PRACTICAL WAYS OF INCORPORATING VARIATION IN FIRE INTENSITY INTO FIRE MANAGEMENT OF AFRICAN SAVANNAS

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Abstract
Fire is important for the maintenance and conservation of African savanna ecosystems. Despite the importance of fire intensity as a key variable of the fire regime, it is seldom measured, included in fire records or explicitly used to manipulate the ecosystem. Throughout the five decades of fire management in the Kruger Park managers have only been able to manipulate the fire intensity variable of the fire regime. In practice, because of a fairly fixed seasonal approach till the 1990's, high intense fires dominated the fire regime. Fire intensity has important effects in savanna vegetation, especially on the dynamics of the tree layer. Intensity varies with season (because of differences in fuel moisture), as well as with fuel load. Managers of African savannas can manipulate fire intensity by choosing the season of fire, and further by burning in years with higher or lower fuel loads. The KNP has implemented a monitoring system guided by Thresholds of Potential Concern and is now attempting to directly influence variation in intensity because of expected beneficial effects for biodiversity.

Key-words: fuel loads, Kruger National Park, long-term ecological experiment, threshold of potential concern

Introduction
African savannas are fire-prone, and the importance of fire in determining the composition, structure and function of these ecosystems (Anderson *et. al.* 2003; Bond and van Wilgen 1996) is probably the oldest issue in savanna ecology that remains contentious (Scholes and Walker 1993).

Savannas are tropical grasslands with scattered trees that occupy about 20 % of the land surface of the Earth and 40 % of Africa. These ecosystems are dynamic in their structure and composition, which changes in response to fluctuations in rainfall, levels of herbivory and occasional fires. Without fire, considerable areas of African savannas could potentially develop into closed woodlands under the current climate, and the occurrence of fires over the past *c.* 8 million years has also seen the evolution of a fire-tolerant and fire-dependant flora (Bond *et. al.* 2005). The appropriate use of fire in savannas is therefore an important consideration for managing these ecosystems.

In African savannas, active fire management has been practised for many decades (van Wilgen *et. al.* 1990), even though policies and practices have changed as new evidence pertaining to the role of fire emerged (Mentis and Bailey 1990; Bond and Archibald 2003). Reasons for changes to policies and practises are often driven by philosophical debates, namely, (i). Is fire necessary? (a protection (no fire) versus a active burning policy), (ii). Are ecosystems stable? (a fixed versus a variable burning policy and (iii). Should we interfere? (a natural fire versus a prescribed burning program).

The question of if and how managers of large conservation areas have been able to influence fire patterns and the fire regime, with different management approaches, is often difficult to answer because it requires comprehensive fire records from large areas, and such records are rare. However, the KNP in South Africa is an exception, since good and long-term fire records are available (van Wilgen *et. al*. 2000).

Recent analysis by van Wilgen *et. al.* 2004, suggests that management had little if any effect on the extent of area burned or on the variability in inter-fire intervals. These elements of the fire regime are strongly influenced by rainfall patterns, regardless of management approaches. However, van Wilgen *et. al.* 2004, stated that managers were able to affect the spatial heterogeneity of fire patterns and the seasonal distribution of fires, thereby influencing the intensities that fires burn.

The influence of factors such as season of fire, post-fire age and fuel moisture content on fire intensity was determined from 956 experimental fires between 1982 and 2003 (Govender *et. al. in press*). These relationships were then used to examine the historic effects of changing fire management approaches on the fire intensity regimes in the park. Finally, a method to monitor the variation in fire intensity, guided by Threshold of Potential Concerns (TPC's) for KNP is discussed.

Methods

Field Site

The Kruger National Park is one of the largest proclaimed and officially protected natural areas in the world. Established in 1926, the park is approximately 1 898 458 ha, occupying almost 2.5 percent of the total land surface area in South Africa (Figure 1). It is situated in the north-eastern region of South Africa and is separated from adjoining Mozambique by the Lebombo mountain range in the east and from Zimbabwe in the north by the Limpopo valley. Mean average rainfall for the entire park is approximately 500 mm, but varies around 350 mm in the north to around 750 mm in the south. The park is also distinctively divided in two by its geology, with granitic sandy soils on the western half of the park and basaltic clay soils on the eastern half. The vegetation of the park is dominated by trees from the *Acacia, Combretum, Sclerocarya* and *Colophospermum* genera. The flora of the park comprises +/- 2000 taxa, including over 400 tree and shrub species, and over 220 grasses. The fauna of the park includes 148 mammal and +/- 500 bird species.

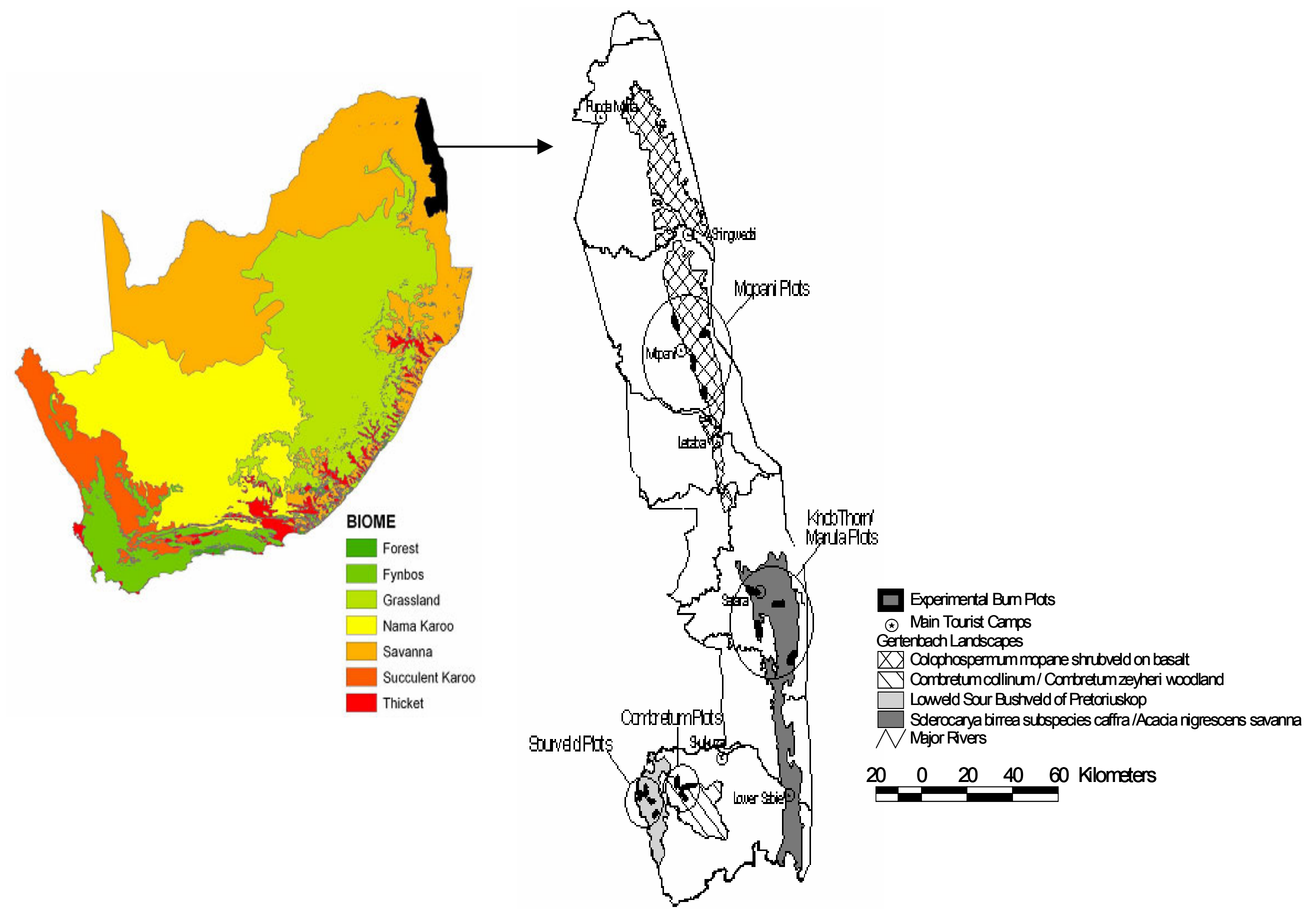

Figure 1. Distribution of the experimental burn plots within the Kruger National Park. KNP's location with South African savanna biome.

KNP Fire History

The park's fire history has been described in detail by van Wilgen e*t. al*. 2000, 2003, 2004. Briefly, between 1957 and 1980, regular prescribed burning was conducted every 3 years, in spring after the first rains. From 1981 to 1991, the regular prescribed burning was replaced by 3-year prescribed fires that were more seasonally flexible and from 1992 to 2001, a "natural" fire policy was adopted, in which all lightning-ignited fires were allowed to burn freely, while at the same time attempts were made to prevent/suppress all other fires.

Experimental Burning Plot
A series of experimental burning plots (7 ha each) was established in savanna vegetation in the Kruger National Park in 1954. The experiment covered fires at annual (in August only), biennial and triennial intervals (in February, April, August, October and December). After 1974, quadrennial and sexennial burns in October were added to the experiment. Treatments were replicated four times in each of four major landscapes in the park (Figure 1). The experiment is described in detail by Biggs *et. al*. 2003.

Fire intensity was determined using Byram's (1959) fire-line intensity as:

$$I = Hwr$$

Where: I = fire intensity (kW m^{-1}), H = heat yield (kJ g^{-1}), w = the mass of fuel combusted (g m^{-2}), and r = rate of spread of the head fire front (m s^{-1}).

Assigning Intensity to Historical Fire Records
In order to estimate the historic fire intensity regime for the entire Kruger National Park (1957-2001), broad classes of fire intensity, based on the mean fire intensities estimated from the experimental burning plots was defined. For each of four seasons (summer, autumn, winter and spring), the mean fire intensity for subsets of plots supporting different categories of fuel loads at the time of the fire (the categories were < 1000, 1000-2000, 2000-4000, 4000-6000, and > 6000 kg ha^{-1} respectively) was determined. For each combination of season and fuel load, we assigned a class of mean fire intensity as follows: Very low (< 500 kW m^{-1}); Low (500-1000 kW m^{-1}); Moderate (1000-2000 kW m^{-1}); High (2000-4000 kW m^{-1}); and Very high (> 4000 kW m^{-1}) (Table 1) (Govender *et. al.* in press). The historical KNP database of fires was divided into the three periods (1957-1980, 1981-1991, and 1992-2001) that were subjected to different management approaches.

Table 1. Classes of fire intensity associated with different fuel loads and seasons of burn in the Kruger National Park. The mean fire intensities, and the number of fires on which these means are based, is shown.

Season of burn	Descriptor	Fuel loads (kg ha^{-1})				
		< 1000	1000 – 2000	2000 – 4000	4000 – 6000	> 6000
Summer (1 December – 31 March)	Fire intensity class	Very low	Low	Moderate	Moderate	Moderate
	Mean fire intensity (kW m^{-1})	287	578	1031	1432	1650
	Number of fires	1	17	95	83	31
Autumn (1 April – 30 May)	Fire intensity class	Very low	Low	Moderate	High	High
	Mean fire intensity (kW m^{-1})	No data	732	1455	2106	1900
	Number of fires	0	19	62	79	23
Winter (1 June – 31 August)	Fire intensity class	Very low	Low	High	High	Very high
	Mean fire intensity (kW m^{-1})	194	835	2082	3625	4385
	Number of fires	4	65	187	83	19
Spring (1 September – 30 November)	Fire intensity class	Very low	Low	Moderate	High	Very high
	Mean fire intensity (kW m^{-1})	No data	712	1570	3066	5253
	Number of fires	0	15	103	55	16

Threshold of Potential Concerns (TPC's)
Threshold of Potential Concerns are a set of operational goals that describe the spatiotemporal heterogeneity conditions for which Kruger ecosystem is managed. TPC's are defined as upper and lower levels along a continuum of acceptable ecosystem change (Biggs and Rogers 2003). When levels are reached, or models predict it will be reached, it prompts an assessment of the cause and extent of change. The assessment provides the basis for deciding whether management action is needed to moderate the change or to recalibrate the TPC.

Fire TPC's
The fire programme and development of fire TPC's is one of the successful and longest running programmes in KNP. Initially the suit of fire TPC's consisted of seven variables (Wilgen e*t. al*. 1998), but through new research and improved understanding there are currently two fire TPC's. One representing "Spatial variation in patchiness (fire patterns)" and the other "Variation in fire intensity". It is believed that these two effectively cover for all prior TPC's. The fire intensity TPC will be flagged when the defined intensity classes (very low to low, moderate & high to very high) is below 20% or exceeds 50% of the total area burnt. Temporally this will be based on a five-year cycle or if there is a dominance of any intensity class in any two-years within a five-year period.

Results
Fuel Load
Significant differences in fuel loads were found between annually burnt plots, those burnt biennially, triennially and quadrennially, and those burnt sexennially ($P < 0.05$) (Figure 2).

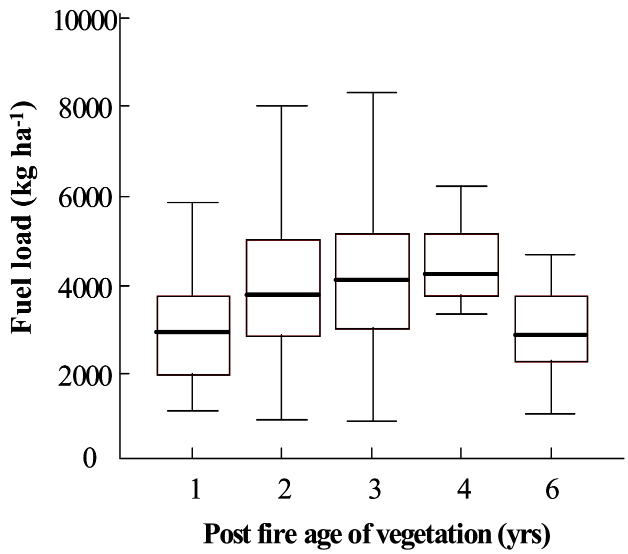

Fig. 2. Grass fuel loads estimated prior to experimental fires at different post- fire ages on experimental burning plots in the Kruger National Park. Box and whisker plots show the median, quartiles and a range excluding outliers (outliers, defined as values >1.5 * inter-quartile range from the upper and lower box edges, not shown).

Fire Season and Fuel Moisture Content
Significant differences in fuel moisture content were found between summer, autumn and spring, and winter ($P < 0.05$). The mean FMC was lowest in winter (28%), increased in spring and autumn (53%), and was highest (88%) in summer (Figure 3).

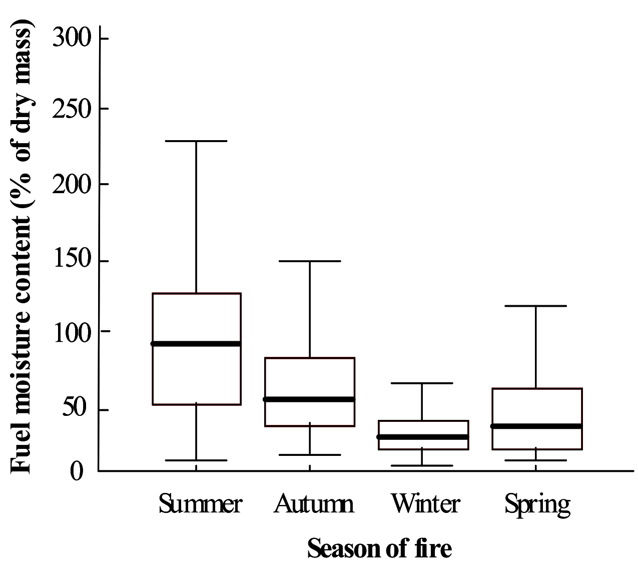

Fig. 3. Grass sward moisture content estimated prior to experimental fires in different seasons on burning plots in the Kruger National Park. Box and whisker plots show the median, quartiles and a range excluding outliers (outliers, defined as values >1.5 * inter-quartile range from the upper and lower box edges, not shown).

Significant differences in fire intensity were found between summer, autumn and winter fires ($P < 0.05$) due to the more than three-fold effect on fuel moisture content differences between summer and winter. Mean fire intensities were lowest in summer (1225 kW m^{-1}), increased in autumn (1724 kW m^{-1}), and were highest in winter (2314 kW m^{-1}) (Figure 4).

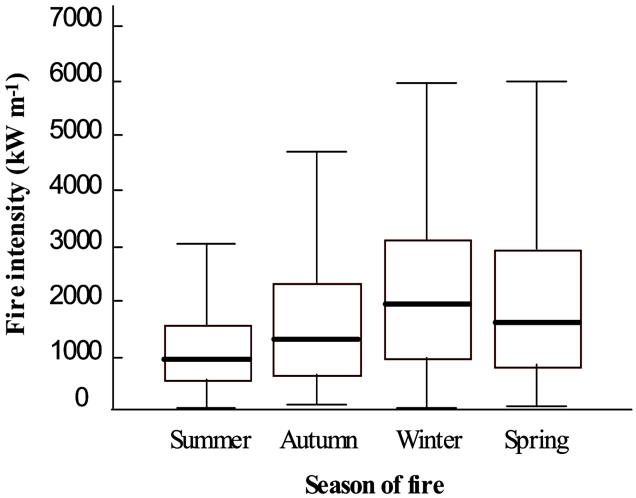

Fig. 4. Fire intensities in different seasons on experimental burning plots in the Kruger National Park. Box and whisker Plots show the median, quartiles and a range excluding outliers (outliers, defined as values >1.5 * inter- quartile range from the upper and lower box edges, not shown).

Changing Management Policies on Fire Intensity

During the period between 1957 and 1980, a total of 7.8 million ha was burnt. Fires were predominantly in the moderate intensity class (59% of the area) (Figure 5). Between 1981 and 1991, when 1.7 million ha was burnt, 71.1% of the area burnt as moderate fires. Between 1992 and 2001, 2.8 million ha was burnt. The majority of fires in this period (50.1% of the area) were in the high intensity class. It was also only in this period that a small number fires (0.2% of the area) were classified as of very high intensity, having occurred in winter or spring when fuel loads exceeded 6000 kg ha^{-1} (Govender *et. al.* in press).

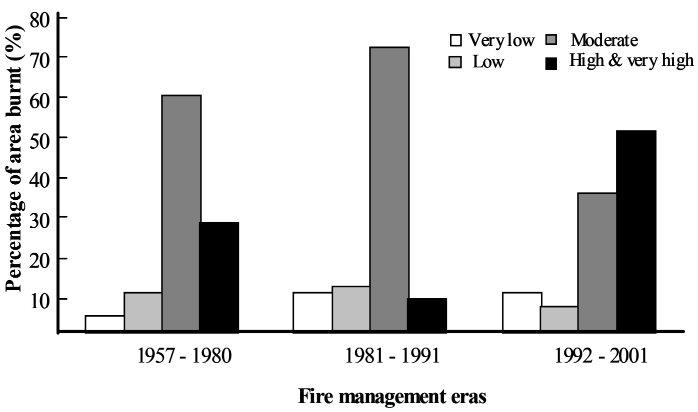

Fig. 5. The proportion of area burnt in classes of fire intensity (see Table 3) during three distinct eras of fire management. The eras are (1) 1957 – 1980, regular prescribed burning; (2) 1981 – 1991, flexible prescribed burning; and (3) 1992 – 2001, "natural" fires; the areas burnt in each era were 7.8, 1.7 and 2.8 million ha respectively.

Discussion

Fire intensity has an appreciable effect on African savanna trees. Relatively high fire intensities will kill the aerial parts of medium-height woody plants, forcing them to re-sprout from the base after fire. It is only when these saplings grow tall enough to escape the flame zone (which increases with increasing intensity), and are able to continue growing from aerial parts, that they are recruited into larger size classes of trees. For example, fires of 3000 kW m^{-1} will "topkill" 90 % of tree saplings 1 m tall, but only 40 % of those that are 2 m tall (van Wilgen *et. al.* 1990). The number of times that these critical intensities are achieved is a key determinant of recruitment of trees into the larger size classes (Higgins *et. al.* 2000).

Our analysis has demonstrated that there has been a recent shift towards higher intensity fires in the most recent decades (Figure 5), which may have resulted in the homogenisation of the landscape (van Wilgen *et. al.* 2003). The KNP have therefore recently adopted an approach that seeks to diversify the range of fire intensities (which will be monitored by the TPC) of management fires. Cooler or lower intensity fires are achieved by applying fires early in the season (April-June), rather than later in the fire season (August-October). Therefore allowing a lower percentage "topkill" and greater recruitment of trees into the larger height class.

Conclusion

Managers of conservation areas in South Africa are currently reviewing their fire management policies, in response to changes in ecological concepts and a new focus on biodiversity conservation (Bond and Archibald 2003). Despite recent advances in understanding, the ecological impacts of fires on all elements of the biota are not known in sufficient detail to be able to prescribe appropriate fire regimes with confidence. The managers of some areas (including the KNP) have, in response, opted to use fire patterns as surrogate measures of achieving diversity goals, on the assumption that a diversity of fire patterns (including a diversity of fire intensities) will promote the conservation of biological diversity (van Wilgen, Biggs and Potgieter 1998).

Acknowledgements

We thank the South African National Parks for access to data. The role of the team that maintained the fire experiment (especially Andre Potgieter) is gratefully acknowledged. Nick Zambatis, Steve Higgins and Peter Dye provided valuable inputs.

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