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Frequency of Fires in the Miombo Woodland of the Gilé National Park. Province of Zambezia

Luís A. Pungulanhe (Corresponding author)

Curso de Ecoturismo e Gestão de Fauna Bravia, Divisão de Economia, Gestão e Turismo

Instituto Superior Politécnico de Manica, Manica, Moçambique

E-mail: lamadeu36@gmail.com

Natasha S. Ribeiro

Departamento de Engenharia Florestal, Faculdade de Agronomia e Engenharia Florestal

Universidade Eduardo Mondlane

Tomázia M. C. Veterano

Serviço Provincial de Ambiente de Manica

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Abstract

Fires occur in a widespread manner in various types of vegetation cover at national level, and are often associated with human hunting, grazing and above all the practice of itinerant agriculture. With the purpose to propose the map of frequency of fire, remote sensing data was collected from 2014 to 2018, using the Moderate Resolution Image Spectroradiometer (MODIS) of the burned area (MCD64A1), which allowed the construction of the map of frequency and intensity of fires, associated with data collected in 59 plots on field. It was observed that the Gilé National Park (PNAG) records an average fire frequency of 0.38 times/year and the return interval of 5.38 years, and an average fire return interval of 2.62 years. During the study period, the PNAG burned 92.8% of the area, which means that on average for each year it burned about 18.56% of its area, there are no significant differences in relation to the area burned per year ($p > 0.942037$) but there are significant differences in relation to the area burned per month ($p < 1.24^{e-07}$).

Keywords: fire, frequency, gilé national park, miombo, MODIS

1. Introduction

Miombo is the most extensive dry tropical forest in Africa, covering an estimated area of about 2.7 million km^2 in southern Africa in regions that receive more than 700 mm of annual rainfall, but on soils that are poor in nutrients (Frost, 1996; Sitoe, 1999; Ribeiro et al., 2008a, b; Campbell et al., 2010; Chidumayo, 2013).

The miombo woodland covers significant portions of 7 countries in the region, namely: Angola, Zimbabwe, Zambia, Malawi, Mozambique and Tanzania, and most of the southern Democratic Republic of Congo (DRC) (Campbell et al., 2010). It is important for the production of valuable wood and based on its services it supports the economic livelihood of 100 million people in rural areas and 50 million people in urban areas across the African continent (Frost, 1996; Ryan et al., 2016).

Climate change (estimates are pointing to a 5 to 15% reduction in precipitation in the miombo region) (Chidumayo, 2004; Le Page et al., 2008) and the population growth recorded in recent decades have been the two agents of change in the composition and structure of miombo forests exerted mainly by pressure on the use of timber and non-timber forest resources (which often serve as a source of energy, collection of food, medicines and production of handicrafts) (Frost, 1996; Chidumayo, 2004), and opening up new areas for the practice of agriculture (Chidumayo, 2004). The frequency of fires within the miombo ecosystem has significantly contributed to the increase in greenhouse gases (Campbell et al., 2010).

The frequency quantifies the occurrence of fire per unit of time and space (Oom, 2014). Soja *et al*., (2006) suggests that the frequency should be interpreted as the area that burns annually.

Gilé National Park (PNAG) is characterized by a high frequency of fires in the central region, with an average frequency of 4 times a year, with an average return interval of 3.9 years. Over a 10-year period, the park was affected by fires in about 41.99% of its total extension (Maúnze, 2016).

The Management Plan for the Gilé National Park, prepared by Fusari et al. (2010) highlights local populations as being responsible for the large number of uncontrolled fires that annually occur in the area and that represent a serious danger to the vegetation.

The PNAG records an average of 828 annual fires, burning on average 8.03% annually, about 229.67 Km2 (Maúnze, 2016). Another study carried out by EtcTerra & Fundação IGF (2017) found that within the PNAG, burnt areas represent, depending on the year, 5% to 30% of the total surface area. In the last 16 years, the average is 295 Km^2 in the central zone (maximum of 730 Km^2 in 2005) and 4.5 Km2 in the buffer zone (maximum of 120 Km^2 in 2010). After a series of prolonged fires between 2009 and 2013, the last 3 years show a relatively low level of burned area, at least in the central area of the reserve (EtcTerra & Fundação IGF, 2017).

Small differences are notable in terms of location (central or southeast and northeast) and density of fires in the PNAG between the data presented by Maúnze (2016) and Serrote

(2017). The most recent studies on PNAG in the burning component carried out by Maúnze (2016), Serrote (2017), EtcTerra & Fundação IGF (2017), were limited to collecting remote sensing data, and little fieldwork, not having collected field data for the most part, the forest inventory carried out within the PNAG (DINAF, 1999) is not available and little is known about the data collected.

The RNG is characterized by having species typical of African savannas and dry forests and has miombo species of high importance for the region's biodiversity (Fusari et al. 2010). Fires greatly influence dry forests and savannas, where it is observed in the miombo that burning at the end of each season inhibits the regeneration of trees (Trapnell, 1959; Chidumayo, 1988), which can lead to a loss of trees over time. trees of the genus Brachystegia and Julbernardia (Chidumayo, 2013).

Vegetation fires occur mainly during the dry season, when the ignition, fuels and fire climate coincide in the same space and time. However, humans have greatly altered the fire season and the seasonality patterns of fire (Oom, 2014). A frequency of fires that occur annually within the miombo ecosystem tends to convert these ecosystems into savannas (Ryan & Williams, 2011), however, the complete absence of fires makes the miombo closed (Trapnell, 1959).

The general objective of this study was to contribute to the management of fires in PNAG by understanding the relationship between fire frequency and miombo vegetation, having described the frequency of fires in the 2014-2018 range.

2. Materials and Methods

2.1. Geographic location

The Gilé National Park was created in 1932, at the time it covered an area of just over 5.000 km^2 (Diploma Legislativo Nº. 1996 I Série, Número 30; MAE, 2014a, 2014b). Currently the PNAG (Figure 1) has an area of about 2.861 km^2, distributed in two districts namely Gilé (40% of the park area) and Pebane (60% of the PNAG area), in the central province of Zambézia, between the coordinates, 16 ° 50 ′ 57 ″ south latitude and 38 ° 21 ′ 10 ″ east longitude (Fusari et al. 2010). Currently, the buffer zone covers an area of about 1.526 km^2.

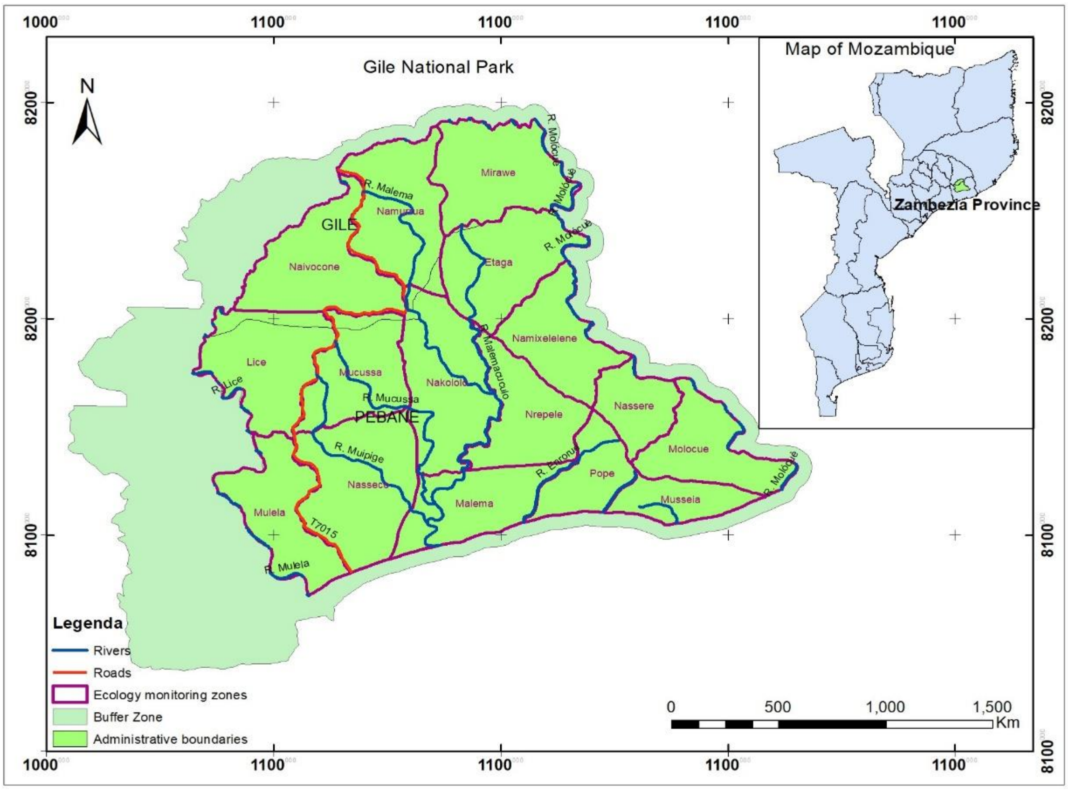

Figure 1. Geographical Location of the Gilé National Park, in Zambézia Province.

Source: Cenacarta (2017)

The three main rivers that cross the park are: Mulela, which forms the western limit of the PNAG, Molocuè, which constitutes the eastern limit of the PNAG and Malema, which is the main watercourse within the PNAG. Other permanent rivers are Naivocone in the North, Nakololo, Malemacuculo and Mucussa within the PNAG, Muipige and Enrorue in the southern sector (Figure 1) (Fusari et al., 2010; Diploma Legislativo Nº. 1996 I Série, Número 30).

The area's climate falls within the climate zone defined as “Tropical summer-rainfall climatic zone” (White, 1983 *apud* Fusari et al., 2010). The average annual rainfall is above 800mm, reaching 1,200 or even 1,400mm, being concentrated in the period between November of one year and the end of March and may locally extend to May (MAE, 2014a, 2014b).

Considering the canopy cover and species composition, six different types of vegetation cover are identified: 1) open scrub; 2) low-lying open forest; 3) low-lying closed forest; 4) woody herbaceous formation; 5) herbaceous formation; 6) Low shrubs (Fusari et al. 2010).

2.2. Acquisition of satellite data

In this study, data from MODIS satellites (Moderate Resolution Imaging Spectroradiometer) Aqua and Terra, from 01/01/2014 to 12/31/2018, were used in order to prepare a map of the frequency of fires and to identify places with greater number of active fires within the PNAG.

MODIS satellite data were obtained free of charge through the internet. The burnt area product (MCD64A1) was downloaded from the ftp://ba1.geog.umd.edu server, this product is distributed by the University of Maryland (United States of America), and was downloaded using the software, *FileZilla FTP Client* 3.43.0 (Kosse, 2018), (Giglio et al., 2018; Giglio et al., 2016b).

2.2.1. Pre-processing of the MODIS MCD64A1 product

The pre-processing of the data obtained using the MODIS instrument was carried out in ArcMap 10.2.1 (ESRI, 2013), based on the methods of spatial statistics, spatial analysis, temporal analysis, description and visualization.

2.2.2. MODIS MCD64A1 Product Processing

Burndate files were filtered using 0 to 366 days (Giglio et al., 2016a), with binary results with the number "0" meaning unburned area and "1" burned area. With the Raster Calculator tool, the operation of adding all the images resulting from the filtering was performed, resulting in 5 files from the years 2014, 2015, 2016, 2017 and 2018. In turn, these were added using the Raster Calculator tool, which resulted in a single image with the frequency of the burned area within the study period (Pungulanhe, 2020).

2.3. Frequency and average interval of return of fires

The fire return interval (Equation 1) is defined as the average time required to burn an area equivalent to the entire ecosystem (Dickmann & Cleland [n.d]; Soja et al., 2006; Ribeiro et al., 2007; Greenpeace, 2014), this concept is considered synonymous with the fire rotation period (PRF) or fire cycle (Dickmann & Cleland [n.d]; Ossene, 2015).

$$IRQ = \mathrm{T} * \left(\frac{\mathrm{A}}{\mathrm{a}}\right) \quad . \tag{1}$$

Where:
IRQ - fires return interval
T - Period in years (5 years)
A - Total area under study (2861km2)
a - Area burned within the study period (2657.2km2)

Average Burn Return Rate (IMRQ) (Equation 2) is the weighted arithmetic mean of the years with burn rate and the burned area (Dickmann & Cleland [n.d]; Soja et al., 2006; Ossene, 2015) and means that fires on average need this time to reoccur in the same place.

$$IMRQ = \sum_{i=l}^{n} \frac{(I_i A_i)}{A_t} \quad . \tag{2}$$

Where:
IMRQ - average fires return interval

Ii = fires return interval
Ai = Land area, fire return interval (Ii)
At = Total ecosystem area

For this study, the frequency of fires (Equation 3) is the inverse of the average fire return interval (Dickmann & Cleland [n.d]; Soja et al., 2006; Ribeiro et al. 2007). It is the number of occurrences of fires in a given space in a given period of time (Dickmann & Cleland [n.d]; Soja et al., 2006; Cangela, 2014; Ribeiro et al., 2007).

$$\text{Frequência} = \frac{1}{IMRQ} \ . \qquad (3)$$

2.4. Assessment of classification accuracy

In the present study, data were generated from the confusion matrix to calculate classification validation indexes. The allocation of sampling points was applied in 59 plots based on the fire frequency map for its validation (Pungulanhe, 2020). In this study, the quality of the mapping of the fires carried out by the MODIS MCD64A1 product was analyzed using the Kappa index:

2.4.1. Kappa Index

Statistical value that measures the perfection of the classification and ranges from 0 to 1 (Cohen, 1960). It measures the effectiveness of the classification in comparison with the class of each plot (Cohen, 1968). For the calculation of the Kappa index, the following Equation (4) is used:

$$K = \frac{N\sum_{i=l}^{l} X_{ii} - \sum_{i=l}^{l}(X_{i+} * X_{+i})}{N^2 - \sum_{i=l}^{i}(X_{i+} * X_{+i})}. \qquad (4)$$

Where: X_ (i +) = Marginal of the column; X_ (i +) = Diagonal of that column

To read the Kappa index, the relationship between the index values and the performance of the classification is used, as shown in Table 1.

Table 1. Kappa Index

Kappa Index	**Classification Perfomance**
<0	Terrible
$0 < K \leq 0.2$	Poor
$0.2 < K \leq 0.4$	Reasonable
$0.4 < K \leq 0.6$	Good
$0.6 < K \leq 0.8$	Very Good
$0.8 < K \leq 1$	Excellent

Source: Adapted from Congalton, 1991.

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2.5. Statistical analysis

For the present study, it was verified whether there is a significant effect (95% confidence level) between the months and years ratio on the burned area registered within the PNAG, through the analysis of variance (ANOVA) of two factors without interaction (as usual in complete randomization (Spiegel, 1993)). Tukey's DHS (Honestly Significant Difference) test (1953) was also carried out between the months and the burned area, as the Tukey test statistically controls the fact that many simultaneous comparisons are being performed. The statistical analysis was performed using the Minitab® 18.1 (2017) statistical package.

3. Results

The frequency of fires within the 5 year's period is 0.38 times / year, that is, the fires occur in the same place every 0.38 times / year, and the return interval is 5.38 years, that is, it takes 5.38 years to burn the entire park area (2861km^2), and the average fire return interval is 2.62 years, that is, the average fires need this time to reoccur in the same location.

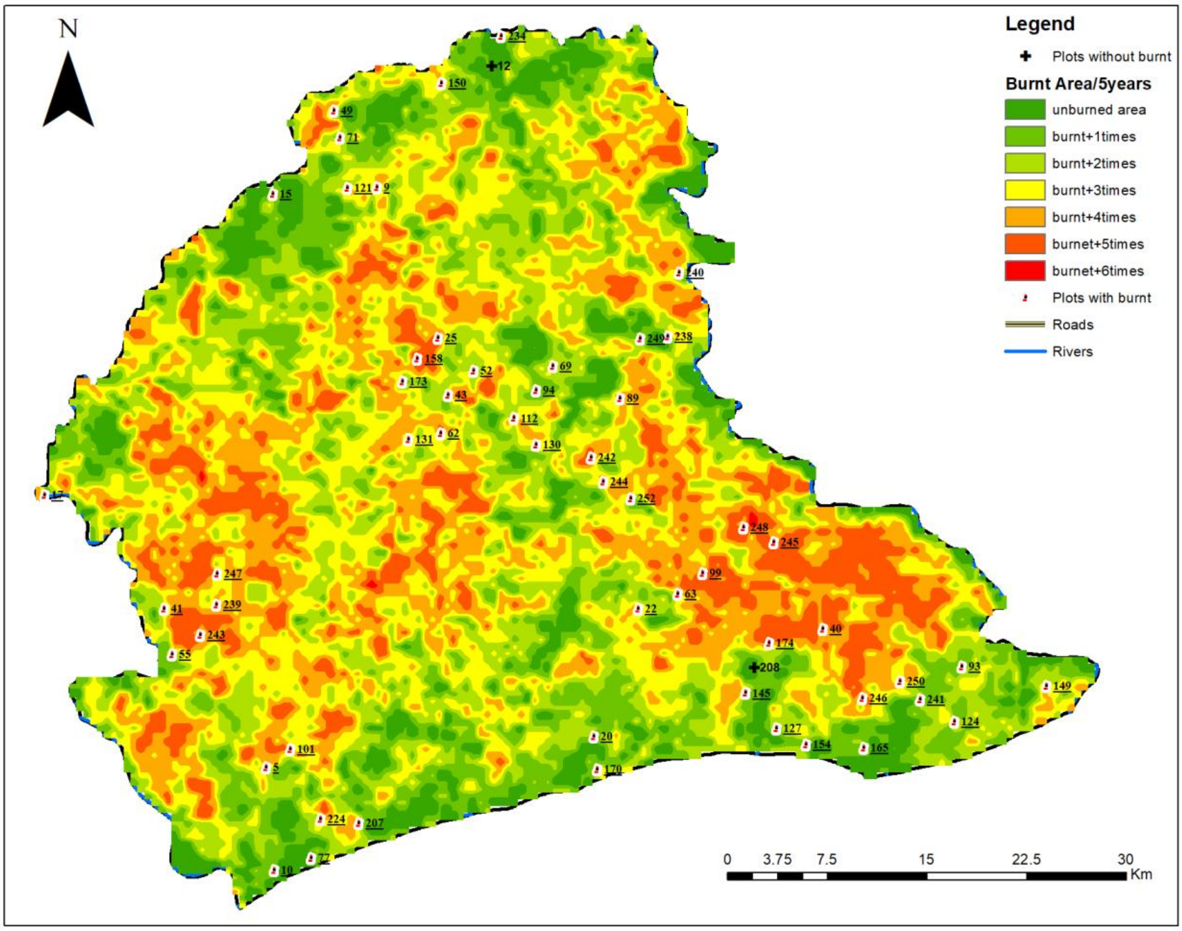

Figure 2. Burn frequency map (MCD64A1).

It is observed that within the period under study (2014 to 2018) the fires were distributed over almost the entire park (Figure 2), corresponding to a total percentage of about 92.8% of the area burned, but 0.036% of the area burned more than once within this period.

In 2014, PNAG burned 58.1% of its area (1660.9 km^2), in 2015 it burned 49.2% (1406.6 km^2), 2016 burned 43.4% (1242.5 km^2), 2017 burned 58.1 % (1662.7 km^2), and the year 2018 burned 53.9% (1540.9 km^2), in general the reserve burns on average about 52.5% per year, which corresponds to 1502.7 km^2 (Table 2).

Table 1. Area burned (MCD64A1) in km^2 per month during 5 years of study.

Year/Month	July	August	September	October	November	Total burned area	% of the burned area
2014	0.0	72.0	952.5	632.7	3.7	1660.9	58.1
2015	0.0	53.2	1347.4	6.0	0.0	1406.6	49.2
2016	9.4	157.3	1066.7	9.1	0.0	1242.5	43.4
2017	0.0	150.8	1376.6	135.4	0.0	1662.7	58.1
2018	0.3	505.2	1024.5	11.0	0.0	1540.9	53.9

4. Discussion

A study carried out at PNAG in 2016, which covered the years 2004 to 2014, found an average frequency of 4 times a year, and an average return interval of 3.9 years (Maúnze, 2016). The differences both in the average frequency of fires as well as in the average return interval between the present study and the one carried out (Maúnze, 2016) are related to two questions (1) the different time horizon (duration and time) of the studies, (2) the methodology used for the calculations is also different.

The burn frequency map (Figure 3), was validated based on the data collected in the field (Justice et al., 2002), of the 59 plots having obtained a Kappa Index with 43% accuracy, considered good (Congalton 1991) (Table 3), which means that the probability that a burnt area is actually found to be burnt is 43%.

Table 3. Accuracy of frequency map classification (MCD64A1)

	Producer accuracy (%)	User accuracy (%)	Omission error (%)	Comission error (%)	Kappa Index (%)
Not burnt	0	95,45	100	100	43,0
Burned	95,45	4,55	4,55	95,45	

Other studies carried out in ecosystems similar to that of PNAG, found a frequency of 0.36 times / year and an average return interval of 3.29 years within a 12-year period in the Niassa National Reserve (NNR) miombo (Ribeiro et al., 2017; Cangela, 2014), results similar to those obtained in this study.

In Kruger National Park (KNP) found an average return interval ranging from 1, 2, 3, 4 and 6 years over a period of 21 years (Govender et al., 2006), and a frequency ranging from 0.05 at 0.9 times / year under an average rainfall of 705mm (Van Wilgen, 2009). These data demonstrate that when the study period is longer, there is a tendency to increase the frequency and a decrease in the average interval of return of the fires, for management purposes the average interval of return is more relevant (Van Wilgen et al., 2004; Cangela, 2014).

The 2016 study found that PNAG was affected by burns in about 41.99% of its total extent (Maúnze, 2016), but the map of burn frequency (Figure 2) presented has not been validated, based on data from field (Justice et al., 2002), for example, or another validation methodology suggested by Giglio et al., (2016a) or by Morisette et al., (2005).

ANOVA allows us to state that the monthly variation has a significant effect on the size of the burned area ($p < 1.24^{e-07}$), and according to the Tukey test, the months of August, July, October and November are significantly equal in the observed burned area, and significantly different to the month of September (which presents a greater burned area).

The increase in the burned area can be explained by the fact that (1) in this study there was no discrimination in the quality of the detection of the burning, which varies from 1 to 4, with 1 - higher level of detection confidence and 4 - less trust (Giglio et al., 2016b, 2018); (2) and also the fact that there are two burning cycles, one characterized by a low frequency of burning (Van Wilgen et al., 2004) and another characterized by a high frequency of burning and consequently an increase in the burned area (Van Wilgen et al., 2004; Le Page et al., 2008) the study carried out by EtcTerra-Fundação IGF (2017) found that fires in recent years tended to reduce after a series of 3 years of high frequency fires (2009, 2011, 2013).

5. Conclusions

After the study on the frequency of fires in the miombo woodland of PNAG, within a period of 5 years (2014 to 2018) it is concluded that the average frequency of burning within the period of 5 years is 0.38 times / year and the average return interval is 5.38 years and the average return interval for fires is 2.62 years. Which means that there is a trend towards an increase in the frequency of fires compared to the study by Maúnze (2016). In the future, there is a need to increase the time horizon for studying the frequency of fires in the PNAG.

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