Journal for Nature Conservation 28 (2015) 1–10

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Assessing the effect of management changes and environmental features on the spatio- temporal pattern of fire in an African Savanna Fire spatio-temporal pattern

Fabio Attorre[a,*], Navashni Govender[b], Anna Hausmann[c], Alessio Farcomeni[d], Alfredo Guillet[e], Edoardo Scepi[f], Izak P.J. Smit[b,g], Marcello Vitale[a]

[a] Department of Environmental Biology—Sapienza Universiy of Rome, P. le A. Moro 5, 00185 Roma, Italy
[b] Scientific Services, SANParks, PrivateBag X402, Skukuza 1350, South Africa
[c] School of Life Sciences, University of KwaZulu-Natal, 4041 Durban, South Africa
[d] Department of Public Health and Infectious Diseases—Sapienza University of Rome, P. le A. Moro 5, 00185 Roma, Italy
[e] Technical Unit—DGCS, Italian Ministry of Foreign Affairs, Via S. Contarini 25, 00194 Roma, Italy
[f] PROGES Consulting – Progetti di Sviluppo – S.r.l., Via Appennini, 46, 00198 Roma, Italy
[g] Centre for African Ecology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Private Bag 3, 2050 Wits, South Africa

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form 27 April 2015
Accepted 28 July 2015

Keywords:
Adaptive management
Fire management system
Generalized linear mixed models
Fire frequency
Fire intensity
Fire policy
Kruger National Park

ABSTRACT

Spatio-temporal variability of the fire regime in the Kruger National Park (KNP) has been analyzed for the 1957–2011 period. Generalized linear mixed models have been used to assess the variability of fire metrics, such as the burnt area, the fire frequency and intensity for the entire area as well as for the main environmental classification systems (geology, soil, vegetation) and fire management zones. This analysis supports the hypothesis that the spatial pattern of fire regime is strongly influenced by the environmental template defined by climatic, geological, pedological and vegetation features. Moreover, contrary to some previous studies, together with the precipitation trend, fire management changes had a significant role in determining the temporal variability of the fire regime at the scale of KNP, particularly regarding the burnt area and the fire frequency.

The complex interaction between the environmental template and management in determining the variability of the fire regime, as underscored by our study, defends the merit of adopting an adaptive planning/management based approach supported by quantitative analytic tools.

1. Introduction

Fire is a key ecological process in several biomes worldwide (Beerling & Osborne, 2006) and is a regular feature of African savanna landscapes (Bond & Keeley, 2005). Dry and warm winters, combined with abundant grass fuels and readily available sources of ignition (both lightning and humans), make these ecosystems naturally fire-prone (Archibald, Roy, van Wilgen, & Scholes, 2009). Hence, fires have been occurring in these environments for thousands of years, shaping the landscape, selecting for fire tolerant or even fire dependent flora and fauna, and determining the structure, function and dynamics of the ecosystem (Anderson, Cook, & Williams, 2003; Bond & Keeley, 2005; Bond & van Wilgen, 1996; Bond, Woodward, & Midgley, 2005; Govender, Trollope, & van Wilgen, 2006). Spatio-temporal fire patterns in a particular ecosystem are usually described in terms of frequency, seasonality, intensity, size and distribution (Gill & Allan, 2008). Several studies showed how fire regime could drive spatial and temporal variations in vegetation composition (Higgins, Bond, & Trollope, 2000; Sankaran et al., 2005; Scholes & Walker, 1993; van Langevelde et al., 2003), structure (Higgins et al., 2007) and dynamics (Ekblom & Gillson, 2010; Trollope, Trollope, Biggs, Pienaar, & Potgieter, 1998), which in turn are important in shaping nutrient patterns (Coetsee, Bond, & February, 2010; Treydte, Heitkonig, Prins, & Ludwig, 2007), habitat suitability, animal distribution (Riginos & Grace, 2008), and other cascading features affecting biodiversity (Parr & Andersen, 2006). However, despite the importance of fire in savannas, the response of species and ecosystems to fire regime and how this

* Corresponding author. Fax: +39 0649912901.
E-mail address: fabio.attorre@uniroma1.it (F. Attorre).

http://dx.doi.org/10.1016/j.jnc.2015.07.001
1617-1381/

could be affected by the environment, remain still to be fully understood (van Wilgen & Biggs, 2011). As a consequence, the way in which fire should be managed for the conservation of biodiversity is still an important and largely unresolved and debated issue in African savannas (Biggs and Potgieter 1999; Bond & Archibald 2003; Parr & Andersen 2006; van Wilgen & Biggs, 2011; van Wilgen, Govender, & MacFadyen, 2008).

In the Kruger National Park (KNP), one of the largest conservation areas in Africa (1,948,528 ha) located in the northeast of South Africa, active fire management has been conducted during the past six decades (Bond & Archibald, 2003; van Wilgen, 2009) and policy has changed over the years hand in hand with the emergence of new understandings of the role of fire in the system (Trollope, 1993; van Wilgen & Biggs, 2011; van Wilgen, Biggs, O'Regan, & Maré, 2000; van Wilgen, Govender, Biggs, Ntsala, & Funda, 2004; van Wilgen et al., 2008) and changing conservation paradigms (from a *nature-in-balance* paradigm to a *nature-evolving* paradigm).

A synthesis of the different fire management policies adopted in KNP since 1926 to present is provided in Table 1. Arguably the most significant change occurred in 2002 when the KNP adopted an adaptive fire management approach in recognition of the heterogeneous nature of ecological systems as a prerequisite for the conservation of biodiversity, which constitutes the main goal of the Park (Pickett, Cadenasso, & Benning, 2003; van Wilgen, Govender, Forsyth, & T. Kraaij, 2011). By ensuring that management actions were spatially dynamic over time, natural and unplanned fires were complemented with prescribed fires on the basis of mean rainfall of the previous two years and the time since the last fire (van Wilgen et al., 2004, 2011, 2008). The policy, which was operational from 2002 to 2011, included a set of annual and monthly target areas to be burnt at the inception of each fire season based on measurements of standing grass biomass taken in March, at the end of the growing season (Brockett, Biggs, & van Wilgen, 2001). This policy was aimed at achieving the Park's biodiversity conservation goal by promoting a variable fire regime (van Wilgen et al., 2011). The assumption being that promoting a variable fire regime would result in the maintenance of biodiversity by creating environmental heterogeneity across the Park (Parr & Chown, 2003; van Wilgen, Biggs, & Potgieter, 1998; van Wilgen et al., 2011). Albeit never fully tested (Parr & Andersen, 2006) such an assumption forms the basis of KNP fire management's goals, which are currently expressed in terms of a desired fire regime whose outcomes are monitored against Thresholds of Potential Concern (TPCs). These TPCs are based on fire metrics such as area burnt and fire intensity based on the knowledge gained so far about fires in the Park (Govender et al., 2006; Higgins et al., 2000; Trollope, 1993; van Wilgen et al., 1998, 2000, 2004, 2007, 2008).

In 2012, changes in fire management were adopted among which, the most important was to set objectives and associated TPCs not for the entire Park as previously done, but for ecologically defined zones which were spatially delineated using long-term annual rainfall, fire return periods, and geological substrata as stratification criteria (van Wilgen et al., 2014).

In order to support such a complex management pursuit, the KNP embarked in developing a thematic fire management system (FMS) containing procedures and tools for automatically organizing, calculating and visualizing relevant fire management information such as precipitation, area burnt, fire frequency and intensity for the entire Park. The FMS allows both the analysis across the entire Park and that of spatial subsets based on a range of relevant environmental and management land classifications. The FMS tested during the 2013/2014 fire season is meant to assist the Park fire managers and scientists to define and execute management activities assessed against predefined TPCs in order to support an adaptive management approach.

In this paper, we used information produced by the FMS to analyze at fine scale and in a systematized manner the spatio-temporal pattern of fire in the Park over the last five decades. This is in order to tap into the extensive and relevant scientific and management contribution emerging from the significant asset of experience, data and knowledge obtained by fire management in the KNP so far, and to assist managers in combining this information for decision-making processes in planning and monitoring.

We did this by quantifying annual extent of burnt area, fire frequency and estimated fire intensity at the scale of the entire KNP as well as at the scales of the recently established fire management zones and the main land classification systems (i.e. geology, soil, vegetation). Furthermore, we analyzed the data across various temporal scales, including the entire time series (1957–2011) as well as time periods defined by the different fire management eras/policies, as outlined in Table 1.

Table 1
Fire management policies in KNP.

Period	Fire policy	Description
1926–1947	No official policy	Following the creation of the Park (in 1926) areas were occasionally burnt mainly to provide new fodder for grazing (Govender, 2003)
1948–1956	Fire exclusion	From 1948 a fire-suppression policy was implemented which, however, led to some very large and dangerous fires (Bond & Archibald 2003)
1957–1980	Fixed prescribed burning system	In 1957, regular prescribed burnings were applied at three-year cycles on fixed areas (454 burning blocks) during the spring. The policy was aimed at assuring c̈old" fires in order to minimize damage to flora and fauna. However, it led to some unexpected effects such as the growing dominance of species of grass characteristic of very poorly managed range and a decline in large tree densities (Bond & Archibald 2003)
1981–1991	Flexible burning system	Fires in burning blocks were timed to account for fuel loads, post-fire age, and mean annual rainfall and it was meant to encourage a more variable fire return interval, a longer fire return interval in drier areas and a wider seasonal distribution of fires (van Wilgen et al., 2004)
1992–2001	"Natural" (lightning-driven) fire regime	All lightning-ignited fires were allowed to burn freely, while other fires were to be suppressed (van Wilgen et al., 2004; van Wilgen, 2009) looking for a more variable, less intense and more "natural" fire regime (Govender, 2003)
2002–2011	Adaptive management	A 2001 assessment of the 9 years of "Natural" fire managementmade clear that the objectives of that policy were not being achieved, and that the anthropogenic ignitions dominated over the lightning ones (van Wilgen et al., 1998). Hence, the lightning-driven "Natural" policy was replaced by an "adaptive" approach, entailing patch ignitions tailored on biomass and 2-year preceding rainfall (see the text for major detail), whose implementation was monitored through a set of Thresholds of Potential Concern (TCPs) for the entire Park
2012–present	Adaptive management—implemented by fire zones	Still patch-mosaic fires, as during the preceding policy, but with fire objectives, associated TCPs and management actions now variable for ecologically delineated management zones (i.e. delineation based on historical fire frequency, rainfall and geology)