

Herb–subshrub diversity in open savanna sites with distinct fire regimes in the Jalapão region, Brazil

Research Article

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Abstract

The fire regime is essential in creating a mosaic of plant structure and diversity in South American open savannas, especially favouring herbs. However, studies investigating diversity patterns in Neotropical savannas rarely focus on the herb–subshrub layer. This study investigated the variation of the herb–subshrub layer under contrasting fire regimes in the most conserved site within the Cerrado Domain, the Jalapão region, Brazil. We selected four sites of open savanna physiognomy with similar topographic, climatic and edaphic features: three burned every 2 years, while the fourth site has remained unburned for at least the last 10 years. We randomly distributed 15 plots of 4 m² in each site and identified all herbs and subshrubs in each plot to estimate density, richness, alpha diversity and species composition. The unburned site had lower herb–subshrub density, richness and diversity than the frequently burned sites. Species composition varied between frequently burned and unburned sites, partially explained by the fire frequency across sites. Although other ecological factors may explain the patterns detected, we cannot rule out the importance of fire in structuring plant communities in the Jalapão region. As in other savannas, our study in the Cerrado Domain reinforces the essential role of the fire regimes in modifying and maintaining the diversity of herbaceous plants at the landscape scale.

Introduction

The Cerrado Domain in Brazil is the most diverse savanna globally and originally covered ca. 2 million km² (Forzza *et al.* 2012, Ratter *et al.* 1997). Although more than 50% of the Cerrado has already been replaced due to human activity (Strassburg *et al.* 2017), the largest extension of well-conserved and protected Cerrado is the Jalapão region, in the far east of Tocantins state (Antar & Sano 2019, Silva & Bates 2002). The main reasons for the Jalapão region still being mostly undisturbed are the dystrophic soils, low human density, the presence of traditional community lands (*quilombolas*' homelands – maroon communities) that are mostly well conserved, and large legally protected areas, of which the most important are Jalapão State Park (JSP), the Serra Geral do Tocantins Ecological Station, Jalapão Environmental Protection Area (JEPA) and Nascentes do Parnaíba National Park (Camará & Leite 2005, Schmidt *et al.* 2007, Silva & Bates 2002). The region is also recognised for its high plant diversity, which, although not completely known, is expected to number more than 1000 species, many of them recently described (Antar & Sano 2019, Araújo *et al.* 2016, Barbosa-Silva & Antar 2020, Devecchi & Pirani 2015, Moreira *et al.* 2017, Pastore & Antar 2021, Proença *et al.* 2007).

One of the major abiotic factors traditionally associated with the ecology and evolution of the Cerrado Domain flora is fire (Coutinho 1990, Miranda *et al.* 2002, Pivello, 2011, Simon *et al.* 2009). In the Jalapão region, fire occurrence is widespread. It generates a mosaic of different degrees of disturbance across the landscape, making it very hard to find areas unburned for more than 3 years (Pereira Jr. *et al.* 2014, Schmidt *et al.* 2007, Schmidt *et al.* 2018). In this environment, the fire occurrence is natural and has shaped its physiognomy and diversity for about 4 million years (Simon *et al.* 2009). Several studies have recognised the importance of fire in structuring plant communities. For example, burned areas in the Cerrado of the Federal District show higher species richness in the herbaceous layer than in unburned areas (César 1980); frequent fires promote intense flowering in several herbaceous species (Coutinho 1976, Fidelis & Zironi 2021); herbaceous species composition differs among areas with different fire frequencies in the Cerrado of southwestern Goiás State (Loiola *et al.* 2010); richness and diversity were higher in experimentally burned areas than in unburned areas of the Jalapão region (Santos 2019); and

recurrent burns during the year increase the dominance of Poaceae in the herbaceous layer (Miranda 2002).

Over time and especially in recent decades, human beings have changed the natural fire regimes according to their activities, increasing frequency and moving the season to the driest period (Pivello 2011, Pivello *et al.* 2021, Schmidt *et al.* 2018). In the 1980s, studies that were part of the Fire Project (*Projeto Fogo* at IBGE Reserve) started to investigate the consequences of human-induced fire regimes on the Cerrado biodiversity (Dias & Miranda 2010). These studies were focused on the woody plants and corroborated previous research (e.g., Coutinho 1976) showing that frequent fires would decrease woody plant density and diversity (Hoffmann 1999, Sato *et al.* 2010, Montenegro 2019) and generate open physiognomies dominated by grasses and subshrubs, with few woody elements. On the other hand, fire suppression would favour the woody vegetation to the detriment of herb and subshrub species, leading to more woody physiognomies (Miranda *et al.* 2010, Moreira, 2000). Further studies have shown that fire exclusion may cause woody plant encroachment and drive the savanna formation to a forest physiognomy (Abreu *et al.* 2017, Gonçalves *et al.* 2021, Mariano *et al.* 2019, Moreira 2000, Stevens *et al.* 2017).

For several decades, the diversity of the Cerrado herbaceous flora has been neglected in floristic studies, and only more recently has its role as an essential component of the Cerrado biodiversity become clear (Amaral *et al.* 2017, Durigan *et al.* 2018). It is now known that the herbaceous component represents about 80% of the biome plant species, making the Cerrado the richest savanna in the world, with more than 12,700 species (BFG 2015, Durigan *et al.* 2018), being most of them – as components of the herbaceous layer – fire-dependent. Also, considering the most abundant or rarest species, the exclusion of fire in the open Cerrado Domain can reduce the diversity of the herb–subshrub layer compared to areas that are burned biennially (Santos 2019).

In the Jalapão region, there is a high demand for knowledge on the biodiversity of protected areas and the factors that regulate them, mostly to direct management for their conservation. Some studies on this subject have been recently conducted but focused mostly on swampy palm forests (*veredas*) and wet fields (Borges *et al.* 2016, Schmidt *et al.* 2017). On the other hand, the unflooded open savannas, the most common physiognomies in the region (Antar & Sano 2019), have been overlooked, with few recent and yet unpublished studies (Montenegro 2019, Santos 2019). Therefore, our aim in this study is to investigate the plant diversity of the herbaceous stratum across different unflooded open savannas in the Jalapão region. Specifically, we compared species density, richness, diversity, and composition in four areas with different fire regimes. We hypothesised that the species composition and structure would differ between areas and that recurrent fires in some areas conditioned the herbaceous stratum to higher density and diversity. Our results can provide detailed information about the spatial variation of plant diversity and fire management in protected areas of the Jalapão region.

Material and methods

Study area

This study was carried out in two neighbouring, protected areas in the Jalapão region (Tocantins state, Brazil): the JSP (10°08'–10°35' S; 47°04'–47°35' W) and the JEPa, which surrounds the JSP. The extension of JSP is 158.885 ha (Seplan 2003a), while that of JEPa is

461.730 ha (Seplan 2003b). The regional climate is tropical seasonal, with humid summers and dry winters (Köppen's Aw) (Alvares *et al.* 2014). Mean temperatures vary from 23.5 to 26.5 °C, and annual precipitation is ca. 1,500 mm, with 90% of rainfall concentrated between October and March (Seplan 2012). The most common phytophysiognomies in the region are (i) the *veredas* (riverine palm forest) with the frequent presence of the palm tree *Mauritia flexuosa* L.f. and (ii) open savannas in unflooded fields, mostly the *campo sujo* (Antar & Sano 2019, Silva *et al.* 2018). These broad areas of open savannas are characterised almost entirely by a continuous herbaceous layer, while scattered shrubs and trees cover up to 3% of the area (Coutinho, 1982, Henriques 2005, Moreira 2000, Ribeiro & Walter 2008).

Economic activities in the region are mostly related to tourism and secondarily to subsistence agriculture and extensive cattle raising (Câmara & Leite, 2005, Eloy *et al.* 2018, Schmidt *et al.* 2007), in which a common practice is to burn the native vegetation in the dry season to promote plant resprouting to feed the animals (Schmidt *et al.* 2018). The burning of native pastures may lead to fire spreading and accidental wildfires in the surrounding areas (Pereira *et al.* 2014). On the other hand, seasonal fire management by traditional cattle ranchers may prevent the spread of wildfires in the Brazilian Cerrado (Eloy *et al.* 2018, Pivello *et al.* 2021). Large-scale agriculture has not reached this region yet, mostly due to the sandy soils and poor infrastructure for access. However, the agricultural business is expanding its frontiers towards Jalapão (Antar & Sano 2019, Antar *et al.* 2017, Barbosa-Silva & Antar 2020, Borges & Antar 2016).

To develop this study, we selected four *campo sujo* sites (open savanna with scattered woody elements) of approximately 30 ha each, with maximum and minimum distances in a straight line of 7 and 2.7 km and spread over 64 km² (Figure 1). For decades, three sites have been under a high fire frequency of about 2 years: sites 1 (10°32'07"S; 46°27'14"W), 2 (10°32'05"S; 46°28'51"W) and 3 (10°30'35"S; 46°30'22"W), while at site 4 (10°34'19"S; 46°30'97"W) fire has been suppressed for the last 10 years. Site 4 was the only area protected from fire for a relatively long time that we could find since burning every 2 years is a widespread practice in the region (Pereira-Júnior *et al.* 2014, Schmidt *et al.* 2007). This area has remained unburned for at least 10 years because it is near the JSP guesthouse and surrounded by firebreaks, which are burned every year. The sites selection was based on information about the last burning event provided by the personnel of the protected areas who have worked there for more than 10 years. In addition, we confirmed the burning history for sites 2, 3 and 4 in satellite images from the past 10 years with 1-km resolution (INPE – <http://queimadas.dgi.inpe.br/queimadas/aq1km>). However, we could not recover the burning history for site 1 due to the unavailability of satellite images.

The four sites are at similar altitudes (ca. 520 m asl) and have similar temperature and precipitation conditions. Also, the vegetation structure and soil characteristics are similar among them (Santos *et al.* 2011). We quantified organic matter and texture at the soil surface (0–5 cm) through five randomly collected soil samples at each site. The granulometric analyses followed the Boyocus dosimeter method (Camargo *et al.* 1986). The organic matter was estimated by oxidation with sodium dichromate in H₂SO₄ and quantified by colorimetry (Raij *et al.* 1987). There is no history of human impact in the area, and native herbivorous animals are rare, represented mainly by the pampas deer (*Ozotocerus benzoarticus*), a species threatened with extinction (Chiarello *et al.* 2008).

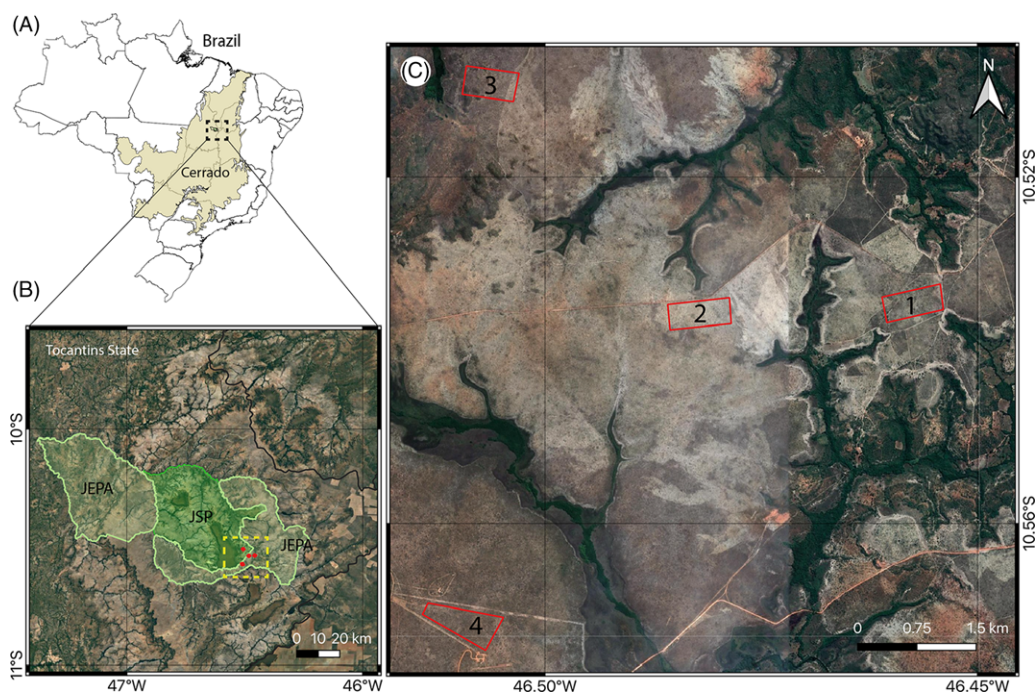


Figure 1A–C. Study area. A. The Cerrado Domain and Jalapão region, Tocantins state, Brazil. B. Jalapão State Park (JSP) and Jalapão Environmental Protection Area (JEPA). The yellow square is shown in detail in C. C. Satellite image of the four *campo sujo* study sites spread over 64 km². Sites 1, 2 and 3 are burned every other year, and site 4 has remained unburned for at least 10 years. Source: Coordenação de Mosaicos e Corredores Ecológicos/DIREP/ICMBio.

Focal species

In this study, we only considered herbs and subshrubs species. We adapted plant habit definitions from Beentje (2012), in which herbs are plants without a persistent woody stem above ground, and subshrubs are small shrubs with herbaceous stems except at the base, which is woody.

In a recent survey in the area (Antar & Sano 2019), the most species-rich families found, regardless of habit, were Leguminosae, Poaceae, Asteraceae, Lamiaceae, Rubiaceae, Myrtaceae, Malpighiaceae and Euphorbiaceae, that agrees overall with the most species-rich families in the Cerrado Domain (Eiten 1972, Gottsberger & Silberbauer-Gottsberger 2006, Ratter *et al.* 1997).

Experimental design and sampling of the herb–subshrub layer

To quantify the different descriptors of plant diversity, we randomly placed 15 plots of 4 m² at each site, totalling 60 plots across sites (Figure 2A–B). The plot randomisation in each site was made by raffling the direction (North, South, East and West) and the number of steps (1–60) taken, starting from the site edge. We sampled all the herb and subshrub individuals whose base was within the plot. Individuals were defined as ramets for subshrubs, and tussocks for grass-like plants due to the clonal habit of some plants, a common feature of herbaceous species in the Cerrado. The specimens collected were morphotyped and identified to the species level by comparing them with nearby reproductive specimens and vouchers in the herbarium of the University of São Paulo (SPF). We followed Antar & Sano (2019) to guide species identification, and taxonomists were consulted to confirm the identification of doubtful species. Family classification followed APG IV (2016), and species names followed Flora do Brasil 2020 (Flora do Brasil 2020). Field data were collected in the rainy season, from the end of October 2013 to March 2014.

Statistical analyses

Species accumulation curves were made to infer the sampling sufficiency of each site, and we used the non-parametric species-rich Jackknife estimator (Palmer, 1991) to assess the ‘true’ species richness for each site.

Plant density and species richness of the herb–subshrub layer were estimated for each plot. We used the Fisher’s alpha index to describe the plot plant diversity, since this index accounts for the number of individuals and species (Fisher *et al.* 1943). To test for differences in the plant density, species richness and diversity index among sites, we applied general linear models with the Gaussian probabilistic distribution having sites as an explanatory variable, followed by a post hoc Tukey’s test ($\alpha = 0.008$ under the Bonferroni correction). Finally, we used the Shapiro–Wilk test and Levene’s test to assess data normality and homogeneity of variances for the three variables (Legendre & Legendre, 1998).

The species composition of the herb–subshrub layer was reduced to two dimensions with non-metric multidimensional scaling (NMDS). Two distinct ordinations were carried out with the plant species composition data: (i) species abundance data (quantitative ordination) and (ii) species occurrence data (qualitative ordination), defined by presence or absence in each plot. For the quantitative ordination, we used the Bray–Curtis distance measure on plot-standardised data (the data for each species were standardised by the plot to the proportions of the total number of individuals). In the qualitative ordination, we used the Sorensen index (Legendre & Legendre, 1998). The ordination using species occurrence data captures the rarer species patterns. In contrast, patterns evaluated with abundance data tend to be more related to the most abundant species in the dataset (Zuquim *et al.* 2009). The statistical significance of each axis of NMDS was based on 1000 Monte Carlo permutations. The first two axes of NMDS were used as dependent variables in inferential tests, given that these two axes captured most of the variation related to species composition (60% for quantitative ordination and 28% for qualitative ordination) and the complete absence of

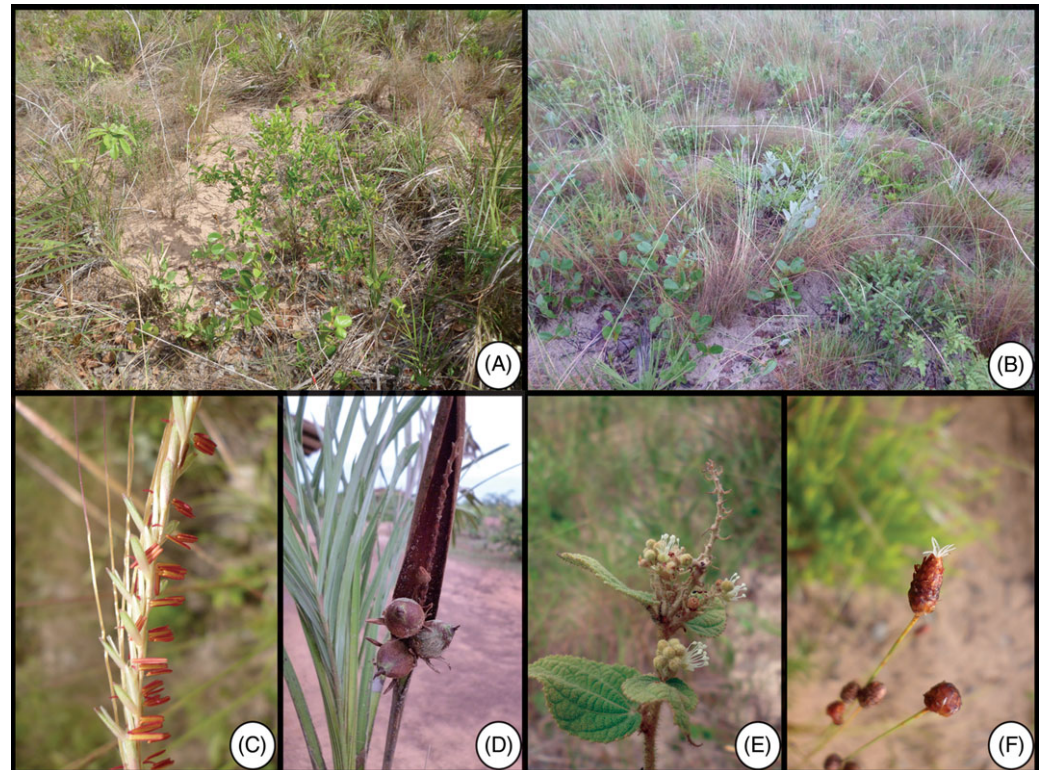


Figure 2A-F. General aspects of the study sites and common herb-subshrub species. A. General view of the 10-year unburned site (site 4). B. General view of a 2-year burned site (site 1). C, D, E and F. Inflorescence of *Trachypogon spicatus* (L.f.) Kuntze (C), *Syagrus glaziouiana* (Dammer) Becc. (D), *Croton agoensis* Baill. (E) and *Bulbostylis junciformis* (Kunth) C.B. Clarke (F).

correlation between the two NMDS axes ($r = 8.4e-17$ and $r = 2.4e-16$). The adjusted r^2 of the dissimilarity matrices of original data regressed against the dissimilarity along the one- and two-dimensional ordination was used to evaluate the adequacy of the ordinations (McCune & Grace, 2002). To test for differences in the two NMDS axes among sites, we carried out two variance analyses (one-way ANOVA), followed by a post hoc Tukey's test, examining each response variable (NMDS axes) separately. We performed all statistical analyses in R software (R CORE TEAM 2020), using the base and the vegan (Oksanen *et al.* 2015) packages.

Results

Species collected and soil variables

A total of 5,249 individuals belonging to 68 species and 15 families were collected at the 4 sites (Table S1). The most representative families in number of individuals were Poaceae, Cyperaceae, Euphorbiaceae, Areaceae and Leguminosae. The most representative families in number of species were Poaceae (17), Leguminosae (7), Cyperaceae (6), Amaranthaceae (3) and Polygalaceae (3). The most common species were *Trachypogon spicatus* (L.f.) Kuntze with 918 individuals found in all plots, *Bulbostylis junciformis* (Kunth) C.B. Clarke, *Croton agoensis* Baill. and *Syagrus glaziouiana* (Dammer) Becc. (Figure 2C-F). The species accumulation curves indicate that sampling sufficiency was reached in the four sites (Figure 3).

Soil analyses showed a very similar texture in the four sites, being very sandy and poor in organic matter (Table S2).

Plant density, richness and diversity

On average, plant density in the herb-subshrub layer was different among sites ($F_{3,56} = 24.5$; $p < 0.001$), with site 4 (unburned) being at

least 50% less dense than sites 1, 2 and 3 ('frequently burned') (Figure 4A). Species richness was similar at sites 1, 2 and 3, but site 4 had, on average, 50% fewer species than the three frequently burned sites 1, 2 and 3 ($F_{3,56} = 19.5$; $p < 0.001$) (Figure 4B). A very similar pattern was found for diversity (Figure 4D), with site 4 being up to 1.4 times less diverse than the other frequently burned sites 1, 2 and 3 ($F_{3,56} = 12.17$; $p < 0.0001$; Figure 4D). Of the three richest families, Poaceae, Leguminosae and Cyperaceae showed distinct richness at the sites (Poaceae - $F_{3,56} = 29.02$; $p < 0.0001$; Leguminosae - $F_{3,56} = 1.02$; $p = 0.38$; Cyperaceae - $F_{3,56} = 14.26$; $p < 0.0001$; Figure 4C).

Species composition across sites

The NMDS ordinations recall a large variation of the species composition of the herb-subshrub layer (Figure 5). In the quantitative ordination using species abundance data, the first and second NMDS axes captured 48% and 12% of the composition variation, respectively (Figure 5A). Thus, considering the first and second NMDS axes of the quantitative ordination, the species composition is not homogeneous across sites (first axis: $F_{3,56} = 22.8$, $p < 0.001$ and the second axis: $F_{3,56} = 16.78$, $p < 0.001$). In the first axis, sites 1, 2 and 4 were similar, but they differed from site 3 (Figure 5B). In the second axis, sites 1, 2 and 3 were similar but different from site 4 (Figure 5C), indicating a different species composition of the unburned site 4 compared to the frequently burned sites 1, 2 and 3. The results of the first and second axes of the qualitative ordination were similar to those of the quantitative ordination (Figure S3).

Discussion

We found that the herb-subshrub layer's plant density, species richness, diversity index and species composition vary among the sampled sites in the Jalapão region. Water availability, soil

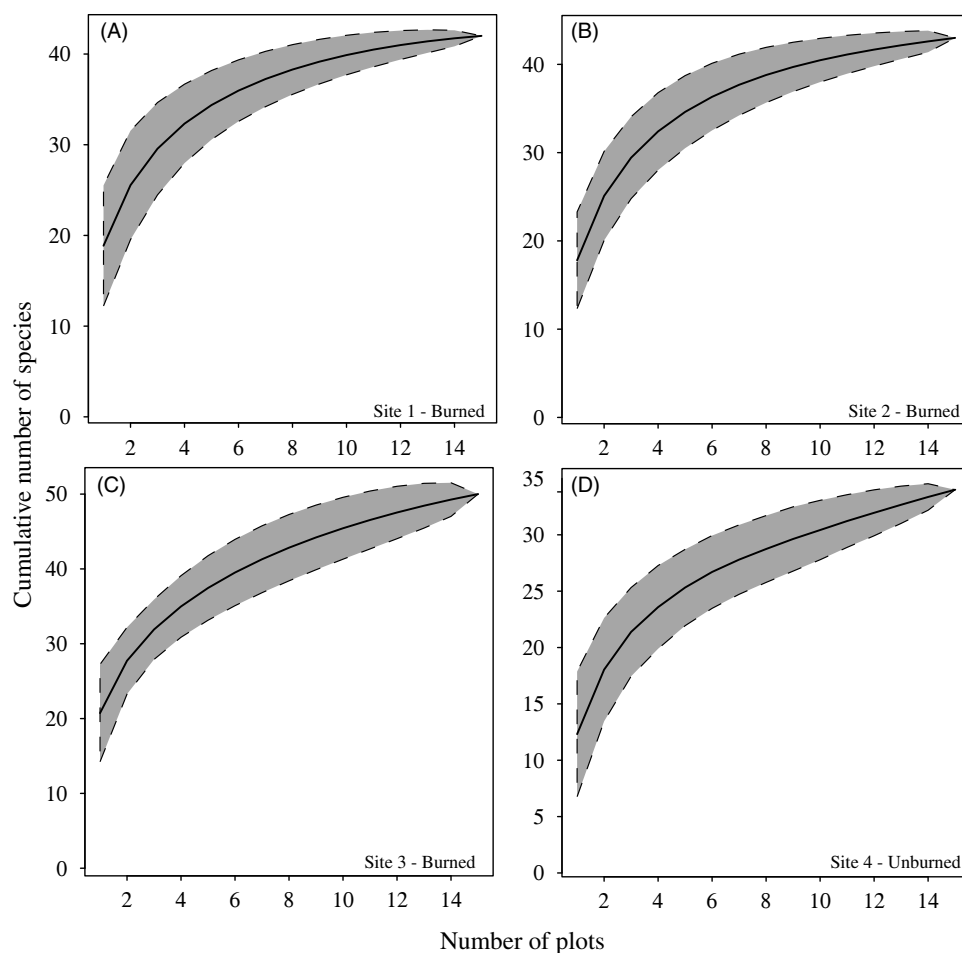


Figure 3. Species accumulation curve for each study site (A = site 1; B = site 2; C = site 3; D = site 4), 95% confidence intervals (dashed lines). Observed and estimated (Jackknife estimator) richness are indicated for each study site.

depth and nutrient availability, topography (e.g., slope), species interactions, grazing, and fire frequency are important factors determining the structure and diversity of the Cerrado Domain (Coutinho, 1990, Pivello & Coutinho 1996, Ratter *et al.* 1997, Moreira 2000, Ribeiro & Walter 2008, Silva & Batalha 2011, Amaral *et al.* 2013). In our study area, only fire frequency varied strongly across the sampled sites since they are close together, sharing the same local climate, topography, soil features and animal grazing patterns. We thus hypothesise that fire plays an essential role in explaining the variation of the herb–subshrub layer diversity and species composition in the study region. Indeed, the differences among the sites sampled matched the predictions according to the fire pattern in the Cerrado. The unburned site 4 had lower density, richness and diversity than the three frequently burned sites (1, 2 and 3). Also, the species composition of the unburned site differed from the other three sites.

We found a lower number of species (68 species) in the herb–subshrub layer of the Jalapão region compared to other similar studies in Neotropical savannas (César 1980, Loiola *et al.* 2010, Amaral *et al.* 2013, Santos 2019), with around 30% fewer species (Loiola *et al.* 2010). Biological reasons or differences in sampling methods can explain this, and the second may be more relevant here. In particular, we considered only herbs and subshrubs in our sampling protocol, while other studies included plants with other habits, such as small shrubs and climbers. Regarding the most frequent plant groups, the families Poaceae, Cyperaceae and Leguminosae have also been the most representative herb–subshrub plants in other *campo sujo* floras (Munhoz 2003,

Ribeiro & Walter 2008, Santos 2019). Corroborating this pattern, these families showed the highest species richness and number of individuals in our plots. They are also very common in other Cerrado regions (Gottsberger & Silberbauer-Gottsberger 2006), including other portions of the Jalapão region (Antar & Sano 2019).

Plant density and richness per plot were higher in the sites under the biennial fire regime than in the unburned site, coinciding with other areas with similar physiognomy in the Cerrado Domain (e.g., César 1980). This pattern can be explained by the role of fire in triggering herb and subshrub species vegetative reproduction (Coutinho 1990), which has also been documented in other savannas worldwide (Sarmiento 1984, Canales *et al.* 1994). Also, fire occurrence increases the light incidence and water availability, as well as nutrient availability for herbaceous plants with shallow roots (Coutinho 1990, Pivello & Coutinho 1992), reducing above- and below-ground competition (César 1980, Abreu *et al.* 2017). Furthermore, we showed that among the three richest families, only Poaceae richness differed between burned and unburned sites, having both abundant (*Axonopus marginatus*, Poaceae) and rare species (*Paspalum marmoratum*, Poaceae) exclusive to sites under the biennial fire regime (Supplementary material Table S1). These results corroborate the evidence that, considering the most abundant and rarest species, the exclusion of fire in *cerrado ralo* can reduce the diversity and co-occurrence of herb–subshrub layer species compared to areas that are biennially burned (Santos 2019).

In our study, Poaceae species represented the most successful group under frequent fires, clearly more abundant and diverse

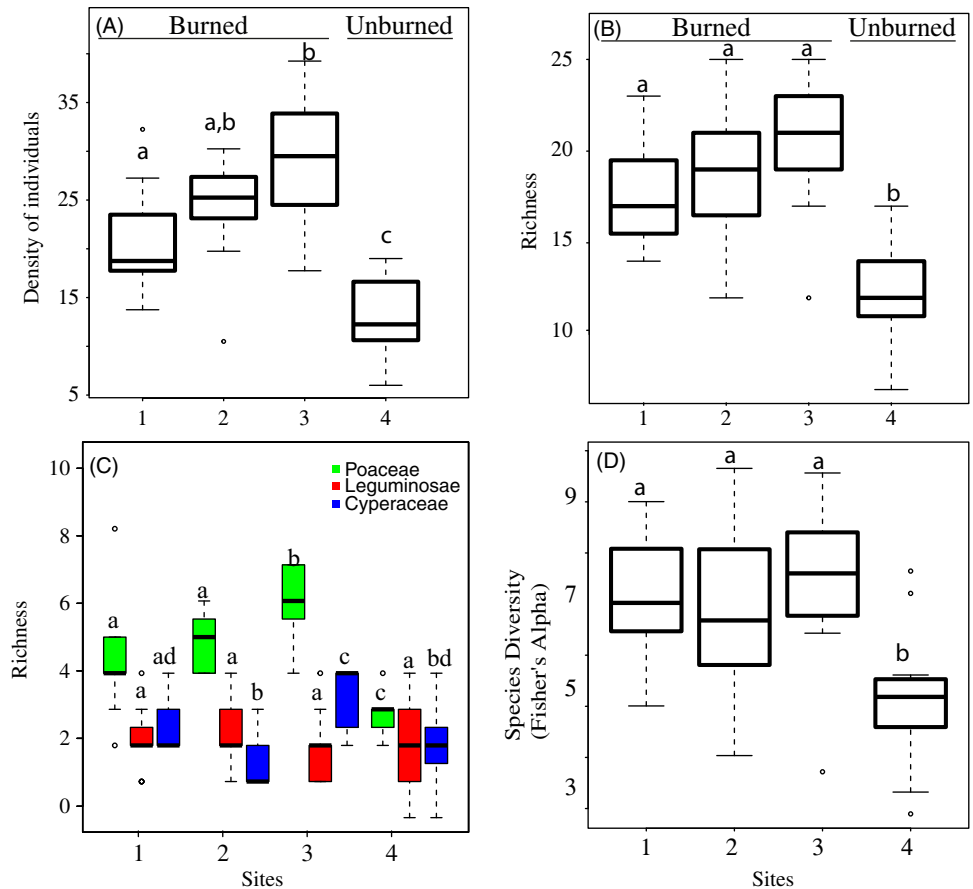


Figure 4. A–C. Variation of the plant density, species richness and diversity index among sites. A. Plant density (number of individuals per plot). B. Species richness (number of species per plot). C. Species richness of the three richest botanical families: Poaceae, Leguminosae and Cyperaceae (number of species per plot). D. Diversity index. Different letters indicate differences among sites based on the post hoc Tukey's HSD multiple comparison test ($p < 0.05$).

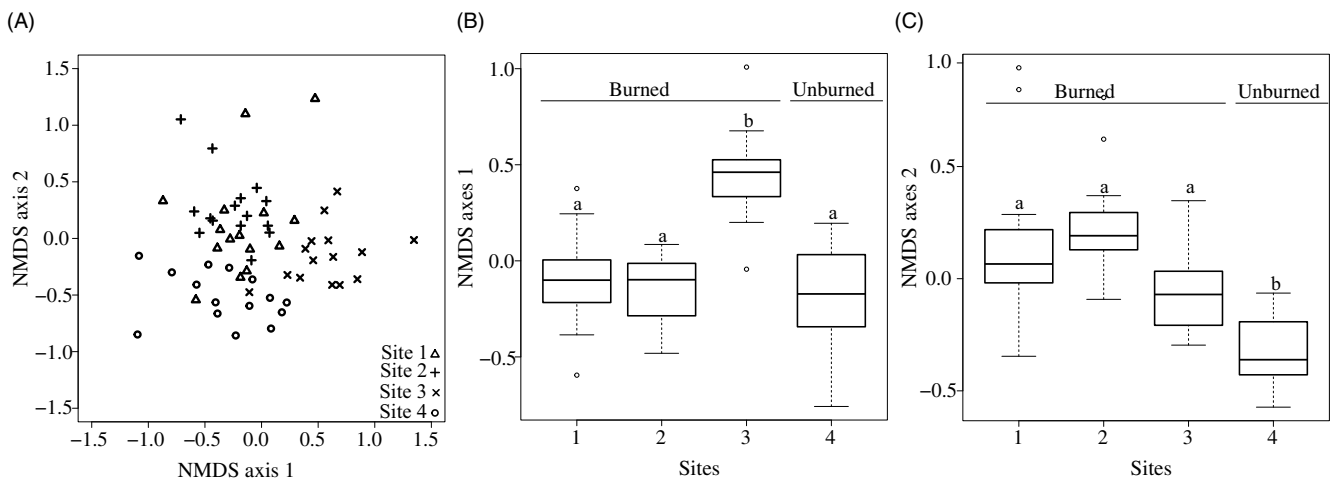


Figure 5. A–C. Variation of the herb-subshrub species composition across the 60 plots distributed at the 4 *campo sujo* sites in the Jalapão region (Tocantins state, Brazil). A. The first two axes of non-metric multidimensional scaling (NMDS, $r^2_{adj} = 0.60$). B and C. Changes in the herb-subshrub species composition represented by the first two axes of the NMDS of abundance data. Different letters indicate differences among sites based on Tukey's HSD multiple comparison post hoc test ($p < 0.05$).

under such conditions. Thus, the pattern of species composition change across sites in both NMDS ordination axes is mainly impacted by differences in the distribution of Poaceae species. However, some studies have shown different patterns of herbaceous species diversity in fire-suppressed areas. For example, in an area free of fire for 7 years, the floristic composition changed by increasing species richness in wet and dry shrubby grassland (Amaral *et al.* 2013). Also, the Poaceae family in areas frequently

burned had less species with a more homogeneous distribution than in unburned areas (Miranda 2002). There is no simple explanation for these contrasting results, but the availability of species (and propagules) at the landscape scale may explain local changes after fire suppression. More correlational studies covering a more comprehensive range of localities and landscape contexts and experimental studies are desired to understand better the role of fire in plant diversity patterns of the Cerrado herb-subshrub layer.

Although the density of herbs and shrubs was lower in the site under fire suppression for at least 10 years (site 4), there was not much bare soil, as the ground was covered by woody shrub individuals, mostly less than 0.5 m tall. Therefore, it is possible that site 4, although still classified as *campo sujo*, is a transitional state with a greater proportion of shrubs towards a more woody vegetation type. This transition to more woody vegetation with fire exclusion has also been reported in other studies in the Cerrado Domain (Coutinho 1990; Moreira 2000, Miranda *et al.* 2010, Amaral *et al.* 2013; Abreu *et al.* 2017). Despite the soil in the Jalapão region being very sandy and, consequently, with a low proportion of nutrients and organic matter for plants, the open vegetation structure and diversity dominated by the herb–subshrub component (Schmidt *et al.* 2007; Antar & Sano 2019) are probably maintained by the effects of high fire frequency (Rodrigues *et al.* 2021). Indeed, 2 years after the last burn, sites 1, 2 and 3 visually showed a complete recovery of the herbaceous vegetation, allowing them to be richer in species composition than the unburned site. This pattern corroborates other studies, which have reported around 8 months (Pilon *et al.* 2020) to 18 months (Batmanian & Haridasan 1985) for a total recovery of the herbaceous vegetation after fire.

The Jalapão region and its vast biological diversity are currently being threatened by the advance of mechanised agriculture expansion, which has been stimulated by the Brazilian government (Borges & Antar, 2016, Antar *et al.* 2017, Silva *et al.* 2018, Antar & Sano 2019, Barbosa-Silva & Antar 2020). Therefore, studies focused on the biodiversity of the Jalapão region can support proposals for well-grounded conservation strategies (Mace 2004), including fire management in areas where burning is widespread (Pereira Jr. *et al.* 2014, Schmidt *et al.* 2018). Unlike forest ecosystems, in which fire is mainly harmful, fire can benefit the dynamics of savannas (Bond & Keeley, 2005; Pivello *et al.* 2021), but this issue is still poorly understood by society and environmental agencies in Brazil. Research studies on Cerrado fire dynamics over the last five decades (Coutinho 1982, 1990, Pivello & Norton 1996, Pivello & Coutinho 1996, Miranda *et al.* 2002, Miranda 2010, Fidelis *et al.* 2018) as well as practical knowledge coming from protected area managers (Borges *et al.* 2016, Berlinck & Batista 2020, Berlinck & Lima 2021) have contributed to slowly change the zero-fire policy rooted in the country for centuries (Durigan & Ratter 2016, Pivello *et al.* 2021) towards prescribed and controlled fires, and integrated fire management. Recent environmental legislation has incorporated these new approaches by accepting controlled fires in specific situations (Schmidt *et al.* 2018; Pivello *et al.* 2021). It has been more and more accepted that prescribed, controlled fires are needed in fire-prone vegetation to avoid biomass accumulation and large and high-intensity fires, which are harmful to flora and fauna (Ramos-Neto & Pivello, 2000, Santos *et al.* 2021). Corroborating previous studies (Coutinho, 1982; 1990; Pivello & Coutinho, 1996; Miranda *et al.* 2002; Miranda, 2010; Fidelis *et al.* 2018), this research shows that adequate fire management to maintain the Cerrado open physiognomies and herbaceous biodiversity should include controlled fires under specific regimes to form a mosaic of burned and unburned sites in protected areas (Ramos-Neto & Pivello, 2000).

Supplementary material. To view supplementary material for this article, please visit <https://doi.org/10.1017/S0266467422000232>

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