

Short Communication

Stature of Juvenile Trees in Response to Anthropogenic Fires in a Tropical Deciduous Forest of Central India

Sonali Saha and Henry F. Howe

Abstract: Fire is an integral component of many temperate and tropical ecosystems, but it can be disruptive when it occurs in normally fire-free environments. Tropical deciduous forests in India have experienced annual anthropogenic fires for hundreds of years. We examined the effects of anthropogenic fires and fire exclusion on the stature of juvenile trees (≤ 1.5 m) in a tropical deciduous forest in central India. Plots burnt for 2 consecutive years showed no difference in juvenile size-class distribution before and after the treatment was imposed, while the juvenile trees in plots protected from fires showed a significant increase in height and attained greater stature. In plots protected from fire, juvenile trees exhibited some die-back as a result of dry season drought; however, the proportion of juveniles that died back was significantly smaller than the plants that experienced die-back in burnt plots. Relative growth rate of juvenile trees was significantly greater in unburned plots than in plots burned consecutively for 2 years ($P < 0.05$). Thus, our results suggest that anthropogenic fires stunt the growth of juvenile trees.

Keywords: tropical deciduous forests, fire, sprouting, tree juveniles

INTRODUCTION

Fire is an integral component of many temperate and tropical ecosystems (Bond and Keeley 2005), but it can be disruptive in normally fire-free environments. The existence of fire as a natural disturbance in dry tropical

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forests is a matter of debate, but repeated fires set by humans clearly degrade these communities by reducing diversity, increasing dominance of a few tree species and admitting exotics (Murphy and Lugo 1986b; Stott et al. 1990; Menaut et al. 1995; Sukumar et al. 1998; Roth 1999; Saha and Howe 2003; Hiremath and Sundaram 2005). Change in species composition is accompanied by reduction in stature of juvenile trees caused by annual die-back in response to fire over and above that due to seasonal drought. Juvenile stunting potentially influences mature forest composition and structure. Some species may take much longer to mature or they may mature as stunted individuals. Such effects have long been suspected from observations in Asian forests (Troup 1921; Sukowong 1982; Saha 2001), and have been experimentally demonstrated in some economically important species (e.g. Dutt 1907; Sengupta 1910; Thomas 1938).

Here we examine the effects of fire on juvenile tree composition and stature. We compare the relative growth rate and size-class distribution of juvenile trees between plots burnt for 2 consecutive years and plots protected from fire. Our study uniquely contributes an experimental test of fire effects on an intact juvenile understorey in a South Asian tropical deciduous forest.

STUDY SITE

The study was conducted in a dry deciduous forest of the lower plateau region in Mendha Village of Gadchiroli District (between 18° 40' and 20° 48' N, 79° 58' and 80° 44' E) in the state of Maharashtra, India. The state has 54,030 km² of land under forest, of which approximately 30% is in the Gadchiroli District. The forests are managed by the Gond tribe. The area receives a mean annual rainfall of 1400 mm, concentrated between June and October, sometimes extending to November, with occasional showers in February and April. Seasonality in rainfall leads to synchronised leaf shedding among trees from February to March. Topography is gentle to moderately sloping and ranges between 150 and 300 m above sea level. Soils are well-drained vertisols with high water holding capacity (Challa et al. 1997). Dominant canopy species are *Diospyros melanoxylon* (Ebenaceae), *Terminalia tomentosa* (Combretaceae), *Pterocarpus marsupium* (Fabaceae) and *Anogeissus latifolia* (Combretaceae) (Saha and Howe 2003).

Natural fires of any extent are largely unknown in the study area. Lightning strikes kill isolated trees (Abraham 1939), but all known fires of more than a few square meters in extent are anthropogenic (Gadgil and Meher-Homji 1985). The fire regime over the past 100 years or so is governed by annual low-intensity fires ignited between February and April by collectors of *D. melanoxylon*. The systematic annual burning practice originated in 1906 when industries manufacturing cigarettes using *D. melanoxylon* leaves were established in central Indian deciduous forests (Srivastava and Choubey 1968) providing the basis for an important part of the indigenous economy. Local

people set fires when enough leaf litter accumulates on the ground to burn; fires shift the phenology of *D. melanoxylon* plants and leads to earlier leaf expansion, compared to plants that are not burnt. Thus, burning enables leaves to be collected before the onset of the monsoonal rains, and are dried and packaged under optimal environmental conditions.

METHODS

Species Composition and Size Distribution

All individuals of trees ≤ 1.5 m tall were tagged in twenty-four 9 m² plots during January 1999. The plots were randomly located in a 4 hectare forest patch managed by the Gond tribe. Plants were differentiated into seedlings and juvenile trees based upon height: those ≤ 10 cm were scored as seedlings, those >10 and <150 cm high (>1 year old) as juveniles. Height of tagged individuals was measured from the base to the apical bud at time of plot establishment in February 1999, and again in 2000 and 2001.

We classified species as clonal if they produced ramets from root tissue and shared below-ground connections, and non-clonal if they did not produce ramets. By this token, the species that produced sprouts from the root crown were considered non-clonal (Del Tredici 2001). Both clonal and non-clonal species may produce sprouts from the root crown; however, only the ramets of clonal species have the ability to sever and establish as independent individuals. We excavated several plants of each species from outside of the plots to determine if they produced ramets. Multiple stems belonging to the same rootstock were counted as a single individual.

Twelve plots of the twenty-four were allowed to burn during the annual fires set by villagers in March and April of 1999 and 2000. Plots missed by fires set by villagers were burned in the 3rd week of March and 1st week of April. We could not find reliable records of the fire history of Mendha forests. Annual fires are known to be the norm, but whether a particular site or plant experiences fire is subject to the amount of dry litter around it. Natural fire breaks due to lack of fuel are very common (Saha 2002). We thus refer to plots that were subjected to fire in this experiment as fire plots, and the plots protected from fire as control plots.

We compared the size-class distribution of marked juveniles in fire and control plots before and after the treatments were imposed. Paired-sample *t*-tests were done to analyse the number of individuals in each size class before and after the treatments were implemented.

Effects of Fire on Juvenile Height Growth

Mean relative height growth rate (RGR_{height}) was calculated for four species that were common to all plots, with a fifth category composed of all remaining species.

RGR_{height} was the measure used to assess the effects of fire on the stature of juveniles. It was measured as:

$RGR_{\text{height}} = (\ln \text{ height (February 2001)} - \ln \text{ height (February 1999)}) / (t_{2 \text{ Feb 2001}} - t_{1 \text{ Feb 99}})$, where t is the time in days yielding RGR in units of $\text{cm cm}^{-1} \text{ day}^{-1}$. Relative growth rate was chosen as a measure of growth because it factors the change in plant size by the initial starting size of the plant, instead of just measuring the change in plant size, thereby accounting for initial height among individuals.

Individuals of different species within a plot are not independent of each other, thus a separate analysis per species will violate the assumption that the response variable is measured independently for each plant. Multivariate analysis of variance was performed with treatments as the independent variable and the mean RGR_{height} per species per plot as a dependent variable. Statistical analyses were performed using Systat 9.0.

RESULTS

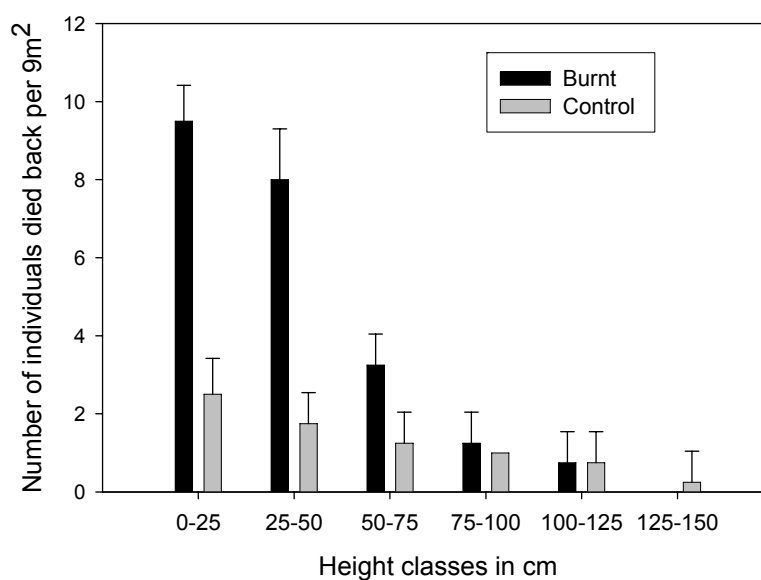
Species Composition and Height-Class Distribution of Tree Juveniles

Juveniles of thirty-two species were recorded in the plots. The pre-treatment density of individuals ($t = -0.37$, $df = 22$, $P > 0.05$) and height ($t = -1.7$, $df = 22$, $P > 0.05$) were homogeneous prior to the burn treatment. The size-class distribution of juveniles was positively skewed with the greatest number of juveniles in the smallest size-class (0–25 cm in height). Four of the thirty-two species: *D. melanoxylon*, *T. tomentosa*, *A. latifolia* and *P. marsupium* occurred in all plots. *P. marsupium* does not reproduce asexually, but the other three common species produce asexual ramets capable of establishing as independent individuals.

Sixty-six per cent of all the individuals in the fire plots, died back as a result of fire. The rest were not impacted due to the heterogeneous distribution of fuel loads or fire-tolerant size (Saha 2002). Surprisingly, there was a 21% die-back of individuals in the plots protected from fire and presumably this was caused by drought. Juveniles <75 cm in height were more susceptible to fire than those >75 cm (Figure 1). Die-back in response to drought was common among individuals in smaller size-classes, but occurred only occasionally among individuals >100 cm in height. Several plants died back to the ground and sprouted after the rains arrived in plots protected from fire. Thus, die-back due to drought was easily detected in fire-protected plots. It is possible that fire and drought interacted in plots subject to fire, as fires may have killed the stems of plant weakened due to drought. However, it was not possible to detect the interaction between fire and drought in fire plots. Maximum die-back in control plots occurred among juveniles of *T. tomentosa*, followed by *A. latifolia*.

Figure 1

Number of stems died back in burnt and control plots. In the burnt plots tree juveniles < 75 cm height were vulnerable to fire-induced die-back. Drought was the cause of die-back in juvenile trees among plots protected from fire. Error bars represent 95% confidence intervals



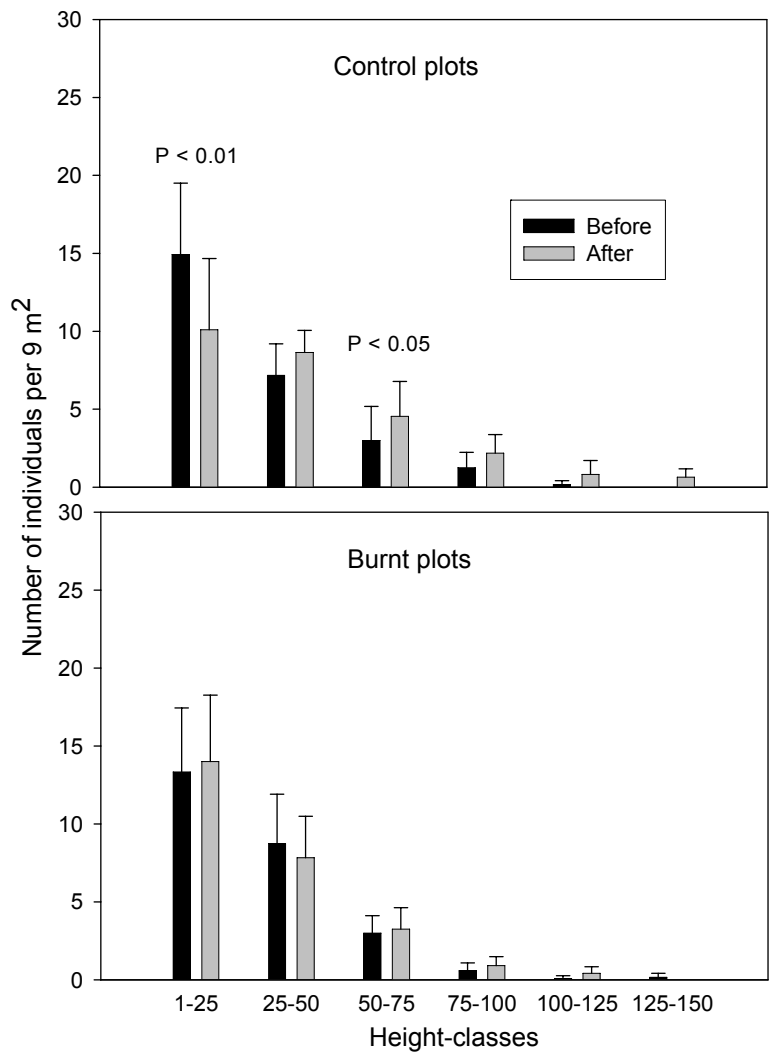
Effects of Fire on Stature and Height Growth

In the control plots, juveniles grew taller and transitioned into next height class before and after fire exclusion was implemented (Figure 2a). Height-class distribution of juvenile trees among burnt plots was comparable before and after fire. It showed a strong positive skew with a large proportion of individuals in lower height classes (Figure 2b). Paired-sample *t*-tests showed significant differences in the number of individuals in the control plots before and after fire protection in two size classes: 0–25 and 50–75 cm ($P < 0.05$).

In terms of absolute growth, the plants in control plots grew on average 19.2 cm while the plants in burnt plots grew 5.6 cm. RGR_{height} after two consecutive seasons yielded a significantly greater RGR_{height} in fire-exclusion plots (Wilk's Lambda = 0.505, $P < 0.05$, $df = 5, 18$; Figure 3). The assumptions of MANOVA were tested by checking for univariate normality of the dependent variables (RGR_{height} of each species) in treatment groups. The height difference was normally distributed for each variable in each treatment group except *D. melanoxylon* in burn treatments. Covariance matrices were visually inspected for homogeneity in sign of correlations between treatments among univariate response variables (Scheiner and Gurevitch 1993).

Figure 2

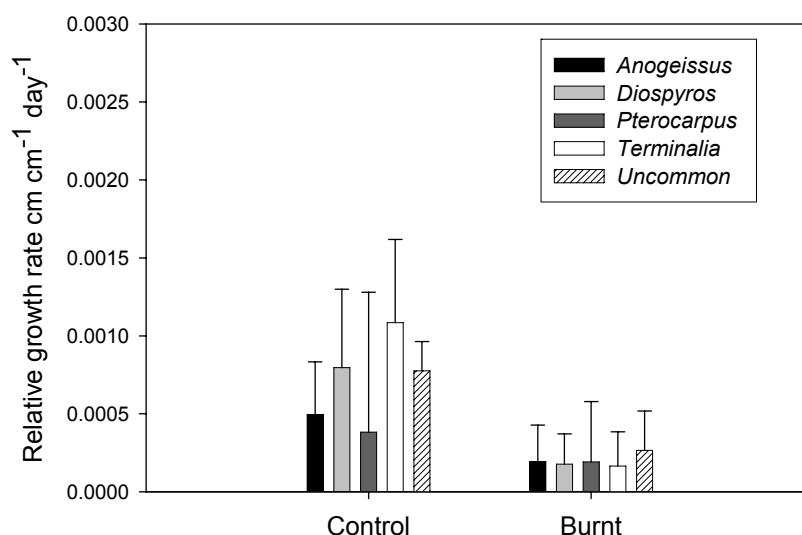
Upper panel: Height-class distribution of tree juveniles in control plots before and after protection from fire. Paired t-tests showed significant difference before and after fire exclusion in the height classes: 0–25 and 50–75 cm. Lower panel: shows height-class distribution of tree juveniles before and after experimental fire regime was imposed. No significant difference was found between distribution of juveniles in height classes before and after experimental fires



The overall significant difference (Wilks Lambda = 0.014, df = 5, 18, $P < 0.05$) suggests that fire reduces height of all species, with significant univariate effects for *T. tomentosa* and *D. melanoxylon*.

Figure 3

Difference between RGR_{height} ($cm\ cm^{-1}\ day^{-1}$) of four common species and a group consisting of uncommon species pooled together between burnt and control plots. MANOVA results indicated that net growth rate was significantly higher for all species in plots protected from fire (Wilk's Lambda = 0.505, $df = 5, 18$, $P < 0.05$)



DISCUSSION

Anthropogenic fires reduce species diversity and affect plant stature in forests where natural fires are absent or rare (Saha and Howe 2003). For example, fires in tropical deciduous forests suppress regeneration of several tree species by killing seedlings; repeated fires additionally impose annual die-back on some species (Rodger 1907; Lieberman and Li 1992; Menaut et al. 1995; Saha and Howe 2003). Often trees continually suppressed as juveniles never attain the canopy height that they do in control plantations and forest plots (Dutt 1907; Osmaston 1937).

Our experimental results confirm observational studies in tropical deciduous forests of India that juveniles exist in an arrested stage before they reach a size that is unaffected by fire (>75 cm in our study; Dutt 1907; Puri et al. 1983; Gadgil and Meher-Homji 1985; Singh et al. 1985; Murphy and Lugo 1986a; Roth 1999; Srivastava 2000). We also found that juveniles protected from fire, show different size-class structures, with each species realising its potential growth rate and architecture. Juvenile trees had significantly greater height after 2 years of protection from fire. Thus, changes documented here have implications for forest composition as well as physical structure. Our results suggest that fire and fire exclusion among tropical deciduous forests lead to two different

scenarios. Repeatedly burned forests have stunted juveniles of uniform size, while unburned forests have juveniles in different size-classes that reflect the intrinsic rates of growth in different species. Lower relative growth rates in burned plots show that fires retard the growth of tree juveniles and initiate stunting of tropical deciduous forest understorey.

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Anthropogenic fires in central India / 627

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