Forest Ecology and Management 284 (2012) 152–162

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Effect of grazing and harvesting on diversity, recruitment and carbon accumulation of juvenile trees in tropical dry forests

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ARTICLE INFO

Article history:
Received 24 May 2012
Received in revised form 28 July 2012
Accepted 30 July 2012
Available online 30 August 2012

Keywords:
Juvenile trees
Tropical dry forest
Grazing
Harvesting
Recruitment
Carbon density

ABSTRACT

We investigated the effect of grazing and harvesting on diversity, mortality, recruitment and carbon accumulation of juvenile trees at five sites in a tropical dry forest (TDF) to address the questions: (i) How is the TDF structured in terms of juvenile trees and their carbon densities? (ii) What is the level of biotic disturbances in the TDF which affect juvenile tree population? And (iii) what is the relationship between species mortality and recruitment in the sites having different disturbance intensities? Across the sites, we recorded juvenile individuals in 41 species belonging to 22 families. Wood specific gravity (WSG) among species varied between 0.36 and 0.66 g cm^{-3}. Carbon density in the juvenile tree populations ranged from 271 to 966 kg-C ha^{-1} and carbon accumulation from 10 to 210 g-C $\text{cm}^{-2}\ \text{yr}^{-1}$. Mortality due to browsing, harvesting, and drought was respectively, 41%, 47% and 12%. Significant differences across sites were observed for species richness, carbon density, carbon accumulation, numbers of dung pellets and damaged juveniles, annual mortality index (AMI) and annual recruitment index (ARI). Species also differed significantly for AMI and ARI. Species richness, carbon density and carbon accumulation were negatively related with AMI and positively with ARI. Soil moisture content, total N and total P across study sites also favored juvenile recruitment. The findings suggest that mortality of juvenile trees in TDF is mainly due to browsing and harvesting. The future floristic composition and carbon accumulation of TDF will depend upon the status of juvenile trees. Therefore, it is important to restrict the livestock grazing in the forest and to particularly protect the juveniles of the dominant canopy trees and those with high carbon accumulation potential.

1. Introduction

Forests are the dynamic mosaics of different ages, generally produced by perturbations, and are affected by various abiotic and biotic conditions (Tabanez and Viana, 2000; Portela and Santos, 2009). Among the major tropical forest types, tropical dry forests (TDFs) are the most threatened, about 90% of these forests are exposed to a variety of threats largely resulting from human activity (Miles et al., 2006). These forests are characterized by seasonal rainfall, with several months of severe drought in the annual cycle (Mooney et al., 1995). In India, TDF is quite extensive and accounts for 38.2% of the total forest cover (MoEF, 1999). These forests supply about 80–95% of fodder needs of the livestock and 81–100% of fuel needs (Singh and Singh, 1992). TDF once covered more than half of the area (about 170 million ha) of the country, however, due to the population pressure, the TDF now covers only around 26–27 million ha (Singh and Singh, 2011). These forests have been traditionally managed through selection felling, i.e., harvesting of individuals above a certain diameter which varies from species to species and leaving a few mother trees for regeneration (Singh and Singh, 2011). Low intensity ground fire occurs every 2–3 yrs. These forests are strongly impacted by anthropogenic activities, particularly, excessive grazing, trampling and firewood removals (Champion and Seth, 1968; Singh et al., 1991), and in many parts are being converted into dry deciduous scrub and savanna. The disturbance intensity is not uniform across the forest. Such disturbances could affect tree density and other structural parameters (Sumina, 1994; Hubbell et al., 1999) and change size class distribution of the desirable species (Luoga et al., 2004).

Excessive grazing in a forest may reduce structural complexity and species richness resulting in deleterious changes (Milner et al., 2002; Mysterud and Østbye, 2004; Pollock et al., 2005). The development of tree seedlings to maturity or attaining canopy status is prevented by grazing (Hester et al., 2000), adversely affecting the continuity of entire forest ecosystems (Pulido et al., 2001; Mountford and Peterken, 2003; Plieninger et al., 2004; Dufour-Dror, 2007). According to Pulido and Díaz (2005), the main

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http://dx.doi.org/10.1016/j.foreco.2012.07.053

direct damage seems to occur at the ‘seedling emergence and establishment stage’ when livestock graze, browse or trample the seedlings. This prevents recruitment of juveniles (Hester et al., 2000). When the regeneration process is continuously hampered, it may then lead to progressive decay of the forest cover (Leiva and Fernandez-Ales, 2003; Quézel and Médail, 2003; Plieninger et al., 2004; Dufour-Dror, 2007). Unlike seedlings, juveniles may not be killed straightway when browsed, however, their development can be severely hampered as the maximum efficiency of photosynthesis is reduced by having insufficient leaf area of photosynthetic tissue (Putman, 1996). The development of woody vegetation can be inhibited by heavy browsing and grazing by mammals (Luoga et al., 2002, 2004), and regeneration of woody species is often assumed to be improved by zero-grazing (Zida et al., 2007).

Survival of juvenile trees is critical for sustaining canopy tree populations, however, little is understood about the extent to which seasonal fire, herbivory, rainfall or overstorey and other mechanisms directly affect the transition of a juvenile tree to canopy size (Midgley et al., 2010; Werner, 2011). Intense harvesting of few locally preferred species of the forest may influence the dynamics of the remaining species and could decrease its biodiversity (Zida et al., 2007). As compared to mature trees, the growth and physiology of juveniles are highly affected due to changes in environmental conditions (Jarvis, 1995). According to Belsky and Blumenthal (1997), the effects of livestock grazing and trampling on vegetative cover vary with rainfall, slope, soil stability and vegetation type, as well as with animal density, season of use, duration of use and animal distribution. Mortality rates of seedlings and saplings, even under ideal conditions are much higher than those by sub-adult and adult trees (Grogan et al., 2011). In the TDF, juveniles are mostly preferred by the local people for harvesting for woodfuel, fencing material and for making domestic implements.

A significant proportion of tree population is comprised of juveniles which have faster growth rates than the higher diameter class trees, and therefore have a higher potential for carbon sequestration. Inspite of a likely impact on the forest carbon dynamics, the carbon stored in the juvenile tree population has been generally ignored in previous studies (Chaturvedi et al., 2012). The array of abiotic and biotic factors in the TDFs mostly affect the recruitment and growth of juvenile trees. Abiotic factors mainly include soil moisture and nutrient content, and among biotic factors major impact is caused by herbivory and harvesting by humans. In this study we have assessed the recruitment, diversity and carbon accumulation in the juvenile trees at five sites in a TDF and addressed following questions: (i) How is the TDF structured in terms of juvenile trees and their carbon densities? (ii) What is the level of biotic disturbances in the TDF which affect juvenile tree population? And (iii) what is the relationship between species mortality and recruitment in the sites having different disturbance intensities?

2. Methods

2.1. Study sites

The study was conducted in five sites, Hathinala West (24°18′07″N and 83°05′57″E, 291 m.a.s.l.), Gaighat (24°24′13″N and 83°12′01″E, 245 m.a.s.l.), Harnakachar (24°18′33″N and 83°23′05″E, 323 m.a.s.l.), Ranitali (24°18′11″N and 83°04′22″E, 287 m.a.s.l.) and Kotwa (25°00′17″N and 82°37′38″E, 196 m.a.s.l.). Hathinala, Gaighat, Harnakachar and Ranitali sites are situated in Sonebhadra district and Kotwa in Mirzapur district of Uttar Pradesh (Fig. 1). They occupy land area of 2555, 394, 1507, 2118 and 199 hectares, respectively. The sites were selected to represent a range in soil water availability. The forests on all the five sites are old-growth forests but have experienced disturbance in the form of grazing and illegal felling. The area experiences tropical monsoon climate with three seasons in a year, *viz.* summer (April–mid June), rainy (mid June–September) and winter (November–February). The months of March and October constitute transition periods, respectively between winter and summer, and between rainy and winter seasons. The maximum monthly temperature varies from 20 °C in January to 46 °C in June, and the mean minimum monthly temperature reaches 12 °C in January and 31 °C in May. According to the data collected from the meteorological stations of the state forest department for 1980–2010, the mean annual rainfall ranges from 1196 mm (Hathinala) to 865 mm (Kotwa site) (Chaturvedi et al., 2011a). About 85% of the annual rainfall occurs during the monsoon (rainy) season from the south-west monsoon, and the remaining from the few showers in December and in May–June. There is an extended dry period of about 9 months (October–mid June) in the annual cycle (Jha and Singh, 1990). The monthly rainfall varies from 6 mm in April to 334 mm in August.

2.2. Study design and field methods

At each of the five sites, nine plots, each of 100 m^2 (20 m × 5 m), were selected for sampling the vegetation and soil. Plots were randomly selected to reduce bias caused by within site differences in soil conditions. The size was decided on the basis of species area curve (Mueller-Dombois and Ellenberg, 1974). Rectangular plots were used because most plant distributions are clumped, and a rectangle can best encompass patches of different species (Kershaw, 1964). Further, rectangular quadrats may survey the landscape heterogeneity better than square quadrats because they intersect a greater number of microhabitats (Reese et al., 2005).

Soil moisture content (SMC) was measured as percentage by volume by theta probe instrument (type ML 1, Delta-T devices, Cambridge, England) at 10 random locations in each plot at 1 mo interval. Composite surface (0–30 cm) soil samples were also collected, but only once, from those locations for physico-chemical analysis. These samples were analyzed for texture (Sheldrick and Wang, 1993), organic carbon (Walkley and Black, 1934), total nitrogen (Bremner and Mulvaney, 1982) and total phosphorus (Olsen and Sommers, 1982) contents. To get the actual organic carbon content, the values obtained by Walkley and Black method were multiplied by a correction factor (1.95) given by Krishan et al. (2009) for similar soils of central India. The correction factor is based on the relationship between Walkley and Black estimate and that from oxidative combustion–infrared analysis method using total organic carbon analyzer. Soil bulk density at each site was determined by the core method (Krzic et al., 2000).

In this study, juveniles were considered as having >30 cm to 1.1 m height (H) and 0.5–3.2 cm stem diameter (D) at 10 cm above the ground. Kobe (1996) considered juvenile trees as having 0.2–7.8 cm diameter at 10 cm above the ground. Dufour-Dror (2007) considered 0.15–1.0 m high oak plants as established seedlings and young saplings. Our juvenile class is therefore midway between young seedlings and young saplings. In each plot, all individuals at juvenile stage were counted, marked with permanent marker and measured for basal area (BA) calculation. In each site, increases in D and H for all the individuals were measured four times per year at an interval of three months from July 2005 to June 2007. The annual increment was calculated as the sum of all the four increments in a year. Increments in D and H were measured with the help of Vernier calliper and metallic measuring tape, respectively. Wood samples were collected from five individuals of variable girths of a species present outside the study plots for the estimation of wood specific gravity (WSG) following the method described in Chaturvedi et al. (2010). Three categories of