23 (2025) 85–92

Contents lists available at ScienceDirect

Perspectives in Ecology and Conservation

journal homepage: www.perspectecolconserv.com

Research Letters

Prioritizing fire management goals in a biodiversity hotspot

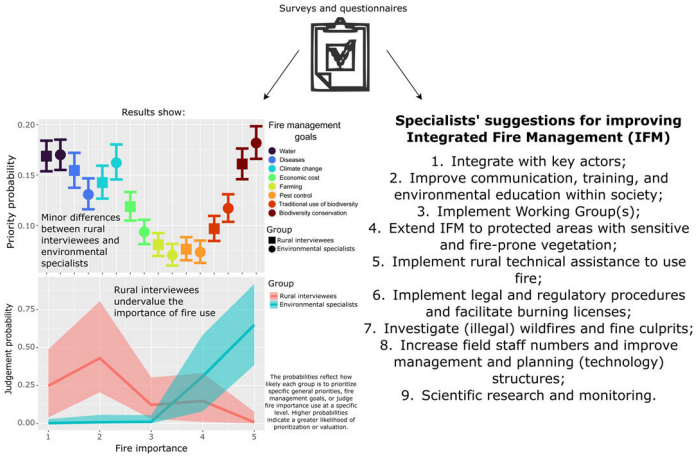
Heitor C. Sousa [a,*], Guarino R. Colli [b], Adriana Malvasio [a]

[a] Universidade Federal do Tocantins – UFT, Quadra 109 Norte Av. NS-15, ALCNO-14, Plano Diretor Norte, CEP: 77001-090, Palmas, Tocantins, Brazil
[b] Universidade de Brasília – UnB, Departamento de Zoologia, Instituto de Ciências Biológicas, Avenida L4 Norte, Asa Norte, CEP: 70910-900, Brasília, Distrito Federal, Brazil

HIGHLIGHTS

- Minor differences exist between rural residents and environmental specialists regarding fire management priorities.
- Both groups prioritize protecting water resources and biodiversity conservation.
- Socioeconomic characteristics explain differences in fire management priorities.
- Most environmental specialists agree that IFM should also apply to private areas.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Brazilian Cerrado savannas
Environmental perception
Integrated fire management (IFM)
Human dimensions
Social attitudes
Sustainable fire regimes

ABSTRACT

Understanding the priorities and motivations of key actors is essential to setting fire management goals toward sustainability and resilience in a changing world. To investigate how key actors in fire management, rural residents and environmental specialists, prioritize fire management goals and assess their attitudes regarding fire use, fire regime effects, and Integrated Fire Management (IFM) in the Brazilian Cerrado savannas, we used an Analytic Hierarchy Process framework and Bayesian multilevel models. We identified minor differences in prioritizing fire management goals between rural interviewees and environmental specialists. Both groups independently regarded (1) pest control and farming as the lowest priorities and (2) protecting water resources and biodiversity conservation as the most important compared to other fire management goals. Despite the similarities, participants with higher education prioritized conserving biodiversity and its traditional use while emphasizing the importance of controlled fire use. Most specialists approved the use of IFM in protected areas (91.84%) and private areas (79.59%). Specialists also suggested improvements to IFM regarding mobilization and education, laws and regulations, surveillance, fund-raising, and scientific research. Our findings show that we should expect minor tradeoffs between key actors and their fire management goals, revealing a fruitful path

* Corresponding author.
E-mail address: heitor.sousa@uft.edu.br (H.C. Sousa).

https://doi.org/10.1016/j.pecon.2025.03.005
Received 2 September 2024; Accepted 24 March 2025
Available online 2 April 2025

for implementing a large-scale IFM in Cerrado that is aligned with the needs of local communities and avoiding conflicts.

Introduction

Ecosystems and humans have coevolved with fire, and its use by humans through varying techno-economic strategies impacts the environment through time and space (Coughlan, 2015). Today, traditional and local communities still use fire for clearing land, opening areas for cultivation, renewing pastures, controlling pests, eliminating wastes, and wildlife hunting and gathering (Coughlan, 2015; Pivello, 2011; Russell-Smith et al., 2013). However, conflicts over fire use and management between rural populations and government agencies are commonplace in fire-prone regions due to fire-suppression policies (Seijo et al., 2020; Smith et al., 2024). In some countries (*e.g.*, Brazil, Mali, and Australia), environmental laws and policies prohibited and stigmatized fire use because of European colonialists' legacy, who perceived open ecosystems (*e.g.*, tropical savannas and grasslands) as degraded forests due to anthropogenic fires (Laris and Wardell, 2006; Moura et al., 2019; Russell-Smith et al., 2013). Until today, this negative perception is still mainstreamed for the public, linking fire use as something destructive and unfavorable (Humphrey et al., 2021). However, fire exclusion policies often lead to uncontrolled, extensive, and intense wildfires, increasing environmental, economic, and social costs in fire-dependent ecosystems (Mariani et al., 2022; Neves et al., 2023; Wieczorkowski and Lehmann, 2022).

The controversy surrounding fire use stems from the conflicting needs and objectives of different societal groups. Although government agencies have tried to involve local communities in fire management, these efforts often fall short. Local people rely on fire as a tool and, at the same time, are disproportionately affected by its negative consequences in rural areas (Hardesty et al., 2005; Myers, 2006). Indeed, there are positive outcomes, such as promoting biodiversity conservation and ecosystem services, when stakeholders make informed decisions by listening to local communities and understanding their needs and preferences (Kremen and Merenlender, 2018; Krug et al., 2020). To address this lack of integration of fire management with cultural preferences and needs, conservationists framed Integrated Fire Management (IFM) with an interdisciplinary and adaptive approach (Myers, 2006). IFM involves three fundamental technical components: prevention, suppression, and use of fire to meet specific goals and objectives within ecological and socioeconomic/cultural contexts, such as reducing fuel accumulation and supporting traditional activities (Myers, 2006). By including the human and ecological dimensions, IFM aims at more resilient ecosystems and populations (Gillson et al., 2019), an essential attribute in a world undergoing human-induced environmental and disturbance regime changes (Kelly et al., 2020).

Recently, national and regional environmental agencies (*e.g.*, Australia, Brazil, and South Africa) started to follow the IFM framework and to prescribe fires in ecologically appropriate seasons (usually the early dry season) to manage landscapes, promote biodiversity, and protect human lives and cultures in protected areas (Hiers et al., 2020; Schmidt et al., 2018; Van Wilgen, 2009). Moreover, sustainable fire regimes should also aim to maintain air quality patterns, contain greenhouse gases, and protect water resources (Roos et al., 2014). As tradeoffs are expected among these goals, prioritization techniques are necessary to rank them according to local and regional contexts (Driscoll et al., 2016; Roos et al., 2014).

The Cerrado is a global biodiversity hotspot that provides habitat to many endemic species and suffers high pressure from agribusiness (Colli et al., 2020; Klink and Machado, 2005). In addition to its biodiversity values, Cerrado supports the main water basins in Brazil and is a significant source of greenhouse emissions because of deforestation and wildfires (Rodrigues et al., 2022). Environmental managers use IFM in some Cerrado protected areas with positive outcomes, such as reducing megafires and rescuing traditional fire uses (Franke et al., 2018; Santos et al., 2021; Schmidt et al., 2018). Recently, the Brazilian Congress approved the law to regularize the IFM nationally (Law 14944/2024), providing legal, economic, and institutional tools for improved sustainable fire management in private and public areas. However, despite these recent advances in fire management (Durigan et al., 2016; Schmidt and Eloy, 2020), Cerrado still lacks broad and comprehensive fire management goals and criteria, suffering from high-severity wildfires and stigmatization of fire use by local people (Gomes et al., 2018; Williams et al., 2017).

Herein, we investigated Cerrado rural residents' and environmental specialists' priorities and attitudes toward fire use and management goals. We addressed the following questions: (Q1) How do environmental specialists and rural residents differ in prioritizing fire management goals? (Q2) How do environmental specialists and rural residents differ in judging the importance of fire use? (Q3) Do individual sociodemographic characteristics and environmental awareness explain the differences between the two groups? (Q4) What are the attitudes of rural residents regarding fire use frequency, applying early dry season fires, and avoiding late dry season fires? (Q5) What are the perceptions of environmental specialists regarding fire use importance for biodiversity, fire regimes' effects on ecosystems, and IFM? We are the first to attempt to prioritize fire management goals and identify the main conflicts regarding fire attitudes and preferences of key social actors. Further, we provide crucial information for planning, policy, and practice related to IFM in Cerrado towards more sustainable fire regimes on a large scale.

Methods

Surveys and questionnaires

We built two comparable questionnaires for rural residents and environmental specialists. We used the questionnaires to survey rural residents in Palmas municipality, Tocantins, Brazil. To select the rural interviewees, we excluded rural properties exclusively dedicated to leisure or without permanent residents. We recorded the audio in the interviews (when participants allowed), helped them read the questions, and presented cards with images representing each fire management goal to facilitate and speed up memorization and answering. We asked 548 environmental specialists to answer an online questionnaire through Google Forms. We contacted researchers involved with Cerrado pyrogeography, agents, and technicians from state and federal environmental agencies, including managers of protected areas, using their publicly available e-mails online (see Appendix S1 for the complete list of environmental specialists contacted). To select the researchers, we searched corresponding authors of publications until 2021 using the words "fire" + "Cerrado" in English and Portuguese at the *Web of Science*. We selected the agents and technicians from the departments linked to conserving and managing biodiversity and natural resources inside the environmental agencies. We gave the participants a consent term signed by the researchers before answering questions. The in-person surveys usually took more time (~ 20−30 min) than online questionnaires (~ 15−20 min) because we had to verbalize the questions more thoroughly. We conducted all surveys and questionnaires using Portuguese. Between July and August 2021, we surveyed 48 rural residents according to our selection criteria, and 49 environmental specialists answered the questionnaires (97 participants).

We used an Analytic Hierarchy Process (AHP) approach to prioritize the fire management goals of both groups of participants (Q1). The AHP offers a structured and hierarchical framework for decomposing

complex decision-making criteria, such as fire management goals, enhancing transparency, understanding, and accuracy of the prioritization process (Forman and Gass, 2001). Using a pairwise comparison among the goals or criteria, the AHP facilitates the systematic aggregation of preferences and the derivation of priority weights and individuals' consistency (Forman and Gass, 2001; Saaty, 2004). Considering the literature about fire use and management, we set eight main goals and made 9-scale-Saaty questions that compared each goal pairwisely. We also used AHP for participants to prioritize biodiversity, economy, human health, and water resources (quantity and quality) goals to check for more general priorities between rural residents and environmental specialists. For both participants (rural residents and environmental specialists), we also asked Likert-scaled questions about the importance of human fire use (Q2). Likert-scaled questions have a format where respondents indicate their level of agreement or disagreement with a statement using a predefined scale (Jebb et al., 2021), such as "Very important" to "Nothing important." To measure environmental awareness and answer Q3, we asked the participants about knowledge and importance of sustainable development, biodiversity (conservation), and perceptions about climate change.

We also made specific Likert-scaled questions for rural interviewees about their perceptions of their fire frequency use and predispositions (attitudes) to apply early dry season fires and avoid late dry season fires (Q4). For environmental specialists only, we asked about their perceptions on the importance of fire for biodiversity, the effects of current fire regimes, early and late dry season fires on ecosystems, the support for the IFM in protected areas and private areas, and how they evaluate IFM in its current terms (Q5). In 2021, when we performed the surveys, IFM of Cerrado's native vegetation was only permitted in protected areas.

Finally, we asked environmental specialists to suggest improvements in the IFM conducted in protected areas by Brazilian environmental agencies. We asked for other socioeconomic information, precisely about their educational level, monthly income, age, gender identification, years of current work (only for specialists) or living in rural areas (only for rural interviewees), and property size. We provide a socioeconomic summary for each group (rural residents and environmental specialists) in Appendix S1. Most rural interviewees were farming producers, but some had other occupations. Considering the extent of Cerrado, we acknowledge that our spatial sampling of rural residents is relatively small. However, we do not expect significant differences in the main patterns of prioritization and attitudes since the socioeconomic characteristics of our sample are similar to those of the National Agricultural Census (IBGE). Even so, local differences probably exist throughout Cerrado, mainly near traditional communities. The levels and descriptions of each question are in Appendix S2.

Statistical analyses

We conducted all analyses in R (R Core Team, 2022), and our codes are publicly available (https://doi.org/10.5281/zenodo.15083402). For the AHP questions (related to Q1), we used the package AHPSURVEY (Cho, 2019) to summarize individuals' priorities using the Dominant Eigenvalues method (Saaty, 2004). Using this method, the individuals' weight priorities sum to one, meaning each priority ranking weight can be interpreted as a priority ranking probability. To estimate the environmental awareness constructs and answer Q3, we reduced the dimensionality of constructs using an exploratory factor analysis (EFA) (Grieder and Steiner, 2022) with the package PSYCH (Revelle, 2022). Psychological constructs such as environmental awareness explain or predict human behavior but cannot be measured directly (Nunnally and Bernstein, 1994). In addition to the EFA, we used complementary analyses to confirm our hypothesis of two environmental awareness constructs: one related to sustainability/conservation awareness and another to climate awareness (Appendix S3).

We built Bayesian multilevel models with the package BRMS (Bürkner, 2017) for a battery of tests: whether fire management goals ranking, general priorities (biodiversity, economy, human health, and water), and fire importance differed between rural interviewees and environmental specialists (Q1 and Q2) and whether environmental awareness constructs and socioeconomic characteristics (age, gender, income, and educational level) explained the differences (Q3). Compared to a frequentist approach, the Bayesian approach can have a profound philosophical argumentation against and in favor of its use (Hackenberger, 2019). However, the Bayesian approach is arguably more similar to scientific thinking, as it can incorporate prior information, updating existing knowledge or beliefs about the parameters in our analyses based on the data collected (McElreath, 2020). Bayesian models can also be more flexible in specifying hierarchical structures and estimating uncertainty through posterior distributions, credible intervals, and posterior predictive checks (McElreath, 2020).

We used a Dirichlet error distribution for models with fire management goals and general priorities as dependent variables. For Likert-scale variables (all others), we used a cumulative distribution. We specified monotonic terms to accommodate the Likert-scale variables appropriately as ordinal predictor categories, which are not assumed to be equidistant in their effects. Here, all models estimate the probability of responses in each priority ranking or rating category. We controlled for individuals' inconsistencies and variances by setting individuals as group-level effects in every model. We compared models with approximate leave-one-out (LOO) cross-validations based on the posterior likelihood using the LOO package (Gelman et al., 2014; Vehtari et al., 2016). We ran four chains for at least 4,000 iterations for each model, discarded the first 2,000 as burn-in, and assessed model convergence based on the potential scale reduction factor, effective sample sizes, density plots, and trace plots.

Results

According to our Bayesian multilevel models, rural residents were less likely than environmental specialists to rank biodiversity as a general priority (Fig. 1a). Nevertheless, both groups independently considered that human health and water resources were the most important general priorities in their lives (Fig. 1a). Overall, we found no differences between rural residents and environmental specialists in their priorities for fire management goals: both groups independently considered that protecting water resources, promoting biodiversity conservation, and mitigating climate change are amongst the most important goals in fire management; and pest control and farming are the least important (Fig. 1b). Despite the similarities, rural interviewees tended to attribute a higher priority ranking to goals related to decreased economic costs and health issues than environmental specialists (Fig. 1b), revealing a minor tradeoff between the groups. Most rural interviewees undervalued the importance of fire in their lands (Fig. 1c).

People with higher sustainability/conservation awareness attributed a higher rank to biodiversity conservation than the economy (Fig. 2a). Additionally, people who are more aware of climate change impacts were less likely to prioritize the economy over other priorities (Fig. 2b). Contrary to our expectations, people's environmental awareness did not explain confidently (neither biodiversity conservation nor climate change awareness constructs) their fire management goals prioritization (Fig. 2c and d; Appendix S3). However, people with high sustainability and climate awareness valued the importance of fire use more than people with low sustainability and climate awareness (Fig. 2e and f).

We found no gender differences in all questions evaluated (Appendix S3). In contrast, socioeconomic characteristics (age, educational level, and income) drove people's prioritization of general priorities, fire management goals, and judgment of fire use (Fig. 3; Appendix S3). Compared to younger people, older people had no clear pattern in prioritizing general priorities (biodiversity conservation, economy, human health, or water; Fig. 3a), attributed a lower priority ranking for the fire management goal of protecting water resources (Fig. 3d), and

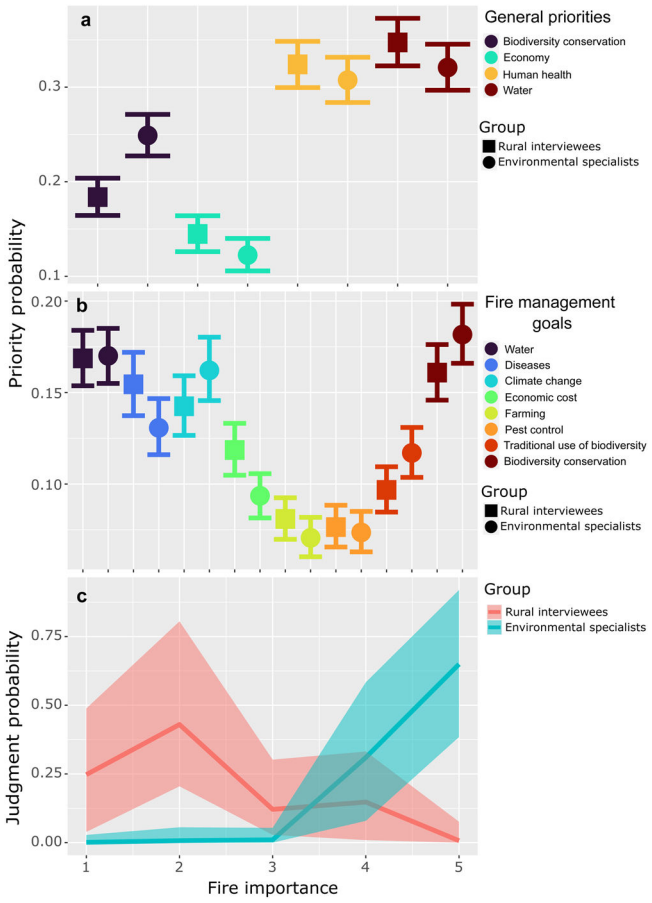


Fig. 1. Probability of rural interviewees and environmental specialists prioritizing general priorities (a), fire management goals (b), and judging fire importance use (c) in the Brazilian Cerrado savannas. The probabilities reflect how likely each group is to prioritize specific general priorities, fire management goals, or judge fire importance use at a specific level. Higher probabilities indicate a greater likelihood of prioritization or valuation. Differences between groups show where priorities and judgment of fire importance diverge or align. Fire importance scale: 1 = nothing important, 2 = little important, 3 = neutral (indifferent), 4 = important, 5 = very important.

tended to undervalue the importance of fire use (Fig. 3f). Regarding general priorities, people with higher income and educational levels prioritized biodiversity conservation more than people with lower educational levels and income (Fig. 3b and c). Within fire management goals, people with higher educational levels prioritized the conservation of biodiversity and its traditional use more than people with lower educational levels (Fig. 3e). Similarly, people with higher educational levels valued the importance of fire use more than people with lower educational levels (Fig. 3g).

We assessed the attitudes of rural residents regarding fire use frequency, applying early dry season fires, and avoiding late dry season fires (Q4). Most rural interviewees (70.83%) responded that they did not use fire for farming in their properties, but for those who did, most (57.14%) used it every year. Regarding the use of early dry-season fires, most (54.17%) rural residents said they would (or maybe) apply these fires on their land, but a high percentage said they would not (45.83%). Most (87.50%) rural interviewees answered that they avoid—or would possibly avoid—late dry-season fires.

We also asked specialists about fire use's importance for biodiversity, fire regimes' effects on ecosystems, and IFM (Q5). Most environmental specialists judged current fire regimes (63.27%) and frequent late dry-season fires (83.67%) are detrimental to the Cerrado ecosystem, that frequent early dry-season fires are beneficial (59.18%), and agree that fire is essential to Cerrado biodiversity (91.84%). Most specialists approved the use of IFM in protected areas (91.84%) and private areas (79.59%). Similarly, most (65.31%) considered the current (back in 2021) IFM good or excellent.

Forty-four environmental specialists suggested improvements to the IFM conducted in Cerrado. We summarized their suggestions into nine separate and applied statements and classified them into five key themes: social mobilization and education, research and development, laws and regulation, budget funding, and surveillance (Table 1). Most of the suggestions (five) were related to social mobilization and education of critical actors involved with fire management (Table 1). In the next section, we discuss how the implications of our survey and questionnaire results relate to the specialists' suggestions.

Discussion

Using an Analytic Hierarchy Process (AHP) approach and Bayesian modeling of an extensive survey in Cerrado, we show minor differences between rural residents and environmental specialists in prioritizing fire management goals (Q1). However, rural residents undervalue the importance of fire use compared to environmental specialists (Q2). The main differences in the prioritization of fire management goals were driven by people's socioeconomic characteristics (age, educational level, and income), while the judgment of the importance of fire use was also driven by people's environmental awareness (Q3). Most rural interviewees affirm they rarely use fire, but most have positive attitudes in prescribing early dry-season fires and avoiding late dry-season fires (Q4). Most environmental specialists agree that fire is essential to Cerrado's biodiversity but that current fire regimes and frequent late dry-season fires are detrimental to the ecosystem (Q5). Moreover, most specialists approved the application of IFM in protected and private areas (Q5).

The results show that we should expect minor tradeoffs in prioritizing fire management goals between rural residents and environmental specialists. This finding reveals a fruitful path for implementing a larger-scale IFM in the Cerrado, aligned with local community needs and avoiding conflicts (Eloy et al., 2018; Mistry et al., 2019). Before the approval of Law 14944/2024, IFM in Cerrado's native vegetation was only permitted in protected areas (indigenous lands and conservation units), which cover less than 10% of Cerrado's area. After the approval of Law 14944/2024, IFM in Cerrado's native vegetation can include private areas for greater efficacy (De Marco et al., 2023) since fires and other related threats (*e.g.*, climate change) do not respect land ownership. Accordingly, most environmental specialists agreed that IFM should occur in private areas and that current fire regimes are detrimental to the Cerrado. Despite negative perceptions towards the use of fire by rural residents, we should not expect high resistance to their participation in fire management. Most interviewees had positive attitudes about prescribing early dry-season fires, which are much less intense and easier to control. They also favored avoiding late dry-season fires, which are much more intense and harder to control. However, rural people should receive more training and technical assistance to use fire in their private areas for sustainable outcomes (as second and fifth suggestions in Table 1). Including rural people in fire management planning and execution should change their negative perception of fire and improve fire management overall, as shown elsewhere (Laris, 2011; Oliveira et al., 2021).

We note that interviewees' responses may be untruthful regarding fire use and controversial fire management goals (such as those for farming and pest control), underestimating potential tradeoffs in fire management goals. We also show that disagreements might occur while managing fire to decrease economic costs and health issues since rural interviewees are inclined to attribute a higher priority ranking to these goals than environmental specialists (Fig. 1b). The same can occur in scenarios when fire management should address the needs of traditional communities while using the biodiversity. However, managers can

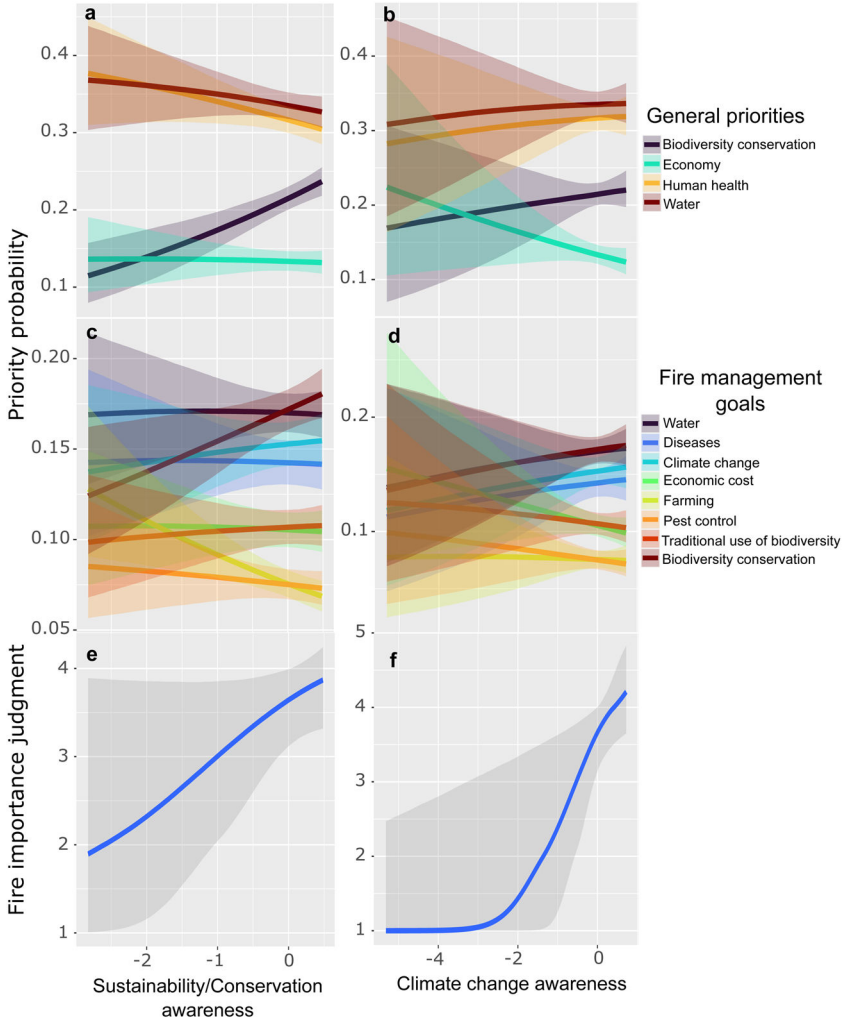


Fig. 2. Relationships between environmental awareness (sustainability/conservation and climate change awareness) with the probability of rural interviewees and environmental specialists prioritizing general priorities (a, b), fire management goals (c, d), and judging fire importance use (e, f) in the Brazilian Cerrado savannas. The probabilities indicate the likelihood that individuals with varying levels of environmental awareness prioritize general priorities, fire management goals, or judge fire importance use. Higher probabilities indicate a greater likelihood of prioritization or valuation. Fire importance scale: 1 = nothing important, 2 = little important, 3 = neutral (indifferent), 4 = important, 5 = very important.

mitigate these potentially divergent priorities by engaging the people affected and democratizing the discussion about fire management decisions (first suggestion in Table 1). Thus, transparent fire management plans with maximum public participation might be the best approach to resolving future fire conflicts and finding optimal solutions, possibly discussing within Working Groups (third suggestion, Table 1). These working groups can have broader and long-term impacts by planning their annual activities for IFM on national and state scales, such as the newly created National Committee of IFM by Law 14944/2024. Managers and researchers should also consider and test the effects of traditional practices on each fire management goal (Coughlan, 2015; Russell-Smith et al., 2013). Other sources of sociocultural perspectives usually result in better fire impact prevention, reduction, and mitigation strategies (Vázquez-Varela et al., 2022).

Many have stressed the importance of changing the public's negative perception of fire use (Scott et al., 2016; Seijo et al., 2020). However, our results show that fire *per se* is still stigmatized in the public culture, mainly among those living in rural areas and not having higher education opportunities. Even inside environmental agencies, some participants undervalued the importance of fire use for biodiversity and condemned the IFM. Our results suggest that deep psychological constructs about the environment (*e.g.*, environmental awareness) do not always reflect in understanding the fire's role in the Cerrado. Surprisingly, socioeconomic characteristics (*i.e.*, age and educational level), but not environmental awareness, are the main drivers of the different social actors in prioritizing fire management goals and recognizing the importance of fire use. Accordingly, highly educated people ranked fire management goals to conserve biodiversity and protect its traditional use higher. Thus, like other studies in tropical fire-prone regions (Archibald, 2016; Aslan et al., 2020; Bizerril, 2004; Ford et al., 2021), we show that knowledge about the ecosystem's natural dependence on fire and how better fire management can benefit land management and ecosystem services may enhance the predisposition of landowners to cooperate in fire management policies. These results align with specialists' suggestions to improve fire awareness policies and mobilize and educate key actors (Table 1, suggestions 1–5).

Media and fire use criminalization often depict fires as destructive events, shaping people's perceptions (Pivello et al., 2021; Roos et al., 2016) and strong negative emotions (*e.g.*, fear, anxiety, and guilt) related to fire use (Ghasemi and Kyle, 2021). Thus, the law approval to regularize the IFM nationally in Brazil (Law 14944/2024) has the potential to change these perceptions and reinforce the best practices of fire, especially in private areas, avoiding uncontrolled and large wildfires (Pivello et al., 2021). This law should also encourage other states to

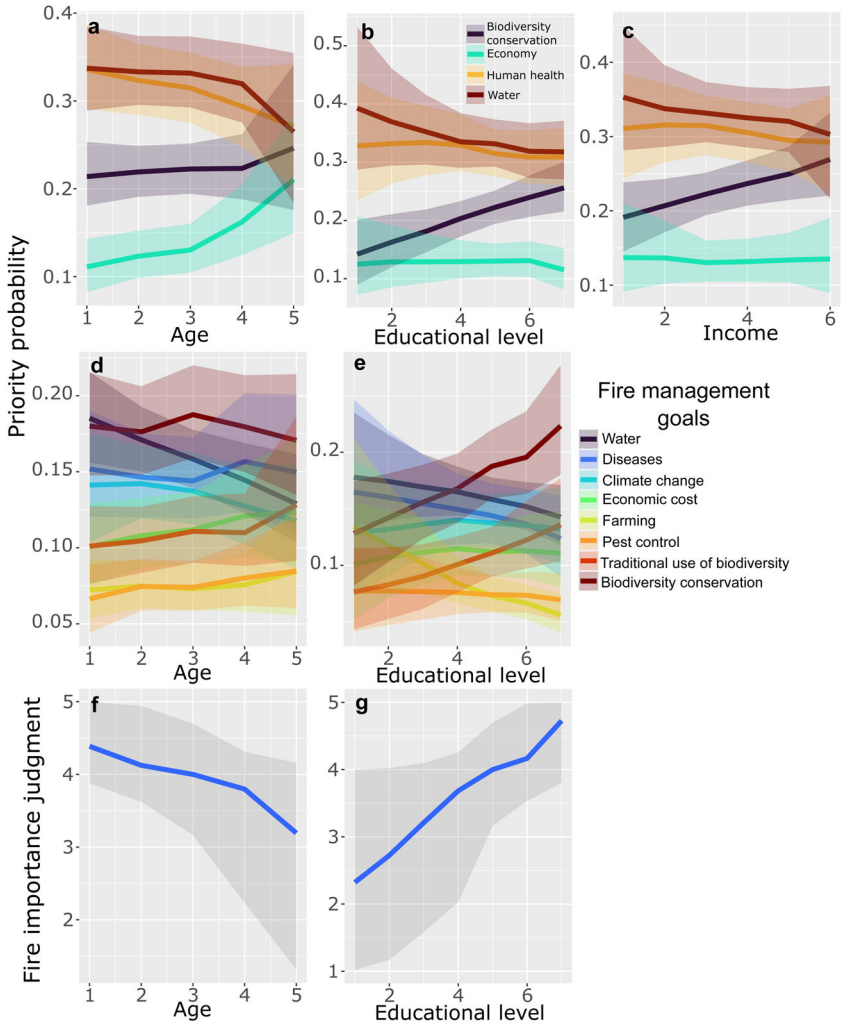


Fig. 3. Relationships between socioeconomic characteristics (age, educational levels, and income) with the probability of rural interviewees and environmental specialists prioritizing general priorities (a, b, c), fire management goals (d, e), and judging fire use importance (f, g) in the Brazilian Cerrado savannas. The probabilities indicate the likelihood that individuals with varying levels of socioeconomic characteristics prioritize general priorities, fire management goals, or judge fire importance use. Higher probabilities indicate a greater likelihood of prioritization or valuation. Fire importance scale: 1 = nothing important, 2 = little important, 3 = neutral (indifferent), 4 = important, 5 = very important; Age scale (years old): 1 = 18–24, 2 = 25–34, 3 = 35–49, 4 = 50–64, 5 = more than 64; Income level scale: 1 = R$501–R$1,000, 2 = R$1,001–R$2,500; 3 = R$2,501–R$5,000, 4 = R$5,001–R$10,000, 5 = R$10,001–R$20,000, 6 = Above R$20,000; Educational level scale: 1 = illiterate, 2 = literate, 3 = fundamental school, 4 = middle school, 5 = bachelor, 6 = MSc, 7 = PhD.

Table 1
Suggestions from 44 environmental specialists to improve the Integrated Fire Management (IFM) practices in the Brazilian Cerrado savannas.

Suggestions	Key theme
1. Integrate with key actors (communities, firefighters, stakeholders, policymakers, federal, state, and municipal agencies/institutions)	Mobilization & Education
2. Improve communication, training, and environmental education within society	
3. Implement Working Group(s)	
4. Extend IFM to protected areas with sensitive and fire-prone vegetation	
5. Implement rural technical assistance to use fire	
6. Implement legal and regulatory procedures (including national and state plans) and facilitate burning licenses	Law & Regulations
7. Investigate (illegal) wildfires and fine culprits	Surveillance
8. Increase field staff numbers and improve management and planning (technology) structures	Fund-raising
9. Scientific research and monitoring (timing, frequency, pyrodiversity, and environmental parameters)	Research & Development

create legal procedures and state-level IFM policies to regulate and improve fire use effectively. These mechanisms can include, for instance, an analytical system management (as sixth and eighth suggestions, Table 1), designed to address the needs of both private and public land managers. Standardized procedures and minimum criteria can speed up burning licenses and improve the surveillance of legal and illegal fires (sixth and seventh suggestions, Table 1). However, local specificities, such as topography, vegetation, habitat sensitivity, and land use, must be considered when planning and licensing the use of fire. Therefore, more investments are necessary to cope with all the needs of public and private areas (Oliveira et al., 2021), such as increasing the numbers of field staff and improving management and planning (technology) structures (eighth suggestion, Table 1).

Despite the increasing knowledge of the effects of timing and frequency of fires on biodiversity (mainly plants) (Rissi et al., 2017; Rodrigues and Fidelis, 2022; Rodrigues et al., 2021), environmental specialists acknowledge the lack of scientific studies to base the best practices of IFM (Table 1, ninth suggestion) and create optimal or sustainable fire regimes to achieve fire management goals. Accordingly, we found little consensus in environmental specialists' perceptions about the effects of early dry season fires in the Cerrado (Appendix S3),

indicating that fire effects can vary among species and regions (Gomes et al., 2018; Mistry, 1998). However, most specialists agree that frequent late dry-season fires harm the Cerrado ecosystem, especially those uncontrolled. This perception aligns with studies reporting the adverse effects of frequent late dry season fires for some species and ecosystem services and why most fires are prescribed in the early dry season in the scope of IFM (Batista et al., 2018). Notwithstanding, few studies have considered the spatio-temporal ecological effects of various characteristics of fire regimes (pyrodiversity, *e.g.*, frequency, intensity, timing, and extent) and their interactions with the biota and human communities (Durigan, 2020; Gomes et al., 2018). Specifically, we still need to consider the spatial heterogeneity and understand how fire regimes drive the short- and long-term ecological mechanisms and processes involved in the taxa responses, especially animals. Thus, researchers and fire managers should receive more incentives to monitor large-scale and long-term ecological responses and increase scientific knowledge to inform fire management decisions in fire-prone habitats, including the proper use of prescribed fires.

Our results bring valuable insights into rural residents' and environmental specialists' perceptions of fire management goals. Despite some differences, rural interviewees and specialists independently ranked pest control and farming as the lowest priority and protecting water resources and biodiversity conservation as the most important to prioritize compared to other fire management goals. Stakeholders and researchers can prioritize these fire management goals and seek partnerships with convergent social actors to implement more effective plans and activities. Using this prior knowledge, stakeholders and local communities may decide on different priorities and solutions depending on the landscape and social contexts, such as land use, conservation degree, and original native vegetation (Williams et al., 2017). Specialists also indicated that IFM should be implemented in fire-prone vegetated regions and all protected areas in Brazil (Table 1, fourth suggestion). For instance, in fire-sensitive vegetation (*e.g.*, forests), land managers should prioritize fire exclusion, prevention, and firefighting when wildfires occur. By implementing the National Policy of IFM, several (if not all) of the environmental specialists' suggestions could be accomplished, benefitting the Cerrado and other ecosystems. Other national, transnational, and intergovernmental agencies (*e.g.*, Amazon Cooperation Treaty Organization) can follow similar policy directions toward integration and resilience to achieve even more positive outcomes. For IFM to be fully integrated worldwide, all critical actors from public, private, and non-governmental sectors must gather forces to achieve convergent goals to create more sustainable fire regimes for people and nature (Gillson et al., 2019; Kelly et al., 2020).

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

HCS thanks the drivers Geremias, João Batista, and Marcos and the tremendous support from Raquel Acácio for performing the surveys. We thank the Tocantins Federal University for supporting and providing transport for the surveys in the rural areas. HCS thanks the scholarship from Coordination of Superior Level Staff Improvement (CAPES) [grant number 88887.484511/2020-00]. GRC thanks CAPES, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Apoio à Pesquisa do Distrito Federal (FAPDF) for their continuous support. All authors thank the valuable contributions to the study development from the Environmental Sciences Post-Graduation Program (PPGCIAMB) professors and the interviewees for participating. All procedures performed in this study involving human participants followed the ethical standards and legislation of the Research Ethics Committees (CEP) from the Federal University of Tocantins (*Universidade Federal do Tocantins* – UFT) and National Research Ethics Commission (*Comissão Nacional de Ética em Pesquisa* – CONEP). The protocol of the Ethical Appreciation Presentation Certificate (*Certificado de Apresentação de Apreciação Ética* – CAAE) has the number 45041921.6.0000.5519, and the approval recommendation document has the number 4.799.043. We obtained informed consent from all individual participants included in the study.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2025.03.005.

References

Archibald, S., 2016. Managing the human component of fire regimes: lessons from Africa. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 371. https://doi.org/10.1098/rstb.2015.0346, 20150346–20150346.

Aslan, C.E., Souther, S., Stortz, S., Sample, M., Sandor, M., Levine, C., Samberg, L., Gray, M., Dickson, B., 2020. Land management objectives and activities in the face of projected fire regime change in the Sonoran desert. J. Environ. Manage. 280. https://doi.org/10.1016/j.jenvman.2020.111644, 111644–111644.

Batista, E.K.L., Russell-Smith, J., França, H., Figueira, J.E.C., 2018. An evaluation of contemporary savanna fire regimes in the Canastra National Park, Brazil: outcomes of fire suppression policies. J. Environ. Manage. 205, 40–49. https://doi.org/10.1016/j.jenvman.2017.09.053.

Bizerril, M.X.A., 2004. Children's perceptions of Brazilian Cerrado landscapes and biodiversity. J. Environ. Educ. 35, 47–58. https://doi.org/10.3200/joee.35.4.47-58.

Bürkner, P.-C., 2017. brms: an R package for Bayesian multilevel models using Stan. J. Stat. Softw. 80, 1–28. https://doi.org/10.18637/jss.v080.i01.

Cho, F., 2019. ahpsurvey: Analytic Hierarchy Process for Survey Data (Version R package version 0.4.1). https://CRAN.R-project.org/package=ahpsurvey.

Colli, G.R., Vieira, C.R., Dianese, J.C., 2020. Biodiversity and conservation of the Cerrado: recent advances and old challenges. Biodivers. Conserv. 29, 1465–1475. https://doi.org/10.1007/s10531-020-01967-x.

Coughlan, M.R., 2015. Traditional fire-use, landscape transition, and the legacies of social theory past. Ambio 44, 705–717. https://doi.org/10.1007/s13280-015-0643-y.

De Marco Jr, P., de Souza, R.A., Andrade, A.F.A., Villen-Perez, S., Nobrega, C.C., Campello, L.M., Caldas, M., 2023. The value of private properties for the conservation of biodiversity in the Brazilian Cerrado. Science (Wash.) 380, 298–301. https://doi.org/10.1126/science.abq7768.

Driscoll, D.A., Bode, M., Bradstock, R.A., Keith, D.A., Penman, T.D., Price, O.F., 2016. Resolving future fire management conflicts using multicriteria decision making. Conserv. Biol. 30, 196–205. https://doi.org/10.1111/cobi.12580.

Durigan, G., 2020. Zero-fire: not possible nor desirable in the Cerrado of Brazil. Flora 268, 151612. https://doi.org/10.1016/j.flora.2020.151612.

Durigan, G., Ratter, J.A., James, J., 2016. The need for a consistent fire policy for Cerrado conservation. J. Appl. Ecol. 53, 11–15. https://doi.org/10.1111/1365-2664.12559.

Eloy, L., Bilbao, B.A., Mistry, J., Schmidt, I.B., 2018. From fire suppression to fire management: advances and resistances to changes in fire policy in the savannas of Brazil and Venezuela. Geogr. J. 185, 1–13. https://doi.org/10.1111/geoj.12245.

Ford, A.E.S., Harrison, S.P., Kountouris, Y., Millington, J.D.A., Mistry, J., Perkins, O., Rabin, S.S., Rein, G., Schreckenberg, K., Smith, C., Smith, T.E.L., Yadav, K., 2021. Modelling human-fire interactions: combining alternative perspectives and approaches. Front. Environ. Sci. 9, 1–23. https://doi.org/10.3389/fenvs.2021.649835.

Forman, E.H., Gass, S.I., 2001. The analytic hierarchy process—an exposition. Oper. Res. 49, 469–486. https://doi.org/10.1287/opre.49.4.469.11231.

Franke, J., Barradas, A.C.S., Borges, M.A., Menezes Costa, M., Dias, P.A., Hoffmann, A.A., Orozco Filho, J.C., Melchiori, A.E., Siegert, F., 2018. Fuel load mapping in the Brazilian Cerrado in support of integrated fire management. Remote Sens. Environ. 217, 221–232. https://doi.org/10.1016/j.rse.2018.08.018.

Gelman, A., Hwang, J., Vehtari, A., 2014. Understanding predictive information criteria for Bayesian models. Stat. Comput. 24, 997–1016.

Ghasemi, B., Kyle, G.T., 2021. Toward moral pathways to motivate wildlife conservation. Biol. Conserv. 259. https://doi.org/10.1016/j.biocon.2021.109170, 109170–109170.

Gillson, L., Whitlock, C., Humphrey, G., 2019. Resilience and fire management in the Anthropocene. Ecol. Soc. 24, 1–13. https://doi.org/10.5751/es-11022-240314.

Gomes, L., Miranda, H.S., Bustamante, M.M.d.C., 2018. How can we advance the knowledge on the behavior and effects of fire in the Cerrado biome? For. Ecol. Manage. 417, 281–290. https://doi.org/10.1016/j.foreco.2018.02.032.

Grieder, S., Steiner, M.D., 2022. Algorithmic jingle jungle: a comparison of implementations of principal axis factoring and promax rotation in R and SPSS. Behav. Res. Methods 54, 54–74. https://doi.org/10.3758/s13428-021-01581.
Hackenberger, B.K., 2019. Bayes or not Bayes, is this the question? Croat. Med. J. 60, 50–52. https://doi.org/10.3325/cmj.2019.60.50.
Hardesty, J., Myers, R., Fulks, W., 2005. Fire, ecosystems and people: a preliminary assessment of fire as a global conservation issue. George Wright Forum 22, 78–87.
Hiers, J.K., O'Brien, J.J., Varner, J.M., Butler, B.W., Dickinson, M., Furman, J., Gallagher, M., Godwin, D., Goodrick, S.L., Hood, S.M., Hudak, A., Kobziar, L.N., Linn, R., Loudermilk, E.L., McCaffrey, S., Robertson, K., Rowell, E.M., Skowronski, N., Watts, A.C., Yedinak, K.M., 2020. Prescribed fire science: the case for a refined research agenda. Fire Ecol. 16, 1–15. https://doi.org/10.1186/s42408-020-0070-8.
Humphrey, G.J., Gillson, L., Ziervogel, G., 2021. How changing fire management policies affect fire seasonality and livelihoods. Ambio 50, 475–491. https://doi.org/10.1007/s13280-020-01351-7.
Jebb, A.T., Ng, V., Tay, L., 2021. A review of key Likert scale development advances: 1995-2019. Front. Psychol. 12, 637547. https://doi.org/10.3389/fpsyg.2021.637547.
Kelly, L.T., Giljohann, K.M., Duane, A., Aquilué, N., Archibald, S., Batllori, E., Bennett, A. F., Buckland, S.T., Canelles, Q., Clarke, M.F., Fortin, M.-J., Hermoso, V., Herrando, S., Keane, R.E., Lake, F.K., McCarthy, M.A., Morán-Ordóñez, A., Parr, C.L., Pausas, J.G., Penman, T.D., Regos, A., Rumpff, L., Santos, J.L., Smith, A.L., Syphard, A.D., Tingley, M.W., Brotons, L., 2020. Fire and biodiversity in the Anthropocene. Science (Wash.) 370. https://doi.org/10.1126/science.abb0355 eabb0355–eabb0355.
Klink, C.A., Machado, R.B., 2005. Conservation of the Brazilian Cerrado. Conserv. Biol. 19, 707–713. https://doi.org/10.1111/j.1523-1739.2005.00702.x.
Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. Science (Wash.) 362, 1–9. https://doi.org/10.1126/science.aau6020.
Krug, C.B., Sterling, E., Cadman, T., Geschke, J., Drummond de Castro, P.F., Schliep, R., Osemwegie, I., Muller-Karger, F.E., Maraseni, T., 2020. Stakeholder participation in IPBES: connecting local environmental work with global decision making. Ecosyst. People 16, 197–211. https://doi.org/10.1080/26395916.2020.1788643.
Laris, P., 2011. Humanizing savanna biogeography: linking human practices with ecological patterns in a frequently burned savanna of Southern Mali. Ann. Assoc. Am. Geogr. 101, 1067–1088. https://doi.org/10.1080/00045608.2011.560063.
Laris, P., Wardell, D.A., 2006. Good, bad or 'necessary evil'? Reinterpreting the colonial burning experiments in the savanna landscapes of West Africa. Geogr. J. 172, 271–290. https://doi.org/10.1111/j.1475-4959.2006.00215.x.
Mariani, M., Connor, S.E., Theuerkauf, M., Herbert, A., Kuneš, P., Bowman, D., Fletcher, M.S., Head, L., Kershaw, A.P., Haberle, S.G., Stevenson, J., Adeleye, M., Cadd, H., Hopf, F., Briles, C., 2022. Disruption of cultural burning promotes shrub encroachment and unprecedented wildfires. Front. Ecol. Environ. 20, 292–300. https://doi.org/10.1002/fee.2395.
McElreath, R., 2020. Statistical Rethinking: A Bayesian Course With Examples in R and Stan, 2nd ed. CRC Press.
Mistry, J., 1998. Fire in the cerrado (savannas) of Brazil: an ecological review. Prog. Phys. Geogr. 22, 425–448. https://doi.org/10.1177/030913339802200401.
Mistry, J., Schmidt, I.B., Eloy, L., Bilbao, B., 2019. New perspectives in fire management in South American savannas: the importance of intercultural governance. Ambio 48, 172–179. https://doi.org/10.1007/s13280-018-1054-7.
Moura, L.C., Scariot, A.O., Schmidt, I.B., Beatty, R., Russell-Smith, J., 2019. The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: impacts, consequences, new directions. J. Environ. Manage. 232, 600–606. https://doi.org/10.1016/j.jenvman.2018.11.057.
Myers, R.L., 2006. Living With Fire: Sustaining Ecosystems & Livelihoods Through Integrated Fire Management. The Nature Conservancy.
Neves, K., Santos, B., Schultz, T., Gotzek, D., Abreu, R.C.R., Durigan, G., Vasconcelos, H. L., 2023. Woody encroachment affects multiple dimensions of ant diversity in a Neotropical savanna. Insect Conserv. Divers. 16, 393–402. https://doi.org/10.21203/rs.3.rs-1103978/v1.
Nunnally, J.C., Bernstein, I.H., 1994. Psychometric Theory, 3rd ed. McGraw-Hill Inc.
Oliveira, A.S., Soares-Filho, B.S., Oliveira, U., Van der Hoff, R., Carvalho-Ribeiro, S.M., Oliveira, A.R., Scheepers, L.C., Vargas, B.A., Rajão, R.G., 2021. Costs and effectiveness of public and private fire management programs in the Brazilian Amazon and Cerrado. For. Policy Econ. 127. https://doi.org/10.1016/j.forpol.2021.102447, 102447–102447.
Pivello, V.R., 2011. The use of fire in the cerrado and Amazonian rainforests of Brazil: Past and present. Fire Ecol. 7, 24–39. https://doi.org/10.4996/fireecology.0701024.
Pivello, V.R., Vieira, I., Christianini, A.V., Ribeiro, D.B., da Silva Menezes, L., Berlinck, C. N., Melo, F.P.L., Marengo, J.A., Tornquist, C.G., Tomas, W.M., Overbeck, G.E., 2021. Understanding Brazil's catastrophic fires: causes, consequences and policy needed to prevent future tragedies. Persp. Ecol. Cons. 19, 233–255. https://doi.org/10.1016/j.pecon.2021.06.005.
R Core Team, 2022. R: A Language and Environment for Statistical Computing (Version 4.2.1). https://www.R-project.org/.
Revelle, W., 2022. psych: Procedures for Personality and Psychological Research (Version 2.2.9). Northwestern University. https://CRAN.R-project.org/package=psych.
Rissi, M.N., Baeza, M.J., Gorgone-Barbosa, E., Zupo, T., Fidelis, A., 2017. Does season affect fire behaviour in the Cerrado? Int. J. Wildland Fire 26, 427–433. https://doi.org/10.1071/WF14210.
Rodrigues, C.A., Fidelis, A., 2022. Should we burn the Cerrado? Effects of fire frequency on open savanna plant communities. J. Veg. Sci. 33, 1–11. https://doi.org/10.1111/jvs.13159.
Rodrigues, C.A., Zirondi, H.L., Fidelis, A., 2021. Fire frequency affects fire behavior in open savannas of the Cerrado. For. Ecol. Manage. 482. https://doi.org/10.1016/j.foreco.2020.118850, 118850–118850.
Rodrigues, A.A., Macedo, M.N., Silverio, D.V., Maracahipes, L., Coe, M.T., Brando, P.M., Shimbo, J.Z., Rajao, R., Soares-Filho, B., Bustamante, M.M.C., 2022. Cerrado deforestation threatens regional climate and water availability for agriculture and ecosystems. Glob. Change Biol. 28, 6807–6822. https://doi.org/10.1111/gcb.16386.
Roos, C.I., Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Cochrane, M., D'Antonio, C.M., Defries, R., Mack, M., Johnston, F.H., Krawchuk, M.A., Kull, C.A., Moritz, M.A., Pyne, S., Scott, A.C., Swetnam, T.W., 2014. Pyrogeography, historical ecology, and the human dimensions of fire regimes. J. Biogeogr. 41, 833–836. https://doi.org/10.1111/jbi.12285.
Roos, C.I., Scott, A.C., Belcher, C.M., Chaloner, W.G., Aylen, J., Bird, R.B., Coughlan, M. R., Johnson, B.R., Johnston, F.H., McMorrow, J., Steelman, T., 2016. Living on a flammable planet: interdisciplinary, cross-scalar and varied cultural lessons, prospects and challenges. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 371. https://doi.org/10.1098/rstb.2015.0469, 20150469–20150469.
Russell-Smith, J., Cook, G.D., Cooke, P.M., Edwards, A.C., Lendrum, M., Meyer, C.P., Whitehead, P.J., 2013. Managing fire regimes in north Australian savannas: applying Aboriginal approaches to contemporary global problems. Front. Ecol. Environ. 11, e55–e63. https://doi.org/10.1890/120251.
Saaty, T.L., 2004. Decision making — the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng. 13, 1–35. https://doi.org/10.1007/s11518-006-0151-5.
Santos, F.L.M., Nogueira, J., de Souza, R.A.F., Falleiro, R.M., Schmidt, I.B., Libonati, R., 2021. Prescribed burning reduces large, high-intensity wildfires and emissions in the Brazilian savanna. Fire 4, 1–21. https://doi.org/10.3390/fire4030056.
Schmidt, I.B., Eloy, L., 2020. Fire regime in the Brazilian Savanna: recent changes, policy and management. Flora 268. https://doi.org/10.1016/j.flora.2020.151613, 151613–151613.
Schmidt, I.B., Moura, L.C., Ferreira, M.C., Eloy, L., Sampaio, A.B., Dias, P.A., Berlinck, C. N., Zenni, R., 2018. Fire management in the Brazilian savanna: first steps and the way forward. J. Appl. Ecol. 55, 2094–2101. https://doi.org/10.1111/1365-2664.13118.
Scott, A.C., Chaloner, W.G., Belcher, C.M., Roos, C.I., 2016. The interaction of fire and mankind: introduction. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 371, 1–8. https://doi.org/10.1098/rstb.2015.0162.
Seijo, F., Godoy, M.M., Guglielmin, D., Ciampoli, C., Ebright, S., Picco, O., Defossé, G., 2020. Conflicting frames about ownership and land use drive wildfire ignitions in a protected conservation area. Environ. Manage. 65, 448–462. https://doi.org/10.1007/s00267-020-01265-w.
Smith, C., Ainscough, J., Alare, R., Croker, A., De Freitas, K., Millington, J., Mistry, J., Perkins, O., Schreckenberg, K., Seijo, F., Thompson, H., Valette, M., Yadav, K., 2024. How policy interventions influence burning to meet cultural and small-scale livelihood objectives. Ecol. Soc. 29, 1–20. https://doi.org/10.5751/es-14850-290135.
Van Wilgen, B.W., 2009. The evolution of fire management practices in savanna protected areas in South Africa. S. Afr. J. Sci. 105, 343–349.
Vázquez-Varela, C., Martínez-Navarro, J.M., Abad-González, L., 2022. Traditional fire knowledge: a thematic synthesis approach. Fire 5, 1–36. https://doi.org/10.3390/fire5020047.
Vehtari, A., Gelman, A., Gabry, J., 2016. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Stat. Comput. 27, 1413–1432. https://doi.org/10.1007/s11222-016-9696-4.
Wieczorkowski, J.D., Lehmann, C.E.R., 2022. Encroachment diminishes herbaceous plant diversity in grassy ecosystems worldwide. Glob. Change Biol. 28, 5532–5546. https://doi.org/10.1111/gcb.16300.
Williams, B.A., Shoo, L.P., Wilson, K.A., Beyer, H.L., 2017. Optimising the spatial planning of prescribed burns to achieve multiple objectives in a fire-dependent ecosystem. J. Appl. Ecol. 54, 1699–1709. https://doi.org/10.1111/1365-2664.12920.