Agriculture, Ecosystems and Environment 185 (2014) 197–207

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

# Fire and grazing modify grass community response to environmental determinants in savannas: Implications for sustainable use

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ARTICLE INFO

*Article history:*
Received 8 May 2013
Received in revised form
24 December 2013
Accepted 4 January 2014
Available online 27 January 2014

*Keywords:*
Herbaceous species composition
Fire frequency
Fire regime
MODIS
Tropical dry forests
Climate change

ABSTRACT

Tropical dry forests and savannas are important repositories of plant diversity and ecosystem services in the tropics. These ecosystems are also used extensively for grazing by livestock, and represent a critical element of the rural economy of many tropical countries. Fire is considered as a part of co-evolution in these ecosystems across the globe. However, in recent decades, there has been a shift in historical fire regime. Fire has become more frequent in these landscapes, and could be further enhanced under climate change. This poses threats to existing biodiversity, ecosystem processes, and rural economy. We asked how variability in fire frequency has influenced diversity and heterogeneity in grass species composition, and richness and abundance of grass species preferred by large herbivores (referred to as grazing acceptability) in a South Indian tropical savanna forest. We assumed that an increase in fire frequency acts as the active constraint and limits an ecosystem from attaining the maximum heterogeneity, and the maximum grazing acceptability (maximum richness and abundance of grass species preferred by herbivores) in its native settings. We used MODIS active fire and burned area products to estimate fire frequency across the landscape. A nested sampling approach was used to collect information on vegetation and soil at different fire frequencies. Quantile regression analyses indicated that diversity and heterogeneity in grass species composition as well as grazing acceptability decreased with increasing fire frequencies. We found that livestock grazing intervened with the observed vegetation patterns; grass species diversity and heterogeneity, and grazing acceptability increased with grazing intensity at lower quantiles. Other measured covariates, rainfall, and soil-fertility, alone were not able to explain the observed vegetation patterns in the landscape. The results show a need to control annual fires but allow and manage intermittent fires in this landscape. A complete suppression of fire is not desirable as fire releases nutrients from burning of deeper-rooted vegetation and thus acts as a periodic nutrient pump. It also played an important role in maintaining the grass cover by reducing shrub cover. Hence, it is important to consider the complex interactions between fires–grazers–soil–vegetation to develop effective management practices. We conclude that fire frequency should be managed at low to intermediate levels (one fire in every 5–9 years, resembling the native settings), and grazing regulated, in order to sustain wild and domestic herbivores, biodiversity, and other key ecosystem processes and services over the long-term.



## 1. Introduction

Tropical dry forests and savannas comprise about 40% of the terrestrial landmass (Scholes and Walker, 1993). These ecosystems are important repositories of plant diversity in the tropics (Uys et al., 2004; Sankaran, 2009) and sustain large mammal herbivore assemblages, which in turn support larger carnivore species (Eisenberg and McKay, 1974; Sankaran, 2009). These landscapes generate valuable provisioning ecosystem services such as fodder for livestock, fire-wood, small timber, and medicinal plants, and represent a critical element of the rural economy of many tropical countries (Burrows et al., 1990; Augustine, 2003). They are also important determinants of local micro-climate, nutrient cycling, carbon sequestration, and storage (Lewis et al., 2009). However, tropical dry forests and savannas are under severe threat from land-cover change (Prance, 2006; Silva et al., 2006). Miles et al. (2006)

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http://dx.doi.org/10.1016/j.agee.2014.01.002

concluded that 97% of tropical dry forests are at risk of destruction. In the remnant patches, one of the major threats to the biodiversity and ecological processes of these ecosystems is the changing fire regime, which is a result of large-scale habitat conversion, changes in fire management practices, and increasing human dependence (Ratter et al., 1997; Bond and Parr, 2010).

Fire has been an integral part in the co-evolution of tropical dry forests and savannas across the globe (Bond and Keeley, 2005; Bond et al., 2005). These ecosystems, characterized by a continuous C4-grass understory, burn often, and their floral and faunal components are believed to have evolved under a constant fire regime (Bond and Parr, 2010). However, with increasing human dependence on forest resources along with increased rate of fragmentation, the extent of burnt areas and frequency and intensity of fire in tropical landscapes have increased several folds over what they were in the past (Cochrane and Laurance, 2002; Cochrane, 2003). For example, Mouillot and Field (2005) reported a 49% increase in burnt areas from 1910 to 2000 in South Asian savannas, which increased from 25.3 Mha in 1910 to 37.7 Mha in 2000. Consequently, the fire return interval decreased from 11.2 years in 1910–1920 to 7.5 years in 1990–2000. Climate change could further exacerbate this threat in some regions (Dale et al., 2001).

In large parts of the Indian sub-continent, seasonally dry tropical forests, and savannas are the natural vegetation types (Ramankutty and Foley, 1999; Cardoso et al., 2008). Here, the majority of fires are surface fires, mainly burning the herbaceous layer, shrubs, and litter (Kodandapani et al., 2008). Kodandapani et al. (2004) have reported a threefold increase in fire frequency in South Indian tropical dry forests over the last 80 years, and the fire return interval shortened from 10, between 1909 and 1920, to 3.3, between 1989 and 2002. Thus, there has been a shift in the historical fire regime and this change is expected to have an impact on vegetation characteristics in these landscapes. However, our knowledge of the consequences of these shifts on diversity and composition of ground flora in these landscapes remains very poor.

The responses of herbaceous layers to increased fire frequencies in tropical savannas, across the globe, do not follow a consistent pattern and cannot be generalized to Indian savannas. For example, studies from the savannas of Cerrados and some drier parts of Africa have reported either an increase in herbaceous species diversity or no changes in diversity under recurring fire conditions (Higgins et al., 2000; Silva and Batalha, 2008); whereas, loss of diversity and abundance of herbaceous species, and changes in species composition have been reported as a response to frequent fires from other parts of the world (Cochrane and Schulze, 1999; Reich et al., 2001; Mehta et al., 2008a; Stephan et al., 2010).

In this study, we looked at the effects of recurring forest fire on herbaceous species in a South Indian tropical savanna forest, characterized by a continuous grass understory. These ecosystems play an important role in sustaining populations of both wild and domestic herbivores. The distribution and abundance of herbaceous species preferred by herbivores can determine the levels of co-existence between wild and domestic large herbivores (Fritz et al., 1996), and also the diversity and abundance of large herbivores (Olff et al., 2002; Archibald et al., 2005). Here, we focused on the effect of fire on the abundance and richness of grass species preferred by large herbivores in this landscape. Leigh and Vermeij (2002) argued that natural ecosystems are organized to support high productivity and diversity in their native settings, and any changes, such as an increase in fire frequency, tend to diminish its productivity and/or diversity in the short term. Fire by reducing the woody cover and increasing the herbaceous biomass (Sankaran et al., 2005) benefits the herbivores. However, increasing fire frequency can limit the use of a site by herbivores by encouraging a few fire tolerant but less preferred species, and thereby, limits an ecosystem from attaining the maximum diversity. We assumed that an increase in fire frequency acts as the active constraint, which limits the study ecosystem from attaining the maximum heterogeneity/diversity in species composition, and the maximum abundance and richness of preferred grass species in its native settings. We tested two specific hypotheses: (1) the diversity and heterogeneity in grass species composition decreases at high fire frequencies; (2) the abundance and richness of grass species preferred by large herbivores (henceforth, referred to as grazing acceptability) reduces at high fire frequencies. Studies have suggested abiotic factors (such as rainfall and soil-fertility) and biotic factors (such as grazing by herbivores) to have a role in shaping savanna vegetation (Polis, 1999; Bond, 2005; Augustine and McNaughton, 2006; Fuhlendorf et al., 2008; Beguin et al., 2011). Therefore, we considered the effects of both biotic and abiotic drivers, along with fire frequency in determining the vegetation patterns. We explain the observed vegetation patterns as a response to changes in fire regime and explore implications of our findings for sustainable management of these ecosystems.

## 2. Material and methods

### 2.1. Study area

Biligiri Rangaswamy Temple Wildlife Sanctuary - Male Mahadeshwara Hills and Kaveri Wildlife Sanctuary (BRT-MM HILLS-KAVERI) landscape forms a contiguous tract of tropical dry forests in South India that covers an area of approximately 3000 $km^2$ (Fig. 1). The elevation varies from 250 m to 1800 m asl. The forest type ranges from evergreen to dry deciduous to scrub, with large tracts of deciduous forests characterized by a sparse canopy and continuous grass undergrowth (Pascal and Ramesh, 1995). Riparian vegetation is characteristic along the river Kaveri. The annual rainfall varies from 500 to 1800 mm (Hijmans et al., 2005). For this study, we considered the drier savanna forest tracts of the landscape. Younger granites and peninsular gneiss characterizes the geology of the area. The soil type is Ustropepts with moderate to shallow gravelly-clay soils, and northern parts of the study site are characterized by rock outcrops associated with shallow gravelly-loamy soils (NBSS and LUP, 1994).

The landscape has a rich floral composition and a diverse assemblage of fauna. This has been identified as one of the most important tiger conservation landscapes (Sanderson et al., 2010). Eight ungulate species have been reported in the area. It supports the single largest population of Asian elephant (*Elephas maximus*) in the world and is one of the few strongholds for four-horned antelope (*Tetracerus quadricornis*) and grizzled giant squirrel (*Ratufa macroura*), two endemic mammals to Indian subcontinent.

Along with diverse wildlife and physiographic features, the landscape has a very high human density and a long history of human use. It has an indigenous Soliga tribal community that is dependent on forest product extraction. An estimated 1.7 million livestock reside in nearly 800 villages within and surrounding this landscape (All India Livestock Census dataset, 2007, http://dahd.nic.in/). These forested tracts play a critical role in supporting the rural economy by providing resources to a large portion of this livestock in the drier periods. Forest fire is a common feature in the savanna parts during the drier months of the year.

### 2.2. Identifying areas with different fire frequencies

We used moderate resolution imaging spectrometer (MODIS) Collection 5 active fire products (http://maps.geog.umd.edu) and burned area products (MCD45) (http://modis-fire.umd.edu), from January 2001 to May 2009, for identifying areas with different fire frequencies. MODIS fire products are used extensively to detect