FIRE HISTORY OF VILA VELHA STATE PARK, PARANÁ, FROM 1997 TO 2018

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ABSTRACT: Grassy-wood steppe formation is characterized as a fire-dependent ecosystem, however the fire regime in these areas has changed over the years. The study aimed to recover the fire history of Vila Velha State Park - PR, which houses one of the main remnants of countryside vegetation in the state, in order to assist the fire management activities in the park. Through Landsat images, there were demarcated scars resulting from the fire passage from 1997 to 2018. Subsequently, frequency maps were generated, time since last fire and fire return interval. It was observed that 56% of the park area already burned at least once in the analyzed period, nine times the maximum frequency occurred. Approximately 23.5% of the burned area has exceeded a time of 10 years since the last burn, with 22 years the maximum period observed. The predominant fire return range in the park was the "mixed range". The southwest zone of the park was the most frequently attained, while the eastern zone concentrated areas with prolonged periods since the last fire occurrence, for which is recommended priority in the next fire management actions.

Keywords: forest fires, fire management, protected areas, grassy steppe, fire regime.

HISTÓRIA DE INCÊNDIO DO PARQUE ESTADUAL DE VILA VELHA, PARANÁ, DE 1997 A 2018

RESUMO: A formação de estepe gramíneo-lenhosa é caracterizada como um ecossistema dependente do fogo, entretanto o regime de fogo nessas áreas foi modificado ao longo dos anos. O estudo teve por objetivo resgatar o histórico de fogo do Parque Estadual de Vila Velha - PR, que abriga um dos principais remanescentes de vegetação campestre no estado, a fim de auxiliar as atividades de manejo do fogo no parque. Por meio de imagens Landsat, foram demarcadas cicatrizes decorrentes da passagem de fogo no período de 1997 a 2018. Posteriormente, foram gerados mapas de frequência, tempo desde a última queima e intervalo de retorno de fogo. Foram observados que 56% da área do parque já queimou pelo menos uma vez no período analisado, sendo nove vezes a frequência máxima ocorrida. Aproximadamente 30% da área queimada teve 8 anos desde a última queima, sendo 22 anos o período máximo observado. O intervalo de retorno de fogo predominante no parque foi o "intervalo misto". A zona sudoeste do parque foi a mais frequentemente atingida, enquanto a zona leste concentrou áreas com períodos prolongados desde a última ocorrência de fogo, para as quais recomenda-se prioridade nas próximas ações de manejo de fogo.

Palavras-chave: incêndios florestais, manejo do fogo, unidades de conservação, estepe gramíneo-lenhosa, regime de fogo.

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INTRODUCTION

Parana's countryside areas are forms of a relic of an ancient Pleistocene semiarid climate, therefore constituting the state's oldest floristic formation (Maack, 2012). Denominated the woody steppe (Brazilian Institute of Geography and Statistics [IBGE], 2012), the extensive field areas are interspersed with arboreal clusters marginal to the rivers or isolated (capons) of Mixed Ombrophilous Forest of shapes and dimensions variables, where *Araucaria angustifolia* stands out (Roderjan et al., 2002).

Most grassland plants have underground rhizomes or burn-resistant bulbs or frequent frosts (Maack, 2012). Fire is a recurring element in these environments, which can benefit from its action and thus ensure its maintenance (Roderjan et al., 2002). In view of this, this ecosystem can be classified as fire dependent.

It is worth noting that potentially every ecosystem has a fire regime, which is defined as a set of recurrent fire conditions that characterize it, being these conditions: frequency, fire behavior, severity, time and extent of occurrence, propagation and distribution pattern. of the affected area. When ecologically appropriate, this regime maintains the viability, composition and proper functioning of the ecosystem (Myers, 2006).

According to Fidelis and Pivello (2011), the use of fire as an agricultural management tool has modified the fire regimes of Cerrado areas and southern fields, in order to increase the frequency of burnings, alter the period, intensity and spatial pattern. This fact was also observed by Maack (2012) in the Parana fields, which describes the selection between grass species and other plants as a consequence of annual burning. In addition to species reduction, frequent or severe burning can negatively impact soil, fauna, atmosphere and human health (Soares et al., 2017).

On the other hand, excluding fire from dependent ecosystems may also be unrealizable. In disturbance-dependent ecosystems, their total exclusion can lead to loss of biodiversity and processes, leading to the decharacterization or degradation of these ecosystems (Schmidt et al., 2016a). According to Fidelis and Pivello (2011), most of the time, when protected areas are established, all kinds of disturbances are removed from them. For that reason, Integrated Fire Management (IFM) programs have been implemented in protected areas on different continents, especially in fire-dependent or pyrophytic environments, such as the Cerrado, however, the IFM programs in Brazilian protected areas are under experimentation (Schmidt et al., 2016b). The main national programs include the *Cerrado-Jalapão* Project (Ministry of the Environment [MMA], 2019) and the one developed at the Emas National Park (França et al., 2007).

According to Schmidt et al. (2016b), the indicators used to monitor fire management programs vary by region, with the most commonly observed being: areas affected, times and places of occurrence (managed or unmanaged), and vegetation structure.

Considering these indicators, the Fire Occurrence Record (FOR) is critical for planning and monitoring fire management activities (Bontempo et al., 2011). However, much data from these FORs in protected areas is incompletely filled out, or without a more accurate criterion by those responsible (Torres et al., 2016). Thus, the use of geoprocessing tools for the characterization of landscape fire regimes in regions in which fire management programs were implemented (Schmidt et al., 2016b) stands out.

In the state of Paraná, one of the main remnants of the grassy steppe is conserved in Vila Velha State Park. According to Silva et al. (2016) the maintenance and conservation of the countryside depends on human intervention, and the use of controlled fire is an alternative for such. As the Vila Velha State Park FOR started in 2009, which makes it impossible to analyze it for a longer period of time, an alternative is the analysis of fire occurrence through satellite images, which will help to understand the current regime of fire in the steppe typology, as well as in decision making about fire management in the park area.

MATERIAL AND METHODS

Study area

Vila Velha State Park (VVSP) is an integral protection area (Brazil, 2000), created by Law No. 1,292, of October 12, 1953 (Paraná, 1953). Located in the municipality of Ponta Grossa, Paraná, between the coordinates 25 ° 12 '34” to 25 ° 15' 35” S, 49 ° 58 '04” to 50 ° 03' 37” W, covering an area of approximately 3122 hectares inserted in the Devonian Escarpment Environmental Protection Area.

According to the Köppen classification system, the climate in the region is Cfb - Temperate climate proper, which is characterized by the average temperature of the coldest month below 18 ° C (mesothermal), with cool summers, with average temperature of the month. warmer than 22 ° C and no defined dry season (Paraná Agronomic Institute [IAPAR], 2019a). According to the same author, January and February have the highest temperatures (22.4 ° C), while June and July have the lowest temperatures (14.6 ° C).

Regarding the rainfall, the VVSP region has an average annual cumulative rainfall of 1554 mm and an average of 126 rainy days (IAPAR, 2019b). According to the Environmental Institute of Paraná (IAP, 2004), the rainy season occurs from September to March, but during November and early December occurrences of short dry periods (summer). According to IAPAR (2019b), January has the highest rainfall, averaging 186.5 mm, followed by February (161.0 mm), while August has the lowest rainfall, averaging 78.9 mm.

The predominant wind direction is northeast (NE), with average velocity between 3 and 4 m / s during the year (IAPAR, 2019b). As for the occurrence of frost, they are concentrated from May to August (IAP, 2004).

Ziller (2000) categorized the grassy woody steppe into four sub-formations, which are observed in the VVEP (IAP, 2004): a) steppe stricto sensu (dry field); b) hygrophilous steppe (wet field); c) pioneer formation of river influence (swamp and floodplains) and d) rupestrian vegetation refuges (characterizing specialized vegetation to sandstone outcrops). Next to the steppes are also found capon-shaped forest physiognomies, the mixed montane ombrophilous forest (araucaria forest) and along the waterways, the alluvial mixed ombrophilous forest (gallery forest).

Fire history

The methodology applied in the present study was based on Alvarado et al. (2017) and Wittkuhn and Hamilton (2010). The ENPV's fire history was based on the determination of fire scars and prescribed burns for the period 1997 to 2018, obtained from Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM +) satellites. and Landsat 8 Operational Land Imager (OLI), extracted from the Earth Explorer database (United States Geological Survey [USGS], 2019). The periodicity of the images took into consideration the indication of Alvarado et al. (2017), in which scars are observed up to two consecutive images (up to 30 days) for the rainy season and up to five consecutive images for the dry season (over 60 days).

Scar demarcation was performed by visual interpretation of the false color composition of Landsat images (Alvarado et al., 2017; Batista et al., 2018). For the TM and ETM + sensors, the Red-Green-Blue composition used was: band 5 (1550-1750 nm), band 4 (760-900 nm) and band 3 (630-690 nm); while for the OLI sensor it was: band 6 (1570-1650 nm), band 5 (850-880 nm) and band 4 (640-670 nm) (Alvarado et al., 2017). Burning scars have a distinct visual appearance compared to most other types of ground cover, but resemble exposed rocks (Alvarado et al., 2017), clouds, watercourses, shadows or topographic features (Batista et al., 2018), which precludes the use of automated classification algorithms.

The years were categorized into 5 classes according to the percentage of burned coverage in relation to the total study area: very small (<1% of the study area surface); small (1 to 10%); average (10 to 30%); large (30 to 50%); and very large (> 50%), adapted from Batista et al. (2018), which in turn considers the area intended for fire management. Fire events were divided into five size categories: I (≤ 0.09 ha); II (1.0 to 4.0 ha); III (4.1 to 40.0 ha); IR (40.1 to 200.0 ha); and V (> 200.0 ha) (Soares et al., 2017).

The fire frequency map was generated from overlapping raster images of the scars. First, for each year a *shapefile* of the scars that were converted into a binary image (1 - affected area; 0 - unaffected area) with 30 meters of elaborated resolution. These were then overlaid by summation using the Arcgis 10.5 raster calculator tool.

The referent map the time since the last fire occurrence indicates the number of years since the last fire or fire in each polygon, 2018 being "year 1" and 1997 "year 22". According to Alvarado et al. (2017), this factor can be seen as an indirect measure of the accumulation of combustible material, fundamental to determine the danger of fire and to predict the intensity of fire.

After binary classification for each year, were united *shapefiles* using Arcgis 10.5's union tool, resulting in a single polygonal mesh for the period 1997-2018. The attribute table was exported to Excel spreadsheet, where it was calculated to each polygon the frequency of fire occurrence and fire return intervals (in years), which were classified and sequenced (Wittkuhn & Hamilton, 2010).

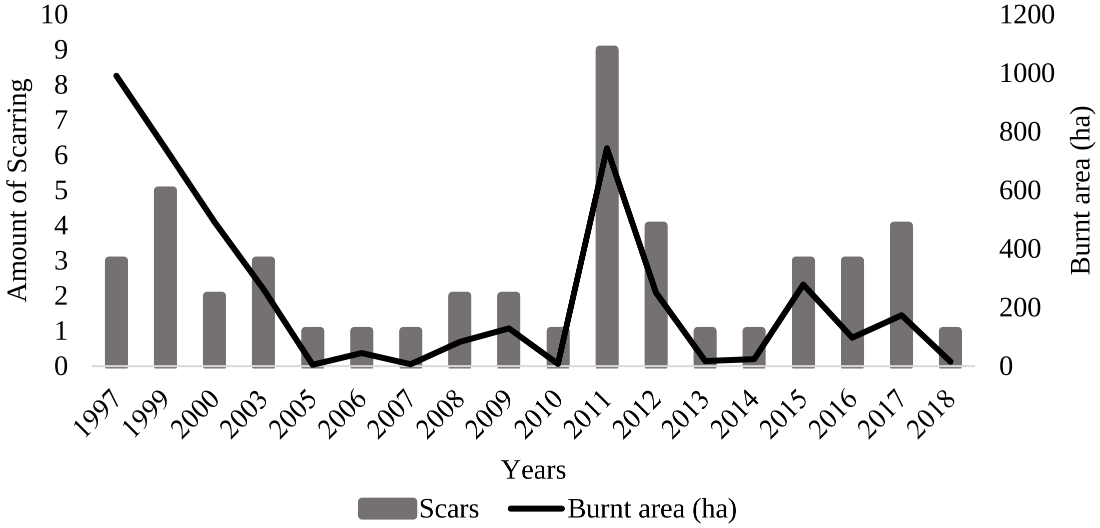
According to Wittkuhn and Hamilton (2010), any number of fire return intervals can be calculated, which is equal to the highest fire frequency minus one. In the case of the present study, the maximum frequency of occurrence was nine and thus eight return intervals were calculated for each polygon.

Each return interval was classified as proposed by Alvarado et al. (2017), which is: very short (fire occurrence every 1-2 years), short (fire occurrence every 3-5 years), moderate (occurrence of fire every 6-10 years) and long (over 11 years), which resulted in a return sequence. Considering the shortest continuous deadlines, this sequence was classified as: a) incomplete fire return interval (only observed fire occurrence); b) single fire interval (struck twice with a very short or short interval; c) single fire interval (struck twice with a moderate or long interval; d) very short fire return interval (more than two occurrences of fire, with a return time of 1 to 2 years); e) short fire return interval (more than two fire occurrences, with return time of 3 to 5 years; and f) mixed fire return interval (more than two fire occurrences, with variable return times. From this classification, the fire return interval map for the VVEP was generated using Arcgis 10.5.

RESULTS

From January 1997 to December 2018, 792 Landsat satellite images were found. Of these, 31.2% were able to demarcate the scars resulting from the fire action, while 68.8% were discarded due to cloud cover (98.2%) or image displacement (1.8%). which made the analysis of 1998 impossible.

Over a 21-year period, 47 scars were observed, of which 89.4% were related to forest fires, while the others were from controlled burns. The practice of fire management for restoration of rural areas in the VVEP began in 2014 (IAP, 2014), totaling approximately 1450 ha (44.3% of the total area) of managed area and mainly in April, August and September. The annual and monthly distribution of scars (fire and controlled burning) is shown in Figure 1.



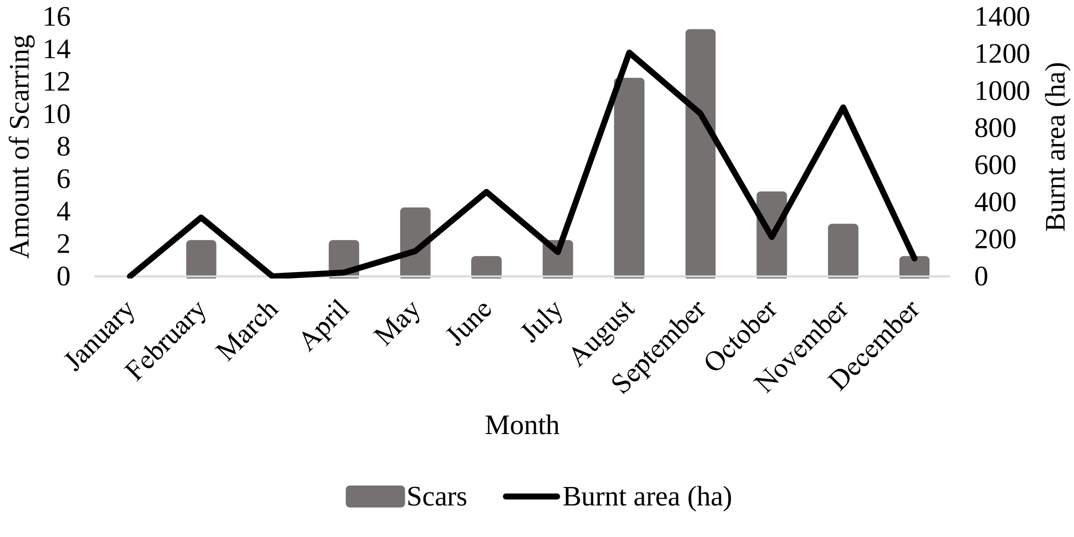


Figure 1. Annual (A) and monthly (B) distribution of the amount of scars and burnt area, forest fires and controlled burning for the Vila Velha State Park from 1997 to 2018.

According to the annual classification of burned coverage, 31.3% of the years were classified in coverage very small (2005, 2007, 2010, 2013 and 2016); 43.8% as small (2003, 2006, 2008, 2009, 2012, 2015, 2017); 18.8% as the average (1999, 2000, 2011); and 6.3% as large (1997).

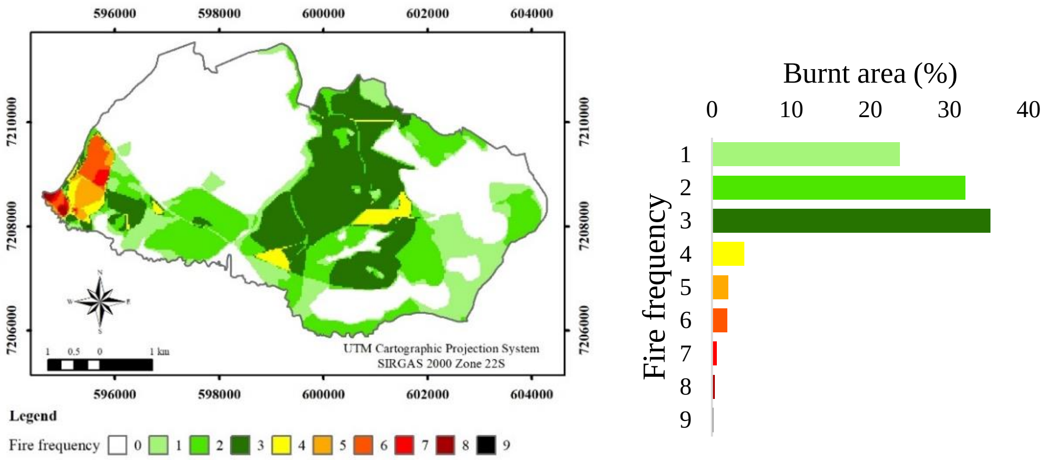
The year 2011 stood out for concentrating 19.1% of the scars, totaling 744.1 ha of burned area. The scar of the largest area (907.3 ha) and perimeter (27.8 km) was observed in August 1997, which contributed to this month totaling the largest burned area (1206.8 ha), with 25.5% of the occurrences, while for September 31.9% of the scars (878.5ha) were observed.

Another prominent event took place in November 1999, which reached an area of 686.1 ha, with November in the second in terms of burned area, with 910.7 ha.

According to the classification of fire scars by size class, 7.1% were classified as class II (≤ 4.0 ha); 45.2% in class III (≤ 40.0 ha); 35.7% in class IV (≤ 200.0 ha); and 12% in class V (> 200.0 ha).

In the reconstruction of fire history, in terms of fire frequency (Figure 2), it can be observed that 56% of the study area (1830.8 ha) was burned at least once, of which 74% correspond to the steppe formation. grassy-woody. The areas not affected by fire correspond predominantly to mixed ombrophilous forest (48%).

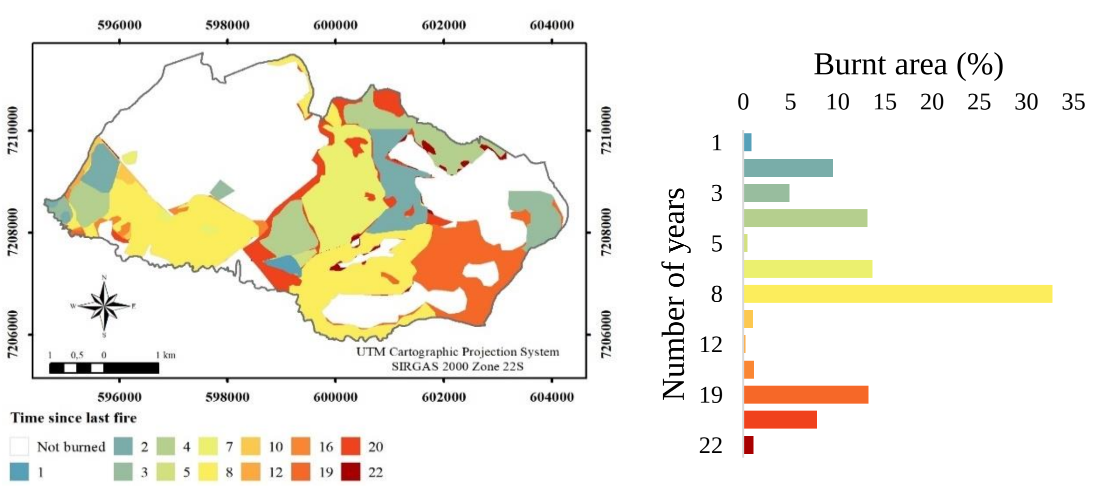
Figure 2. Spacial distribution of fire frequency (A) and burnt area (%) by fire frequency (B), for Vila Velha State Park from 1997 to 2018.



A B

Concerning the affected areas, 91% burned one to three times, 8.1% four to six times and 0.9% seven to nine times, with the Southwest being the most frequently affected by fire, while in the East area it was a lower frequency has been identified. In the Eastern region of the VVSP, areas with longer fire-free times (19 years) were also observed (Figure 3).

Figure 3. Spacial distribution of time since last burn (A) and burned area (%) by time since last burn (B), for Vila Velha State Park from 1997 to 2018.



A B

Temporally, 28.9% of the burned area occurred in the last 5 years, 47.6% last burned from 6 to 10 years and 23.5% surpassed 10 years without fire. The fire return range map is shown in Figure 4.

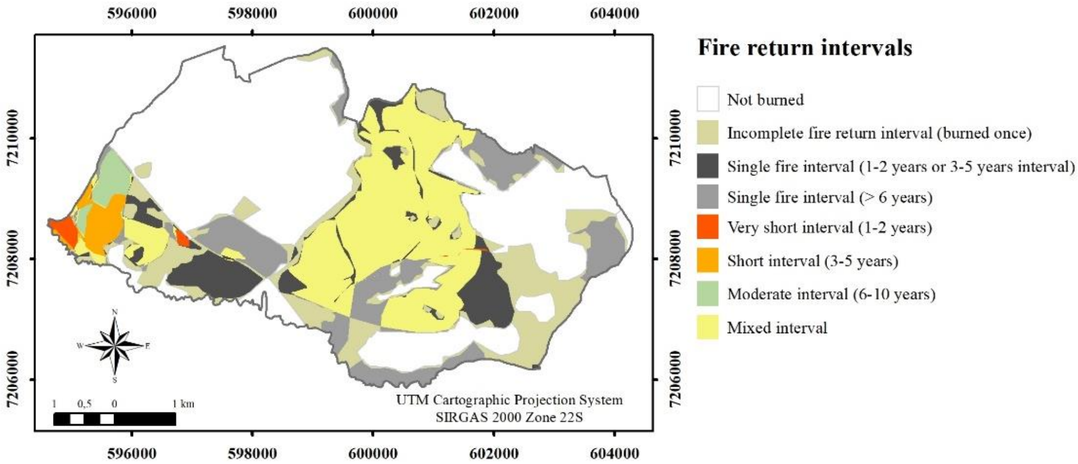


Figure 4. Spatial distribution of fire return interval for Vila Velha State Park from 1997 to 2018.

The mixed fire return interval was predominant, with 37.8% of the burned area, followed by an incomplete interval (23.8%), with areas that burned only once. Other ranges: moderate-long single (19.4%), single short-very short (12.6%), short (3%), moderate (2.4%), very short (1%).

DISCUSSION

According to Torres et al. (2016), the critical period of fire occurrence in the Brazilian protected areas extends from July to November, concentrating the burned area peaks in the months of August and September, corroborating with the present study. It is noteworthy that the Landsat satellites used have a periodicity of 16 days, which makes it impossible to determine the exact start date of the occurrences. According to Rodrigues et al. (2017) forest fires in the park area originate mainly from criminal acts, not differing from national statistics, in which anthropic action is often identified as a major cause, and arsonists are one of the main causal agents (Torres et al. , 2016).

According to Tetto et al. (2012), the concentration of fires in size classes I and II is indicative of an efficient combat system (detection, mobilization, displacement and combat). However, no scars corresponding to class I (≤ 0.09 ha) were observed, however this fact may be related to the resolution of satellite images (30 meters), which makes it difficult to determine fire scars in this category. On the other hand, Rodrigues et al. (2017), when analyzing the park's ROI (2009 to 2013), also did not show fires in this class. Following the publication of the park management plan in 2004, a reduction in class V fires was observed.

As much as the Brazilian Forest Code provides for the use of fire in protected areas aimed at maintaining certain ecosystems (Brazil, 2012), in many of them, including the Cerrado, the predominant policy is to exclude fire (Schmidt et al. ., 2016a), which modifies vegetation, resulting in large homogeneous areas with fuel accumulation (Myers, 2006; Schmidt et al., 2016a).

Oliveira and Maranho (2011) reported that, until at least 2011, fire was considered an enemy of the grassy steppe and the policy of total suppression and absence of fire in the VVEP prevailed. This practice is rarely effective for long periods, as fires are recurrent (Schmidt et al., 2016a), and especially when they occur in atypically dry years or at the end of the dry season, they tend to be more extensive, more intense and with more released heat (Myers, 2006; Schmidt et al., 2016a; Seger et al., 2018), which can reach vegetation that is fire-sensitive, such as riparian formations, cause higher mortality rates and reduce the reproductive capacity of several species in dependent ecosystems (Schmidt et al., 2016a).

Among the ecological models described by Myers (2006), the one currently developed in the VVEP is based on maintaining and restoring the remnants as a “microcosm”, so that the burnings are small when compared to what once existed in the landscape, thus allowing greater habitat diversity. In this sense, Alvarado et al. (2017) also observed for Serra do Cipó National Park a low and moderate frequency prevalence, which, according to the authors, configures a mosaic of burnt areas, differing in frequency, intensity and seasonality. Silva et al. (2011) suggest that some areas have low fire frequencies, aiming at the preservation of more fire-sensitive species, interspersed with others more frequently and shorter times since the last burn, in order to avoid extensive areas with biomass accumulation.

The time after fire occurs is considered by Batista et al. (2018) an important factor not only in estimating biomass accumulation (mainly grass), but also in the ratio between dry and wet material and its connectivity. In this sense, Alves et al. (2018) observed a higher amount of dry biomass in areas with longer periods without fire, which, according to the authors, makes these areas more prone to fire ignition and propagation.

For countryside areas, Batista et al. (2018) observed a deceleration of biomass accumulation after the third year without burning, stabilizing at approximately 10 $Mg.ha^{-1}$. In turn, Rodrigues (2017) found 12.6 $Mg.ha^{-1}$ of fine combustible material (alive: 13.5%; dead: 54%; miscellaneous: 32.5%) for areas with more than 5 years without fire north of the VVEP. In a similar scenario, Seger et al. (2013) suggest the technique of burning against the wind, since the fire intensity values observed by them are within the acceptable limits of vegetation damage, besides this technique allow better fire control.

According to Wilgen (2009), in wet savannas (annual average rainfall greater than 650 mm), the incidence of fires occurs more regularly when compared to arid savannas, due to the temporal distribution of precipitation, which allows a regular accumulation of sufficient fuel to withstand a booming fire. According to Pereira Junior et al. (2014), the return time for tropical savannas commonly ranges from three years for open savannah areas, as already noted for the Serra do Cipó National Park (Alvarado et al., 2017) and for savannah areas of the Jalapão State Park , six years for dense forest formations (Pereira Júnior et al., 2014).

According to Knapp et al. (2009) substantial changes in community composition usually require several prescribed burning cycles, when applied repeatedly at the same time of year can be detrimental, as the response to the burning season differs between species. Consequently the authors suggest that a heterogeneous fire regime maximizes biodiversity. However, in addition to frequency and time maps since the last fire occurrence, Silva et al. (2011) mention the preparation of biomass distribution maps, monitored in situ annually, as well as the monitoring of tree richness, density and floristic composition, to evaluate the effects of long-term fire management.

CONCLUSION

Winter was the predominant fire season, especially August and September.

In the southwest portion of Vila Velha State Park, a high frequency of fire occurrence was observed and the areas with a very short to short fire return interval were concentrated.

In the eastern portion of Vila Velha State Park were observed areas of low frequency of fire and incomplete return interval, where the period without fire was more than 15 years, which indicates an accumulation of combustible material and high risk of fire.

The park presented a mosaic of areas affected by fire, in order to generate a diversity of habitats, with distinct fire return intervals, with the mixed range being the predominant one.

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