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Fire activity on drylands and floodplains in the southern Okavango Delta, Botswana

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Abstract

Satellite imagery derived fire history data for the southern Okavango Delta, Botswana from 1989 to 2003 were used to analyse the temporal and spatial distribution of fires and to assess changes in fire activity. Maximum fire activity was encountered for 1997 with 24.1% of the study area burned. The annual extent of the burned area fluctuated considerably, but there appeared to be a regular oscillation apparently induced by floodplain fires. The main fire activity on drylands is in September at the end of the dry season, while most floodplains burn earlier in the year. Both burning of floodplains and drylands appear to peak prior to floods and rainfall-events, respectively. Areas with highest fire frequency were outlined and spatial analyses showed that fires on the drylands are largely due to burning of adjacent floodplains. The floodplains were therefore identified as the centres of fire activity, being the regions with the highest fire frequency and serving as source of fires spreading into drylands. Floodplains showed higher fire frequencies compared to drylands, but no increase in fire activity was detected over the study period for both floodplains and drylands.

Keywords: Savanna; Fire season; Fire regime; Fire frequency; Wetland; Southern Africa

1. Introduction

Fire is a natural process that has been part of the functioning of many ecosystems for millennia, particularly in southern Africa. Even fires started by people must be

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considered as part of the process, given the antiquity of human existence in Africa. Evidence for the use of fire by Stone-Age people in Zambia goes back as far as 55,000 years ago (Clark and van Zinderen Bakker, 1964), pre-dating present plant communities. Brain and Sillen (1988) report signs of even earlier use of fire by hominids at the Swartkrans Cave, South Africa, dated at about 1.2 million years BP.

Today, fire is a widespread phenomenon throughout tropical and subtropical southern Africa, occurring mostly during the annual dry season (May–October in southern Africa) when the herbaceous vegetation is either dormant or, in the case of annual grasslands, dead, and when deciduous trees have shed their leaves (Frost, 1999). These conditions contribute to an accumulation of dry, easily combustible, fine fuels. Fire is generally less frequent in drier regions where low rainfall limits the production of biomass fuels (grass, shrubs, litter and dead wood) (Bond, 1997; van Wilgen and Scholes, 1997). In these areas, several years of fuel accumulation, or an exceptionally wet preceding growing season, are needed to produce sufficient fuel to support a spreading fire.

The Okavango Delta is unique in that it is an extensive wetland ecosystem within an otherwise arid environment. Plant production and, in turn, the output of potential fuel for fire, depends more on the extent, level and duration of flooding, particularly in the seasonal swamps and floodplains of the southern Delta, than on the level of incident rainfall (Heinl et al., 2006). Towards the southern parts of the Delta, where flooding is more seasonal and there is more woody vegetation, fires occur across all landscape units, though they are most extensive in the seasonally flooded grasslands (Heinl et al., 2006). Burning within the woodlands is limited largely by the amount of fuel present to maintain a fire, itself inversely proportional to tree canopy cover (Frost, 1996). Generally, fuel loads in the area are relatively low, because of the herbaceous production is limited by low incident rainfall, infertile sandy soils, and high levels of herbivory. When fires do occur, they are usually surface fires of low intensity.

Fires in the Okavango Delta have basically two main sources of ignition: lightning strikes, especially during the ‘dry’ thunderstorms that are common at the start of the rainy season (October–November), and fires set by people for various purposes, potentially at any time of the year. Reasons for burning include efforts to induce higher quality grass regrowth for grazing animals or to attract wildlife for hunting, to clear land for cultivation close to or in floodplains where flood-recession (or molapo) farming is practiced or to clear channels on the floodplains to improve access to fishing grounds. Accidental fires are caused by campfires, fish-smoking or collecting honey (Cassidy, 2003). Although most fires are considered to have an anthropogenic origin, they usually spread uncontrolled and can extend over many square kilometres, if fuel loads are sufficient.

In recent years, concerns have been expressed by local organizations that fire regimes have changed significantly in recent times as human population densities, and therefore the number of potential ignition sources, have risen (OWLS, 1998; Cassidy, 2003). Fires are said to be more frequent than in the past and, in aggregate, to burn a greater portion of the landscape. Though quantitative data are lacking. To address these concerns and the lack of data, a series of satellite images covering a 15-year period were analysed to reconstruct the spatial and temporal distribution of fires for the southern floodplains of the Okavango Delta.

2. Materials and methods

2.1. Study site

The Okavango Delta in northern Botswana (southern Africa) is situated approximately between E22.0°–E24.0° and S18.5°–S20.5° (Fig. 1). The vast tropical wetland in the Kalahari Desert is supplied by the Okavango River, which has its catchment in central Angola. The mean annual rainfall over the Okavango Delta is about 490 mm, and the season of rainfall is typically from November to March (McCarthy et al., 2000).

The Okavango Delta is an alluvial fan with a very low elevation gradient of approximately 1:3300 (McCarthy et al., 2000) over the whole extension of roughly 20,000 km^2, forming a wetland composed of an intricate system of channels, lakes, active floodplains, drying floodplains and slightly elevated dry islands. The water inflow into the system through the Okavango River as well as the annual amount of rainfall is highly variable. As a consequence, there are marked annual shifts in water distribution, with dry areas becoming inundated and swamps being desiccated regularly. At the distal reaches of the permanently flooded areas the intensity and duration of the flooding decreases and the permanent swamps change to seasonal swamps and irregularly inundated floodplains (Ellery et al., 2003).

These floodplains in the southern, drier section of the Okavango Delta are primarily the focus of the present study (Fig. 1). The habitats in this section of the Okavango Delta range from small permanently flooded swamps and channels, dominated by *Phragmites* ssp. and aquatic herbs (e.g. *Nymphaea* ssp., *Potamogeton thunbergii*) to regularly inundated

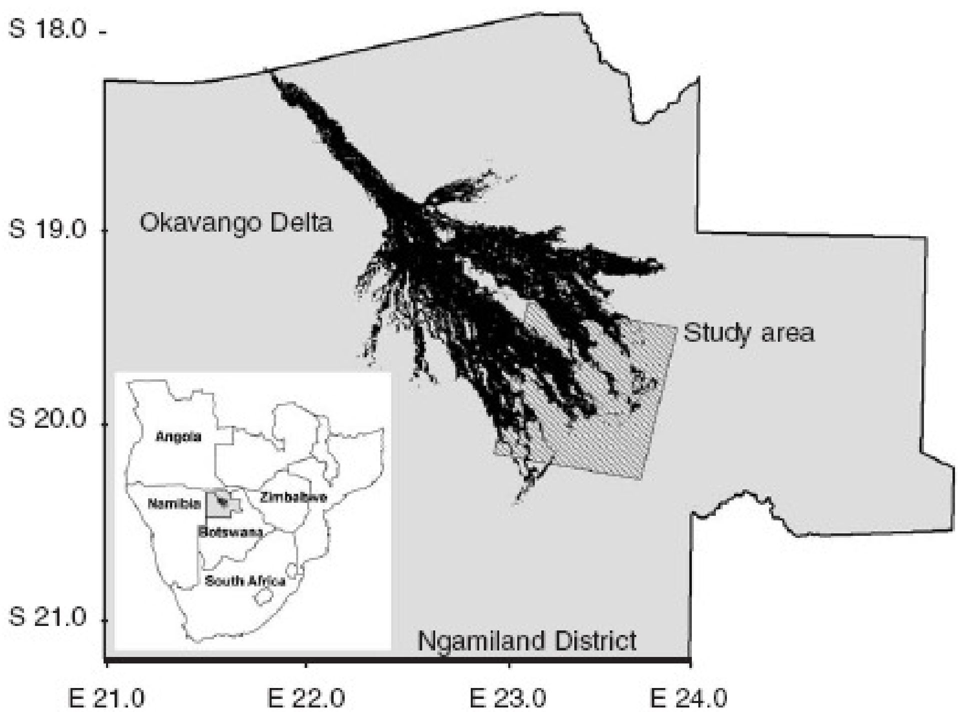

Fig. 1. Location of the study area. The quadrate indicates the study area in the southern part of the Okavango Delta Fan in northern Botswana (Ngamiland District), represented by the upper left quarter of the Landsat scene 174/074.

floodplains, dominated by tall sedges (e.g. *Cyperus articulatus, Schoenoplectus corymbosus*) and old floodplains that have not been flooded for years, dominated by grasses (e.g. *Eragrostis* ssp., *Panicum* spp., *Stipagrostis uniplumis*) with scattered shrubs and trees (e.g. *Pechuel-loeschea leubnitziae, Acacia* spp.). Besides these Okavango floodplains, a large portion of the study area is covered by typical savanna vegetation, with *Acacia* spp. or *Colophospermum mopane*, unaffected by the floodwaters from the Okavango River.

2.2. Determination of the fire and flood history

A series of 98 satellite images (91 Landsat Thematic Mapper (TM, ETM+) and 7 EO-1 Advanced Land Imager (ALI) scenes) with a spatial resolution (pixel size) of 30_30m were used to obtain information about flooded and burned areas for a 15-year period from 1989 through 2003 (Heinl et al., 2006). The investigated area is represented by the upper left quarter of the Landsat scene 174/074 with an extent of approximately 6141.1 km^2 (Fig. 1).

Annual fire and flood distribution maps were generated from the image analysis. The fire distribution maps contain information about the spatial extent and the date of each fire, while the flood distribution maps show all areas inundated for a particular year. Fire frequency data were generated by summarizing the annual fire distribution maps. The fire season (time of the year with the main fire activity) was determined by calculating the mean area burned for each month. The study area was divided into floodplains and drylands, following Heinl et al. (2006), with floodplains defined as areas inundated at least once during the study period from 1989 to 2003 and drylands as areas that never flooded during that period. Drylands and floodplains account for approximately 75% and 25% of the study area, respectively.

3. Results

3.1. Annual fire activity

The analyses of the temporal fire distribution showed a high variability of the extent of the area burned annually over the 15-year study period. The highest level of fire activity in the study area was recorded for 1997 with 1479.0 km^2 burned, covering 24.1% of the study area. The minimum area burned was recorded for 1998 with 56.2km^2 (0.9%). The mean annual extent of the burned area between 1989 and 2003 is of 435.9km^2 (7.1%).

For floodplains, the greatest fire activity was observed for 1997 with 41.6% of all floodplains in the study area burned (Fig. 2). The lowest fire activity on floodplains was in 1989, when during an exceptionally high flood (cf. Fig. 2) most floodplains remained inundated and only 0.3% of the floodplains burned. In the mean, 15.1% of the floodplains burned every year. For drylands, maximum fire activity was also calculated for 1997 with 18.4% of the drylands burned, while the minimum fire activity was in the following year 1998 with only 0.1% (Fig. 2). The mean portion of drylands burned per year is 4.5%.

The high fire activity for the years 1990, 1996/97 and 2002 indicate a regular oscillation of the fire activity, with peaks about every 6 years, especially for the floodplains. This variation of the fire activity does not indicate any trend in rising or declining fire activity. Also more detailed analyses considering only selected areas with extremely high fire frequency, for which the clearest trend in the development of the fire activity can be

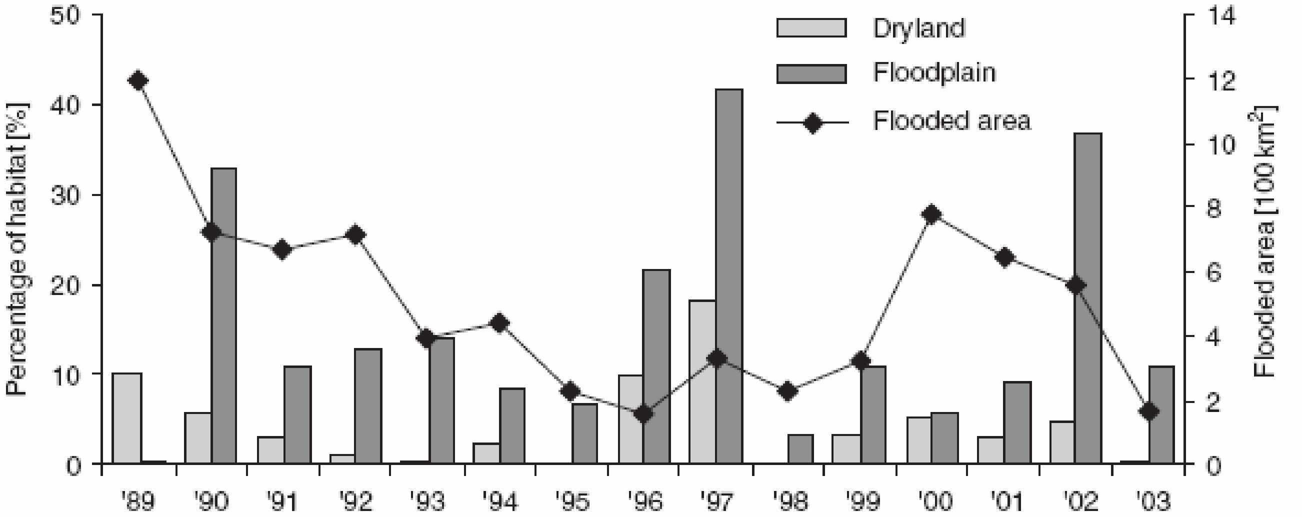

Fig. 2. Burned area on drylands and floodplains per year from 1989 to 2003, in percent of the extent of the habitat (dryland, floodplain). The line with markers refers to the second axis and shows the extent of the flooded area per year.

expected due to the most fire records, showed no significant changes in the fire activity during the 15-year study period.

3.2. Fire season

Determining the period with the main fire activity (fire season) showed that most drylands burned during the dry period, with a steady rise of the fire activity from May to a peak in September (Fig. 3A). From December to April, during the wettest part of the rainy season, fires on the drylands were extremely rare. Fire on the floodplains showed a similar pattern, occurring mainly during the dry period from May to September (Fig. 3B). However, the fire activity was distributed more evenly over the fire season, as for each of the months an almost similar extent of the burned area was recorded.

3.3. Spatial distribution of the fire activity

According to analyses on the distribution of the fire frequency, about 60% of the drylands were never recorded as burned during the study period, while only 20% of the floodplains remained unburned from 1989 until 2003 (Fig. 4). Highest fire frequencies were recorded for floodplains, and drylands rarely burned more often than three times during the study period. The areas with the highest fire activity showed fire frequencies of up to 10 burns during the 15-year study period.

Based on these findings, thresholds for defining high fire frequency were set to determine the spatial distribution of areas with extremely high fire activity and to investigate the interaction between the fire activity on floodplains and drylands. Only the 10% of each habitat type with the highest fire frequency were taken into account in these analyses, i.e. for drylands areas that burned three times or more and for floodplains areas that burned five times or more (cf. Fig. 4). The analyses of the spatial distribution of these areas with high fire frequency revealed the highest fire activity for the floodplain systems that are connected to the main distributary channels. Highest fire activity was found for the

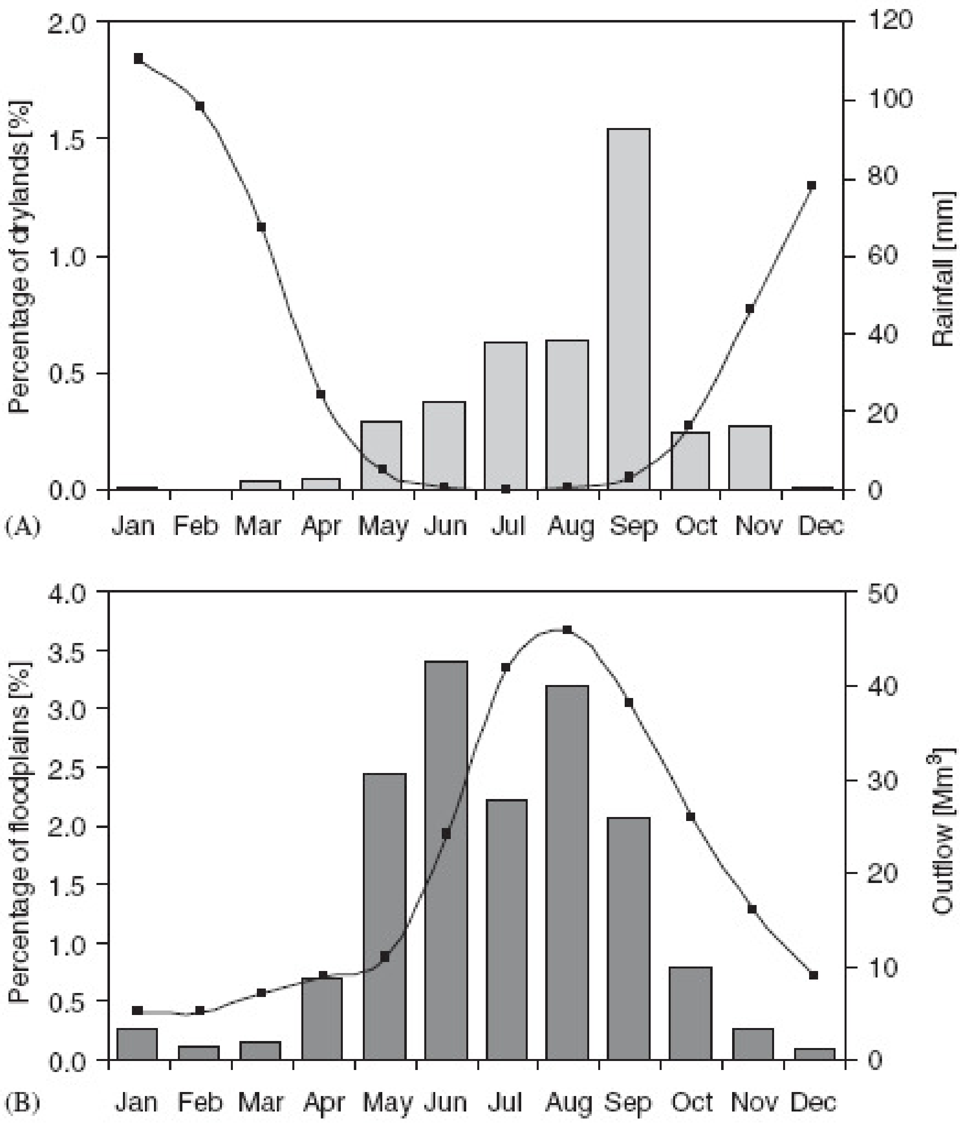

Fig. 3. The main fire season for drylands and floodplains. Presented are the mean area burned on drylands (A) and floodplains (B) per year, relative to the total extent of the habitat (dryland, floodplain) for each month. The lines with markers refer to the second axis. Mean monthly rainfall data were obtained at Maun. The outflow data, measured for the Thamalakane River at Maun are used to represent the extent of the flooding for the study area in the specific months (derived from McCarthy et al., 1998).

south-eastern Boro River system (Fig. 5), with exceptional high fire frequency close to the Veterinary Fence. The fence, running along a geological fault-line, separates the typical floodplain area in the north from the southern savanna habitats, where a combination of infrequent flooding and grazing pressure by livestock leads to a clearly reduced fire activity. The areas with high fire activity are hence not evenly distributed in the study area, but are rather concentrated along floodplains. High fire frequency on drylands could only be reported close to floodplains.

4. Discussion

The findings of this study are the differences in fire activity for the investigated years and no significant increase in fire activity over the years. Specific areas around the floodplains

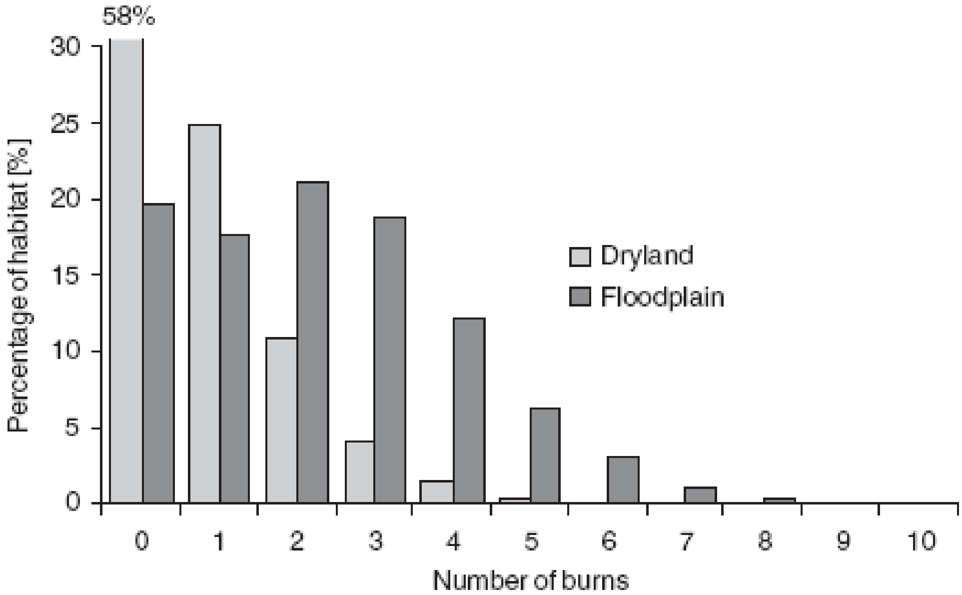

Fig. 4. The area covered by fire frequency classes (number of burns between 1989 and 2003), relative to the extent of the habitat (dryland, floodplain).

of the main distributary channels show highest fire frequency and the main fire season differs for floodplains and drylands.

The main fire season for both habitat types was determined to be during the dry period between May and October. As lighting, the only natural ignition source in this region, does not occur between May and August, most of these fires have an anthropogenic origin. As the incidence of lightning increases from September to November, in advance of the coming rainy season, fires can then also be ignited by lightning. September is typically the period with the most and largest fires, especially on the drylands, as the biomass has dried out completely and strong winds and frequent lighting strikes occur, often without any following rainfall, allowing the fires to spread extensively. With most of the fires on floodplains being earlier in the dry season, and clearly before the beginning of the rainy season and first lightning strikes, natural ignition sources are definitely of marginal importance for floodplains. However, burning floodplains were also recorded during the rainy season, although the extent was relatively small.

Comparing the temporal distribution of fires in the two habitats showed that floodplains tend to burn earlier during the year than drylands (Fig. 3). But interestingly, for both habitats fire activity peaked shortly before water became available to the system: the highest fire activity on drylands was observed in September, before the beginning of the rainy season (Fig. 3A), while the floodplains in the study area showed their highest fire activity immediately before the flooding (Fig. 3B). This supports the assumption of fires being basically man-made. Apparently, people use fire as a tool to clear land and to remove dead biomass in order to optimize conditions for cultivation and harvesting in the new growing season (Cassidy, 2003). Similar shifts of the fire activity towards the dry season earlier in the year due to anthropogenic burning has also been reported by Bond (1997).

While the fire season shows a rather regular pattern, with the main fire activity during the dry period, the extent of the burned area clearly varies between the years. This indicates that the probability of a fire is not equal for all years. The analysis of the annual fire activity revealed a maximum burned area for 1997 and a minimum burned area for 1998.

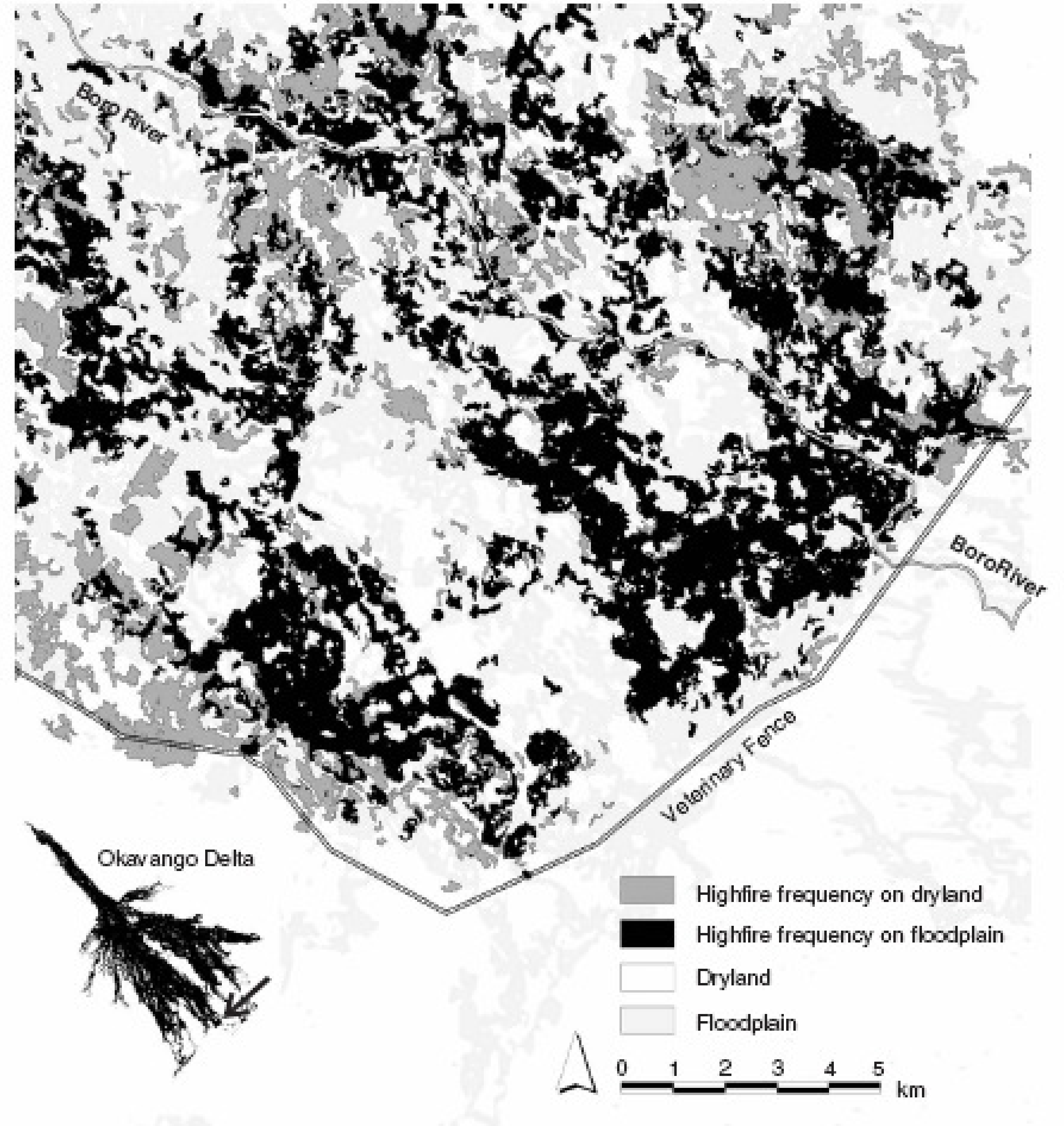

Fig. 5. Selected part of the study area, showing regions with high fire frequency on drylands and floodplains along the Boro River in the southern floodplains of the Okavango Delta. As high fire frequency are considered three or more burns for drylands and five or more burns for floodplains during the 15-year study period.

Thus, these two extremes in fire activity were found for two consecutive years, indicating a low fire activity due to reduced fuel loads after a year with high fire activity. Similar relations were found for the peaks in 1990 and 2002 (Fig. 2).

The years with high fire activity appear to be even separated by a sequence of years with a relatively constant extent of the burned area on a significantly lower level. The data suggest an oscillation in fire activity that peaks roughly every 6 years. However, this oscillation cannot be projected to predict main fire-events, as the peaks in fire activity are not simply dependant on the length of the inter-fire interval but rather depend on the inter-fire conditions. The oscillation of the fire-activity might for instance be influenced by changes in the extent of the flooding during the pre-fire period, as for the study area, the highest fire activities could be observed after a sequence of years with declining flood intensity: the fire maxima in 1990, 1996/1997 and 2002 occurred after the flood intensity clearly dropped from 1989 to 1990, between 1992 and 1996, and between 2000 and 2002, respectively (Fig. 2). As flooded areas usually build up much biomass, high fuel loads are available when these areas are exposed and dry for consecutive years, which makes them more susceptible to fire with time-since-flooding. A sequence of flooding and drying might therefore be responsible for the observed oscillation in fire activity.

This explanation of the fire activity based on regular inundation and exposure applies to floodplains only. Fire occurrences in dry savanna habitats are rather dependant on the amount of rainfall during the previous season, which determines the accumulated fuel loads (van Wilgen et al., 2004). Similar conclusions could be drawn for the Okavango Delta drylands, for which a significant positive correlation between rainfall and extent of burned area could be described (Heinl et al., 2006; Fig. 6). But the separate analyses of floodplains and drylands showed for both habitat types a similar oscillation of the fire activity (Fig. 2) and a spatial relationship between the burned area on floodplains and on drylands (Fig. 5). As the oscillation is much more pronounced for floodplains and as they show higher fire frequencies than drylands, dryland fires are most likely not only determined by rainfall but also affected by the fire activity on the floodplains. The mean portion burned for the two habitat types differ substantially, with about 15.1% of the floodplains and only 4.5% of the drylands burned per year on average. This implies a mean fire return interval for floodplains of 6.6 years and for drylands of 22.2 years (Heinl et al., 2006). Hence, the observed oscillation of the fire activity in the study area is most likely induced and dominated by the fire activity on the floodplains, while the peaks in fire activity on the drylands have much wider phases, which are not detectable by a 15-year data set. The however observed oscillation of the fire activity on the drylands might therefore be linked to fires started on the floodplains, affecting fire activity in adjacent drier sections. This could be caused by the more frequent fires on floodplains simply spreading into drylands. The drylands adjacent to floodplains might also differ from the ones further away from the wet areas. Although they are both not inundated, more water is supplied close to the floodplains due to lateral movement of water through the soil from the floodplains, increasing grass production, making more fuel load available and creating

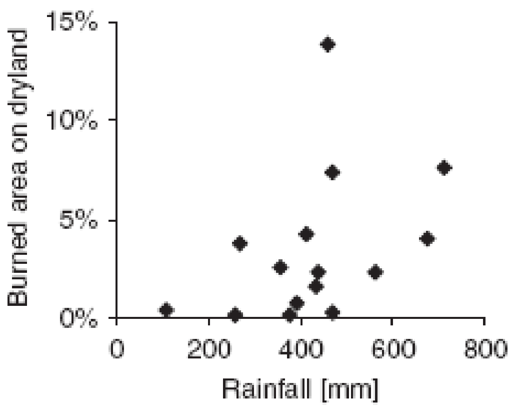

Fig. 6. Relationship between the extent of the burned area on drylands and the amount of rainfall over the preceding rainy season for 1989–2003 ($r_S = 0.54$; $p = 0.04$) (Heinl et al., 2006).

conditions that support higher fire frequencies. Probably both the proximity to floodplains and a better water supply and hence more biomass play an important role in determining the fire frequency on these drylands, with the first factor affecting the time of ignition, as floodplains burn more often than drylands and floodplain fires simply spread into adjacent drylands, and the latter determining the conditions influencing the extent of the fire.

This suggests that fires on drylands are partially due to the fire activity on floodplains, given their spatial proximity and the fact that the floodplains show significantly higher fire frequency than drylands because of their higher fuel loads (Heinl et al., 2006). However, the specific extent of the fire is on the drylands very much determined by rainfall (van Wilgen et al., 2004; Fig. 6). Floodplain fires are rather determined by the flood frequency (Heinl et al., 2006) and a period of years of drying and receding flood-levels (Fig. 2). The specific timing of a fire , especially on the floodplains, is very much influenced by human intervention (Fig. 3).

The analyses of the extent of the annual fires and of the temporal development of fire occurrences revealed no significant changes in fire activity over the 15-year study period. Hence, particular areas with high fire frequency are not expected to result from high fire activities during the last few years only, but rather reflect a regular high fire activity during the whole 15-year period. Areas with high fire frequency are currently of limited extent in the southern parts of the Okavango Delta and the mean fire frequency both on floodplains and drylands are overall in line with other studies (Scholes et al., 1996; Du Plessis, 1997; Russel-Smith et al., 1997). But even if these areas are small, regions with high fire frequency, especially on floodplains deserve special attention, as they are not only the regions of outstanding high fire activity but also the sources of fires on adjacent drylands and transition zones. Reasons for localized high fire frequency and ecological consequences need to be identified and understood. If human activities are connected to these high fire frequencies, rising anthropogenic impacts on the Okavango Delta can lead to more areas experiencing high fire activity in the future. Rather than changing significantly the overall extent of burning, the increase in human impact is more likely to result in specific areas being affected more frequently, especially where fire is used intentionally as a tool to manage certain resources.

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