



HAL
open science

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

► To cite this version:

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. *AMBIO: A Journal of Environment and Society*, 2018, 48 (8), pp.890-899. 10.1007/s13280-018-1118-8 . halshs-01926005

HAL Id: halshs-01926005

<https://shs.hal.science/halshs-01926005>

Submitted on 22 Aug 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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

3
4 Ludivine Eloy, PhD

5 Isabel Schmidt

6 Silvia Laine Borges

7 Maxmiller Cardoso Ferreira

8 Teomenilton Almeida dos Santos

9 **Abstract**

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

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

25

26 **Introduction**

27 The use of fire for swidden agriculture and livestock grazing is essential for the
28 production systems of small-scale farmers in tropical regions (Padoch and Pinedo-Vasquez
29 2010; Bowman et al. 2011). In fire-prone ecosystems, such as grasslands and savannas, cattle
30 ranchers use fire to promote grass regrowth (Kull and Laris 2009; Lucio et al. 2014). Pastoral
31 management creates mosaic patterns of burning across different vegetation types, producing a
32 landscape that is “annually re-created by people, and which contains patches of unburned, early
33 burned, and recently burned vegetation” (Laris 2002:156). Seasonal burning associated with
34 traditional management practices has been shown to produce positive impacts on biodiversity
35 and wildfire prevention in tropical savannas in Australia (Russell-Smith et al. 1997; Bird et al.
36 2008; Russell-Smith et al. 2013), South Africa (Parr and Brockett 1999), western Africa
37 (Mbow et al. 2000; Laris 2002; Caillault et al. 2015), Venezuela (Bilbao et al. 2010) and Brazil
38 (Welch et al. 2013).

39 However, pastoral systems using fire have rarely been described, and are poorly
40 understood by environmental agencies and protected area (PA) managers. They have frequently
41 led to conflicts between conservationists and local communities (Métailié 2006; Kull and Laris
42 2009; Lucio et al. 2014).

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

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

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

65 Since 2014, some *Cerrado* PAs managers have carried out prescribed early dry season
66 fires, aiming to change the main fire season, protect fire-sensitive vegetation, and reduce
67 conflicts with local communities within and around the PA (Schmidt et al. 2018). But cattle
68 ranching, which is a major activity in these communities (Eloy et al. 2016), is one of the main
69 bones of contention between local communities and PA managers, mostly because of a lack of
70 understanding of the uses of fire related to this activity (Ribeiro and Figueira 2011; Lucio et al.
71 2014). Pastoral burning is simplistically described as uncontrolled and irrational, referring only
72 to one burning period (the "dry season"), without distinguishing between uncultivated pastures

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

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

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

92

93 **Materials and Methods**

94 **The study region: the Jalapão**

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

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

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

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

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

121

122 **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 resolution¹. For our study region (Aqua MT scenes 221_067 and 221_068), this website
140 offers regular burn scar mapping data². 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.

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

149

150 **Data Analysis**

151 *Transect walk*

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

158

159 *Spatial analysis*

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

167

168 **Results**

169 **Transect walks**

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

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

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

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

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

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

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

215

216 **Spatial analysis**

217 For the two study years, 3 823 burn scars were identified using INPE data. Between
218 82% (2014) and 90% (2015) of them were smaller than 50 hectares, and 97% (2014) and 99%
219 (2015) of the burns were smaller than 1000 hectares in both community- and government-
220 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

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

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

286 The Brazilian government has recently begun to shift from a fire suppression to a fire
287 management policy, adopting the concept of Integrated Fire Management (IFM) (Mistry et al.
288 2018). Through the "Cerrado-Jalapão" project, PA managers have since 2014 consulted
289 stakeholders with knowledge of traditional fire practices and started using prescribed early dry
290 season burnings. Since this pioneer initiative in the *Cerrado* began, both late dry season
291 wildfires and conflicts between government agencies and local communities have lessened
292 (Schmidt et al. 2018). The findings of this paper should help to avoid a narrow focus on early
293 dry season fires that fails to recognize the complexity of traditional fire management systems,
294 reducing local acceptance of prescribed burnings policies, as happened in Australian and
295 African savannas (Caillault et al. 2015; Petty et al. 2015).

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

308 Finally, these seasonal mosaic patterns are under threat because setting fires is still
309 portrayed as a damaging and archaic process (Mistry et al. 2018). While the well documented
310 swidden cultivation in tropical forests is gaining increasing recognition for its environmental
311 and sociocultural importance (Padoch and Pinedo-Vasquez 2010), and prescribed burning
312 policies have gained legitimacy in fire-prone ecosystems (Lambert 2010; Russell-Smith et al.
313 2013; Mistry et al. 2018), little attention has been paid to the traditional ecological knowledge
314 that sustains pastoral management in tropical savannas and dry forests. Indeed, local
315 regulations controlling fire use and promoting modern agricultural techniques are commonly
316 based on a stereotype of fire users as irrational and ignorant, as observed in Mexico (Mathews
317 2005), France (Dumez 2010), and Ethiopia (Johansson et al. 2012).

318

319 **Conclusion**

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

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

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

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

337

338 **References**

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

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

343 Bilbao, B. A., A. V. Leal, and C. L. Méndez. 2010. Indigenous use of fire and forest loss in
344 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. Coddington, 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. Brasília, 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)*. Brasília:
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. Relatório 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.

- 393 Kull, C. A., and P. Laris. 2009. Fire ecology and fire politics in Mali and Madagascar. In
394 *Tropical Fire Ecology: Climate Change, Land Use and Ecosystem Dynamics*, ed.
395 Cochrane, M., 171-226. Heidelberg, Germany: Springer-Praxis.
- 396 Lahsen, M., M. M. C. Bustamante, and E. L. Dalla-Nora. 2016. Undervaluing and
397 Overexploiting the Brazilian Cerrado at Our Peril. *Environment: Science and Policy for*
398 *Sustainable Development* 58 (6): 4-15.
- 399 Lambert, B. 2010. The French prescribed burning network and its professional team in
400 Pyrénées-Orientales. Lessons drawn from 20 years of experience. In *Best practices of*
401 *fire use - Prescribed burning and suppression of fire programs in selected case-study*
402 *regions in Europe*, ed. Montiel, C. and Kraus, D., 89-108. European Forest Institute.
- 403 Laris, P. 2002. Burning the seasonal mosaic: Preventive burning strategies in the wooded
404 savanna of southern Mali. *Human Ecology* 30 (2): 155-186.
- 405 Laris, P., M. Koné, S. Dadashi, and F. Dembele. 2016. The early/late fire dichotomy. *Progress*
406 *in Physical Geography* 41 (1): 68-94.
- 407 Lucio, S. L. B., L. Eloy, and T. Ludewigs. 2014. O gado que circulava: desafios da gestão
408 participativa de Unidades de Conservação no gerais de norte de Minas. *BioBrasil* 2014
409 (1): 130-156.
- 410 Mathews, A. S. 2005. Power/Knowledge, Power/Ignorance: Forest Fires and the State in
411 Mexico. *Human Ecology* 33 (6): 795-820.
- 412 Mbow, C., T. T. Nielsen, and K. Rasmussen. 2000. Savanna Fires in East-Central Senegal:
413 Distribution Patterns, Resource Management and Perceptions. *Human Ecology* 28 (4):
414 561-583.
- 415 Métaillé, J.-P. 2006. Mountain landscape, pastoral management and traditional practices in the
416 Northern Pyrenees (France). In *The conservation of cultural landscapes*, ed. Agnoletti,
417 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 of *Syngonanthus nitens* (bong.) ruhlund (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

467 evolution of adaptations to fire. *Proceedings of the National Academy of Sciences* 106
468 (48): 20359-20364.

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

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

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

477

478