
Assessing the impacts of fire on the vegetation resources that are available to the local communities of the seasonal wetlands of the Okavango, Botswana, in the context of different land uses and key government policies

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Abstract

The Okavango wetlands in north western Botswana are the most fire-prone environment in Botswana. Most of these fires are anthropogenic. The fires in this environment are thought to impact the environment negatively and therefore practices that are associated with extensive use of fire have been strongly criticized. Despite this, there has been little work done to understand how these fires impact the wetlands environment and its dynamics, especially the vegetation resources that are used by the local communities in the wetlands. The objective of the study was to identify fire spatial and temporal trends in relation to settlement distribution, through the use of remote sensing, socio-economic and *phytosociological* surveys. The fire history results show that geographically there has not been any significant change in vegetation structure and that in fact fires may have promoted biodiversity. The results of analysis show an overall variance on vegetation structure of 23% whereas the rest are unaccounted for. There is a strong association between settlements, ethnicities, literacy and fire occurrences. The most fire-prone areas are inhabited by communities that have used fire in the past for various resource use practices.

Key words: fires, land use, Okavango, resources, vegetation

Introduction

Fires have been part of savannas since their origins, i.e. the characteristics of savanna vegetation are associated with

prevailing historic fire regimes in these ecosystems (van Wilgen *et al.*, 1997). However, recently human access to pristine environments, changing land use and natural resources management practices have led to higher fire incidences in some ecosystems that used to experience less frequent fire regimes, with fire characteristics depending mostly on climatic variables and accumulation of fuel loads.

The impact of fires on southern African savanna vegetation and their distribution has been studied by among others Justice *et al.* (1996), Trollope *et al.* (1996) and van Wilgen *et al.* (1997). According to the work of Trollope, van Wilgen and others, there are a number of factors to consider when assessing the impacts of fire on vegetation, including type of fire, period of fire (season), vegetation status (desiccated or moist), climate (wind, rainfall, temperature and relative humidity of the air), plant species synecology (especially stage of development), and the frequency and distribution of fire events (Justice *et al.*, 1996). According to Bond & van Wilgen (1996), fire regimes have *event* and *interval* dependant effects. *Graminoid* and forbs species behave differently compared to woody species during and after fire events. Certain grass species have been shown to respond positively to fire regimes, e.g. *Imperata cylindrica* (L) P.Beauv., a floodplain grass species in the Okavango wetlands, responds to fire by flowering, hence fire events trigger one form of reproduction (Ellery & Ellery, 1997).

In succession terms, a high-intensity fire will reduce a climax plant community to a pioneer stage, initiating primary succession, whereas a fire of low or moderate intensity will only slightly alter the plant community, resulting in regeneration at a serial stage or climax plant community stage, hence secondary succession (Bond &

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van Wilgen, 1996). Clementsian theory categorizes fire as a regeneration succession agent, however, aspects of fire induced succession correspond to other models which includes biogenic succession, regeneration succession and allogenic succession (Begon, Harper & Townsend, 1986).

The study area, Okavango wetlands (Fig. 1), has a number of conflicting natural resources management practices when it comes to fire issues. The current limitation on research information relating to occurrence of fires in the area makes it difficult to put in place a management strategy, especially without an operational fire management plan. Generally, there has been limited literature relating to management of fires in the wetlands (Denny, 1985).

To develop a holistic fire management plan, the biophysical aspects, i.e. fire distribution and vegetation dynamics have to be integrated with the human element intervention. This involves taking into account all natural resources management and land-use practices including the use of fire to identify the most prominent among these and then assess the notable impacts on the vegetation resources.

Materials and methods

Twenty-six Landsat TM quarter scenes (covering the period 1989–2001) were processed geometrically and radiometrically to identify burned areas. The Mid Infra Red

Burn Index (MIRBI) (Trigg & Flasse, 2001), a technique developed to detect burned surfaces based on empirical ground spectroradiometry data was used. The burn index is expressed as:

$$\text{MIRBI} = 10\text{LMIR} - 9.8\text{SMIR} + 2, \quad (1)$$

where MIRBI is mid infra red burn index, LMIR is long mid infra red bands and SMIR is short mid infra red bands.

The burned area extraction was based on Landsat images, bands 5 (1.55–1.75 μm) and 7 (2.08–2.35 μm). A standard threshold at 1.7 was used to separate burned area from other features, except water bodies. These bands fall within the mid infrared range of the electromagnetic spectrum and therefore are most appropriate for detecting burned surface ash which has a peak reflectance at around 1.6 μm for complete combustion vegetation fuel loads (Eva & Lambin, 1998). The Thermal band 6 (10.4–12.50 μm) in the form of brightness temperature ($^{\circ}\text{K}$) and near infrared band 4 (0.75–0.90 μm) were used to complement MIRBI by masking out water bodies. The burned area maps were overlain with vector data for quantitative and qualitative analysis, and for navigation purposes. Primary quantitative data included Landsat data. Secondary data were MODIS active fire data and vector data files including those from Heintz (2005) fire maps.

A vegetation survey was conducted during the wet season of 2006. Plant identification keys were used as

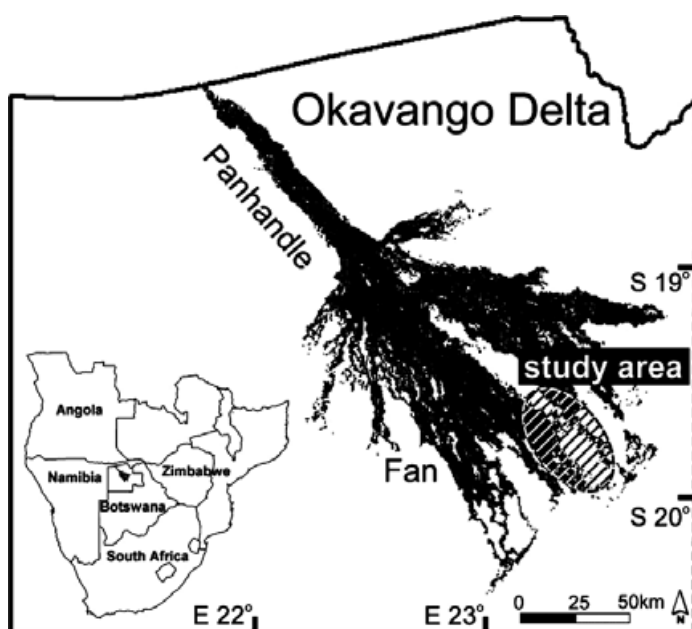


Fig 1 Study area location on the seasonal floodplains of the Okavango wetlands in Botswana

quick reference for common and Latin names of specimen. OKAGRASS (van Oeveren *et al.*, 2000) a grass identification key was useful in the field and in the laboratory, especially the illustrative figures of about 199 grass species in the Okavango. The Peter Smith Herbarium collection of about 6000 specimen in Maun was instrumental in identification of specimen.

Identification of variable fire frequency sites and navigation to these features was achieved using a hand held GPS receiver (Garmin 72, Kansas, MI, USA). Stratified random sampling design was used for vegetation sampling, and was conducted along 100-m line transects at each site. The transects were laid across obvious gradients, e.g. from river bank to woodland instead of along river bank. Vegetation surveys used *phyto-sociological* technique based on *braun blanquet* (Mueller-Dombois & Ellenberg, 1974; Westhoff & van der Maarel, 1978; Ellenbroek, 1987), with modifications from Londo (1984). The herbaceous layer cover was assessed over 2 × 2 m plots whereas the woody cover was assessed over a 10 × 20 m plot, with the smaller plot nested within the larger plot as according to Ellery & Tacheba (2003). Above ground biomass, clippings were collected over a surface 20 × 20, 50 × 50 or 100 × 100 cm depending on the amount of biomass at site (Ellery & Tacheba, 2003). To estimate live biomass the clippings were weighed and oven dried at 80°C for 48 h.

The socio-economic data were collected through an administered questionnaire. A total of 190 households were visited, but only 166 household data were obtained. The questionnaire was centred on the use of fires by the different ethnicities, perception on current policies against fire use and state of fires in the environment as observed by the local communities. Other household data included household head, gender, education, marital status, settlement and ethnicity. The data were analysed using Statistical Package for Social Sciences (SPSS, 13.0, Chicago, IL, USA).

Results

Fire surveys

The analysis of Landsat TM data at specific sites corresponding to human settlements showed trends in spatial distribution of fires, through detection of burn scars. Total burned area was recorded over each site of 144 km² through the twelve seasons. Table 1 shows the area burned during the early and late season. The sites at

Table 1 Burned area total from 1989 to 2001 for the image subsets in square kilometres

	Area (km ²)			
	Xaxaba	Disthipi	Boro	Maun
Late season total	122.36	192.16	112.13	28.33
Early season Total	155.30	112.94	43.36	5.74
Overall accuracy (Pr)	53.81%	43.38%	41.30%	55.78%
Kappa coefficient (K)	0.3465%	0.1421%	0.0226%	0.4327%

Xaxaba and Ditshipi are located in a Wildlife Management Area (WMA) whereas Boro and Maun are in communal areas (Fig. 1). The accuracy assessment of the mapped products, e.g. landcover changes and burned areas, was conducted using the standard matrix (Congalton, 1991), with results expressed through user accuracy, producer accuracy, errors of omission and commission, overall accuracy and kappa coefficients (Table 1).

The analysis of the spatial distribution of burning identified floodplains and grasslands as the most fire-prone vegetation types in the seasonal wetlands. Woodlands and Pans are rarely burned primarily due to relatively low biomass cover. Figure 2 shows the spatial distribution of the landcover types in 2001 with cumulative burning in the areas as extracted from the images at Xaxaba (1989–2001). The sites at Xaxaba and Ditshipi had the highest incidences of fires based on both the burned area scars and active fire detections. Areas that are regularly inundated are the most fire prone in the wetland.

Vegetation surveys

The analysis of vegetation data shows that fire frequency did not have long-term negative impact on vegetation structure and species composition. The herbaceous layer comprised 116 plant species recorded. Most of the species are replaced in the following season after the fire. The Shannon–Wiener index of diversity (*H*) shows that floodplain and grasslands that are frequently burned have a relatively high biodiversity compared to other vegetation types.

The canonical correspondence analysis result plot was used to plot data based on fire frequency (Fig. 3). This result

shows that the most fire-prone plant communities include species like *Imperata cylindrica*, *Miscanthus junceous* (L) and *Phragmites australis* (L), i.e. floodplain communities. The first and second axes show that the high fire frequencies are most prominent in the first and second quadrant of the ordination axis. Fire frequencies are observed at lower elevation due to inundation at these sites.

The Monte Carlo test analysis of association between environmental variables and species distribution showed that 1% of randomized runs has species–environment correlations greater than the observed. Therefore, the null hypothesis H_0 that there is no relationship between the matrices (species and environment variables) is rejected and the alternative H_1 is accepted, that there is a relationship between the species and environmental data ($P \leq 0.01$).

These results therefore show that using the Monte Carlo test the relationship between species data and environmental variables can be accepted to be more than just by chance and as such, the environmental variables can be accepted to have significant associations with the observed species distributions and plant communities. However, the level of variability that can be explained on the species data through their associations based on these datasets is only 23%. The rest of the variation in the species data is not explained.

Socio-economic survey

The analysis of the socio-economic data identified the association between cultural practices, settlements distribution and fires. The results generally identify the settlement distribution as having a strong association with fire distribution. Further analysis shows that cultural practices associated with natural resources management that involves use of fires are more popular with some cultural groups than others. Bayei culture which mainly practices harvesting vegetation based resources, e.g. *Phragmites* reeds, use fires regularly for clearing floodplains that these resources grow in. The results show that most of the illiterate respondents are against policies because they do not have a background on conservation education, but rather they stay with their cultural beliefs or regular burning despite the chances of conviction when caught.

The chi-squared test for independence between respondents' perception of fire policy and their culture show significant results, i.e. there is a significant difference between the perception of the Bayei and that of other ethnicities regarding current fire policies. This test statistic

Table 2 Presentation of respondents' opinion on policy based on chi-squared test

Culture	Do you believe that fire management policies could be improved by allowing local stakeholders to burn the area they have traditionally burned for social and cultural purposes?			Total
	No change	No	Yes	
Others				
Count	5	52	15	72
Expected count	4.4	41.5	26.1	72.0
% Within culture	6.9	72.2	20.8	100.0
% Within (question)	50.0	55.3	25.4	44.2
% of total	3.1	31.9	9.2	44.2
Bayei				
Count	5	42	44	91
Expected count	5.6	52.5	32.9	91.0
% Within culture	5.5	46.2	48.4	100.0
% Within (question)	50.0	44.7	74.6	55.8
% of total	3.1	25.8	27.0	55.8
Total				
Count	10	94	59	163
Expected count	10.0	94.0	59.0	163.0
% Within Culture	6.1	57.7	36.2	100.0
% Within (question)	100.0	100.0	100.0	100.0
% of total	6.1	57.7	36.2	100.0
	Value	df	Asymp. Sig. (two-sided)	
Pearson chi-square	13.284 ^a	2	0.001	
Likelihood ratio	13.738	2	0.001	
No. valid cases	163			

^aOne cell (16.7%) has expected count <5. The minimum expected count is 4.42.

illustrates the significant difference shown by the Bayei against other cultures mainly because of their traditional use of fires (Table 2). Natural resources management practices that are associated with other cultures include livestock and crop farming which mainly avoid the use of fire as it damages forage.

Discussion

The burned area extraction method used in the study has been proved to be effective in mapping burned area through comparison and validation with field data (Roy *et al.*, 2005) as well as in comparison to unsupervised

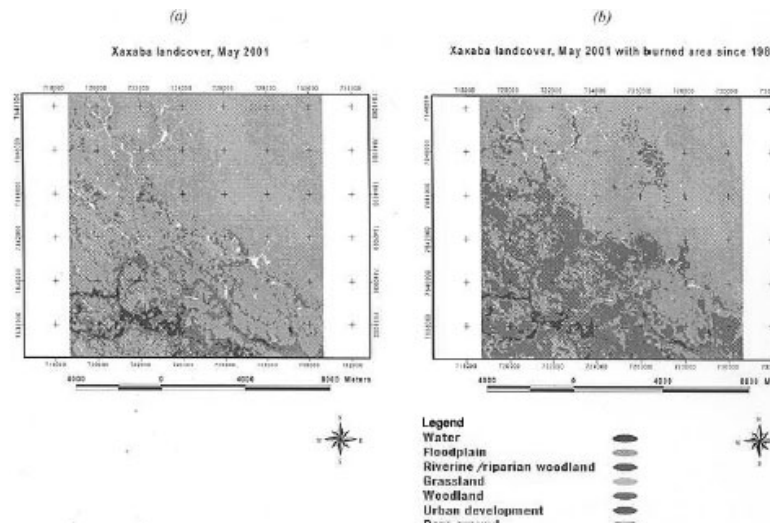


Fig 2 Landcover as of May 2001, and the cumulative burning since 1989

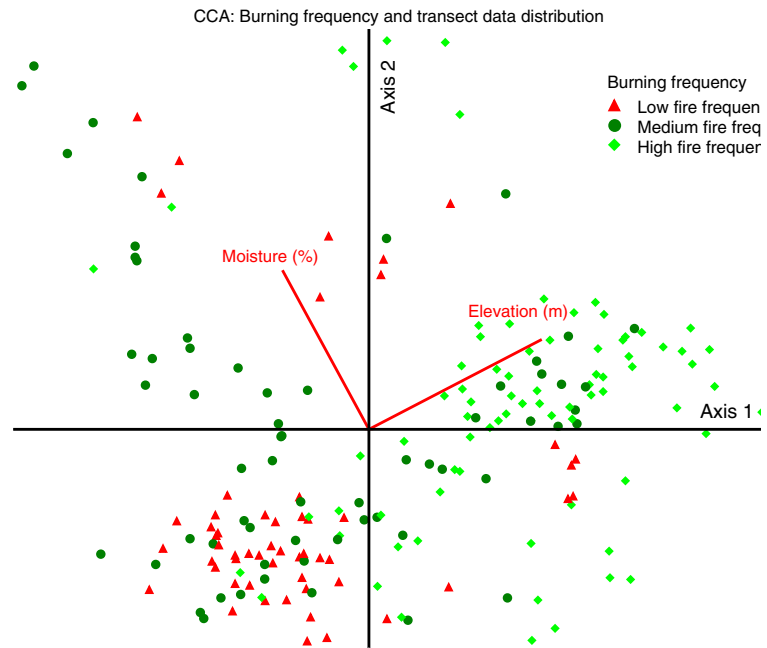


Fig 3 Burning frequency and plot data distribution

classification techniques that have been used by Heil (2005). Unsupervised classification, though used by many authors (Wisell, 2001; Cassidy, 2003), is not the most effective in extracting burned area surfaces of noncalibrated images (Stropiana *et al.*, 2003). The burned area mapping in this study was based on a combination of the physical characteristics of vegetation (Eva & Lambin, 1998) and the radiometry of burned scars (Trigg & Flasse, 2001).

The objective was to assess landcover changes due to burning and impacts on vegetation resources. The results of the burned area (1989–2001) show a trend in the burning regime of the seasonal wetlands. Firstly as shown in Table 1, burning is more widespread in WMA’s than in communal areas. This can be associated with the land-use practices and policies in this area. The practices in these areas include tourism, hunting and vegetation resource extraction, e.g. *Phragmites* reeds. This association is further

connected to the settlement and cultural practices. The results also show that fires mainly occur in areas that are occasionally inundated, i.e. watercourses and floodplains, while they are less common in woodlands and dryland areas. The observed changes in fire regimes across seasons can be associated with a number of factors, including physical, environmental and climatic conditions as discussed by Trollope *et al.* (1996), e.g. presence of dry biomass, environmental characteristics and rainfall patterns.

The impact of fire on vegetation structure and species composition was shown to be very low by the ordination of environmental variables, also shown by others (Heinl, Sliva & Tacheba, 2004; Heinl, 2005). However, it has been shown through plotting fire as categorical data, i.e. low medium and high frequency plots, that it follows some major variables on the seasonal wetlands. In an area that had been burned, the vegetation showed differences in biomass and species diversity that could be attributed to fire frequencies.

Although fire frequency is just one factor of fire regime used to investigate its impact on the vegetation, other factors including intensity and period of fire, i.e. event and interval-dependant effects (Bond & van Wilgen, 1996) can also be used to strengthen the understanding of how fires affect vegetation resources, however, these can only be brought into the picture under controlled experiments which are costly to maintain. Limited research has been carried out in southern Africa focused on these and have emphasized the need for controlled experiments (Bond & van Wilgen, 1996; Trollope *et al.*, 1996; Stocks *et al.* 1997), these included the studies carried out in the Kruger national park during SAFARI 92 and SAFARI 2000. Based on the results, it is still not clear how other fire factors influence the vegetation, except that high intensity fire has been shown to destroy below ground biomass and plant propagules (Ellery *et al.*, 1989). This study results have shown that despite the high fire disturbance regime in floodplains and grasslands, these fires do not seem to impact negatively biodiversity. The plant communities that emerge following fires have been shown to support a relatively high species of mice in the seasonal wetlands compared to unburned sites, based on surveys carried out concurrently with the vegetation surveys (M. Plasvic, pers. comm.).

The results have provided a link between fires of anthropogenic nature with (i) the major natural resources management practices, (ii) settlement distribution (primarily between WMA and communal area), (iii) eth-

nicity of groups, (iv) literacy of respondents, and (v) fire policies.

Based on the results, the fire distribution as according to the respondents can be broadly categorized into land use and fire frequencies based on practices associated with fire. In communal areas, low fire prevalence is observed where there is (i) flood recession farming, (ii) livestock keeping, (iii) hunting, and (iv) thatching grass collection. High fire prevalence area only pertain to areas where there is harvesting of palm wine (*muchema*), e.g. communal near Dagonara and Ditshipi. In the WMA, low fire prevalence is in area where tourism practices are strictly for photographic safaris, while high fire prevalence is common in (i) reeds collection floodplains, (ii) hunting safari areas, (iii) thatching grass collection areas, (iv) lagoon and floodplains where fishing is common, and (v) near tour operator camps especially those with walking safaris and *mokoro* trips. The results show that natural resources management practices in the communal areas generally have less association with fires, hence low fire prevalence, whereas on the WMA more of these practices are associated with fire, hence high fire prevalence. These results suggest that natural resources management practices are not entirely the driving agent behind the fire regimes, but other factors such as ethnicity and literacy also play a part. Taking for example, hunting and thatching grass collection are still practiced in communal areas but there are less fires than in WMA, where the same practices are observed.

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Conflicts of interest

This authors declare no conflicts of interests.

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