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Fire management in the Brazilian savanna: First steps and the way forward

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Abstract

1. Several decades of frustrated attempts to prevent fires in the Brazilian Savanna (Cerrado) have led to deleterious ecological and management consequences. In 2014, the first Integrated Fire Management (IFM) programme was launched in three protected areas (PAs).
2. The IFM programme considers local practices, ecological information, management options and aims to create landscape mosaics of different fire histories to conserve biodiversity, reduce the prevalence of late-dry season (LDS) wildfires, protect fire-sensitive vegetation and reduce conflicts between PA managers and local communities.
3. The first 3 years of imposed fire management regimes led to 40%–57% reduction in LDS fires, improved dialogue between researchers, managers and local communities, generating fire management learning communities.
4. *Synthesis and applications*. This Integrated Fire Management programme represents a major advance in Cerrado management and conservation, by actively managing fires and decreasing the proportion of areas burnt by late-dry season wildfires. It can contribute to PAs' management in the Cerrado and other South American fire-prone ecosystems. Long-term monitoring and research are essential to understand the ecological implications and to improve fire management practices.

KEYWORDS

Brazil, Cerrado, landscape management, neotropic, policy, prescribed fires, savanna tropical, wildfires

1 | INTRODUCTION

Fire has an important role in savanna ecosystems (Bowman et al., 2009). Ecological (Miranda, Sato, Neto, & Aires, 2009), palynological (Salgado-Labouriau et al., 1997) and phylogenetic evidence (Simon & Pennington, 2012) indicates that historical fire regimes contributed in shaping the structure, biodiversity and ecosystem functions in the Brazilian savanna (Cerrado) (Durigan & Ratter, 2016).

Local communities regularly use fire to manage Cerrado landscapes for swidden cultivation (Borges, Eloy, Schmidt, Barradas, & Santos, 2016), plant harvesting (Schmidt, Figueiredo, & Scariot, 2007), hunting and cattle raising (Mistry, Bilbao, & Berardi, 2016), creating seasonal mosaic burning patterns that could prevent the propagation of large wildfires L. Eloy, I. B. Schmidt, A. Duverger, C. Fernandes, S. L. B. Lúcio, & M. C. Ferreira, unpublished data), as described in other tropical savannas (Mistry et al., 2016; Russell-Smith et al., 2013). Despite local practices and scientific evidence of the role of fire, a "zero-fire" official policy has prevailed in the Cerrado for decades (Durigan & Ratter, 2016).

"Zero-fire" policies have led to fine fuel accumulation and to disastrous large wildfires in fire-prone ecosystems (Russell-Smith et al., 2013). These intense late-dry season (LDS) fires frequently cover large areas, negatively affecting biodiversity, homogenizing landscapes (Murphy, Cochrane, & Russell-Smith, 2015), causing great animal mortality (Silveira, Rodrigues, Jacomo, & Filho, 1999), putting properties and human lives at risk, thereby generating high firefighting costs (Freeman, Kobziar, Rose, & Cropper, 2017). Additionally, environmental conflicts and litigation commonly emerge when local communities are prohibited from using fire as a management tool, as described in other regions (e.g. Kull, 2002; Mistry et al., 2016), leading to the development of community and official fire management programmes run in several fire-prone ecosystems (Russell-Smith et al., 2013; Van Wilgen, 2013).

In Cerrado, protected area (PA) managers have tried to prevent most fires through firebreaks around and/or within PAs and prohibition of fire use (Pivello, 2011), leading to increases in fine fuel load and consequent frequent LDS wildfires in the majority of Cerrado PAs, where frequent (2–5 years) megafires can burn areas >50,000 ha over a few days (Barradas, 2017; Pereira, Oliveira, Pereira, & Turkman, 2014). Firefighting costs frequently exceed 100,000 USD per week in a single PA, representing several times PA annual budgets of approximately USD 1 ha^{-1} $year^{-1}$ (the largest Cerrado PA is 733,000 ha, Godoy & Leuzinger, 2015). In some smaller, relatively well-structured PAs (Durigan & Ratter, 2016), the zero-fire policy has led to the virtual absence of fire. Where soil structure and/or fertility allow for woody encroachment, vegetation thickening and biodiversity losses have been reported (Abreu et al., 2017).

Trying to avoid all fires in Cerrado has not led to effective biodiversity conservation. Legislation explicitly allows fire management for conservation purposes in private and public areas within fire-prone ecosystems (Law 12651/2012). The National Fire Policy is still to be published (Durigan & Ratter, 2016). Understanding that fire management is complex, management experience is needed and no policy provides readily applied recipes, a pilot Integrated Fire Management (IFM) programme was implemented for the first time in 2014. We review principles of fire ecology in Cerrado pointing out knowledge gaps, present the IFM programme, discuss policy/management implications and indicate future directions to improve the programme.

2 | FIRE ECOLOGY IN CERRADO

Cerrado is a biodiversity hotspot comprising mosaics of grasslands, savannas and forests that originally occupied ca. 2,000,000 km^2 in central Brazil (Silva & Bates, 2002). The vegetation distribution is mostly determined by seasonal water relations, soil type and fire history (Pivello, 2011). Natural (lightning) fires occur mainly at dry–rainy season transitions (September–November). Natural fire return intervals may vary from 1 to 9 years (Ramos-Neto & Pivello, 2000). Anthropogenic fires have been present for at least 4,000 years and intensified in recent decades, when LDS fires became prevalent (reviewed by Pivello, 2011).

Savannas and grasslands are fire prone due to a continuous gramineous layer, whereas forest vegetation is fire sensitive; both ecosystem types are intermixed within Cerrado landscapes. Fires can cause high tree mortality (Franco, Rossatto, Silva, & Ferreira, 2014), having negative impacts on vertebrate species that depend on riparian forests (Silva & Bates, 2002). Frequent fires in forests can cause degradation and decrease the size of forest natural fragments (Hoffmann et al., 2012).

Natural fires and anthropogenic early dry season (EDS) fires are rarely large in forest areas due to high humidity and the absence of a continuous grass layer (Hoffmann et al., 2012). Contrarily, during the LDS, fast surface fires commonly spread through all ecosystem types due to highly cured ground fuels, high winds and low-air humidity (Pivello, 2011). The zero-fire policy frequently causes accumulation of dry fuel that is responsible for the rise of the frequency and size of LDS wildfires that spread through fire-resistant and fire-sensitive areas in Cerrado PAs (Durigan & Ratter, 2016).

As for other fire-prone ecosystems (Russell-Smith et al., 2013; Van Wilgen, Govender, & Biggs, 2007), EDS fires result in lower woody plant mortality compared to LDS fires (Hoffmann & Solbrig, 2003; Sato & Miranda, 1996). Frequent fires favour herbaceous species over woody plants (Moreira, 2000), whereas long-term fire exclusion may promote the exclusion of light-dependent herbaceous species (e.g. Abreu et al., 2017).

The ecological knowledge on fire ecology is mostly concentrated in southern and central Cerrado, based on accidental LDS fires, experimental fires in different fire seasons (e.g. Hoffmann, 1998), or in firebreak areas, mostly performed in EDS (e.g. Dantas, Pausas, Batalha, Depaula-Loiola, & Cianciaruso, 2013). After decades of fire prohibition, there is strong resistance in adopting fire management, due to a lack of management experience and limited knowledge on the effects of different fire regimes on numerous biotic groups within this highly diverse savanna.

3 | THE CERRADO IFM PILOT PROGRAMME

The IFM programme, co-funded by the Brazilian and German governments within the 'Cerrado-Jalapão' project, is based on Australian savanna fire management experience (Russell-Smith et al., 2013), and on patch mosaic burning techniques that (re)create mosaics of burnt and unburnt areas aiming to decrease the probability of large wildfires and increase fire interval in fire-sensitive areas (Murphy et al., 2015). The project included the hiring of international specialists, national and international exchanges, research and monitoring activities.

Facing the existing knowledge limitations and considering the pyrodiversity–biodiversity hypothesis (see Maravalhas & Vasconcelos, 2014), the IFM pilot programme in the Cerrado mainly aims to improve PAs' ability to conserve biodiversity, improve communication with local communities and decrease firefighting costs. The prescribed EDS fires aim to create landscape mosaics with different fire histories to reduce the areas affected by LDS wildfires and decrease wildfire frequency in fire-sensitive vegetation. As with other international experience (e.g. Freeman et al., 2017; Van Wilgen et al., 2007), strictly restoring natural fire regimes is not the goal of this programme, especially considering the novel Cerrado landscape conditions, where remnant vegetation frequently represent islands within an agribusiness matrix.

The focus on creating landscape pyrodiversity mosaics to avoid large LDS wildfires and protect fire-sensitive vegetation may seem simplistic. However, these are arguably valid management targets with clear benefits for biodiversity conservation (Maravalhas & Vasconcelos, 2014) and local livelihoods. Fire is part of the local communities' livelihoods, a natural determinant and a common risk in Cerrado. Managing fire instead of trying to prevent it represents a major advance and an initial step towards identifying more complex management targets such as the conservation of specific species or habitat and maintaining specific vegetation structure. The programme should not be narrowed to its initial targets of creating landscape mosaics of different fire histories and imposing prescribed EDS fires. Management goals, fire regimes to be imposed in each PA should be determined according to local conditions, conservation targets and threats, including woody encroachment due to fire exclusion.

3.1 | Protected areas

The IFM pilot programme started in three PAs: Chapada das Mesas National Park (CMNP), Serra Geral do Tocantins Ecological Station (SGTES) and Jalapão State Park (JSP) (Figure 1 and Table 1), dominated by fire-prone vegetation, especially grasslands and woodland savannas, on nutrient-poor, well-drained sandy soils. Fire-sensitive forests occur along the numerous watercourses. Annual precipitation (1,500–1,700 mm) is concentrated between October and May (ANA, 2017). Lightning fires generally do not turn into large wildfires.

Local communities have lived where the PAs were created for more than 120 years. Legally (Law 9985/2000), agreements can regulate the uses of strictly PAs by local inhabitants until a permanent solution is found. The main local economic activities are swidden agriculture, extensive cattle raising utilizing native vegetation, extractivism and tourism (Borges et al., 2016; Schmidt et al., 2007). All these activities, except tourism, involve the use of different types of

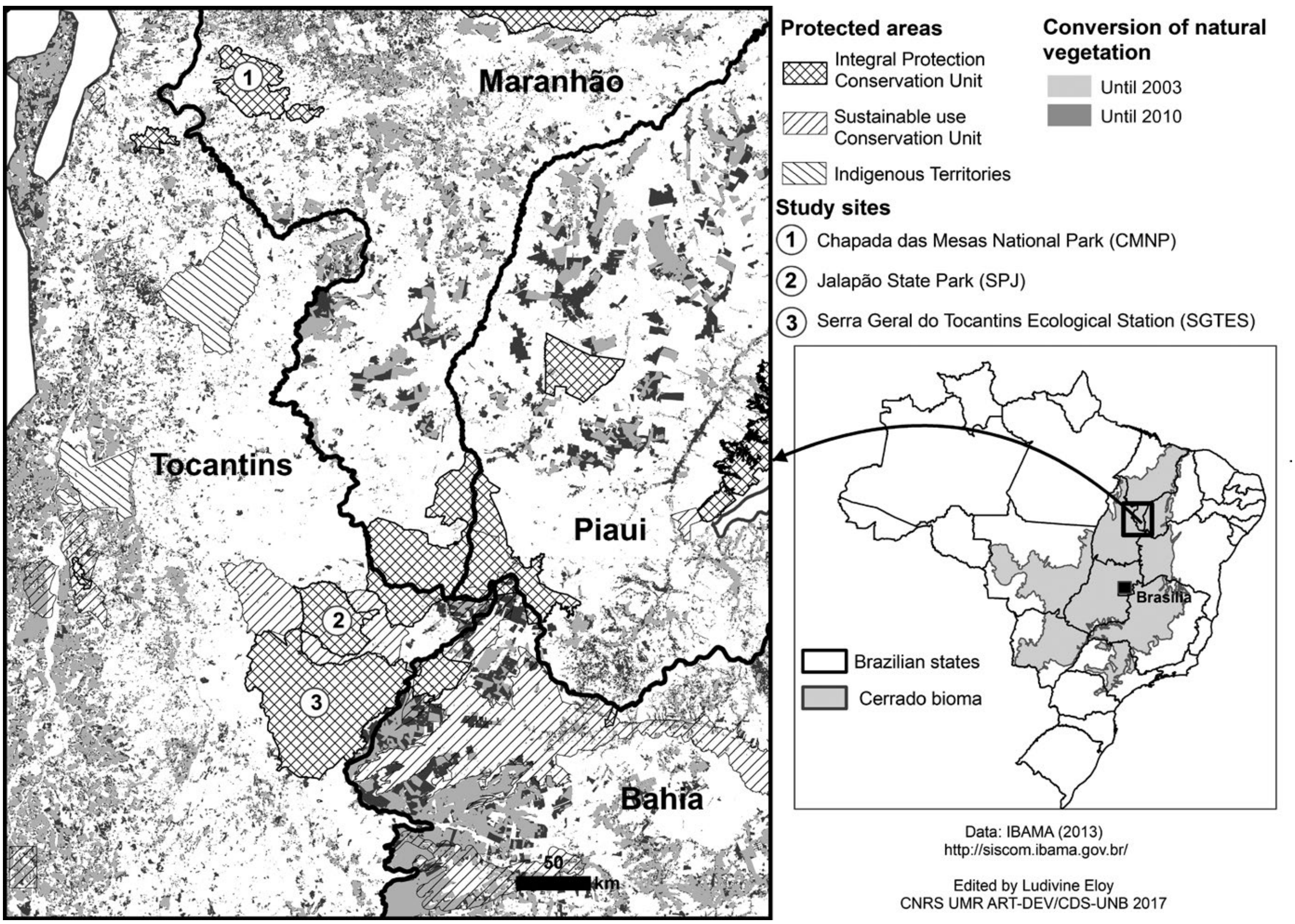

FIGURE 1 Cerrado protected areas (PAs) where pilot Integrated Fire Management programme was carried out from 2014 to 2016

fire. The creation of PAs and the enforcement of a zero-fire policy have generated conflicts. LDS wildfires are frequent (2–3-year intervals, Barradas, 2017; Pereira et al., 2014) and fire-prone vegetation (grassland and savanna) unburnt for >5 years rarely exists. Managers and local inhabitants report riparian forest losses due to wildfires; there is no evidence of woody encroachment in these PAs, probably due to the soil characteristics and frequent LDS wildfires.

3.2 | IFM programme: Planning activities

The IFM programme applies an adaptive management approach with planning, implementation and evaluation stages. Lessons learned from evaluation processes are incorporated into future activities. Planning activities included:

1. Technical meetings with PA managers, researchers, staff from environmental institutions, high-level decision-makers including the governor of Tocantins State and Ministry representatives.
2. Community meetings, during which managers, researchers and local residents identified conservation/management targets (Table 1) and created community-burning calendars based on local fire practices (Table 2).
3. Yearly operative planning, based on community-burning calendars, logistics and fuel load maps, prepared from satellite images (Landsat, RapidEye), indicating the proportion of exposed soil, live and dead biomass (Franke, 2014). They can be downloaded onto smartphones and used in field conditions to identify areas with higher quantities of cured ground fuels.

Each PA was divided into fire management zones (FMZ) according to local communities' occupancy, road access and landscape features.

3.3 | IFM programme: Implementation

The IFM implementation phase comprised the imposition of EDS-prescribed fires started by PA staff and/or local dwellers in strategic locations and times, according to conservation/management targets, such as areas with high fuel loads; along roads and along natural firebreaks such as riparian forest to protect these areas from wildfires (Figure 2). These EDS fires are strategically undertaken to go extinct naturally, with no need for fire brigades to control them. For that, burning patches vary according to local conditions, such as vegetation type, topography, wind, fuel load and air humidity.

In 2014, due to lack of experience, PA staff carried out few and mostly small (<50 ha) prescribed fires, partly managing only few FMZ. Managers identified the "safe-burning window", that is, the timeframe and weather conditions in which EDS fires stop before reaching fire-sensitive vegetation due to natural high humidity and lower temperature in these areas, especially after sunset. In 2015 and 2016, managers and fire brigades performed a higher number of prescribed fires, managing more FMZ (Table 1). Along with local communities' burns, these prescribed fires helped in creating landscape

TABLE 1 PA and fire management parameters. Fire Management Zones (FMZ) are PA zoning for fire management. Conservation targets are priority assets for protection against wildfires. Safe-burning window indicate when prescribed fires extinguished by themselves at night

Region	Protected area	Size (ha)	PA creation	Management agency	# FMZ	FMZ managed in 2014	FMZ managed in 2015	FMZ managed in 2016	Conservation targets	Safe-burning window[a]
Southern Maranhão	Chapada das Mesas National Park	160.000	2005	ICMBio (federal)	10	3	10	10	Riparian and dry forests, hills, *Euterpe oleraceae* (açai) forests, croplands	January-late May
Jalapão, TO	Serra Geral do Tocantins Ecological Station	716.000	2001	ICMBio (federal)	10	1	4	10	Riparian and dry forests, hills, croplands, *Syngonanthus nitens* (golden-grass) harvesting areas, *Mergus octosetaceus* (Brazilian Merganser) nesting areas	January-mid-July
	Jalapão State Park	154.000	2001	Naturatins (state)	4	1	4	4		

[a]safe-burning window can vary yearly according to rainfall patterns.

TABLE 2 Main fire practices performed by local communities in Jalapão and Chapada das Mesas regions

Goal	Period	Size of areas burnt	Vegetation types
Cattle rising	May–October	Tens to hundreds of hectares	Savanna, dry and wet grasslands
Swidden agriculture	September–November	0.5–3 ha	Riparian and swampy forests
Syngonanthus nitens (golden-grass) harvesting	June–October	0.5 to tens of ha	Wet grasslands
Firebreaks to protect fire-sensitive vegetation	January–June[a]	Tens of ha	Wet and dry grasslands

[a]The use of fire during rain season (October–April) happens during dry spells that commonly occur from December to February.

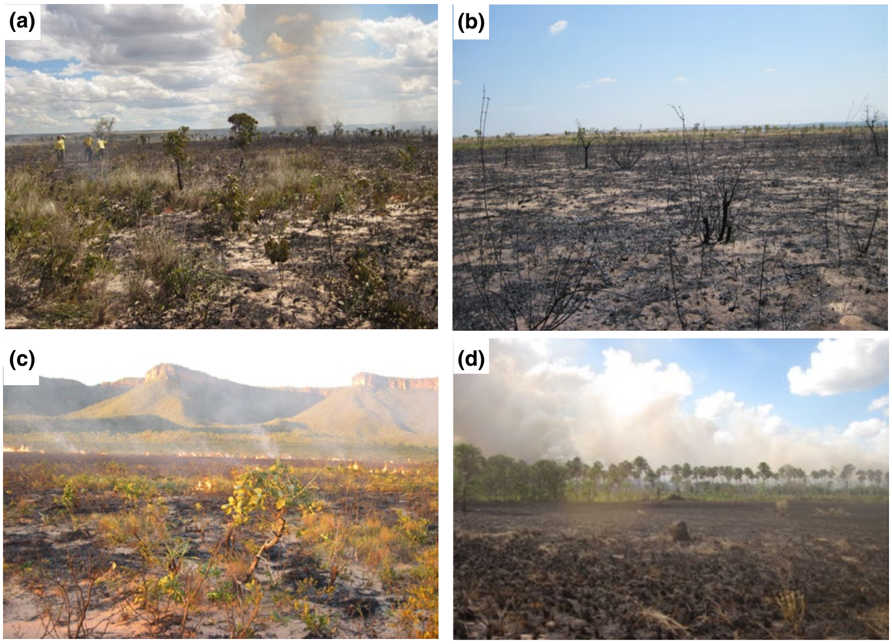

FIGURE 2 Early dry season (a) vs. late-dry season fire (b); management fires in grasslands to protect fire-sensitive vegetation in hills (c) and swampy forest (d) [Colour figure can be viewed at wileyonlinelibrary.com]

mosaics with different fire histories, decreasing the homogeneity of fuel in large areas.

3.4 | IFM programme: Short-term evaluation and results

Short-term evaluation consisted of burn scars' mapping of the preceding dry season through satellite imagery, technical and community meetings. The meetings, participatory prescribed burnings and other field activities increased the dialogue and knowledge exchange between PAs, communities and researchers. The number of community meetings and local dwellers' participation increased (e.g. in CMNP: 80 participants in three meetings in 2014 increased to 240 participants in eight meetings in 2016). During evaluation community meetings, burning calendars were compared to maps of burnt scars sometimes showing high correspondence. The possible reasons for the disparities between planned and actual burnt areas were collectively discussed. The lessons learned were incorporated into following planning.

There were advances in formal agreements for fire and natural resources uses between PAs and local communities. In JSP, the first formal agreement was established in 2016, whereas in SGTES the existing agreement (from 2012) was substantially reviewed in 2017 (Barradas, 2017). These documents now consider the diversity of local fire uses and established rules based on the reality of local communities and PA management.

Uncontrolled wildfires in LDS still occurred, but decreased in comparison to previous years (e.g. in SGTES, the single largest wildfire decreased from >85,000 ha in 2014 to <32,000 ha in 2016). From 2014 to 2016, there was a 40%–57% reduction in areas affected by LDS wildfires in the three PAs, whereas the total area burnt did not significantly reduce. Reducing burnt areas might not be a desirable outcome in fire-prone ecosystems, where open vegetation types are maintained by fires (Murphy et al., 2015; Van Wilgen, 2013). In the CMNP and SGTES, there was a shift in the predominant fire season from LDS to EDS (Figure 3). Firefighting costs, that were very high before IFM programme in these PAs (>USD 500,000 per year in 2011, 2012 and 2014 in SGTES), decreased, with no large firefighting operation since 2015.

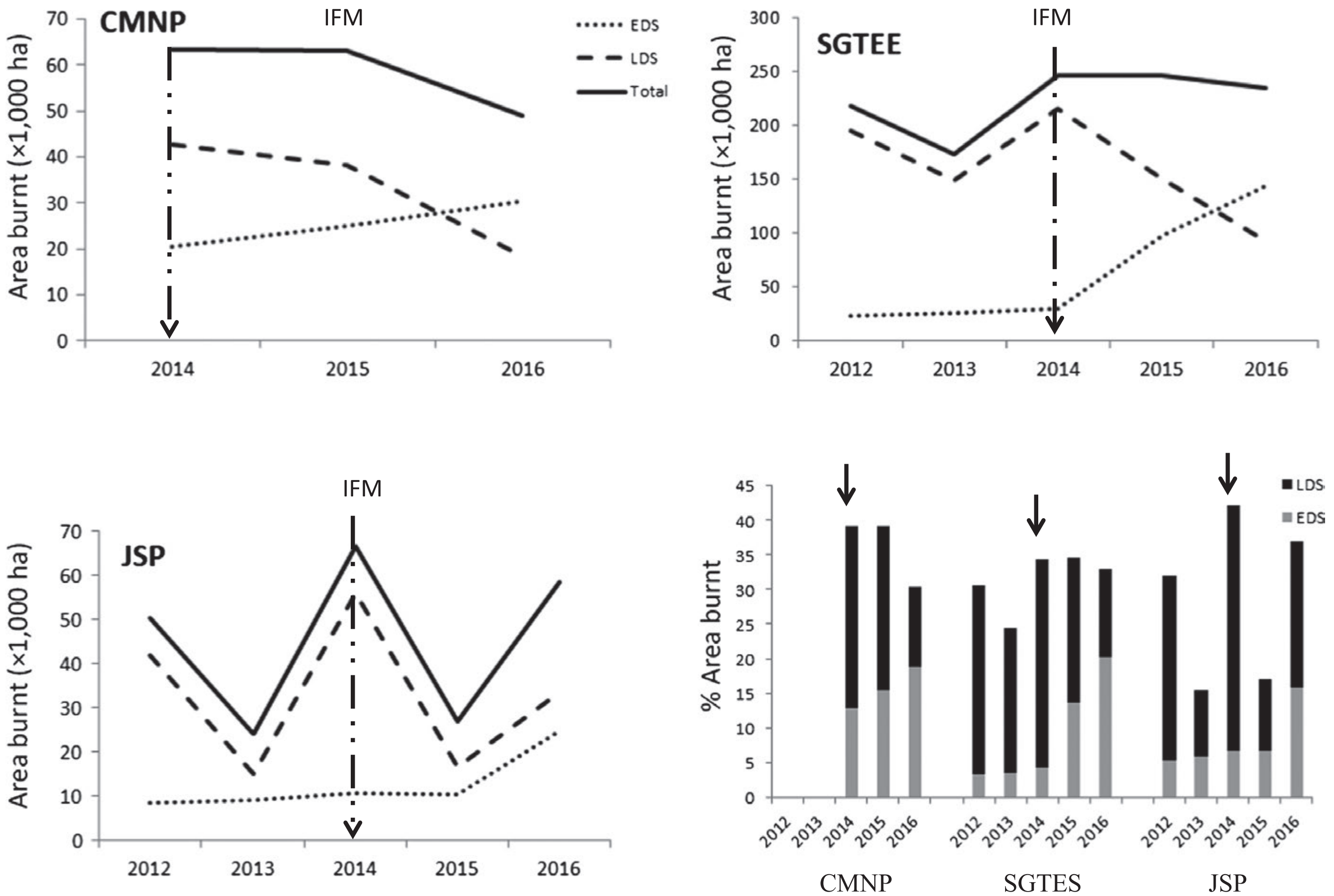

FIGURE 3 Total and % area burnt during early dry season (EDS, 16 October–15 July) and late-dry season (LDS, 16 July to 15 October) in Chapada das Mesas National Park (CMNP), Serra Geral do Tocantins Ecological Station (SGTES) and Jalapão State Park (JSP), arrows indicate the start of the IFM programme. CMPN 2012 and 2013 data are missing due to unavailable comparable satellite imagery

The results achieved in 3 years indicate that well-structured programmes can rapidly change fire regime patterns in the Cerrado. These initial results have led to the programme expansion to 8 other PAs and 11 Indigenous Territories since 2015.

4 | FUTURE PERSPECTIVES FOR POLICY, RESEARCH AND MANAGEMENT

The National Fire Policy should consider existing local and scientific knowledge and the experiences acquired within this IFM programme. It should allow for fire management planning according to the diverse Brazilian socioecological contexts. According to Durigan and Ratter (2016), it should support fire research and monitoring in PAs and clearly state the benefits of fire management in fire-prone ecosystems, helping disseminate information on fire management throughout society.

Research is needed to evaluate the effectiveness of fire management programmes. We established 98 permanent plots (50 × 50 m, totalling 24.5 ha) within the three PAs to monitor the effects of EDS and LDS experimental fires and fire exclusion on woody vegetation dynamics and fine fuel production. More research is needed to investigate, for example: (1) the effectiveness of prescribed fires in protecting fire-sensitive vegetation from wildfires; (2) greenhouse gas emissions and carbon uptake by herbaceous and woody plants under different fire regimes; (3) which types of burnt patterns maintain suitable habitat for different fauna groups; (4) reproductive and potential evolutionary consequences of different fire regimes on fauna, herbaceous and woody plants.

Research cannot completely inform management (Van Wilgen et al., 2007). Institutional monitoring programmes are necessary and should include simplified monitoring protocols, standardized photo records, permanent monitoring plots and methods to map separately managed from unmanaged LDS fires, since such fires may have productive and conservation functions.

This IFM programme created learning environments that can improve decision-making and regulatory processes (Van Wilgen, Govender, Biggs, Ntsala, & Funda, 2004). It promoted a long-demanded effective break in the “zero-fire” paradigm in the Cerrado (Durigan & Ratter, 2016; Maravalhas & Vasconcelos, 2014) and represents a major opportunity to advance in research, policy and management in the Cerrado. A National Fire Policy that allows for adaptative fire management, adequate to the context of each PA and region as well as the development of applied research in effective collaboration with management can promote significant advances in our understanding of the resultant ecological effects of different fire regimes to better inform fire management in Cerrado and other South American savannas.

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AUTHORS' CONTRIBUTIONS

All authors conceived the ideas, contributed to fire management implementation, discussed results, contributed critically to the drafts and gave final approval for publication. I.B.S., L.E. acquired and analysed data, I.B.S. led the writing of the manuscript.

DATA ACCESSIBILITY

Data available from the Dryad Digital Repository https://doi.org/10.5061/dryad.4gc81 (Schmidt et al., 2018).

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