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EVOLVING FIRE MANAGEMENT STRATEGIES AND THEIR IMPACT ON THE OCCURRENCE AND SPATIAL EXTENT OF UNPLANNED WILDFIRES IN A LARGE AFRICAN SAVANNA PARK*

EVOLUÇÃO DAS ESTRATÉGIAS DE GESTÃO DE INCÊNDIOS E SEU IMPACTE NA OCORRÊNCIA E EXTENSÃO ESPACIAL DOS INCÊNDIOS FLORESTAIS ACIDENTAIS NUM GRANDE PARQUE DA SAVANA AFRICANA

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ABSTRACT

Savannas cover approximately 20 % of the global land surface. In African savannas, fire is an important agent for controlling these ecosystems. Kruger National Park (KNP) is a large African savanna park which has implemented a variety of fire management strategies over the years. Using KNP's recorded fire history (from 1941-2017), we examined the occurrence and spatial extent of accidental wildfires in KNP in relation to adaptations in the fire management strategies over time. From 1941 to 2017 fires were a regular, almost annual occurrence in KNP. However, fuel loads accumulate over time when fires are extinguished or controlled burning in these landscapes is prevented, and the result is a substantial amount of combustible material to support large unplanned wildfires. Therefore, fire management strategies influence the occurrence and spatial extent of unplanned wildfires in African savannas. Prescribed burning is a critical management tool which should be used in fire-prone landscapes, however, research is needed to determine the appropriate fire regime needed to manage a fire-driven system.

Keywords: Accidental wildfires, anthropogenic fires, fire history.

RESUMO

As savanas cobrem aproximadamente 20 % da superfície terrestre global. Nas savanas africanas, o fogo é um importante agente que controla esses ecossistemas. O Parque Nacional Kruger (KNP) é um grande parque da savana africana que implementou uma variedade de estratégias de manejo de fogo ao longo do tempo. Usando o histórico de incêndios registado do KNP (durante 1941-2017), examinamos a ocorrência e a extensão espacial dos incêndios não programados no KNP em relação às adaptações das estratégias de manejo do fogo ao longo do tempo. Durante 1941-2017, os incêndios foram uma ocorrência regular quase anual no PNK. No entanto, as cargas de combustível acumulam-se ao longo do tempo, devido à extinção dos incêndios ou evitando a queima controlada nestas paisagens, e resultam em material combustível suficiente para suportar grandes incêndios não programados. Portanto, as estratégias de manejo do fogo influenciam a ocorrência e a extensão espacial dos incêndios não programados nas savanas africanas. A queima prescrita é uma ferramenta de gestão crítica que deve ser aplicada em paisagens propensas a incêndios, no entanto, são necessárias pesquisas para determinar o regime de fogo apropriado, necessário para gerir um sistema acionado por fogo.

Palavras-chave: Incêndios acidentais, incêndios antropogénicos, histórico de incêndios.

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Introduction

Nearly 20 % of the earth's land surface is covered by Savannas which are characterized by a balanced mix of woodland and grassland (Scholes & Archer, 1997; Sankaran, Ratnam, & Hanan, 2004). Savannas are found in South America, India and Australia whilst the largest proportion is found in Africa (van Wilgen, 2009). These dynamic systems support a large proportion of the world's human population along with their rangelands, livestock and wildlife (Scholes & Archer, 1997; Sankaran *et al.*, 2005). African savannas are driven by fluctuations in rainfall, herbivory, nutrients and fires (Walker & Noy-Meir, 1982; Sankaran *et al.*, 2005; Archibald & Hempson, 2016). The impact of these various drivers in controlling savanna ecosystem functioning and processes differs according to the persistence and frequency of the disturbance. Fire ignition sources in these African savannas are due to either human origins, whether accidentally or purposefully as arson, or natural origins through lightning (Archibald, Roy, Van Wilgen, & Scholes, 2009). Lightning fires are less common and often do not burn through large areas of woodland (Walter, 1971; Van Wilgen, Biggs, O'regan, & Mare, 2000).

Fire is an important agent in these African savannas where it has been part of this system for thousands of years (Scott, 1970). As such, the fauna and flora in these fire-prone ecosystems have co-evolved with fire and ultimately, resulted in a resilient fire-adapted system whereby savanna vegetation consists of many fire-adapted plant species (Bond & Keeley, 2005; Furley, Rees, Ryan, & Saiz, 2008). It is believed that, in South Africa, humans have been using and controlling fires to manipulate their environment for roughly 55 000 years (Smith, 2007). Humans would have learnt to use fires to manage their environments for agricultural purposes, to cycle soil nutrients and to control herbivore movements to facilitate easy hunting of wildlife (Whitlock, Colombaroli, Conedera & Tinner, 2018). As such, the presence of people in a large African savanna park like Kruger National Park (KNP) in South Africa, would have promoted the occurrence of fires in this fire-driven ecosystem. According to Scott (1970), early authors such as Kanthack (1907) and Thompson (1936) documented records of early Portuguese explorers who referred to the interior of South Africa as "Terra dos fumos", meaning the land of smoke and fire. This further confirms the large-scale occurrence of fires in this African landscape.

The Evolution of Fire Management in Kruger National Park (KNP)

Since the official proclamation of KNP in 1926, the first park Warden, Colonel James Stevenson-Hamilton, implemented a general ban on any deliberate burning

as he believed that fires had a detrimental impact of vegetation and wildlife (Pienaar, 2012). Roughly a decade later in 1935, the Parks Board had decided that fires should not be explicitly banned but rather controlled, and in 1937 Stevenson-Hamilton had suggested a burn policy whereby the bush would be burnt every second year to avoid the accumulation of moribund material (Joubert, 2007; Pienaar, 2012). In 1947, Stevenson-Hamilton had suggested that half the park should be burnt every year between February and April in order to promote low intensity fires while vegetation is still green, and that areas to be burnt will alternate between years. Due to the limited resources available during this period, most of these suggested policies were nearly impossible to implement as an official fire management strategy. In addition, there are scarce and limited records available on spatial extent and causes of fires during this time. Therefore, the period between 1926 and 1947 may be considered as a time in which KNP did not have a clear and, more importantly, an achievable strategy towards fire management. Notwithstanding, limited fires were still applied in order to provide improved grazing for animals (Van Wilgen *et al.*, 2000; Govender, Mutanga & Ntsala, 2012).

However, in the 1940s, philosophies on prescribed burning changed with the declaration of the Soil Conservation Act No. 45 of 1946 whereby the South African Government had promoted the establishment of Soil Conservation District Committees who would oversee soil conservation schemes enforced upon landowners (Rabie, 1974). One aspect of these soil conservation schemes was the prohibiting of prescribed burning which would have resulted in expropriation of land if landowners contravened this legislation (Rabie, 1974). These early ideas were based on the perceived negative effects of fires on land degradation and soil erosion, thus resulting in complete prohibition of prescribed burning in KNP during 1948-1956 known as the Fire Suppression or Protection Era (Trollope, 1984; van Wilgen, 2009). In 1950, KNP's second Park Warden, Colonel J.A.B. Sandenbergh declared that "*I am convinced that the past policy of burning has caused a change, for the worse, in our vegetation, and that this change has had a profound influence on the distribution and breeding rate of the wildlife in the Park. Deliberate burning in an area which must be kept natural, must cause an upset to any natural balance*" (Joubert, 2007). Colonel Sandenbergh's statement provides further insight into the philosophy of park management during that period whereby anthropogenic ignition sources were not considered as "natural" and part of the ecosystem. During the Fire Suppression period in the 1950s, a major programme aimed at grading a network of firebreaks across the park was initiated in order to gain control of wildfires (Joubert, 2007).

By the time, KNP management had adopted and implemented a Fixed Prescribed Burning strategy (1957-1980), the graded firebreak network resulted in more than 400 burn blocks ranging between 50 and 24 000 ha (Van Wilgen *et al.*, 2000). This prescribed burning strategy led to a fixed fire regime whereby fires were applied every three years in Spring (after the first rains) in each burn block (Brynard, 1971; Joubert, 2007; Govender *et al.*, 2012). In 1981, this rigid burning programme was declared unsuitable and adapted so as to allow for seasonal variation in the timing of prescribed burns, whilst retaining the three year block rotation (van Wilgen, Govender, Smit & MacFadyen, 2014). This fire management strategy lasted until 1990 and was known as the Flexible Prescribed Burning period. In 1991, park management had shifted their fire strategy towards a “Natural” Fire Policy (hereafter referred to as the Lightning Policy) which only allowed for lightning fires as it was deemed to be the only natural ignition source. Lightning fires were allowed to burn to their fullest extent and were no longer confined by burn blocks as the park decided to reduce the firebreak network (Van Wilgen, Govender, Biggs, Ntsala & Funda, 2004). Due to the substantial extent of area burnt per year during that period by all other ignition sources besides lightning, the fire management strategy was adapted once again in 2001 when management had realised the role of people in the landscape as an ignition source (Van Wilgen *et al.*, 2004; Govender *et al.*, 2012).

Between 2001 and 2011, an Integrated Fire Management Strategy was implemented which allowed for multiple ignition sources such as lightning, game rangers and migrants traversing the park from Mozambique into South Africa (Govender *et al.*, 2012). The amount to burn would be calculated based on preceding rainfall and subsequent fuel load accumulation (van Wilgen *et al.*, 2014). This strategy aimed at promoting variability by influencing fire intensities and spatial patterns whilst allowing for lightning-ignited fires and acknowledging the occurrence of inevitable wildfires. In 2012, the concept of Fire Management Zones (FMZ) was developed as part of the updated Integrated Fire Management Strategy (hereafter referred to as Integrated Fire Management - FMZ). These fire management zones were delineated based on the underlying geology, fire return period and mean annual rainfall (Smit, Smit, Govender, Linde & MacFadyen, 2013). These zones are used to describe regions of KNP where different fire strategies will be implemented to achieve specific ecological objectives based on ecological concerns which may be attributed to and/or exacerbated by certain fire regimes.

KNP has adapted its fire management strategy at least seven times since proclamation in 1926. This is evident of an adaptive management strategy which is consistently informed by the best available information and knowledge at the time.

Materials and Methods

Study Area

The study area is a large conservation area, known as Kruger National Park (KNP), situated in the north-eastern region of South Africa bordering Zimbabwe in the north and Mozambique on the east (fig. 1). The park was first proclaimed in 1926 and covers approximately 2 million hectares, making it the largest game reserve within South African borders. KNP is underlain by a variety of igneous, sedimentary and metamorphic geological formations (Venter, Scholes & Eckhardt, 2003). Geologically, the park is divided roughly into the granites on the west and basalts on the east, separated by a narrow north-south stretch of sedimentary rocks while a rhyolite band runs parallel on the eastern boundary of the park along the Mozambican border. The vegetation of KNP includes nearly 1 968 different plant species in a range of structural features varying from dense forest through to open plains with low shrubs (Venter & Gertenbach, 1986; Mabunda, Pienaar & Verhoef, 2003).

The regional climate is driven by anticyclonic systems travelling over southern Africa in a westerly direction (Venter & Gertenbach, 1986). Summers are wet and hot, with a daily average temperature of 34°C during November to February, whilst the winters are characterized by dry conditions with mild temperatures averaging at a maximum of 27°C during June to August



Fig. 1 - Location of Kruger National Park in South Africa.

Fig. 1 - Localização do Parque Nacional Kruger, na África do Sul.

(Kennedy & Potgieter, 2003). The southern and central regions of KNP receives a Mean Annual Rainfall (MAR) of 500-700 mm whilst the northern more arid parts of KNP receives 300 - 500 mm MAR (Venter *et al.*, 2003). The beginning of the rainy season is characterized by thunderstorms with extreme lightning events at the end of the dry season. KNP's distinct wet and dry periods provides a conducive environment with ideal conditions for fires to occur (Kennedy & Potgieter, 2003). The wet summer period allows for the accumulation of biomass and increases available fuel loads for dry winter fires. Besides fuel load, fuel moisture content and topography, certain weather conditions promote the spread of fires, i.e. temperature, relative humidity and wind speed.

Fire Records and Monitoring

KNP has a long history of fire records where fires have been monitored since 1941. According to van Wilgen *et al.* (2000), these fire records are likely the most extensive fire history available for any savanna ecosystem around the world. Although these earlier records were relatively crude hand-drawn maps of fire occurrence, they are still extremely valuable in providing estimates on fire location and spatial extent nearly eight decades ago. Park management and game rangers, who are responsible for designated regions of KNP and apply prescribed burns and/or suppress unplanned wildfires, were instrumental in developing these initial fire records. During 1941 and 1956, there were only eight rangers responsible for roughly 240 000 ha each, who produced these hand-drawn maps on an annual basis (Govender *et al.*, 2012). Since 1941-1947 coincided with the period where KNP had no official and feasible fire management strategy, it was not possible to distinguish all fire causes (ignition sources) during that period. During 1948 and 1956 when KNP adopted its Fire Suppression strategy, all fires were thus unplanned and actively suppressed. Unfortunately, no distinction was made in the fire records as to the occurrence and spatial extent of fires resulting from lightning events. After the implementation of the Fixed Prescribed Burning strategy, game rangers began recording additional information on fire cause which continues to be recorded to date. In light of more recent developments in fire monitoring around the world with the use of satellite imagery (e.g. Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on board EOS-AM (Terra) and EOS-PM (Aqua) satellites), on-the-ground fire reports provided by game rangers are critical in validating fire detections derived from satellites. Often, smaller and/or low intensity fires are not detected by MODIS, which makes ranger reports very important to ensure our fire records are updated as accurately as possible. Furthermore, MODIS may detect false detections of fires due to stark differences in surface temperatures between a patch of bare

ground, e.g. a granitic outcrop, and surrounding green vegetation (Justice *et al.*, 2002; Schroeder *et al.*, 2008). Beyond those minor disadvantages, MODIS still provides some of the more reliable satellite imagery available to date, and with recent launches such as Sentinel-2 and -3, fire detection and monitoring will significantly improve in the next few years.

In this paper, we used digitized hand-drawn maps and more recent, satellite-derived fire scar maps provided by KNP's fire history database to determine the annual occurrence and spatial extent of unplanned fires in KNP between 1941 and 2017. Information related to unplanned fires were analysed in relation to the Fire Management Strategy adopted at the time to determine the impact of a certain strategy on unplanned wildfire occurrence and spatial extent. Unplanned fires refers to any unscheduled fires which may include accidental wildfires caused within KNP's boundaries by staff, tourists, poachers, etc. as well as fires which have jumped into KNP from neighbouring communities within South Africa and/or Mozambique. In essence, unplanned fires are all recorded fires which are confirmed as not being any prescribed management burns or lightning (natural) fires. Management burns and lightning-derived fires were determined as separate fire causes. In some instances, fire causes were not recorded and thus are unknown; these were classified as Not Specified. Rainfall records between 1941 and 2017 were also sourced from KNP's rainfall database, and mean annual rainfall was calculated for each of the different fire management eras.

Results and Discussion

During 1941-2017, fires have been a regular (nearly annual) occurrence in KNP irrespective of the fire management strategy at the time (fig. 2 a, b). Following the 1969-1970 drought, there were no records of fires in KNP during 1971. This regular occurrence of fires within this African savanna is evident of the key role and need for fires in this fire-prone landscape. During the 76 years analysed, the only periods in which less than 100 000 ha of KNP had been burnt, i.e. 1945, 1954, 1966, 1971, 1984-1984, 1992-1994, 1998, 2016-2017, it had coincided with a recent major El-Niño phenomenon resulting in below average rainfall years (Richard, Fauchereau, Pocard, Rouault & Trzaska, 2001; Rouault & Richard, 2003; Masih, Maskey, Mussá & Trambauer, 2014). The lack of fire extent experienced during and/ or after a drought year is expected given that mean annual rainfall for the preceding two years, has a significant impact on fire occurrence and return intervals (Van Wilgen *et al.*, 2000, 2004).

Between 1941 and 1980, the fire management strategy in KNP had gone through three distinct phases, i.e. No Strategy during 1941-1947, Fire Suppression during

1948-1956 and Fixed Prescribed Burning during 1957-1980 (fig. 2a). During 1941-1947 when KNP did not have a clear strategy towards fire management, fires occurred annually and the spatial extent of these fires varied between years. On average, fires burnt about 13 % of the park during this period (fig. 3). The amount of area burnt (fire extent) during that “No Strategy” period ranged between 17 910 (during a drought year in 1945) and 622 466 ha the following year. It is interesting to note that the year in which the greatest fire extent had been recorded, i.e. 1946, these fires were all as a result of unplanned fires recorded as being “Accidental”. Unfortunately, the exact causes of most of these fires during this “No Strategy” phases are unknown, as this was not a major concern during this period of KNP’s history. It is conceivable that lightning fires may have occurred but the spatial extent is unknown, although it is believed to be a minimal proportion of the overall area burnt. Lightning fires are known to not be a regular ignition source and do not often burn through large areas of woodland (Walter, 1971; Van Wilgen *et al.*, 2000). Fire occurrence, its extent and its perceived negative impacts on land degradation and erosion was more important than the actual fire cause (Rabie, 1974; Trollope, 1984), hence the adoption of the Fire Suppression period as of 1948. Although the intention was to protect against fires and suppress all fires across KNP (including lightning fires), this proved impossible as large areas had still burnt on an annual basis during 1948 and 1956 (fig. 2a). Due to no prescribed management burns allowed during this time, all fires which occurred are classified as unplanned burns (except in 1955). Throughout the fire suppression phase, roughly 20 % of the park would burn each year (fig. 3). This provides insight into the inevitable occurrence of fires in these savanna systems, where an active fire protection and suppression policy resulted in even larger burnt areas than the previous “laissez faire” philosophy with no clear fire strategy. The greatest spatial extent of unplanned fires on record occurred in 1953, during the Fire Suppression period, when nearly 900 000 ha (about 45 %) of KNP had burnt due to multiple unplanned wildfires. By excluding fires in these landscapes, fuel loads will accumulate over time and provide sufficient amounts of fuel to support large-scale, uncontrollable wildfires.

As a result of the large, unplanned fires which occurred during the Fire Suppression phase, KNP management had begun to realise the need for fires in this ecosystem and implemented a Prescribed Burning strategy from 1957 onwards. In 1981, the strategy was slightly adapted to allow for seasonal variation in the timing of prescribed burns until 1990. This four-decade long period was characterized by less and smaller unplanned fires due to the active rotational burns applied by park rangers (fig. 2a, b). By burning blocks of KNP in a regular rotation

(every three years) and creating a patchy mosaic of fuel loads across the park, unplanned fires were not able to burn continuously through large regions of KNP. Unplanned burns accounted for less than 34 % and 33 % of all fires which occurred during the Fixed Prescribed Burning and Flexible Prescribed Burning period, respectively, which is the lowest proportion of unplanned fires in all of the various fire management strategies applied (fig. 4). However, on average 23 % and 19 % of the park would burn (as a result of all fires) on an annual basis during the Fixed and Flexible prescribed burning eras, respectively (fig. 3). It was during these prescribed burning eras, between 1957 and 1990, that most of the park would burn annually yet very few of those fires were unplanned as a result of large areas being burnt by regular rotational block burns. Throughout KNP’s documented fire history between 1941 and 2017, the greatest proportion of the park (i.e. > 50 %) was burnt in 1978 following a wet cycle between 1975 and 1977 which consecutively experienced more than 25 % of the mean annual rainfall (Van Wilgen *et al.*, 2004; MacFadyen, Zambatis, Van Teeffelen & Hui, 2018). Most of the area burnt during 1978 was as a result of the prescribed management rotational burns and not unplanned fires.

During the Lightning Fire strategy between 1991 and 2000 (fig. 2b), whereby no prescribed management burns were allowed, unplanned wildfires had consistently accounted for more area burnt than lightning fires (except in 1996). Due to the lack of active burning by park management, more hectares within the park were subject to being burnt by large wildfires. Between 1991 and 2000, about 14 % of KNP would burn on average per year, similarly to the No Strategy period (fig. 3). The proportion of unplanned fires during the Lightning Fire era was more than during the prescribed burning period 40 years prior whereby 64 % of annual fires were unplanned as compared to 33-34 % unplanned during the prescribed burning period (fig. 4). The frequent occurrence and spread of unplanned fires continued until the strategy changed in 2001 following two consecutive years of substantially more area burnt by unplanned fires than lightning in 1999 and 2000. It is likely attributed to above-average rainfall during 1999-2000 which promoted the accumulation of very high fuel loads which provided substantial combustible material for the spread of unplanned fires in 1999-2001 (Van Wilgen *et al.*, 2004). The largest accidental fire on record during the Lightning Fire era burnt roughly 155 000 ha in 1999. Even though more mean annual rainfall fell during this era, less area was nonetheless burnt due to the prohibiting of prescribed management burns and suppression of any other fires besides lightning fires. This provides further clarity on the effect of fire management strategies on wildfire occurrence and spatial extent, which overrides the influence of mean annual rainfall in the longer term.

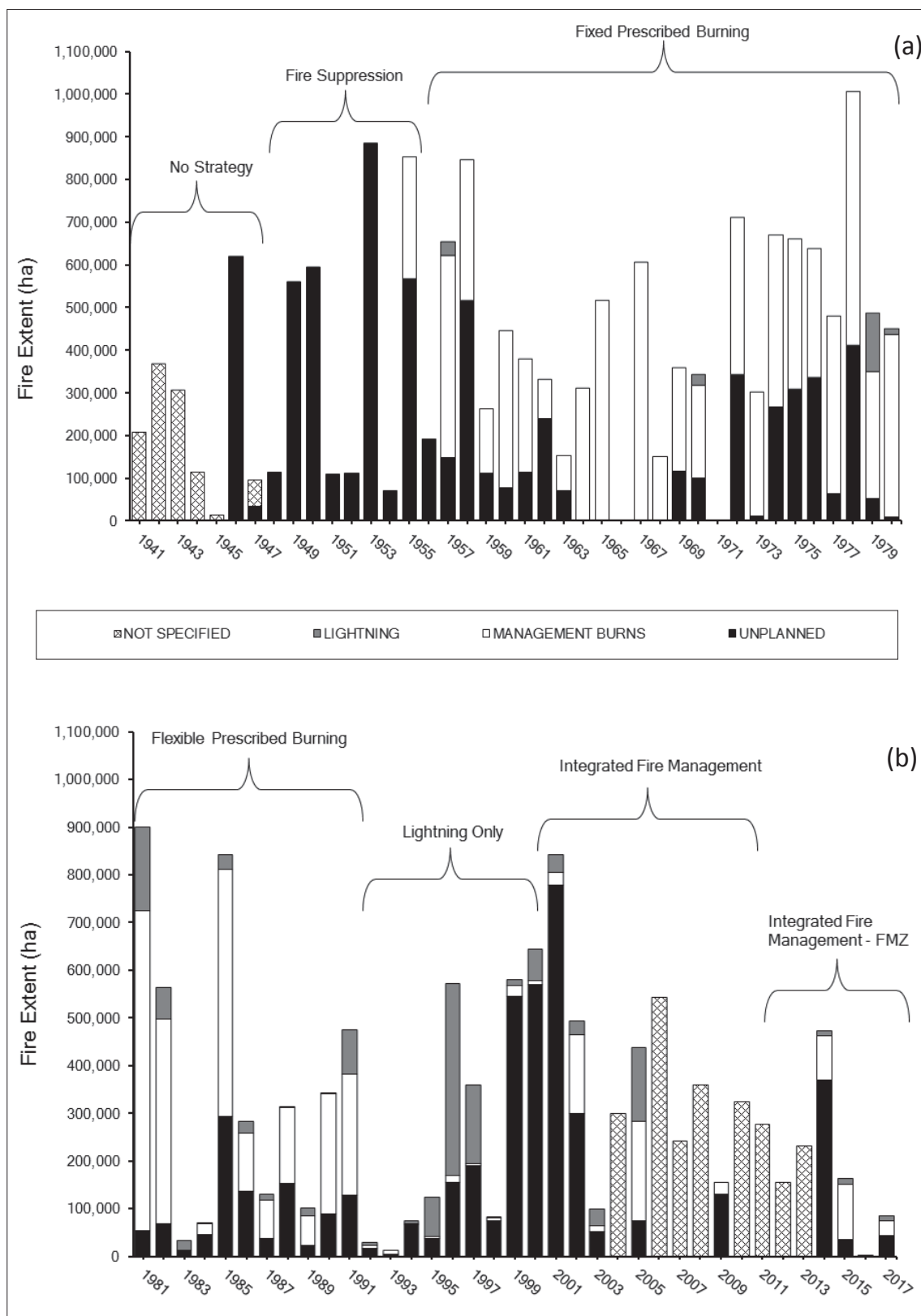


Fig. 2 - The occurrence of accidental fires relative to management burns and lightning fires per fire management strategy between 1941-1980 (a), and 1981-2017 (b).

Fig. 2 - Ocorrência de incêndios acidentais referentes a queimadas de gestão e a incêndios por raios e por estratégia de manejo de fogo entre 1941-1980 (a) e 1981-2017 (b).

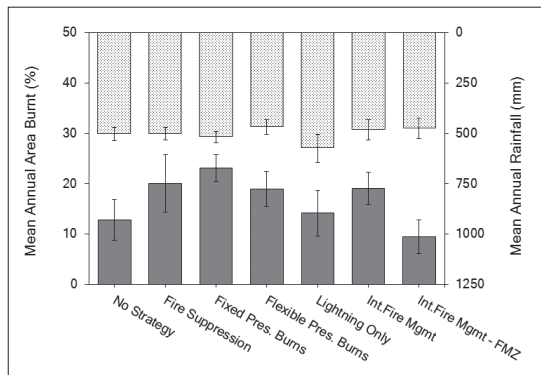


Fig. 3 - Mean area burnt per year under various fire management strategies in KNP between 1941 and 2017. Error bars denote Standard Error. Fixed Pres. Burns: Fixed Prescribed Burning; Flexible Pres. Burns: Flexible Prescribed Burning period; Int. Fire Mgmt: Integrated Fire Management; Int. Fire Mgmt-FMZ: Integrated Fire Management with updated Fire Management Zones.

Fig. 3 - Área média queimada por ano em função das várias estratégias de manejo de fogo no PNK entre 1941 e 2017. As barras de erro indicam o erro padrão. Fixed Pres. Burns: Queimas prescritas fixas; Flexible Pres. Burns: período flexível de queimas prescritas; Int. Fire Mgmt: Gerenciamento Integrado de Incêndio; Int. Fire Mgmt-FMZ: Gestão integrada de incêndios com zonas atualizadas de gestão de incêndios.

The Integrated Fire Management strategy was adopted in 2001 which allowed for various ignition sources, including lightning, management burns, trans-migrants traversing the park between South Africa and Mozambique, etc. Prescribed burning was based on calculated burn targets derived from preceding rainfall and available biomass (fuel load) which defined the amount of area to be burnt each year. For years in which fire causes are known, unplanned fires generally burnt through less area than all other fires, i.e. management and lightning fires (fig. 2b). The largest fire during this period had burnt just over 78 000 ha. After the updated Integrated Fire Management strategy with specified Fire Management Zones, the spatial extent of fires had declined likely due to certain areas no longer being burnt as a result of specific ecological objectives and limiting fire applications in that area (fig. 3). However, 2014 was a particularly dry year which received nearly 35 % less of the mean annual rainfall and followed two consecutive years of above average rainfall of about 20 % which would have resulted in decent fuel load accumulation (MacFadyen *et al.*, 2018). During 08th and 23rd of September 2014, a particular sequence of six accidental wildfires contributed to roughly 177 260 ha (47 %) of the 375 243 ha burnt by unplanned fires that year. The largest of these fires burnt more than 54 000 ha. Due to the scattered localities of multiple and concurrent wildfires, KNP required the assistance of external fire fighting teams and aerial support to contain the fires which had threatened concessions (safari lodges) which would have resulted in damage to property and possible loss of lives.

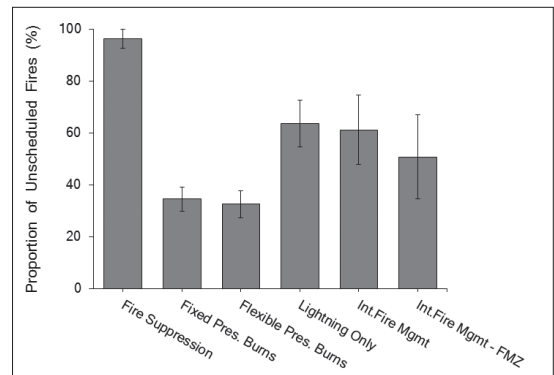


Fig. 4 - Proportion of unplanned fires relative to all other fire causes under various fire management strategies in KNP between 1947 and 2017. Excludes the No Strategy period due to the lack of confirmed unplanned fires. Error bars denote Standard Error. Fixed Pres. Burns: Fixed Prescribed Burning; Flexible Pres. Burns: Flexible Prescribed Burning period; Int. Fire Mgmt: Integrated Fire Management; Int. Fire Mgmt-FMZ: Integrated Fire Management with updated Fire Management Zones.

Fig. 4 - Proporção de incêndios não programados em relação a todas as outras causas de incêndio durante várias estratégias de gestão de incêndios no PNK entre 1947 e 2017. Exclui a era Sem Estratégia devido à falta de incêndios não programados confirmados. Barras de erro indica erro padrão. Fixed Pres. Burns: Queimas prescritas fixas; Flexible Pres. Burns: período flexível de queimas prescritas; Int. Fire Mgmt: Gerenciamento Integrado de Incêndio; Int. Fire Mgmt-FMZ: Gestão integrada de incêndios com zonas atualizadas de gestão de incêndios.

Throughout KNP's fire history and its various fire management strategies, unplanned wildfires have been a frequent occurrence. Particular strategies where fires were either actively suppressed or prescribed burning prohibited, resulted in situations where wildfires were more frequent and burnt through much larger areas. This has been shown in other fire-prone landscapes such as conifer forests in North America where inappropriate fire management strategies were ineffective in limiting large, uncontrollable wildfires (van Wagtenonk, 2007). Fires should be promoted as a natural ecosystem process and land management practices need to be designed in order to ensure the role of fires (Hann & Bunnell, 2001).

The use of prescribed burning will assist in the creation of a patchy mosaic of recently-burnt areas with lower fuel loads which, in turn, could limit the spread of wildfires through large tracts of bush. These breaks in fuel load will assist park management in controlling wildfires, if they occur. Fortunately, KNP has an extensive road network that act as firebreaks which, depending on the intensity of the fire and weather conditions, can be used to stop the spread of a wildfire. Prescribed fires should be promoted and tolerated in fire-prone landscapes whilst ensuring safety to people and properties. The avoidance and suppression of fires will increase the risk of large-scale uncontrollable wildfires which will require additional fire-fighting support in order to contain and extinguish these wildfires.

Conclusion

Fires are inevitable in these fire-driven savanna landscapes and will occur on an annual basis in various parts of KNP, except in extremely low rainfall years. Fire management strategies influence the occurrence and spatial extent of unplanned wildfires over time. An inappropriate strategy such as banning prescribed burning in these ecosystems, will lead to extensive areas being burnt by inevitable wildfires due to the accumulation of fuel over time. This will increase the potential risk of the occurrence and spread of devastating wildfires which will threaten loss of life and damage to property. Therefore, prescribed burns by park management should continue to be implemented in order to limit the occurrence and spread of unplanned and uncontrollable wildfires.

Prescribed burning is a critical management tool which should be applied in fire-prone landscapes where people would have traditionally used fires. However, research and monitoring is needed in order to determine the appropriate fire regime necessary which describes the ideal fire frequencies and intensities needed to manage a fire-driven system. Archiving of historical records of fires is of utmost importance to allow for the review of previous eras and how management strategies at the time may have influenced fire occurrence and extent within a certain area. Without such information, it renders the development of an appropriate fire management strategy extremely difficult.

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