Seasonal fire management by traditional cattle ranchers prevents the spread of wildfire in the Brazilian Cerrado

Ludivine Eloy, Isabel Belloni Schmidt, Silvia Laine Borges, Maxmiller Cardoso Ferreira, Teomenilton dos Santos

Seasonal fire management by traditional cattle ranchers prevents the spread of wildfire in the Brazilian Cerrado

Ludivine Eloy, PhD

Isabel Schmidt

Silvia Laine Borges

Maxmiller Cardoso Ferreira

Teomenilton Almeida dos Santos

Abstract

The use of fire by cattle ranchers is a major source of conflict between conservationists and local communities in tropical savannas. We evaluate the role of traditional pastoral management in wildfire prevention in two Protected Areas within the Brazilian savanna. Fine-grain field data from transect walks and interviews were combined with geospatial data at landscape scale to compare fire regimes in community-managed areas with those in governmental-managed areas. Local pastoral management creates seasonal mosaic patterns of burnings performed for productive activities and for deliberate landscape management, i.e., to protect fire-sensitive vegetation and avoid wildfires. Whereas government-managed areas were affected by large biennial late dry season wildfires, community-managed areas with a regular fire regime suffered less damage. These systems are under threat and poorly understood by researchers and environmental managers. In order to improve fire management in tropical savannas, greater understanding of pastoral management practices and their spatiotemporal dimensions is required.

Key words: Cerrado; Neotropical savanna; pastoral management; protected areas; *quilombola*; traditional ecological knowledge

Introduction

The use of fire for swidden agriculture and livestock grazing is essential for the production systems of small-scale farmers in tropical regions (Padoch and Pinedo-Vasquez 2010; Bowman et al. 2011). In fire-prone ecosystems, such as grasslands and savannas, cattle ranchers use fire to promote grass regrowth (Kull and Laris 2009; Lucio et al. 2014). Pastoral management creates mosaic patterns of burning across different vegetation types, producing a landscape that is "annually re-created by people, and which contains patches of unburned, early burned, and recently burned vegetation" (Laris 2002:156). Seasonal burning associated with traditional management practices has been shown to produce positive impacts on biodiversity and wildfire prevention in tropical savannas in Australia (Russell-Smith et al. 1997; Bird et al. 2008; Russell-Smith et al. 2013), South Africa (Parr and Brockett 1999), western Africa (Mbow et al. 2000; Laris 2002; Caillault et al. 2015), Venezuela (Bilbao et al. 2010) and Brazil (Welch et al. 2013).

However, pastoral systems using fire have rarely been described, and are poorly understood by environmental agencies and protected area (PA) managers. They have frequently led to conflicts between conservationists and local communities (Métailié 2006; Kull and Laris 2009; Lucio et al. 2014).

In Latin America, the increasing frequency and intensity of wildfires in the last few decades have commonly been attributed to misuse of fire by local communities, resulting in many efforts to suppress agropastoral burning. However, fire suppression policies have led to fuel accumulation and increased conflicts between government institutions and local communities, contributing to more frequent and larger wildfires (Mistry and Berardi 2016).

Despite recent research on traditional uses of fire and their effects on landscape dynamics (Coughlan 2015), there is still little evidence about, much less political acceptance of, how savanna ecosystems can be managed in this way (Mistry et al. 2018).

In Central Brazil, the savanna (*Cerrado*) comprises a mosaic of different vegetation types, fire-resistant vegetation (grasslands and savannas) growing alongside fire-sensitive vegetation, especially riparian forests (Walter and Ribeiro 2010). Natural fires have shaped *Cerrado* landscapes for millions of years (Simon et al. 2009). Traditional communities use fire for several purposes (Mistry et al. 2018). Despite evidence of its importance both ecologically and ethnoecologically a zero-fire policy has been implemented in the *Cerrado* region for decades. PA managers have tried to suppress the use of fire, mainly through fire breaks around or within PAs, and legal enforcement of the prohibition; this has led to increased fine fuel load and social conflicts. As a result, several decades of frustrated attempts to avoid fires have had damaging ecological and management consequences (Durigan and Ratter 2016). Extensive late dry season wildfires (>50,000 hectares) occur every two to five years in most *Cerrado* PAs, threatening local communities and infrastructure and causing economic and environmental losses (França 2010). Late dry season fires affect fire-sensitive vegetation and cause high rates of tree and animal mortality (Silveira et al. 1999; Miranda 2010).

Since 2014, some *Cerrado* PAs managers have carried out prescribed early dry season fires, aiming to change the main fire season, protect fire-sensitive vegetation, and reduce conflicts with local communities within and around the PA (Schmidt et al. 2018). But cattle ranching, which is a major activity in these communities (Eloy et al. 2016), is one of the main bones of contention between local communities and PA managers, mostly because of a lack of understanding of the uses of fire related to this activity (Ribeiro and Figueira 2011; Lucio et al. 2014). Pastoral burning is simplistically described as uncontrolled and irrational, referring only to one burning period (the "dry season"), without distinguishing between uncultivated pastures

and those planted with exotic grass species (Pivello 2011).

We argue that, in order to reduce conflicts and improve fire management in *Cerrado* PAs, the spatiotemporal dimensions of pastoral management practices need to be better understood, so that traditional ecological knowledge can be better reflected in fire management programmes. Investigation of fire regimes in *Cerrado* PAs usually relies on remote sensing (França 2010; Pereira Júnior et al. 2014), with no consideration of local practices. Most studies on traditional fire practices focus on indigenous communities (Posey 1985; Mistry et al. 2005; Welch et al. 2013) but little is known about the burning practices of non-indigenous traditional communities, such as *quilombola* (descendants of Maroon communities) and peasant farmers, who occupy most of the remaining *Cerrado* land, and commonly use fire for pastoral management. Specially, no attention has been paid to the spatiotemporal dimensions of cattle ranchers' burning practices and their effects on the *Cerrado* landscape.

In this paper, we evaluate the role of traditional pastoral management in wildfire prevention in two *Cerrado* PAs. It describes and maps pastoral burning practices through household-level data, and compares burning patterns for 2014 and 2015 in areas managed by local communities (hereinafter 'community-managed areas') with those in the rest of the PA ('government-managed areas') where fire suppression policies were applied. Finally, we discuss the policy implications of those findings in the light of recent changes in fire policy in Latin America (Mistry et al. 2018).

Materials and Methods

The study region: the Jalapão

The Jalapão region (10° 22' 40" S; 46° 40' 30" W) forms the largest area of *Cerrado* PA and is under serious threat of large-scale deforestation (Lahsen et al. 2016). The State Park of Jalapão (SPJ; 158 000 ha) is managed by the Nature Institute of Tocantins State (Naturatins).

The Serra Geral do Tocantins Ecological Station (SGTES; 713 000 ha) is a managed by a federal agency, the Chico Mendes Institute of Biodiversity Conservation (ICMBio). The mean annual precipitation in the region is 1,600 mm, 90% of which occurs between October and May (ANA 2017). Both PAs were created in 2001 and encompass areas occupied by indigenous people for centuries, and by afro-descendant (*quilombola*) communities since the 19th century.

Today, three *quilombola* communities within SPJ account for approximately 95 households. Population density in SGTES is lower: some 15 households undertake productive activities in the northern part of the PA with cattle herds varying from two to 95 animals per household. These communities manage natural resources parts of the PAs (community-managed areas), representing 15% and 32% of the total SGTES and JPS areas respectively (Eloy and Lucio, unpublished report, 2013).

Traditional production consists predominantly of swidden cultivation, extensive cattle ranching on native pastures, and handicrafts made from 'golden grass' flower stalks (*Syngonanthus nitens*, Eriocaulaceae), all of which depend on fire use (Schmidt et al. 2007). The creation of the PAs led to conflicts between environmental managers and local communities due to threats of expulsion, restrictions on the use of natural resources, and the prohibition of burning.

Since the mid 2000s extensive biennial wildfires in the late dry season affecting different vegetation types, including fire-sensitive forested areas, have become common in the region (Pereira Júnior et al. 2014). Since 2012, various formal agreements and collaborations between PA managers and local communities have increased dialogue between these stakeholders (Barradas 2017), but spatiotemporal information on the use of fire for cattle raising was still limited.

Data collection

123 All research goals and methods were developed with the participation of PA managers
124 and members of the *quilombola* communities, who were involved in planning, data gathering,
125 and result validation. In order to evaluate the role of traditional pastoral burning practices on
126 wildfire prevention, household-level field data were combined with geospatial data at landscape
127 scale.

128 *Transect walks*

129 In order to describe and map the pastoral burning practices, transect walks were
130 conducted with 18 local cattle ranchers in the two PAs between October 2014 and October
131 2016. Ranchers were asked to identify and interpret landscape components (e.g. native
132 vegetation types, burn scars, rivers, fields, fallows, soil types). Changes in vegetation cover
133 (including from native to cultivated grass species), vegetation use, and burned patches were
134 recorded using a Global Positioning System (GPS). For each burned patch, the reason, date,
135 and method of burning were recorded.

136 *Spatial analysis*

137 All the burn scars within JSP and SGTEE were mapped by reference to Brazilian
138 Institute of Space Research (INPE) data (https://prodwww-queimadas.dgi.inpe.br/aq30m/), with
139 a 30-m resolution[1]. For our study region (Aqua MT scenes 221_067 and 221_068), this website
140 offers regular burn scar mapping data[2]. Data from two consecutive years (2014 and 2015) were
141 examined to ascertain the dynamics of fire at landscape scale in order to cover the generally
142 biennial management regime. 2014 and 2015 were the first two years of an integrated fire
143 management pilot programme within the *Cerrado* and these two PAs (Schmidt et al. 2018).

144 To compare burning patterns in areas managed by local communities with those in
145 government-management areas (where fire suppression policies were dominant) within the PA,

[1] The AQUA M-T satellite detects a fire front as small as 30 m in length and 1 m in width. The data are updated daily, producing new maps every month or two, depending on visibility.

[2] For scene 221_067, INPE provides 6 data series for 2015 and 10 for 2014. For scene 221_068, 11 data series were downloaded for 2015 and 10 for 2014.

we used official shapefiles for the limits of protected areas, and created new shapes to map community-managed areas based on other official maps (produced by ICMBio for SGTES) and participatory maps from previous years (for JPS) (Eloy and Fernandes 2015).

Data Analysis

Transect walk

Qualitative and quantitative data collected during the transect walks (on dates of and reasons for burning in each landscape component) revealed details of the annual burning regime and its link with cattle feeding schedules. Spatial data (points identified by GPS at the limit of burn scars) were compiled in ArcGis software and projected in Landsat images to produce individual maps of the distribution of burn scars at a scale revealing each *quilombola* family production unit. This allowed the identification of patterns of burning by cattle ranchers.

Spatial analysis

In order to compare the size and temporal distribution of burn scars in community-managed areas with those in government-managed areas, ArcGis software was used to document the shapes of all burn scars from 2014 to 2015. These were divided into three periods: early (16 October to 15 July), mid (16 July to 15 August) and late dry season (15 August to 15 October), reflecting the periods used by environmental agencies for fire management activities. The proportion of each area burned was examined according to season and management type (community- vs. government-managed areas) using the X^2 test.

Results

Transect walks

Cattle ranchers use fires in four periods of time across the dry and rainy season (April to

November) in areas with four different vegetation types (Table 1). Burn scars in areas they managed varied in size from 10 to 150 ha, and were situated next to each other (figure 1). During the transect walks, cattle ranchers explained that they burn different areas to ensure grazing for cattle at different sites throughout the year to cope with the spatial and temporal dispersion of grazing resources. They use fire in areas of both native and exotic grasses.

During the rainy season and the early dry season, each rancher keeps his livestock on cultivated pastures and native grazing areas near his family home. During early dry season, fires are set in shrubby grasslands (*campo sujo)* and savannas (*cerrado strictu sensu)* allowing cattle to graze on the regrowth of grasses, shrubs and trees following the fire. During mid and late dry season, only the wet grasslands (*campos úmidos das veredas)* support vegetation that resprouts after fire, so these areas are burned then to provide grazing later.

Small burned patches (< 30 ha) close to houses are used for animals requiring daily attention during the dry season (pregnant or sick cows, those with calves, and horses). The larger patches are used for the rest of the herd, which moves freely in remote areas. Herds belonging to different ranchers can mingle, grazing together in burned areas. Cattle graze each burned patch for 30 to 60 days, depending on the size of the burned area, the size of the herd, and the rainfall level. Fires also have other functions: in wet grassland, for example, fire for cattle grazing in one year promotes the flowering of golden-grass in the following year. During early rainy season, ranchers burn savanna areas and exotic grass pastures near the family house, keeping the herd close to home. The cattle graze on exotic grass pastures until the following early or mid dry season, according to grass availability. Ranchers with larger cultivated areas are able to keep their cattle on exotic pastures closer to home for longer, and therefore have less need of early dry season fires in natural vegetation. However, they still depend on fires in the mid and late dry season when cultivated pastures provide limited grazing.

Cattle ranchers report that grazing both native and exotic pastures allows cattle to regain

weight and helps treat or limit cattle diseases. According to them, the spatial and temporal variations of grazing resources result partly from different vegetation responses to fire, determined mainly by soil humidity and species composition. For example, in early rainy season savanna vegetation resprouts relatively fast: cattle can graze these areas within 15 to 20 days after burning. Ranchers aim to keep cattle on these native grazing areas and protect cultivated pastures from grazing for 30 to 45 days after burning, so that they remain productive throughout the rainy season (table 1).

Finally, transect walks also demonstrated that the regularity and patchiness of this burning regime reflect deliberate landscape management for wildfire prevention. Although ranchers recognize that late dry season fires in wet grasslands are the most dangerous and hardest to control, they are also the most important for their cattle's survival. The early dry season fires in upland grasslands and savannas, used for grazing during early and mid dry season, create fire breaks, restricting the spread of wildfires during the mid and late dry season when wet grasslands are burned. To burn wet grassland bordering on riparian forest, cattle ranchers start fires in the late afternoon, taking account of the ground and weather conditions (especially wind direction) to avoid affecting the forest. These fires stop burning when they reach uplands (grasslands and savannas) burned earlier in that dry season or in the previous year. Cattle ranchers claim that the risk of wildfires is reduced if upland areas have been grazed, since little dry fuel is then left.

Spatial analysis

For the two study years, 3 823 burn scars were identified using INPE data. Between 82% (2014) and 90% (2015) of them were smaller than 50 hectares, and 97% (2014) and 99% (2015) of the burns were smaller than 1000 hectares in both community- and government-managed areas. Importantly, all six burn scars larger than 10 000 hectares were located in

221 government-managed areas, from fires during the late dry season (figure 2). Such late dry
222 season fires affected 41% (44,450 ha) of the government-managed area in JSP in 2014, a
223 significantly higher proportion of the area burned in that year's late dry season than in the area
224 managed by local communities (4%, i.e. 2.402 ha; X^2= 33.3, df= 3, p<0.0001). Apart from that
225 difference, the proportions of area burned during the late dry season in community-managed
226 areas (4-16%) and in government-managed areas (5-21%) were similar in SGTEE in both
227 years, and in JSP in 2015 (Figure 3).
228
229 **Discussion**
230 Results obtained at household level (during the transect walks) showed that traditional
231 cattle ranching systems in the Jalapão produce and rely on a landscape combining burned and
232 unburned areas of different sizes. These burns are performed for productive activities, at the
233 scale of the individual production unit, not only to promote vegetation resprout for cattle, but
234 also to protect fire-sensitive vegetation and avoid wildfires, i.e. to intentionally manage the
235 landscape.
236 Spatial analysis at landscape level showed that this seasonal mosaic pattern helps
237 prevent wildfires: whereas government-managed areas were mostly affected by large biennial
238 wildfires, community-managed areas practiced a regular fire regime. While 55% of the
239 government-managed JSP was burnt in 2014 and 11% in 2015, community-managed areas in
240 JSP burnt only 23% and 12% in these same years. In other words, within community-managed
241 areas the total area burned, and especially the proportion hit by late dry season fires, tends to
242 vary less than in government-managed areas. This mostly biennial pattern of large wildfire
243 recurrence in the region has been ascribed to biomass accumulation (Pereira Júnior et al. 2014;
244 Barradas 2017; Schmidt et al. 2018) and are common in fire-prone ecosystems where zero-fire
245 policies prevailed (Métailié 2006; Russell-Smith et al. 2013). As a result, it is likely that

246 institutional attempts to avoid fires led to a high cured fuel load across a large landscape,
247 resulting in large fires (>10,000 ha) within governmental-managed areas. By contrast, seasonal
248 productive uses of fire ensure landscape mosaics with different fire histories, producing a
249 regular fire regime that helps to avoid such large, hard to control wildfires.

250 The role played by seasonal mosaic patterns produced by traditional burning in
251 preventing wildfires prevention can be explained by biomass fragmentation at the landscape
252 scale and (as described above) in several fire-prone ecosystems related to indigenous burning
253 practices associated with hunting, foraging, and farming (Bird et al. 2008; Bilbao et al. 2010;
254 Welch et al. 2013). Before the recent publications on western African savannas (Caillault et al.
255 2015; Laris et al. 2016) and on Europe (Métailié 2006; Dumez 2010), few studies had
256 addressed the contribution made by traditional pastoral management to the production of such
257 regular seasonal patterns. This may explain why pastoral fires cause conflicts between
258 conservation policies and local communities, as reported in western (Hough 1993; Laris 2002)
259 and eastern Africa (Boutrais 2008; Johansson et al. 2012), Madagascar (Kull and Laris 2009),
260 southern Europe (Métailié 2006; Dumez 2010), central America (Mathews 2005), and the
261 Brazilian *Cerrado* (Lucio et al. 2014:).

262 This paper's findings provide a valuable basis for future research in other Latin
263 American tropical savannas where free-range cattle ranching still underpins the local culture
264 and economy but causes conflicts with PA managers (Ribeiro 1998; Eloy et al. 2016).
265 Moreover, the persistence and complexity of seasonal fire management in *quilombola*
266 communities of the *Cerrado* may provide new evidence of the role of the African diaspora in
267 shaping Brazil's biological and cultural landscapes (Carney and Voeks 2003; Sluyter and
268 Duvall 2016).

269 Such research is important because, although these practices are under threat, they are
270 and still poorly understood by researchers and environmental managers. Along with fire use

prohibitions, many of these traditional practices are threatened by large-scale land use changes associated with agribusiness expansion and climate change (Huffman 2013).

In the *Cerrado* the intensification of cattle ranching threatens the traditional seasonal mosaic patterns produced by burning. Since the 1990s cattle ranchers have been gradually expanding their exotic grass pastures for several reasons: changes in cattle breeds, availability of wire fencing, land titling policies, agricultural intensification projects, and fire prohibition (Eloy et al. 2017). As described above, many ranchers are less dependent on early dry season fires: their cattle can graze on cultivated pastures until the mid dry season, in June or July. However, ranchers still need to carry out late dry season burning in wet grasslands, due to lack of drinking water and the low productivity of exotic grasses. Early dry season burning is therefore gradually losing its productive function, as opposed to the mid and late dry season burnings, possibly leading to more wildfires. These land use changes are accompanied by climate changes: according to residents, swampy forests and wet grasslands are drying out due to changing rainfall patterns and land use around the region (e.g. soybean expansion), creating conditions that challenge traditional burning practices.

The Brazilian government has recently begun to shift from a fire suppression to a fire management policy, adopting the concept of Integrated Fire Management (IFM) (Mistry et al. 2018). Through the "Cerrado-Jalapão" project, PA managers have since 2014 consulted stakeholders with knowledge of traditional fire practices and started using prescribed early dry season burnings. Since this pioneer initiative in the *Cerrado* began, both late dry season wildfires and conflicts between government agencies and local communities have lessened (Schmidt et al. 2018). The findings of this paper should help to avoid a narrow focus on early dry season fires that fails to recognize the complexity of traditional fire management systems, reducing local acceptance of prescribed burnings policies, as happened in Australian and African savannas (Caillault et al. 2015; Petty et al. 2015).

Moreover, our findings challenge the idea of "alternatives to fire use" as a way to prevent wildfires. Rotational grazing on exotic grass pastures, as part of fire-free pastureland management, has been used in the *Cerrado* to preserve native areas, avoid wildfires, and increase land productivity. However, our results show that extending exotic grass pasture decreases the usefulness of early dry season burnings, but does not allow cattle ranchers to avoid using late dry season fires. The net result reduces the seasonal mosaic patterns that prevent wildfires. Moreover, the expansion of exotic grass pastures for livestock grazing is the main cause of natural vegetation loss in Brazil (Fearnside 2005; Klink and Machado 2005). In other words, the promotion of "alternatives to fire use" may reduce the use of fire, but at the cost of native biodiversity in the *Cerrado*, since these exotic grasses may be highly invasive (Pivello et al. 1999). Moreover, they may also in fact not reduce the risk of wildfires, as it has been clearly demonstrated by the decades of zero-fire policy (Durigan and Ratter 2016) .

Finally, these seasonal mosaic patterns are under threat because setting fires is still portrayed as a damaging and archaic process (Mistry et al. 2018). While the well documented swidden cultivation in tropical forests is gaining increasing recognition for its environmental and sociocultural importance (Padoch and Pinedo-Vasquez 2010), and prescribed burning policies have gained legitimacy in fire-prone ecosystems (Lambert 2010; Russell-Smith et al. 2013; Mistry et al. 2018), little attention has been paid to the traditional ecological knowledge that sustains pastoral management in tropical savannas and dry forests. Indeed, local regulations controlling fire use and promoting modern agricultural techniques are commonly based on a stereotype of fire users as irrational and ignorant, as observed in Mexico (Mathews 2005), France (Dumez 2010), and Ethiopia (Johansson et al. 2012).

Conclusion

Our findings show that the seasonal mosaic patterns created by cattle ranchers using

traditional burning practices in the Brazilian *Cerrado* play an important role in wildfire prevention. This system is currently under threat and still poorly understood by researchers and environmental managers. Representing such pastoral management as archaic and damaging prevents serious consideration of practitioners' ecological knowledge and its application in fire management programmes.

In order to reduce conflicts and improve fire management in protected areas of the *Cerrado* better understanding is needed of pastoral management practices and their spatiotemporal dimensions, combining fine-grain field data with geospatial data at landscape scale. Such research reveals how the changing economic, technological, environmental and political conditions of tropical savannas are contributing to the transformation of fire practices.

Improved knowledge about and integration of the human aspects of fire into fire science and policy in Brazil can only be achieved by improving the dialogue about the spatial and temporal dimensions of burning practices between scientists, government institutions, and traditional communities. Such integration has important policy implications for conservation, especially concerning the current policy shift from fire suppression to prescribed burning in Latin America.

References

ANA (2017) Hidroweb. Agência Nacional de Águas (www.hidroweb.ana.gov.br). Brasília.

Barradas, A. C. S. 2017. *A Gestão do fogo na Estação Ecológica Serra Geral do Tocantins, Brasil*. Master thesis. Rio de Janeiro: Instituto de Pesquisas Jardim Botânico do Rio de Janeiro.

Bilbao, B. A., A. V. Leal, and C. L. Méndez. 2010. Indigenous use of fire and forest loss in Canaima National Park, Venezuela. Assessment of and tools for alternative strategies

345 of fire management in Pemón indigenous landscape ecology. *Human ecology* 38: 663-
346 673.
347 Bird, R. B., D. W. Bird, B. F. Codding, C. H. Parker, and J. H. Jones. 2008. The "fire stick
348 farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and
349 anthropogenic fire mosaics. *Proceedings of the National Academy of Sciences* 105 (39):
350 14796–14801.
351 Boutrais, J. 2008. Pastoralisme et aires protégées d'Afrique de l'Ouest en regard de l'Afrique de
352 l'Est. In *Aires protégées : espaces durables ?*, ed. Aubertin, C. and Rodary, E., 215-
353 246. Marseille: IRD.
354 Bowman, D. M. J. S., J. Balch, P. Artaxo, W. J. Bond, M. A. Cochrane, C. M. D'Antonio, R.
355 DeFries, F. H. Johnston, et al. 2011. The human dimension of fire regimes on Earth.
356 *Journal of Biogeography* 38 (12): 2223-2236.
357 Caillault, S., A. Ballouche, and D. Delahaye. 2015. Where are the 'bad fires' in West African
358 savannas? Rethinking burning management through a space–time analysis in Burkina
359 Faso. *The geographical journal* 181 (4): 375-387.
360 Carney, J. A., and R. A. Voeks. 2003. Landscape legacies of the African diaspora in Brazil.
361 *Progress in Human Geography* 27 (2): 139-152.
362 Coughlan, M. R. 2015. Traditional fire-use, landscape transition, and the legacies of social
363 theory past. *Ambio* 44 (8): 705-717.
364 Dumez, R. 2010. *Le feu, savoirs et pratiques en Cévennes.* Versailles: Editions Quæ
365 Durigan, G., and J. A. Ratter. 2016. The need for a consistent fire policy for Cerrado
366 conservation. *Journal of Applied Ecology* 53 (1): 11-15.
367 Eloy, L., C. Aubertin, F. Toni, S. L. B. Lúcio, and M. Bosgiraud. 2016. On the margins of soy
368 farms: traditional populations and selective environmental policies in the Brazilian
369 Cerrado. *The Journal of Peasant Studies* 43 (2): 494-516.

370 Eloy, L., I. S. Carvalho, and I. Figueiredo. 2017. Sistemas agrícolas tradicionais no Cerrado:
371 caracterização, transformações e perspectivas. In *Conservação e uso da*
372 *agrobiodiversidade. Relatos de experiências locais*, ed. Santilli, J., Bustamante, P.,
373 Barbieri, R. L., 129-164. Brasilia, DF: Embrapa.
374 Eloy, L., and C. Fernandes (2015) *Manejo Integrado do Fogo (MIF) e sistemas agropastoris no*
375 *Jalapão: primeiras considerações a partir de um trabalho de campo na comunidade*
376 *quilombola de Mumbuca, Parque Estadual do Jalapão (relatorio de pesquisa).* Brasilia:
377 GIZ/UNB.
378 Fearnside, P. M. 2005. Deforestation in Brazilian Amazonia: History, Rates, and
379 Consequences. *Conservation biology* 19 (3): 680-688.
380 França, H. (2010) Os incêndios de 2010 nos parques nacionais do Cerrado. Relatorio técnico.
381 Universidade Federal do ABC, Santo André, SP, Brazil. [online] URL:
382 http://www.ufabc.edu.br/images/stories/comunicacao/queimadas-2010-1.pdf
383 Hough, J. L. 1993. Why burn the bush? Social approaches to bush-fire management in West
384 African national parks. *Biological Conservation* 65 (1): 23-28.
385 Huffman, M. R. 2013. The Many Elements of Traditional Fire Knowledge: Synthesis,
386 Classification, and Aids to Cross-cultural Problem Solving in Fire-dependent Systems
387 Around the World. *Ecology and Society* 18 (4): 3.
388 Johansson, M. U., M. Fetene, A. Malmer, and A. Granström. 2012. Tending for Cattle:
389 Traditional Fire Management in Ethiopian Montane Heathlands. *Ecology and Society*
390 17 (3): 19.
391 Klink, C. A., and R. B. Machado. 2005. Conservation of the Brazilian Cerrado. *Conservation*
392 *biology* 19 (3): 707-713.

Kull, C. A., and P. Laris. 2009. Fire ecology and fire politics in Mali and Madagascar. In *Tropical Fire Ecology: Climate Change, Land Use and Ecosystem Dynamics*, ed. Cochrane, M., 171-226. Heidelberg, Germany: Springer-Praxis.

Lahsen, M., M. M. C. Bustamante, and E. L. Dalla-Nora. 2016. Undervaluing and Overexploiting the Brazilian Cerrado at Our Peril. *Environment: Science and Policy for Sustainable Development* 58 (6): 4-15.

Lambert, B. 2010. The French prescribed burning network ant its professional team in Pyrénées-Orientales. Lessons drawn from 20 years of experience. In *Best practices of fire use - Prescribed burning and suppression of fire programs in selected case-study regions in Europe*, ed. Montiel, C. and Kraus, D., 89-108. European Forest Institute.

Laris, P. 2002. Burning the seasonal mosaic: Preventive burning strategies in the wooded savanna of southern Mali. *Human Ecology* 30 (2): 155–186.

Laris, P., M. Koné, S. Dadashi, and F. Dembele. 2016. The early/late fire dichotomy. *Progress in Physical Geography* 41 (1): 68-94.

Lucio, S. L. B., L. Eloy, and T. Ludewigs. 2014. O gado que circulava: desafios da gestão participativa de Unidades de Conservação no gerais de norte de Minas. *BioBrasil* 2014 (1): 130-156.

Mathews, A. S. 2005. Power/Knowledge, Power/Ignorance: Forest Fires and the State in Mexico. *Human Ecology* 33 (6): 795-820.

Mbow, C., T. T. Nielsen, and K. Rasmussen. 2000. Savanna Fires in East-Central Senegal: Distribution Patterns, Resource Management and Perceptions. *Human Ecology* 28 (4): 561-583.

Métailié, J.-P. 2006. Mountain landscape, pastoral management and traditional practices in the Northern Pyrenees (France). In *The conservation of cultural landscapes*, ed. Agnoletti, M., 108-124. Florence, Italy: CABI.

418 Miranda, H. S. (editor) 2010. *Efeitos do regime de fogo sobre a estrutura de comunidades de*
419 *Cerrado: Projeto Fogo.* Brasília: Ibama.
420 Mistry, J., and A. Berardi. 2016. Bridging indigenous and scientific knowledge. *Science* 352
421 (6291): 1274-1275.
422 Mistry, J., A. Berardi, V. Andrade, T. Krahô, P. Krahô, and O. Leonardos. 2005. Indigenous
423 Fire Management in the cerrado of Brazil: The Case of the Krahô of Tocantíns. *Human*
424 *Ecology* 33 (3): 365-386.
425 Mistry, J., I. B. Schmidt, L. Eloy, and B. Bilbao. 2018. New perspectives in fire management in
426 South American savannas: The importance of intercultural governance. *Ambio*:
427 https://doi.org/10.1007/s13280-018-1054-7.
428 Padoch, C., and M. Pinedo-Vasquez. 2010. Saving Slash-and-Burn to Save Biodiversity.
429 *Biotropica* 42 (5): 550–552.
430 Parr, C. L., and B. H. Brockett. 1999. Patch-mosaic burning: a new paradigm for savanna fire
431 management in protected areas? *Koedoe* 42 (2): 117-130.
432 Pereira Júnior, A., S. Oliveira, J. Pereira, and M. Turkman. 2014. Modelling Fire Frequency in
433 a Cerrado Savanna Protected Area. *PLoS ONE* 9 (7): e102380.
434 Petty, A. M., V. DeKoninck, and B. Orlove. 2015. Cleaning, Protecting, or Abating? Making
435 Indigenous Fire Management "Work" in Northern Australia. *Journal of Ethnobiology*
436 35 (1): 140-162.
437 Pivello, V. R. 2011. The Use of Fire in the Cerrado and Amazonian Rainforests of Brazil: Past
438 and Present. *The Journal of the Association for Fire Ecology* 7 (1): 24-39.
439 Pivello, V. R., C. N. Shida, and S. T. Meirelles. 1999. Alien grasses in Brazilian savannas: a
440 threat to the biodiversity. *Biodiversity and Conservation* 8: 1281-1294.
441 Posey, D. 1985. Indigenous management of tropical forest ecosystems: the case of the Kayapó
442 indians of the Brazilian Amazon. *Agroforestry Systems* 3 (2): 139-158.

443 Ribeiro, E. M. 1998. Vaqueiros, bois e boiadas – trabalho, negócio e cultura na pecuária do
444 nordeste mineiro. *Estudos Sociedade e Agricultura* 6 (1): 135-164.
445 Ribeiro, M. C., and J. E. C. Figueira. 2011. Uma Abordagem Histórica do Fogo no Parque
446 Nacional da Serra do Cipó, Minas Gerais - Brasil. *Revista Biodiversidade Brasileira* 2:
447 212-227.
448 Russell-Smith, J., G. D. Cook, P. M. Cooke, A. C. Edwards, M. Lendrum, C. Meyer, and P. J.
449 Whitehead. 2013. Managing fire regimes in north Australian savannas: applying
450 Aboriginal approaches to contemporary global problems. *Frontiers in Ecology and the*
451 *Environment* 11 (s1): e55-e63.
452 Russell-Smith, J., D. Lucas, M. Gapindi, B. Gunbunuka, N. Kapirigi, G. Namingum, K. Lucas,
453 P. Giuliani, et al. 1997. Aboriginal Resource Utilization and Fire Management Practice
454 in Western Arnhem Land, Monsoonal Northern Australia: Notes for Prehistory, Lessons
455 for the Future. *Human Ecology* 25 (2): 159-195.
456 Schmidt, I., I. Figueiredo, and A. Scariot. 2007. Ethnobotany and effects of harvesting on the
457 population ecology ofsyngonanthus nitens (bong.) ruhland (eriocaulaceae), a NTFP
458 from Jalapão region, central Brazil. *Economic Botany* 61 (1): 73-85.
459 Schmidt, I. B., L. C. Moura, M. C. Ferreira, L. Eloy, A. B. Sampaio, P. A. Dias, and C. N.
460 Berlinck. 2018. Fire management in the Brazilian Savanna: first steps and the way
461 forward. *Journal of Applied Ecology* 00: 1-8, https://doi.org/10.1111/1365-2664.13118.
462 Silveira, L., J. A. T. De Almeida, J. A. F. Diniz Filho, and F. H. G. Rodrigues. 1999. Impact of
463 wildfires on the megafauna of Emas National Park, central Brazil. *Oryx* 33 (2): 108-
464 114.
465 Simon, M. F., R. Grether, L. P. de Queiroz, C. Skema, R. T. Pennington, and C. E. Hughes.
466 2009. Recent assembly of the Cerrado, a neotropical plant diversity hotspot, by in situ

evolution of adaptations to fire. *Proceedings of the National Academy of Sciences* 106 (48): 20359-20364.

Sluyter, A., and C. Duvall. 2016. African Fire Cultures, Cattle Ranching, and Colonial Landscape Transformations in the Neotropics. *Geographical Review* 106 (2): 294-311.

Walter, B. M. T., and J. F. Ribeiro. 2010. Diversidade fitofisionômica e o papel do fogo no bioma Cerrado. In *Efeitos do regime de fogo sobre a estrutura de comunidades de Cerrado: Projeto Fogo*, ed. Miranda, H. S., 59-76. Brasília, Brazil: IBAMA.

Welch, J. R., E. Brondizio, S. S. Hetrick, and C. E. A. Coimbra Jr. 2013. Indigenous Burning as Conservation Practice: Neotropical Savanna Recovery amid Agribusiness Deforestation in Central Brazil. *PLOS ONE* 8 (12): e81226.