in 1999 and 2000. The total weight of fuel-load was similar in all three years, except for 2001 when leaf litter accumulation was completed by late March as a result of early senescence due to early

Table 1. Rainfall in early dry season (Station – Nagpur)

	February	March
1999	4–5 February (4 mm)	–
2000	24–25 February (10 mm)	–
2001	–	7–8 March (8 mm)

retreat of monsoons and lower-than-average rainfall in 2000. No sampling in fuel-load accumulation was done after late March in 2001, as all the trees were leafless by then. The increase in fuel-load with dry season was homogeneous in 1999 and 2000. The fuel-load in February 2001 was higher than in early dry season of 1999 and 2000.

Under the current fire regime, the fire-return interval of one year is an anthropogenic artifact. Fires occurred in the region more than once during the fire season, but a forest patch was burnt only once a year. Variation in weather conditions such as brief rainy spells in February and/or March, and the rainfall distribution in the previous monsoon season affects the timing of burns (pers. observation; Table 2). In 2001, the fires started in the neighbouring areas and hills in the third week of February itself, and retreated because of thunderstorms and mild showers in first week of March. Fires occurred in mid-March in the areas that had remained unburnt. Many sites have the potential to burn twice in such a case. Rainfall data in 2001 were collected at the study site using a rain gauge; for 1999 and 2000 rainfall data from Nagpur city, 180 km from the site, is reported. During all the three years, the study sites were burnt once in the dry season, but in 2001 there was potential for burning more than once.

The trends in fuel-load and fire intensity were homogeneous in 1999 and 2000 (Figure 1). A maximum of 510°C and minimum of 316°C was attained in April compared to a high of 510°C and a low of < 45°C in the March burns in all the years. Coefficient of variation for March fires was 19% compared to 7% in the April fire in 1999. In 2000 and 2001, the coefficient of variation in fire intensity was 13.38 and 20% respectively. Fires scorched most plants, while some did not even wilt. The fuel-loads governed fire intensity, which in turn governed the total time of contact between fire and a tree juvenile. This time ranged from 0 to 35 s with a median time of 12 s. Mean burn time in March was 12.8 min, 10 min for April burns in 1999, 12.6 min in March 2000, and 10.6 min in 2001. Flame height was similar in the two treatments and never exceeded 75 cm in any of the burnt plots, the average flame height in March 1999 was 55 ± 11.6 cm and in March 2001 it was 60 ± 6 cm.

Plants were, charred, scorched, had leaves curled up, or showed no effect in the plots after the burns. Seedlings were readily charred by fires, juveniles 10–75 cm in height were scorched and died-back, and juveniles > 75 cm occasionally died-back in response to fire.

Table 2. Fuel load (mean per plot g/0.25 m^2 ± SE) in dry season

	February	March	April	May
1999	73.76 ± 4.07	91.81 ± 4.93	104.35 ± 3.35	106 ± 2.9
2000	72.67 ± 5.3	95 ± 5.12	100.37 ± 3.01	107 ± 3.43
2001	92.6 ± 19.91	112.5 ± 6.21	NA	NA

Annual low-intensity surface fires affecting the forest understorey characterize the anthropogenic fire regime in India. The trend in leaf litter (serving as fuel) accumulation is similar to that in the monsoonal forests of the Western Ghats, Australia, and East Africa[24–28]. The fuel-load comprises senesced and dry leaves that sustain low intensity ground fires. The plots protected from fire had no fuel-load accumulation from the previous year, the leaf litter had decomposed (pers. observation). This is contrary to many ecosystems where fire suppression leads to fuel-load accumulation causing catastrophic fires[29]. The variation in fuel-load deposition is due to variation in leaf-shedding pattern of tree species.

The variation in fuel-load accumulation translates into spatial variation in fire intensity. The spatial variation in fire intensity affects seedlings establishment, because seedlings (< 1-year-old) are susceptible to fire and undergo heavy mortality[30,31]. Within the main study plot of 9 m^2 where the response of juveniles to fire was examined and fire intensity was monitored, the maximum temperatures attained varied ten-fold. This result can be related to the effects of fire on juvenile die-back, which is about 66% in burnt plots. Several juveniles escaped fire and did not undergo stem die-back, they exhibit height and growth patterns similar to unburnt juveniles (Saha., in review).

Litter is an important source of nutrients for the deciduous forests plants[32]. More than 75% of the leaf litter is shed by late March, and the burnt sites accumulate only one-quarter of the litter compared to unburnt sites. The temperatures at the ground level are lower than those recorded in savanna-woodlands of SE Asia[33] (Stott reported a range of temperatures from 275 to 700°C), where adult trees are also affected by fire, which was never observed during this study. The fire intensity reported here is also lower than that reported during the

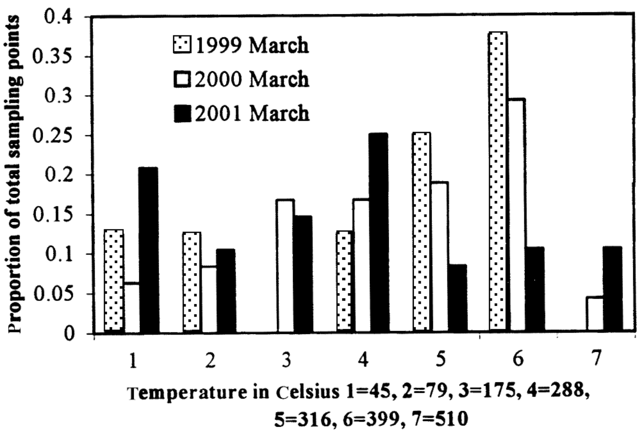

Figure 1. Frequency distribution of temperatures attained at different sample points in March 1999, 2000 and 2001. Proportion instead of raw data is reported, because the total number of sampling points in March 1999 is 24, while in 2000 and 2001 it is 48 as the two fire treatments were amalgamated into one. Variation in temperature attained during single time-frame is noticeable.

early stage of slash-and-burn agriculture[34]. The above-ground temperatures in the study area are sufficient (> 200°C) to cause complete volatilization of nitrogen and to some extent phosphorus[18]. The below-ground temperatures are low to have any significant impact on mineralization of soil organic matter.

The fire affects tree juveniles by exposing them to lethal temperatures. For flame residence times of 141 s, the bark thickness needs to be 6.4 mm to protect the plant from lethal cambial temperatures[35,36]. Small-sized individuals up to 10 cm in height were burnt even upon exposure of less than 10 s. The flame height and time of exposure to fire were not high enough for juveniles of 1.5 m to burn and die-back. A large proportion of juvenile die-back occurred among individuals up to 75 cm.

The fire regime in Mendha forests is characterized by low-intensity fires affecting juveniles < 75 cm in height, sustained by fuel-load consisting of leaf litter. The leaf litter accumulates with the dry season, but shows heterogeneity in deposition that leads to microsite level variation in fire intensity, flame height and fire residence time. The results from this study reiterate the complex nature of the relationship between fire and ecosystems over space and time. What can be understood from this study is that there seems to be a pattern in anthropogenic fire regime, which can be predicted if local weather patterns are monitored. The predictability seems to be driven by an objective behind the setting of fires. The objective behind fires in this region of central India is facilitation of *D. melanoxylon* leaf flushing before the onset of monsoons. The fires are related to the tribal economy, therefore a blanket recommendation of fire control is not feasible. At the same time, there is no need for large-scale fires because the activity is limited to restricted areas in the forests, and forest and agricultural field edges. Results of this study can be used to protect the forests from fire by assessing the fire hazard potential based upon the rainfall distribution of the previous year, pattern in leaf shedding, and relative humidity in the air. Fire is a local phenomenon and any fire-management plan has to take into account the local variation in components of fire regime.

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ACKNOWLEDGEMENTS. J. Watumull Foundation and Kalpavriksha funded this study. I am grateful to Barbara Zorn-Arnold and two anonymous reviewers for useful comments.

Received 22 May 2001; revised accepted 13 February 2002