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FLÁVIA NOGUEIRA PEREIRA

PROCESSOS SUCESSIONAIS PÓS-FOGO DE ASSEMBLEIAS VEGETAIS EM CAMPOS DE ALTITUDE

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FLÁVIA NOGUEIRA PEREIRA

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Dissertação apresentada como parte dos requisitos para obtenção do título de Mestre em Ciências Ambientais pela Universidade Federal de Alfenas. Área de concentração: Diversidade Biológica e Conservação

Orientador: Prof. Dr. Ernesto de Oliveira Canedo Júnior
Coorientadora: Profª. Drª. Luciana Botezelli

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FLÁVIA NOGUEIRA PEREIRA

“ PROCESSOS SUCESSIONAIS PÓS-FOGO DE ASSEMBLEIAS VEGETAIS EM CAMPOS DE ALTITUDE. ”

A Banca examinadora abaixo-assinada aprova a Dissertação apresentada como parte dos requisitos para a obtenção do título de Mestre em Ciências Ambientais pela Universidade Federal de Alfenas. Área de concentração: Ciências Ambientais.

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Prof. Dr. Ernesto de Oliveira Canedo Júnior

Instituição: Universidade Federal de Alfenas

Prof. Dr. Evandro Luiz Mendonça Machado

Instituição: Universidade Federal dos Vales do Jequitinhonha e Mucuri

Prof. Dr. Guilherme Ramos Demetrio

Instituição: Universidade Federal de Alagoas

À pequena Maria Flor (*in memoriam*), a Flor mais linda que qualquer campo de altitude jamais viu...

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RESUMO

Os campos de altitude são ambientes altomontanos que apresentam alta representatividade biótica e abiótica, desempenhando papel fundamental na manutenção dos ciclos hidrológicos e na preservação de espécies endêmicas. São ambientes que enfrentam ameaças crescentes, devido a intensidade de processos antrópicos, como a incidência constante de queimadas. O objetivo do artigo apresentado a seguir é compreender os processos sucessionais das espécies vegetais em dois campos de altitude localizados no município de Poços de Caldas/MG, denominados campo A e campo B, após eventos de fogo. Foram realizadas coletas periódicas de dados sobre a riqueza e composição de espécies, a fim de compreender a sucessão pós-fogo da vegetação. Para as análises dos dados, foram aplicados Modelos Lineares Generalizados Mistos e Modelos Quadráticos, assim como uma Análise de Variância Permutacional, através do software R, para compreender como o fogo afeta a riqueza e a composição de espécies ao longo do tempo. Constatou-se que a riqueza de espécies foi influenciada positivamente pelo tempo pós-fogo, apresentando aumento progressivo no número de espécies em ambos os campos, seguido por uma tendência à estabilização. A composição de espécies, por sua vez, variou de acordo com o tempo, sob a provável influência dos micro-habitats e do tempo pós-fogo, sendo o *turnover* o principal mecanismo de alteração da composição florística. O estudo também demonstrou a predominância de famílias como Asteraceae e Poaceae, além de uma grande representação de espécies hemicriptófitas e caméfitas. As adaptações biológicas de algumas espécies, como a capacidade de rebrota após a queima ou a rápida alocação de estruturas reprodutivas, foram fatores decisivos para a recuperação das assembleias vegetais. Esse é o primeiro estudo a analisar os efeitos do fogo antrópico em campos de altitude em Poços de Caldas, o que denota a importância de mais estudos que corroborem com a compreensão dos processos da ecologia do fogo sobre as assembleias vegetais nestes ambientes.

Palavras-chave: queimada antrópica; ecologia do fogo; vegetação de altitude; distúrbio antrópico.

ABSTRACT

High-altitude grasslands are montane environments that exhibit high biotic and abiotic representativeness, playing a key role in maintaining hydrological cycles and preserving endemic species. These environments face increasing threats due to the intensity of anthropogenic processes, such as the constant occurrence of fires. The aim of the following article is to understand the successional processes of plant species in two high-altitude grasslands located in the municipality of Poços de Caldas, Minas Gerais, Brazil, referred to as Field A and Field B, after fire events. Periodic data collection was conducted on species richness and composition to understand the post-fire succession of vegetation. Generalized Linear Mixed Models and Quadratic Models were applied to the data, as well as a Permutational Analysis of Variance using the R software, to understand how fire affects species richness and composition over time. It was found that species richness was positively influenced by the post-fire time, showing a progressive increase in the number of species in both fields, followed by a trend toward stabilization. Species composition, in turn, varied over time, likely influenced by microhabitats and the post-fire period, with turnover being the main mechanism driving changes in floristic composition. The study also demonstrated the predominance of families such as Asteraceae and Poaceae, as well as a significant representation of hemicryptophytes and chamaephytes. The biological adaptations of some species, such as the ability to resprout after burning or the rapid allocation of reproductive structures, were decisive factors for the recovery of plant communities. This is the first study to analyze the effects of anthropogenic fire in high-altitude grasslands in Poços de Caldas, highlighting the importance of further research to enhance the understanding of fire ecology processes on plant communities in these environments.

Keywords: anthropogenic fire; fire ecology; high-altitude vegetation; anthropogenic disturbance.

SUMÁRIO

1 INTRODUÇÃO GERAL

Os Campos de Altitude, pertencentes ao bioma da Mata Atlântica, são ambientes altomontanos de grande relevância biológica, caracterizados por uma rica biodiversidade e alto grau de endemismo de espécies (Martinelli, 2007; Brasil, 2010). São encontrados na Serra da Mantiqueira e Serra do Mar, em regiões montanhosas que apresentam condições abióticas únicas e variações climáticas específicas, como baixa temperatura e alta umidade (Assis; Mattos, 2016). Exibem uma vegetação em formas mosaicas, compostas de espécies arbóreas de pequeno porte, arbustivas e subarbustivas, fortemente permeadas por um estrato gramíneo herbáceo (Campos *et al.*, 2020; Safford, 2001).

No município de Poços de Caldas, sul de Minas Gerais ao sudeste do Brasil, a fitofisionomia apresenta-se restrita às paisagens de maior altitude e são consideradas importantes áreas de drenagem e recarga hídrica, com uma grande diversidade de espécies gramíneo-lenhosas (Pereira *et al.*, 2021). Atualmente, sofrem constantemente perda de diversidade decorrente de pressões crescentes e enfrentam uma série de desafios impostos pelos processos antrópicos, tais como avanço de práticas agrícolas, urbanização, mineração, pastoreio, invasão de espécies exóticas e incêndios constantes (Silva *et al.*, 2024).

Considerado um elemento intrínseco da ecologia de alguns ecossistemas, o fogo ocorre naturalmente em diversas fisionomias campestres, fator este que o associa como importante agente no manejo ecossistêmico e manutenção biológica natural (Alves; Silva, 2011; Herrmann *et al.*, 2023). O problema é que com a intensificação dos processos antrópicos, associados ao desinteresse político e social sobre essas áreas, há uma maior recorrência dos registros de incêndios (Aximoff, 2011; Ramalho *et al.*, 2024), fator que denota atenção dada às características peculiares da fitofisionomia (Aximoff; Nunes-Freitas; Braga, 2016).

O fogo exerce uma influência significativa sobre as espécies vegetais nos Campos de Altitude, afetando a riqueza, composição da vegetação, a dinâmica do ecossistema e a biodiversidade (Overbeck *et al.*, 2007; Safford, 2001). O fogo pode favorecer espécies vegetais que são mais adaptadas a condições de incêndio, como aquelas que possuem estruturas adaptativas que favorecem a sobrevivência e o rápido desenvolvimento pós-fogo (Bombo *et al.*, 2023; Prochazka *et al.*, 2024). Em contrapartida, espécies mais vulneráveis podem ser eliminadas das áreas afetadas, resultando em uma diminuição da diversidade biológica e perda de interações ecológicas (Salim *et al.*, 2022). Após um incêndio, as assembleias vegetais podem passar pelo processo de sucessão ecológica, onde algumas espécies de crescimento rápido e tolerância ao fogo colonizam primeiro, e posteriormente com o decorrer do tempo, outras espécies podem se estabelecer, levando a uma nova composição de vegetação (Prochazka *et al.*, 2024). Porém, outras alterações nos ciclos de vida das espécies também podem ocorrer, decorrente da frequência e intensidade dos incêndios, promovendo adaptações evolutivas ou levando a mudanças significativas na fitofisionomia (Aximoff; Nunes-Freitas; Braga, 2016).

Desta forma, a sucessão ecológica impulsionada pelo fogo em Campos de Altitude representa um fenômeno biológico complexo e bastante dinâmico. Dada a deficiência de estudos sobre a relação do fogo e os Campos de Altitude localizados no município de Poços de Caldas, sul de Minas Gerais, sudeste do Brasil, há um desconhecimento sobre os reais impactos desse agente sobre espécies vegetais nativas, e o quanto ele afeta nos processos de sucessão ecológica. Posto isso, o presente estudo explora como a dinâmica do fogo antrópico influencia a sucessão ecológica das espécies vegetais, a fim de compreender como o fogo afeta a estrutura dos Campos de Altitude ao longo do tempo.

2 ARTIGO

O artigo a seguir está formatado conforme as normas de publicação do periódico *Journal of Mountain Science* (ISSN 1672-6316)

2.1 FIRE-DRIVEN SUCCESSION IN HIGH-ALTITUDE GRASSLANDS: INSIGHTS FROM A THREATENED MONTANE AREA IN THE ATLANTIC FOREST OF SOUTHEASTERN BRAZIL

ABSTRACT

High-altitude grasslands exhibit high biological and hydrogeological representativeness; however, they are experiencing a constant loss of diversity due to anthropogenic processes. With the recurrence of anthropogenic fires and the lack of studies on the effects of fire on plant communities, the objective of this work was to understand the successional processes of species in two high-altitude grassland areas after fire events. We hypothesized that: i) species richness initially increases, followed by a decline and stabilization; ii) the composition of species changes over time post-fire according to the life forms of the species and their development strategies. To assess the post-fire influence on species richness over time, we applied Generalized Linear Mixed Models and Quadratic Models to compare their potential for stabilization. To analyze the change in the composition of plant species over time post-fire and between transects, we performed Permutational Analysis of Variance to compare different times and transects pairwise using R software. We found that species richness showed a progressive increase in both fields, followed by a trend toward stabilization. The composition of species changed over time, influenced by the transects and their interaction with post-fire time, suggesting the probable influence of different microhabitats. The mechanism of change in composition was turnover. Asteraceae and Poaceae were the most frequent families, with a predominance of hemicryptophyte and chamaephyte species. Biological characteristics of some species ensured survival and rapid development after fire. This was the first study to evaluate the effects of anthropogenic fire in high-altitude grasslands in Poços de Caldas/MG, highlighting the importance of more similar studies to enhance the understanding of fire ecology processes in altitude fields, which are considered priority areas for conservation.

Keywords: Anthropogenic fire; Fire ecology; Altitude vegetation; Anthropogenic disturbance.

1 INTRODUCTION

High-altitude grasslands (*Campos de altitude*) are montane environments of significant hydrogeological importance within the Atlantic Forest domain, playing a crucial role in water retention and supporting a wide range of biological diversity, particularly of grass-woody species (Pereira et al. 2021; Pinheiro et al. 2020). These ecosystems are under constant threat of biodiversity loss due to intense fragmentation and suppression driven by human activities (Dos Santos et al. 2023). Factors such as urban expansion, deforestation, mining, improper agricultural management, grazing, forestry practices, invasion of exotic species, and recurrent fires exacerbate biodiversity loss in high-altitude grasslands (Silva et al. 2024). This increases the fragmentation of the remaining areas (Fonseca et al. 2022) and leads to species extinction (Martinelli 2007).

High-altitude grasslands, like other montane ecosystems, are characterized by unique abiotic conditions, including low temperatures, acidic soils, and seasonal water stress (Scarano et al. 2016). These ecosystems, particularly within the Atlantic Forest domain, are biodiversity hotspots with high levels of endemism (Martinelli 2007). However, fire a disturbance both intrinsic and anthropogenic plays a major role in shaping plant communities. While natural fire regimes can promote biodiversity, frequent human-induced fires pose a significant threat to the long-term conservation of these systems (Fidelis and Pivello 2011). Understanding how plant species respond to fire is crucial not only for biodiversity conservation but also for maintaining the hydrological functions these ecosystems support.

Globally, fire plays a key role in maintaining biodiversity in montane ecosystems, particularly in regions where environmental conditions such as low temperatures and seasonal water stress impose limitations on plant growth (Scarano et al. 2016). In tropical montane environments, frequent anthropogenic fires pose additional challenges, often resulting in altered successional trajectories and a shift toward fire-tolerant species (Behling and Safford 2010). Given the insular nature of these ecosystems and their high levels of endemism, it is critical to understand how fire influences both short- and long-term vegetation dynamics, especially in the face of increasing human pressures.

Alongside population growth, unregulated urban expansion and increased human activities, combined with societal and political neglect of native grassland areas, have led to a rising frequency of human-induced fires in these environments (Aximoff 2011; Rocha and Nascimento 2021). The peculiar characteristics of this vegetation type such as its insular occurrence at specific altitudes, acidic soils, and extreme variations in temperature and water availability (Scarano et al. 2016) make it particularly vulnerable to anthropogenic disturbances (Aximoff et al. 2016; Assis and Mattos 2016).

Fire is considered a common and intrinsic disturbance in the ecology of high-altitude grasslands (Overbeck et al. 2007; Hermann et al. 2023), having occurred naturally for thousands of years (Behling et al. 2007; Behling and Safford 2010), primarily due to lightning strikes during rainy seasons (Ramos-Neto and Pivello 2000). When fire is of anthropogenic origin, it tends to occur during drier seasons, with greater frequency and intensity (Fidelis and Pivello 2011), what can exert various effects on plant assemblages, influencing species richness, composition, and ecological succession depending on the frequency and scale of the fires (Aximoff 2011; Bombo et al. 2023). Factors such as the timing of fire events, the type of landscape burned, the amount of available fuel, topography, and adverse climatic conditions also strongly influence both the intensity of the disturbance (Souza 2011; Walter and Ribeiro 2010) and the process of natural regeneration.

According to Safford (2001), the rapid post-fire regeneration of plant assemblages in high-altitude grasslands varies depending on environmental heterogeneity. In rocky grasslands environments that share physiognomic similarities and taxonomic overlap with high-altitude grasslands (Vasconcelos 2011) the presence of species adapted to environmental peculiarities enhances the uniqueness of the vegetation composition, contributing to environmental heterogeneity (Le Stradic et al. 2015). In this sense, fire acts as a shaping agent in grassland vegetation, where the rapid recovery of plant assemblages depends on the persistence or replacement of taxa within the ecosystem (Souza 2011). Species that are better adapted and conditioned by the pre-fire environment tend to dominate, utilizing survival strategies that allow them to remain or establish themselves after fire events (Aximoff et al. 2016).

Strategically, some plant species exhibit distinct structural, functional, and phenological traits that enable their survival in high-altitude environments, even in the face of frequent disturbances such as fire (Prochazka et al. 2024). Raunkiaer's classification of life forms (Raunkiaer 1934) allows for the analysis and understanding of the strategies employed by taxa in response to various selective pressures imposed by the environment over time, linking these environmental influences to their morphological and functional traits in species development (Martins and Batalha 2011; Prochazka et al. 2024). Thus, in environments prone to physiognomic restrictions and disturbance interference, such as high-altitude grasslands (Scarano et al. 2016; Silva et al. 2024), the presence of species with specific traits may be related to pressures and adaptations that have occurred over time (Ramalho et al. 2024). Therefore, understanding post-fire processes in high-altitude grasslands is essential for comprehending the temporal patterns of changes in individuals, plant assemblages, and vegetation physiognomy over time (Neves and Conceição 2010). Establishing parameters that support the maintenance of native vegetation in line with natural patterns is crucial for ensuring the conservation of biodiversity in these important areas (Canedo-Júnior et al. 2016; Moras Filho et al. 2017).

Considering the biological importance and richness of this vegetation, along with its vulnerability to human activities and the high risk of species extinction (Pereira et al. 2024; Ribeiro and Freitas 2011), more scientific research is needed to support the conservation and restoration of high-altitude grasslands. In particular, studies aimed at understanding floristic, taxonomic, and phytosociological parameters, especially in the face of recurrent anthropogenic factors such as fire, which is frequently observed in many remaining high-altitude grasslands. In this context, the objective of the present study is to understand the successional processes of plant species in the high-altitude grasslands of Poços de Caldas, Minas Gerais, after fire events, in order to assess how fire affects the structure of these environments over time. We propose the following hypotheses: i) Plant species richness initially increases after a fire event, followed by a decline and stabilization in species richness; ii) Plant species composition changes over time post-fire, depending on life forms and their post-fire development strategies.

2 MATERIAL AND METHODS

2.1 Study area

The municipality of Poços de Caldas, located in southern Minas Gerais, is characterized by its mountainous terrain, with altitudes ranging from 1,200 to 1,640 meters (Cipriani et al. 2011), formed from a volcanic caldera. The region's climate is classified as Cwb, a subtropical highland climate, mesothermal, according to the Köppen classification, with an average annual temperature of 17.7°C and a rainfall index of 1,706 mm (Alvares et al. 2013). Low temperatures occur during the driest period, from May to September, with frost recorded in the coldest months, while summers are mild and rainy (Oliveira-Filho 2017; Sardinha et al. 2016).

Located within the Atlantic Forest Biome, the dominant phytophysiognomies arise from variations along altitudinal gradients, including high-altitude grasslands and montane forests (Costa et al. 2011). High-altitude grasslands are found on mountaintops and are composed of alkaline igneous rocks of the tinguaito type (Moraes and Jiménez-Rueda 2008). These areas exhibit rugged terrain, shallow soils, and rocky outcrops, which are crucial for maintaining hydrological regulation processes (Brasil 2010; Mocochinski and Scheer 2008). The vegetation, which holds significant biological and ecological importance, is arranged in mosaic patterns and consists of small-statured tree species, shrubs, and subshrubs, heavily interspersed with a grass/herb layer (Campos et al. 2020; Safford 2001), exhibiting a high degree of endemism (Brasil 2010).

The areas studied consist of two remnants of high-altitude grasslands (designated as Field A and Field B), located within the urban perimeter of the municipality. These sites are periodically monitored by the Poços de Caldas Botanical Garden Foundation (FJBPC) for scientific studies and floristic surveys. Both remnants have a history of recurrent fire events, being affected annually by wildfires, which are mostly of anthropogenic origin, according to observations by the FJBPC technical team. Field A (Figure 1-A) is situated in the sub-basin of the Vai-e-volta stream, with coordinates 21°49'04.27” S and 46°34’42.90” W, at an average altitude of 1,400 m. It spans approximately 28 hectares, where the different slopes exhibit corresponding altitudes and inclinations, with minimal variation between them. This area features characteristics of Grassland (Williams et al. 2023), interspersed with a few shrubs and rocky outcrops. In contrast, Field B (Figure 1-B) is located at coordinates 21°48’11.57” S and 46°33’25.55” W, with an average altitude of 1,360 m. It covers about 40 hectares, with varying altitudes and slopes among its different aspects, displaying characteristics that range from Grassland to Shrubby (Williams et al. 2023), interspersed with some small trees. The terrain is quite rugged, heavily dotted with rocky outcrops.

2.2 Sampling Design

The high-altitude grasslands were periodically monitored by the FJBPC technical team to document fire occurrences. The dates of the wildfires were estimated to be between August 22 and 28, 2020, in Fields A and B, respectively. Following the fires, the affected areas were analyzed, and transects and plots were properly marked, recording the geographic location and altitude of each plot.

In each field, three transects were established, each approximately eighty meters long and one meter wide, with an approximate distance of 260 meters between them. The transects were designed to encompass the various slopes and altitudinal differences of each field, allowing for the documentation and analysis of the floristic and structural compositions of the vegetation in different areas. In Field A, the transects were more aligned due to the area's characteristics, covering similar slopes where the different transects exhibited plots with corresponding altitudes and inclinations. In contrast, Field B's transects were more distinct, accommodating the different altitudes and slopes of the area, resulting in plots with varying altitudes and inclinations among the different transects (Figure 1).

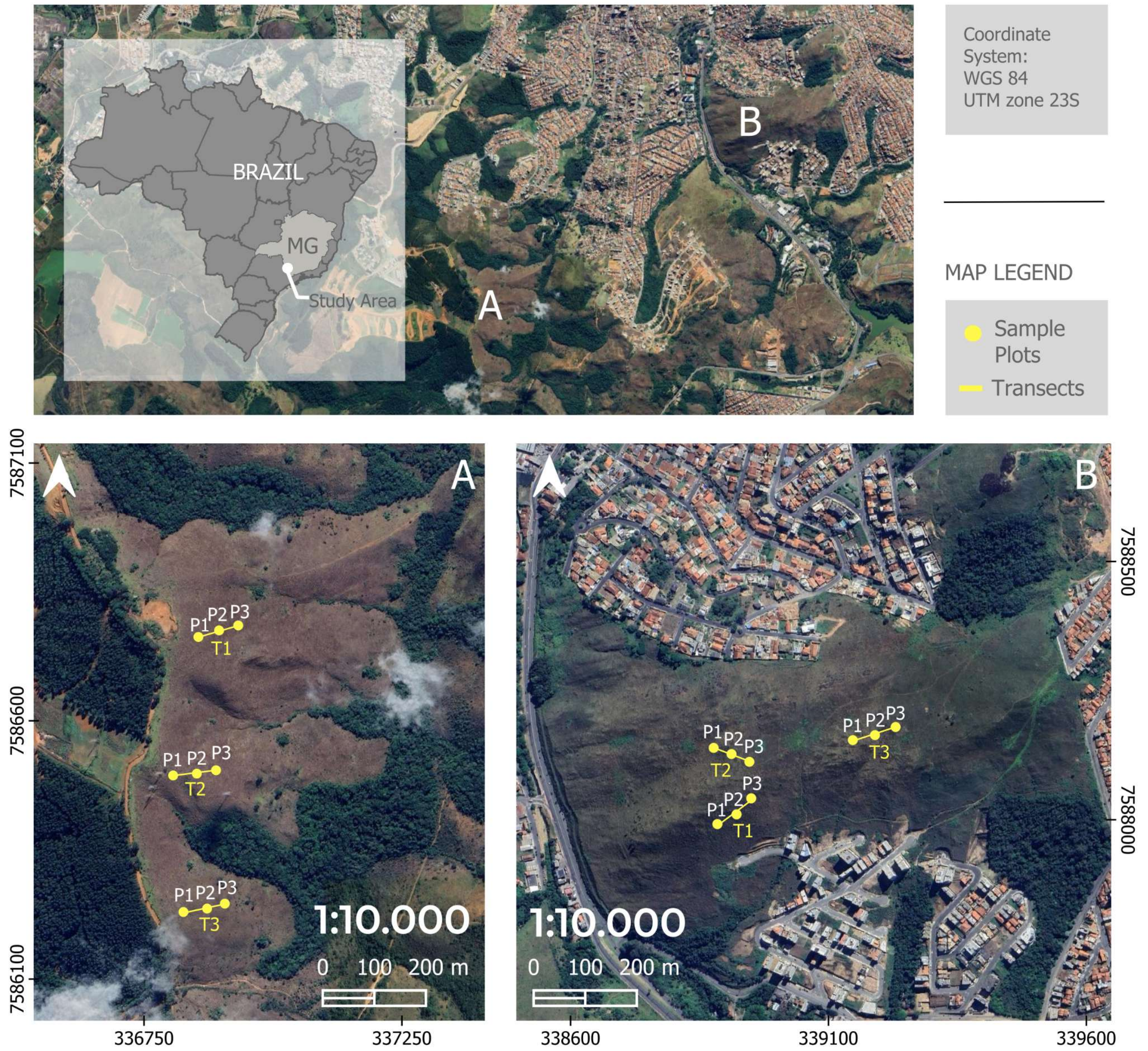


Fig. 1 Transects and their respective plots in the high-altitude grasslands, Field A and Field B, both located within the urban perimeter of the municipality of Poços de Caldas, MG.

Each transect was subdivided into three plots, measuring one meter in length by one meter in width, with forty meters between them. The plots used for data collection consisted of sampling frames of 1m x 1m, constructed laterally from PVC (polyvinyl chloride), divided into 100 subplots of 10cm x 10cm. The subplots were delineated using strings attached to the PVC, woven transversely, allowing for slight flexibility in the subplots to facilitate data collection in areas with uneven terrain (especially in rocky outcrop regions) and ensuring that samples were consistently included throughout the development of the vegetation.

2.3 Data sampling

Data collection began shortly after the first sprouting was observed in both fields (approximately 20 days post-burn). This occurred from September 11, 2020, to January 14, 2021, in Field A, and from September 15, 2020, to January 19, 2021, in Field B. A total of eleven data collection sessions (readings) were conducted in each field, with three consecutive weekly collections during the first month to closely monitor the development of the plant community in its early stages, shortly after the fire (Zirondi et al. 2021; Fidelis et al. 2012; Overbeck et al. 2005). Subsequently, data collections were conducted biweekly to track the gradual and progressive changes in the vegetation until it reached a stage of apparent stability (Supplementary Materials I - Table S1).

Species richness and composition were recorded for each plot. The floristic composition assessment was conducted individually in each plot, where the taxa were accurately identified with the assistance of specific literature, consultations with the Anders Fredrik Regnell Herbarium (AFR), and support from researchers at FJBPC. Scientific names were updated according to the Flora and Funga do Brasil database (Flora e Funga do Brasil 2023), families were classified based on the APG IV classification system - Angiosperm Phylogeny Group

(APG IV 2016), and species were categorized according to Raunkiaer's life form classes (Raunkiaer 1934).

2.4 Data analysis

To assess the influence of post-fire time on the species richness of both fields, we applied Generalized Linear Mixed Models (GLMM) and Quadratic Models to compare the models regarding the potential stabilization of species richness over time. We used post-fire time as a fixed predictor variable, with random variables including the nested plot within the transect and the plot itself, as certain specific characteristics of a transect or plot may influence succession, and we did not control for these variables. The response variable was the species richness in both fields. The models were analyzed using a Poisson distribution, as the data are counts, utilizing the 'glmmTMB' package in R (R Core Team 2021). The Generalized Linear Mixed Model (GLMM) was selected to analyze species richness over time post-fire due to its ability to account for both fixed effects (post-fire time) and random effects (transects and plots). The use of a Poisson distribution is appropriate given that species richness is count data, which aligns with the model assumptions of GLMM.

To analyze the change in plant species composition over post-fire time and between transects in both studied fields, we employed the transect and post-fire time as predictor variables and the change in species composition as the response variable. We performed a Permutational Analysis of Variance (PERMANOVA) using the 'adonis2' function from the 'vegan' package (Oksanen 2024). After this, we ran pairwise comparisons among different post-fire times and transects using the 'pairWise.adonis' function from the 'pairwiseadonis' package (Arbizu 2017) to conduct pairwise comparisons. Subsequently, to investigate the mechanisms (turnover or nestedness) responsible for possible changes in species composition across both fields, we utilized Beta Diversity Partitioning analysis through the 'betapart' package and Jaccard index, considering the presence/absence data. This analysis was also conducted in R (R Core Team 2021). We chose PERMANOVA for the analysis of species composition due to its robustness in handling multivariate datasets and its non-parametric nature, which is essential when data deviate from normality (Anderson 2001). The pairwise adonis test further allows us to pinpoint differences between specific time points and transects, a critical factor given the spatial variability of high-altitude grasslands (Oksanen et al. 2024).

To analyze the occurrence of different life forms of species over time in each field, we calculated the number of subplots in which each life form occurred, divided by the total number of subplots sampled throughout the readings in each field. These values were used to construct graphs showing the distribution of life form occurrences in each field over time.

3 RESULTS

In total, 98 taxa were recorded, belonging to 23 botanical families, with 54 found in Field A and 74 in Field B (Supplementary Materials I – Table S2). In Field A, the most representative families were Asteraceae (18.87%), Poaceae (11.32%), Fabaceae, and Euphorbiaceae (9.43% each), followed by Convolvulaceae, Cyperaceae, and Lamiaceae (7.54% each). The remaining families (Acanthaceae, Iridaceae, Malvaceae, Melastomataceae, Moraceae, Myrtaceae, Polygalaceae, Rubiaceae, and Turneraceae) accounted for 28.33%. In Field B, the most representative families were Asteraceae (20%), Poaceae (12%), Fabaceae (9.33%), and Rubiaceae (6.66%), with Convolvulaceae, Cyperaceae, Euphorbiaceae, and Iridaceae contributing 5.34% each. The other families totaled 30.65%, including Acanthaceae, Amaranthaceae, Anemiaceae, Apiaceae, Hypoxidaceae, Iridaceae, Lythraceae, Malpighiaceae, Malvaceae, Melastomataceae, Moraceae, Orobanchaceae, Polygalaceae, and Turneraceae (Figure 2).

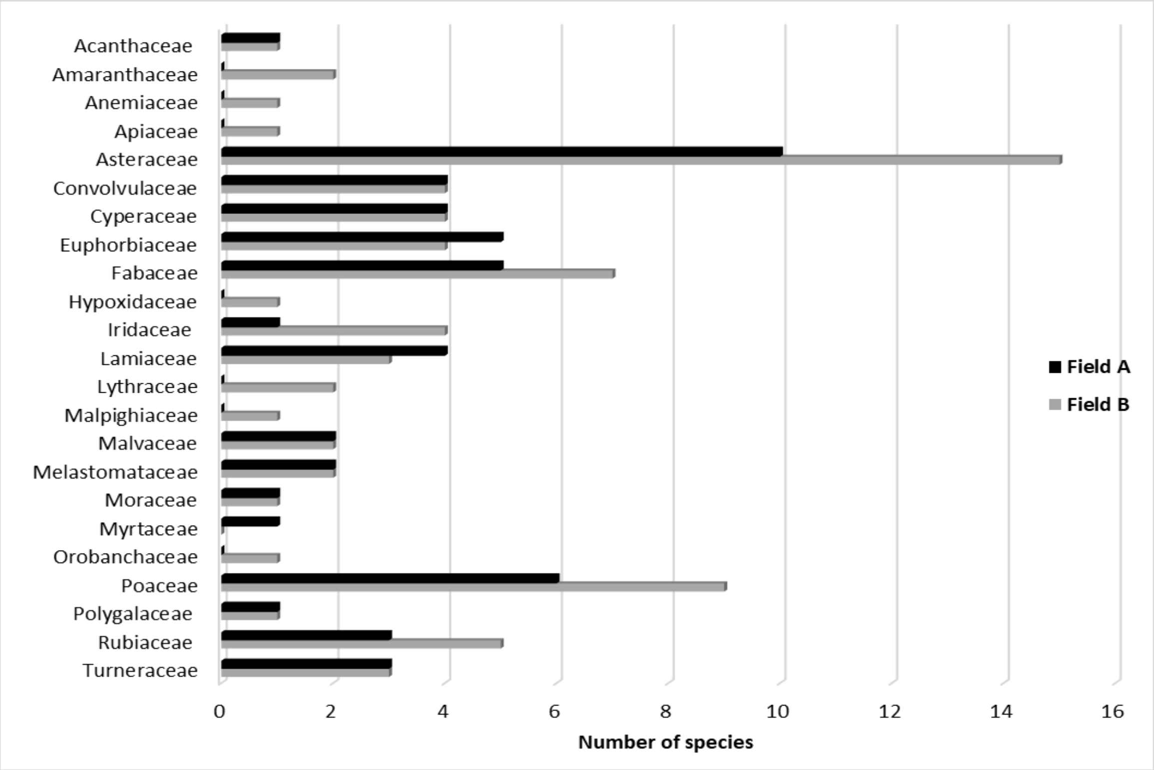
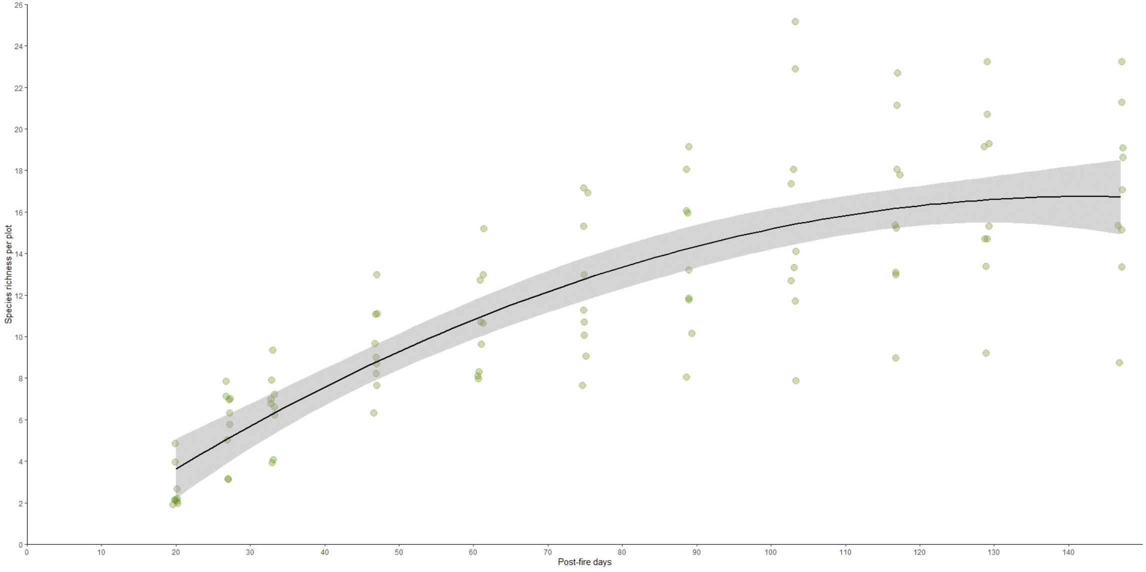


Fig. 2 – Most frequent families found after fire events in high-altitude grasslands A and B, Located in the Municipality of Poços de Caldas/MG.

Among the taxa that exhibited greater regularity in each field over the days following the fire, the following were highlighted for Field A: Poaceae *Axonopus* sp., *Echinolaena inflexa* (Poir.) Chase, Morph A01, and Morph A02; Lamiaceae *Eriope crassipes* Benth.; Cyperaceae *Bulbostylis sphaerocephala* (Boeckeler) C.B. Clarke; Asteraceae *Aspilia foliacea* (Spreng.) Baker and *Baccharis humilis* Sch.Bip. ex Baker; Acanthaceae *Ruellia geminiflora* Kunth and Melastomataceae *Chaetogastra hieracioides* Schrank et Mart. ex. DC. In Field B, the following were found: Poaceae Morph B01, Morph B02, *Axonopus* sp., *Echinolaena inflexa* (Poir.) and *Andropogon* sp.; Asteraceae *Calea asclepiifolia* Hassl., *Porophyllum obscurum* (Spreng.) DC. and *Aspilia foliacea* (Spreng.) Baker; Acanthaceae *Ruellia geminiflora* Kunth and Fabaceae *Eriosema campestre* var. *macrophyllum* (Grear) Fortunato.

The first hypothesis posited that an increase in time post-fire there would be positively related to species richness, followed by stabilization, was partially confirmed. It was found that the richness of plant species was positively influenced by the time post-fire in both Field A (Z= 13.12, p<0.001) and Field B (Z= 15.34, p<0.001). Initially, there was an increase in the number of species in the first days post-fire, and later, towards the end of the sampled time, demonstrating a tendency to stabilize the number of species in both fields (Figure 3).



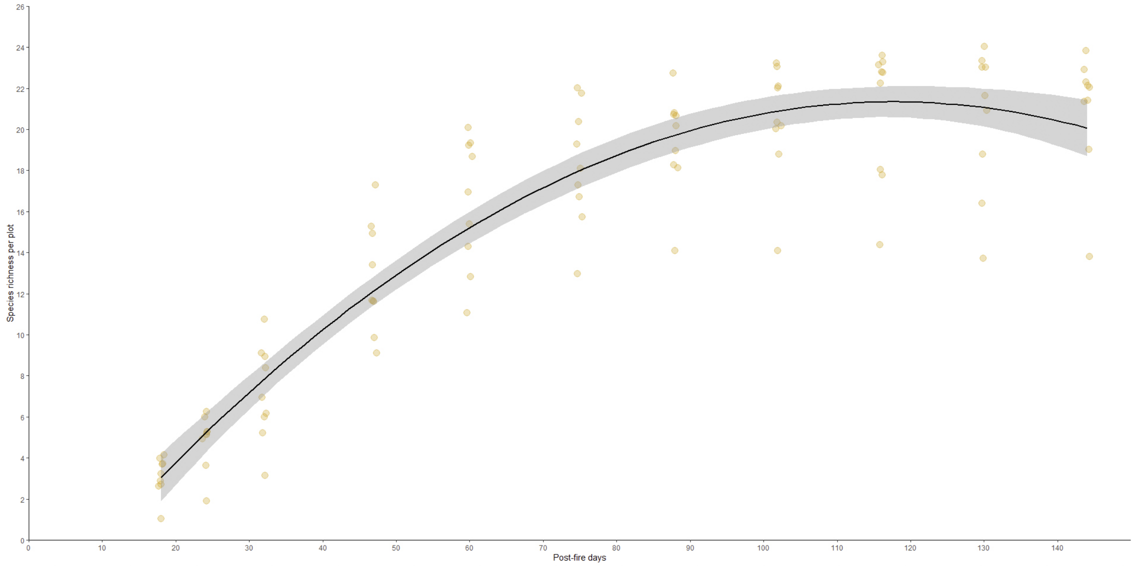


Fig. 3 - Species richness by plots over the days post-fire in high-altitude grasslands areas A and B, respectively, located in the municipality of Poços de Caldas/MG.

Regarding species composition, the hypothesis was supported by the results of the analyses, where the composition changed over the post-fire period for both Field A (F= 14.7742, p<0.001) and Field B (F= 15.2433, p<0.001). The changes in species composition occurred most significantly between the first and third readings, with a more homogeneous composition between the fourth and fifth readings, maintaining this state until the end of the experiment, as can be seen in Supplementary material I (Tables S3 and S4). We also found that the transects influenced species composition in both fields (Field A (F= 12.3619, p<0.001); Field B (F= 14.9111, p<0.001)), as well as the interaction between post-fire time and transects (Field A (F= 2.4378, p= 0.001); Field B (F= 3.4042, p<0.001)). Through the partitioning of Beta diversity, we observed that the mechanism responsible for the change in species composition in both fields was turnover, with values for Field A (beta Turnover= 0.9674) and Field B (beta Turnover= 0.9753).

After proper classification according to Raunkiaer's life form, based on the position and degree of protection of each taxon's buds (Raunkiaer 1934), we analyzed the distribution of their occurrences in each field. Thus, it was possible to verify throughout the study a higher number of chamaephytes (36), followed by hemicryptophytes (33). The other life forms totaled 29 species, comprising: phanerophytes (11), therophytes (6), geophytes (4), and undetermined/classified as morpho species (8) (Figure 4).

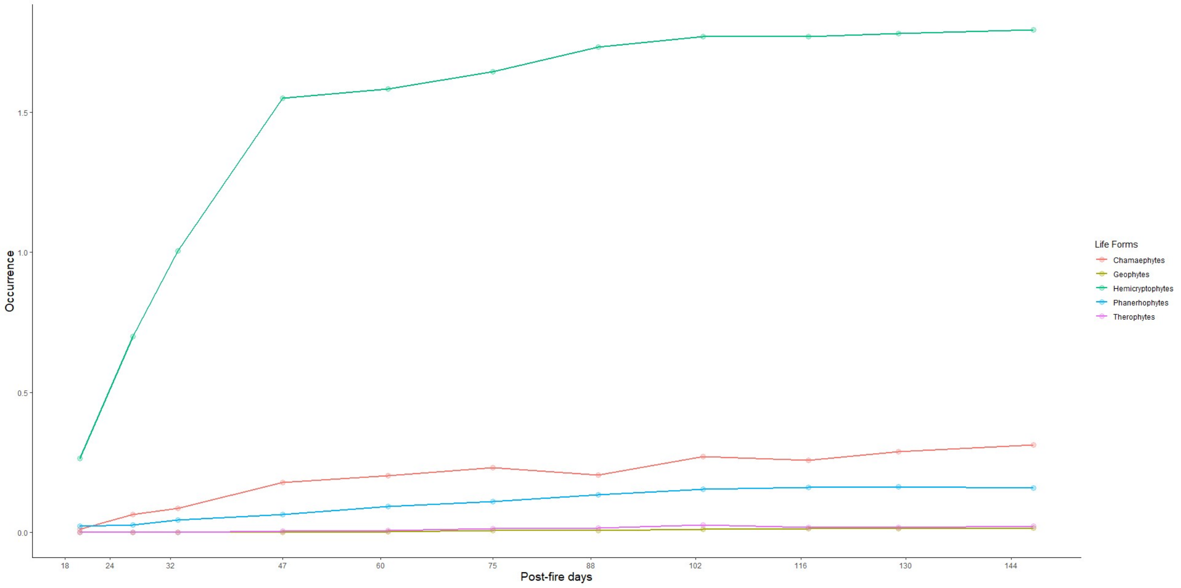


Fig. 4 Most frequent life forms over time after the fire event in high-altitude grasslands areas A and B, respectively, located in the municipality of Poços de Caldas/MG.

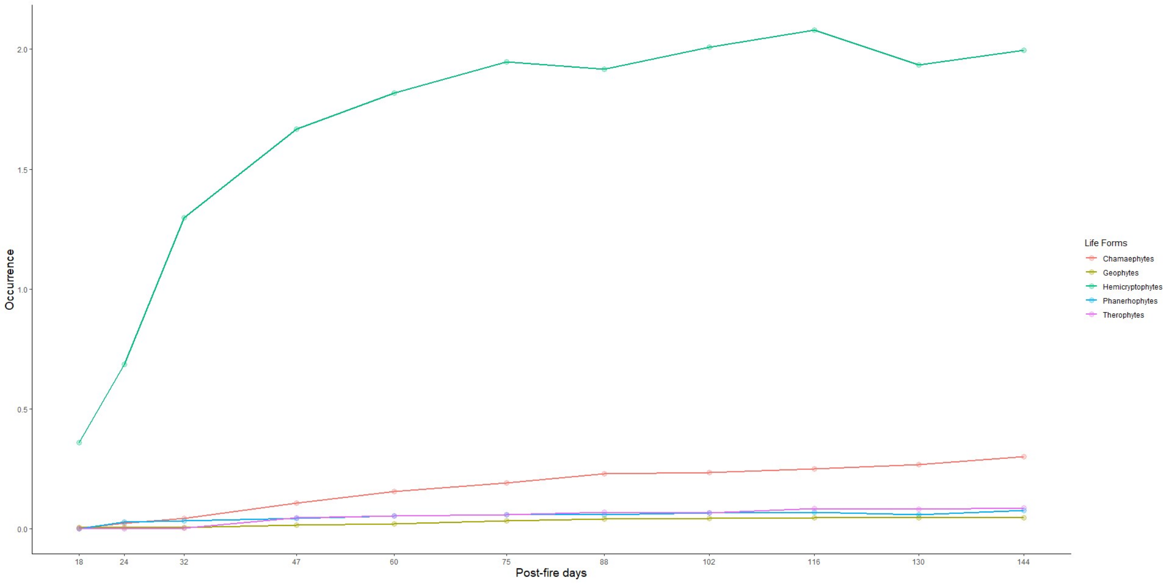


Fig. 4 Most frequent life forms over time after the fire event in high-altitude grasslands areas A and B, respectively, located in the municipality of Poços de Caldas/MG.

4 DISCUSSION

Asteraceae and Poaceae were the most expressive families in both studied high-altitude grasslands, resembling the results found in the studies by Ribeiro et al. (2007); Caiafa and Silva (2005); Aximoff et al. (2016); and Campos et al. (2020). These families stand out in richness during the early stages of post-fire succession of plant assemblies (Alves and Silva 2011; Durigan 2020) and play an important role after burning, as they exhibit a rapid recovery of coverage and contribute significantly to increasing plant richness in grassland areas (Cordeiro et al. 2023; Fidelis et al. 2012).

The 145-day monitoring period was selected based on prior studies indicating that post-fire recovery in grasslands follows an accelerated phase within the first few months, characterized by rapid regrowth of herbaceous species (Fidelis et al. 2012). Although longer-term monitoring is necessary to capture full successional cycles, this temporal scope is adequate for observing early successional changes, particularly for species with high resprouting capacity and rapid seedling establishment (Overbeck et al. 2005). The temporal analysis of the data demonstrated that post-fire time positively favored species richness in both fields, showing a progressive increase from the first 20 days until the 115th day post-fire. After this period, there was a slight trend toward stabilization in the number of species in both fields. Compared to the studies of Overbeck et al. (2005) and Aximoff et al. (2016), it can be inferred that sampling time may influence species richness over time, and the use of space-time metrics is essential for understanding the successional processes in native vegetation (Gomes et al. 2018). However, further research should extend beyond this period to assess longer-term patterns of stabilization or degradation in species richness and composition.

The increase in species richness during the early stages after burns is evidenced in studies of similar grassland environments, as observed by Fidelis et al. (2012); Overbeck et al. (2005); and Harrison et al. (2003), and is often attributed to the presence of certain species and their survival strategies. Species that, even suffering severe damage, temporarily modify their vegetative structures, react to the stress endured through seeds or by resprouting, and employ important strategies that allow regeneration under favorable conditions, according to the evolution of their life forms (Prochazka et al. 2024; Gurevitch et al. 2009), influenced by different pressures imposed by environmental conditions over the years (Bombo et al. 2023).

During the study, the rapid development of the species *Bulbostylis paradoxa* (Spreng.) Lindm. in Field A, and *Euphorbia potentilloides* Boiss. in Fields A and B, was observed, which initially appeared after the burn and presented inflorescences in a short time post-fire. The rapid development of the reproductive cycle of these species demonstrates an important survival strategy, also noted in the studies by Fidelis et al. (2019) and Bombo et al. (2023). In environments with peculiar characteristics and susceptible to frequent burning, such as high-altitude grasslands, the presence of short-lived taxa is evident, which develop little vegetative structure and greater reproductive investment, favoring rapid seed production and dispersal (Dovrat et al. 2019).

Other species exhibit storage structures such as rhizomes, tubers, xylopodia, stolons, and bulbs, which play an important role in environments with a higher incidence of disturbance and lower water availability, allowing for the rapid development of taxa through resprouting (Prochazka et al. 2024). The increasing number of species over time during the experiment is attributed to the presence of species equipped with these underground structures that, strategically isolated in the soil, ensure the maintenance of the post-fire plant assembly (Ferreira 2023; Brito 2011). Poaceae *Echinolaena inflexa*, for example, is a native grass, not endemic to Brazil, with a wide distribution, considered a generalist species that occurs in different types of vegetation such as altitude fields, campinarana, campo limpo, campo rupestre, cerrado, restinga, Amazon savanna, and on rocky outcrops (Silva and Oliveira 2024). It exhibits morphological and physiological characteristics, such as the presence of rhizomes and stolons, which guarantee its survival after disturbances, showing a rapid capacity for vegetative allocation as a colonization strategy (Filgueiras and Fagg 2008), particularly in newly burned areas (Conceição and Pirani 2007).

Regarding species composition, the process of vegetation cover regeneration is relatively rapid, occurring more intensively during the first 33 days after the fire in both fields, demonstrating significant changes during this period. Between the 48th and 60th days post-fire, the composition begins to suggest a certain homogeneity, maintaining this until the end of the temporal analysis, around the 145th day after the burn. The rapid recovery of cover was mainly due to herbaceous and subshrubs species, which play a fundamental role in post-fire processes (Gordijn et al. 2018; Fidelis et al. 2012).

Fire recurrence is a crucial factor influencing the trajectory of ecological succession. While this study focused on single fire events, the increasing frequency of anthropogenic fires in high-altitude grasslands could have long-term detrimental effects on species composition and richness (Durigan 2020; Salim et al. 2022). Recurrent fires may reduce the resilience of certain species, particularly those without strong resprouting or seeding strategies, leading to shifts toward fire-tolerant species and ultimately decreasing biodiversity (Gomes et al. 2018). Understanding how fire intervals affect recovery is vital for developing management strategies aimed at preventing biodiversity loss in these priority conservation areas. Fire recurrence not only affects species composition but also has the potential to drive changes in functional diversity. Repeated fires may favor traits such as resprouting and seed bank persistence, leading to a dominance of fire-tolerant species and potentially lowering overall ecosystem resilience (Durigan 2020). In similar montane systems, shorter fire intervals have been shown to progressively reduce functional diversity, ultimately simplifying community structure (Gomes et al. 2018; Salim et al. 2022). Therefore, future studies should investigate the effects of varying fire intervals on both species and functional diversity to develop better management strategies.

The presence of some common species in Fields A and B demonstrates the maintenance of part of the plant composition after burning, recognizing this events strongly support the functionality and structuring of post-fire plant assemblies (Magurran and Henderson 2010; Magurran and Dornelas 2010). The occurrence and development of some taxa common to both studied areas may also be linked to environmental conditions restricting water availability (Munhoz and Felfili 2005; Neves and Conceição 2010). Considering that, although the experiment took place during the rainy season, the recorded rains in the region between September and December of 2020 were atypical compared to other years, according to data from the rainfall station in Caldas/MG (available at https://tempo.inmet.gov.br/A530). This lower recorded rainfall index may have influenced the development of species after the burn, demonstrating the plant responses and changes that occurred over time, both for richness and for plant composition. According to Prochazka et al. (2024), the maintenance of the plant assembly in environments with lower water availability is directly linked to life forms and survival strategies of the species.

Raunkiaer's classification system provided a useful framework for understanding the adaptive strategies of species in post-fire environments. The dominance of chamaephytes and hemicryptophytes is consistent with other studies in fire-prone ecosystems, where species with protected buds and strong resprouting capabilities tend to thrive (Bombo et al. 2024). This suggests that life-form traits play a critical role in post-fire succession, particularly in high-altitude grasslands with limited water availability and extreme temperature fluctuations (Prochazka et al. 2024). Future research should explore the functional traits of species across different life forms to better understand the mechanisms of resilience in these ecosystems. The higher frequency of hemicryptophyte species in Fields A and B, such as *Axonopus sp.*, *Andropogon sp.*, *Bulbostylis sphaerocephala* (Boeckeler) C.B.Clarke, *Calea asclepiifolia* Hassl., *Echinolaena inflexa* (Poir.) Chase, and those represented by morphs A01, A02, B01, and B02, demonstrates the relationship between the life forms of these taxa and the environmental conditioning variables of the high-altitude grasslands (Aximoff et al. 2016; Ribeiro et al. 2007), especially in the early stages of post-fire regeneration (Brito 2011). Such species are commonly found in mountainous areas at high altitudes, as they possess vegetative buds that are well protected at ground level by scales, leaves, or living or dead leaf sheaths (Martins and Batalha 2001), indicating good tolerance to thermal variation and water availability, showing good adaptability to well-defined seasonality (Caiafa and Silva 2005).

In addition to hemicryptophytes, the higher occurrence of chamophyte species, such as *Eriope crassipes* Benth., *Eriosema campestre* var. *macrophyllum* (Grear) Fortunato, and *Ruellia geminiflora* Kunth, throughout the sampling period demonstrates a biological spectrum pattern of succession also observed in the studies of Caiafa and Silva (2005) and Aximoff et al. (2016). These species are often related to seasonal environments at high altitudes, as they have vegetative buds above the soil surface, located in the aerial system, which ensures their survival through resistance strategies, such as escape or tolerance (Prochazka et al. 2024; Martins and Batalha 2001).

The different transects also had a considerable influence on species composition in both fields, as well as in interaction with the time post-fire, demonstrating that species composition changes with the formation of different microhabitats. According to Prochazka et al. (2024), different microhabitats can also influence the evolution of the morphological, functional, and phenological characteristics of species over the years. Given the environmental characteristics of Fields A and B, which present different structural formations such as relief, slope, and distinct land-use histories, combined with conditioning environmental factors, they favor the heterogeneity of floristic composition, the endemism of species, and biodiversity (Benites et al. 2012; Harrison et al. 2003; Ferreira 2023). Another factor is the presence of rocky outcrops, as high-altitude grasslands exhibit a spatial distribution tendency of species in vegetation mosaics, which, when permeated by exposed rocks, allow for the heterogeneity of microhabitats, contributing to the emergence of unique species (Brito 2011; Mota et al. 2014). Furthermore, the rapid modification of vegetation cover caused by fire also promotes changes in ecological processes, favoring the presence of new microenvironments that support the emergence of species (Fidelis et al. 2012; Ribeiro et al. 2007) or hinder the establishment of others (Aximoff et al. 2016; Salim et al. 2022).

Turnover was the main mechanism of change in the behavior of plant community composition throughout the temporal sampling, demonstrating through Beta diversity the patterns of species distribution by spatial substitution (Baselga 2010; Gordijn et al. 2018). This high species turnover in complex, elevated environments, such as high-altitude grasslands, illustrates a process generating diversity in post-fire plant communities (Cordeiro et al. 2023), where life forms adapted with different survival strategies are strongly conditioned by environmental variations in these habitats. Thus, the results highlight the importance of evaluating the effects of fire on plant communities, especially in light of different temporal metrics, in order to more precisely analyze the responses of different microhabitats over time.

It is worth noting that this is the first study to assess the post-fire process of plant communities in the altitude fields of the municipality of Poços de Caldas/MG, and this research was limited to the effects of two distinct fires, one in each field, whose temporal scope already shows significant results. These findings confirm the importance of evaluating the diversity of altitude fields and their processes more deeply, regarding different temporal metrics, in order to better understand their relationships and effects.

It is essential that further scientific investigations provide support for the revision of public policies, territorial management, and planning, corroborating the recommendations of Pinheiro et al. (2023), in order to ensure the proper maintenance, conservation, and protection of native fields, which are currently strongly threatened both by the intensification of anthropogenic actions and by the implementation of Bill 364/2019, which is under consideration in the National Congress and seriously threatens the biodiversity of native Brazilian fields (Overbeck et al. 2024). Therefore, it is necessary to establish and apply effective legal instruments that ensure the efficient preservation of the fields (Moras Filho et al. 2017), such as the creation of Conservation Units as a strategy to safeguard local biodiversity and environmental balance; effective monitoring actions and Environmental Education directed at civil society and other public and private bodies (Pereira et al. 2021; Overbeck et al. 2007; Williams et al. 2023), demonstrating the biological and ecological importance of the altitude fields of Poços de Caldas/MG.

The findings of this study have important implications for conservation and restoration efforts in high-altitude grasslands. Given the resilience of some species, particularly hemicryptophytes and chamaephytes, these ecosystems may recover after isolated fire events. However, recurrent fires, particularly those of anthropogenic origin, threaten to reduce species diversity and alter ecosystem functionality (Fidelis et al. 2012; Salim et al. 2022). Effective conservation strategies must prioritize the reduction of fire frequency through public policy and land management interventions, such as firebreak creation and community-based fire management (Overbeck et al. 2024). Additionally, there is an urgent need to establish protected areas in fire-prone regions to safeguard these unique ecosystems.

5 CONCLUSION

This study demonstrates that anthropogenic fire in altitude fields has a significant influence on the richness and composition of plant species over time. We observed a progressive increase in species richness, followed by a trend toward stabilization, and the composition of species was impacted by both transects and time post-fire, with turnover being the primary mechanism of change. Hemicryptophyte and chamaephyte species exhibit a greater adaptive capacity, ensuring survival and rapid development after burning.

We emphasize that although anthropogenic fires cause severe impacts, the study shows that some ecosystems, such as high-altitude grasslands, have mechanisms that allow for the regeneration of plant communities after fire. However, the recurrence of burning should be avoided, as it directly affects fauna, soil microbiota, and ecological balance, which depend on the maintenance of natural conditions and appropriate conservation actions. Fire can also reach uncontrollable dimensions and affect urban areas. Furthermore, we underline the need for effective public policies to protect these vulnerable ecosystems that are of great biological importance.

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SUPPLEMENTARY MATERIALS I

Table S1 - Date of each data collection and time (days) post-fire in each altitude field analyzed (Field A and B) in the municipality of Poços de Caldas/MG.

	Field A		**Field B**	
Data collection	**Date**	**Time post-fire**	**Date**	**Time post-fire**
1	11/09/2020	20 days	15/09/2020	18 days
2	18/09/2020	27 days	21/09/2020	24 days
3	24/09/2020	33 days	29/09/2020	32 days
4	08/10/2020	47 days	14/10/2020	47 days
5	22/10/2020	61 days	27/10/2020	60 days
6	05/11/2020	75 days	11/11/2020	75 days
7	19/11/2020	89 days	24/11/2020	88 days
8	03/12/2020	103 days	08/12/2020	102 days
9	17/12/2020	117 days	22/12/2020	116 days
10	29/12/2020	129 days	05/01/2021	130 days
11	14/01/2021	145 days	19/01/2021	144 days

Table S2 - Species recorded in the high-altitude grasslands (Field A and Field B) of the municipality of Poços de Caldas/MG, after the fire event.

Family/Species	**Field A**	**Field B**	**Habit**	**Life Forms**	**Occurrence**
Acanthaceae					
Ruellia geminiflora Kunth	X	X	Subshrubs	Chamaephytes	Generalist
Amaranthaceae					
Gomphrena arborescens L.f.		X	Subshrubs	Hemicryptophytes	Field (HG, TS)
Pfaffia jubata Mart.		X	Forbs	Geophytes	Field (HG, TS)
Anemiaceae					
Anemia villosa Humb. & Bonpl. ex Willd.		X	Forbs	Hemicryptophytes	Generalist
Apiaceae					
Morfo Apiaceae B01		X	Forbs	Chamaephytes	Generalist
Asteraceae					
Aldama sp.		X	Subshrubs	Chamaephytes	Generalist
Aspilia foliacea (Spreng.) Baker	X	X	Forbs	Phanerhophytes	Field (HG, RG, TS)
Aspilia reflexa (Sch.Bip. ex Baker) Baker	X		Subshrubs	Chamaephytes	Field (RG, TS)
Baccharis humilis Sch.Bip. ex Baker	X	X	Subshrubs	Phanerhophytes	Field (TS)
Baccharis sp.	X	X	Subshrubs	Phanerhophytes	Generalist
Calea asclepiifolia Hassl.		X	Forbs	Hemicryptophytes	Field (GV)
Chaptalia integerrima (Vell.) Burkart	X	X	Forbs	Hemicryptophytes	Generalist
Chromolaena congesta (Hook. & Arn.) R.M.King & H.Rob.	X	X	Subshrubs	Phanerhophytes	Field (HG, GV)
Chromolaena sp.	X	X	Subshrubs	Phanerhophytes	Generalist
Chrysolaena desertorum (Mart. ex DC.) Dematt.	X	X	Forbs	Chamaephytes	Field (RG, TS)
Chrysolaena obovata (Less.) Dematt.		X	Subshrubs	Chamaephytes	Field (HG, RG, GV, TS)
Chrysolaena sp.		X	Forbs	Chamaephytes	Field (HG, RG, GV, TS)
Lucilia sp.	X		Forbs	Chamaephytes	Field (HG, GV, RG)
Morfo Asteraceae A01	X		Forbs	-	-
Morfo Asteraceae B01		X	Subshrubs	-	-
Morfo Asteraceae B02		X	Subshrubs	-	-
Porophyllum obscurum (Spreng.) DC		X	Forbs	Therophytes	Field (GV, RG, TS)
Stevia lundiana DC.		X	Forbs	Therophytes	Field (GV, RG, TS)
Convolvulaceae					
Distimake hirsutus (O'Donell) Petrongari & Sim.-Bianch.	X	X	Forbs	Therophytes	Field (GV, TS)
Evolvulus macroblepharis Mart.	X		Forbs	Chamaephytes	Field (HG, GV)
Evolvulus sericeus Sw. var. *sericeus*	X	X	Forbs	Chamaephytes	Generalist

HG – High-altitude Grassland; RG - Rocky Grasslands; GV - Grassland Vegetation; TS – Tropical Savanna

Continuation

Family/Species	**Field A**	**Field B**	**Habit**	**Life Forms**	**Occurrence**
Convolvulaceae					
Ipomoea sp.	X		Forbs	Hemicryptophytes	Generalist
Morfo Convolvulaceae B01		X	Forbs	-	-
Morfo Convolvulaceae B02		X	Forbs	-	-
Cyperaceae					
Bulbostylis paradoxa (Spreng.) Lindm.	X		Forbs	Hemicryptophytes	Generalist
Bulbostylis sphaerocephala (Boeckeler) C.B.Clarke	X	X	Forbs	Hemicryptophytes	Field (HG, RG, GV, TS)
Bulbostylis sp.	X	X	Forbs	Hemicryptophytes	Generalist
Morfo Cyperaceae B01		X	Forbs	Hemicryptophytes	-
Rhynchospora elatior Kunth		X	Forbs	Hemicryptophytes	Field (RG, TS)
Rhynchospora sp.	X		Forbs	Hemicryptophytes	Generalist
Euphorbiaceae					
Acalypha claussenii (Turcz.) Müll.Arg.	X		Subshrubs	Therophytes	Field (GV, TS)
Croton antisyphiliticus Mart.	X		Subshrubs	Chamaephytes	Generalist
Croton glandulosus L.	X	X	Subshrubs	Phanerhophytes	Generalist
Croton lundianus (Didr.) Müll.Arg.	X		Subshrubs	Phanerhophytes	Generalist
Croton sp.		X	Subshrubs	Phanerhophytes	Generalist
Euphorbia potentilloides Boiss.	X	X	Forbs	Hemicryptophytes	Field (GV, RG)
Morfo Euphorbiaceae B01		X	Subshrubs	-	-
Fabaceae					
Cerradicola decumbens (Benth.) L.P.Queiroz	X	X	Subshrubs	Chamaephytes	Field (TS)
Cerradicola sp.		X	Subshrubs	Chamaephytes	Field (GV, TS)
Clitoria sp.	X		Forbs	Chamaephytes	Generalist
Desmodium sp.		X	Subshrubs	Chamaephytes	Generalist
Eriosema campestre var. *macrophyllum* (Grear) Fortunato	X	X	Subshrubs	Chamaephytes	Field (HG, GV, TS)
Eriosema glabrum Mart. ex Benth.		X	Subshrubs	Hemicryptophytes	Field (HG, GV, RG, TS)
Eriosema sp.		X	Subshrubs	Hemicryptophytes	Generalist
Morfo Fabaceae A01	X		Subshrubs	Chamaephytes	-
Morfo Fabaceae B01		X	Subshrubs	Chamaephytes	-
Zornia reticulata Sm.	X		Subshrubs	Hemicryptophytes	Generalist

HG – High-altitude Grassland; RG - Rocky Grasslands; GV - Grassland Vegetation; TS – Tropical Savanna

Continuuation

Family/Species	Field A	Field B	Habit	Life Forms	Occurrence
Hypoxidaceae					
Curculigo scorzonerifolia (Lam.) Baker		X	Forbs	Geophytes	Generalist
Iridaceae					
Sisyrinchium commutatum Klatt	X	X	Forbs	Hemicryptophytes	Field (HG, GV, TS)
Sisyrinchium luzula Klotzsch ex Klatt		X	Forbs	Hemicryptophytes	Field (HG,GV,RG,TS)
Sisyrinchium sp.		X	Forbs	Hemicryptophytes	Generalist
Sisyrinchium vaginatum Spreng.		X	Forbs	Hemicryptophytes	Field (HG, GV, TS)
Lamiaceae					
Eriope crassipes Benth.	X		Subshrubs	Chamaephytes	Generalist
Eriope sp.	X		Subshrubs	Chamaephytes	Generalist
Hypenia macrantha (A.St.-Hil. ex Benth.) Harley	X		Subshrubs	Hemicryptophytes	Generalist
Hyptis nudicaulis Benth.	X	X	Subshrubs	Chamaephytes	Field (HG, GV, RG, TS)
Hyptis sp.		X	Subshrubs	Chamaephytes	Generalist
Morfo Lamiaceae B01		X	Subshrubs	Chamaephytes	-
Lythraceae					
Cuphea linarioides Cham. & Schltdl.		X	Subshrubs	Chamaephytes	Field (HG, GV,TS)
Cuphea sp.		X	Subshrubs	Chamaephytes	Generalist
Malpighiaceae					
Byrsonima verbascifolia (L.) DC.		X	Subshrubs	Geophytes	Generalist field species
Malvaceae					
Krapovickasia macrodon (A.DC.) Fryxell	X	X	Forbs	Chamaephytes	Field (GV, TS)
Peltaea polymorpha (A.St.-Hil.) Krapov. & Cristóbal	X	X	Subshrubs	Chamaephytes	Field (TS)
Melastomataceae					
Chaetogastra hieracioides Schrank et Mart. ex. DC.	X		Subshrubs	Phanerhophytes	Field (HG, GV, TS)
Morfo Melastomataceae A01	X		Subshrubs	-	-
Morfo Melastomataceae B01		X	Subshrubs	-	-
Trembleya phlogiformis Mart. & Schrank ex DC.		X	Subshrubs	Phanerhophytes	Generalist
Moraceae					
Dorstenia cayapia Vell.	X	X	Forbs	Geophytes	Generalist
Myrtaceae					
Morfo Myrtaceae A01	X		Subshrubs	Phanerhophytes	-

HG – High-altitude Grassland; RG - Rocky Grasslands; GV - Grassland Vegetation; TS – Tropical Savanna

Continuation

Family/Species	Field A	Field B	Habit	Life Forms	Occurrence
Orobanchaceae					
Buchnera ternifolia Kunth		X	Forbs	Chamaephytes	Field (HG, GV, TS)
Poaceae					
Andropogon sp.		X	Grasses	Hemicryptophytes	Generalist
Axonopus brasiliensis (Spreng.) Kuhlm.		X	Grasses	Hemicryptophytes	Generalist field species
Axonopus sp.	X	X	Grasses	Hemicryptophytes	Generalist
Echinolaena inflexa (Poir.) Chase	X	X	Grasses	Hemicryptophytes	Generalist field species
Morfo Poaceae A01	X		Grasses	Hemicryptophytes	-
Morfo Poaceae A02	X		Grasses	Hemicryptophytes	-
Morfo Poaceae A03	X		Grasses	Hemicryptophytes	-
Morfo Poaceae A04	X		Grasses	Hemicryptophytes	-
Morfo Poaceae B01		X	Grasses	Hemicryptophytes	-
Morfo Poaceae B02		X	Grasses	Hemicryptophytes	-
Morfo Poaceae B03		X	Grasses	Hemicryptophytes	-
Morfo Poaceae B04		X	Grasses	Hemicryptophytes	-
Morfo Poaceae B05		X	Grasses	Hemicryptophytes	-
Polygalaceae					
Asemeia hirsuta (A.St.-Hil. & Moq.) J.F.B.Pastore & J.R.Abbott	X	X	Forbs	Chamaephytes	Field (GV, RG, TS)
Rubiaceae					
Borreria sp.	X	X	Forbs	Therophytes	Generalist
Borreria tenella (Kunth) Cham. & Schltdl.	X	X	Forbs	Therophytes	Field (GV, TS)
Declieuxia cordigera Mart. & Zucc. ex Schult. & Schult.f.	X	X	Forbs	Chamaephytes	Field (RG, TS)
Galium megapotamicum Spreng.		X	Subshrubs	Chamaephytes	Generalist
Galium sp.		X	Subshrubs	Chamaephytes	Generalist
Turneraceae					
Morfo Turneraceae A01	X		Forbs	Chamaephytes	-
Morfo Turneraceae B01		X	Forbs	Chamaephytes	-
Turnera hilaireana Urb.	X	X	Forbs	Chamaephytes	Generalist
Turnera sp.	X	X	Forbs	Chamaephytes	Generalist

HG – High-altitude Grassland; RG - Rocky Grasslands; GV - Grassland Vegetation; TS – Tropical Savanna

Table S3 – Composition of species compared pairwise between different post-fire times and transects in high-altitude grassland A in the municipality of Poços de Caldas/MG.

Campo	**Tempo pós-fogo (par a par*)**	**R²**	**p****
A	1 vs 2	0.1225155443	**0.046**
A	1 vs 3	0.1827623312	**0.005**
A	1 vs 4	0.2249230578	**0.001**
A	1 vs 5	0.2304417740	**0.001**
A	1 vs 6	0.2391088463	**0.001**
A	1 vs 7	0.2497296089	**0.001**
A	1 vs 8	0.2607440310	**0.001**
A	1 vs 9	0.2712174397	**0.001**
A	1 vs 10	0.2789923563	**0.001**
A	1 vs 11	0.2803427089	**0.001**
A	2 vs 3	0.0094742627	0.982
A	2 vs 4	0.0555479324	0.463
A	2 vs 5	0.0743092576	0.248
A	2 vs 6	0.1022983729	**0.048**
A	2 vs 7	0.1230553702	**0.016**
A	2 vs 8	0.1410243899	**0.003**
A	2 vs 9	0.1529575988	**0.004**
A	2 vs 10	0.1580448054	**0.001**
A	2 vs 11	0.1601149376	**0.002**
A	3 vs 4	0.0370560565	0.815
A	3 vs 5	0.0592876971	0.449
A	3 vs 6	0.0971233325	**0.050**
A	3 vs 7	0.1261302352	**0.006**
A	3 vs 8	0.1476813011	**0.001**
A	3 vs 9	0.1619237193	**0.001**
A	3 vs 10	0.1636464278	**0.001**
A	3 vs 11	0.1670599154	**0.001**
A	4 vs 5	0.0039449031	0.990
A	4 vs 6	0.0287294910	0.898
A	4 vs 7	0.0571110163	0.483
A	4 vs 8	0.0757775786	0.207
A	4 vs 9	0.0923440193	0.073
A	4 vs 10	0.0908936830	0.091
A	4 vs 11	0.0936515694	0.063
A	5 vs 6	0.0115181595	0.978
A	5 vs 7	0.0300873551	0.898
A	5 vs 8	0.0448301664	0.722
A	5 vs 9	0.0575463316	0.477
A	5 vs 10	0.0564434106	0.513
A	5 vs 11	0.0593700519	0.485
A	6 vs 7	0.0065785653	0.993
A	6 vs 8	0.0174130333	0.966
A	6 vs 9	0.0252101702	0.935
A	6 vs 10	0.0246641287	0.942
A	6 vs 11	0.0267752535	0.931
A	7 vs 8	0.0059083369	0.987
A	7 vs 9	0.0048492272	0.997
A	7 vs 10	0.0057089517	0.996
A	7 vs 11	0.0076696663	0.992
A	8 vs 9	0.0020438628	0.998
A	8 vs 10	0.0006209671	0.998
A	8 vs 11	0.0012489879	0.995
A	9 vs 10	0.0022622011	0.993
A	9 vs 11	0.0004035277	0.997
A	10 vs 11	0.0001854547	1.000

* From the first to the fourth week, the readings were weekly, and from the 5th reading onwards, the readings were biweekly.

** Significant p-values are shown in bold.

Continuation

Table S4 – Composition of species compared pairwise between different post-fire times and transects in high-altitude grassland B in the municipality of Poços de Caldas/MG.

Field	**Post-fire time (pairwise*)**	**R^2**	**p****
B	1 vs 2	0.0319993123	0.839
B	1 vs 3	0.0662247622	0.337
B	1 vs 4	0.1552387123	**0.001**
B	1 vs 5	0.2050131964	**0.001**
B	1 vs 6	0.2182827197	**0.002**
B	1 vs 7	0.2264619299	**0.001**
B	1 vs 8	0.2278194903	**0.001**
B	1 vs 9	0.2294692979	**0.001**
B	1 vs 10	0.2293990208	**0.001**
B	1 vs 11	0.2402829394	**0.001**
B	2 vs 3	0.0234112220	0.930
B	2 vs 4	0.1047326648	**0.019**
B	2 vs 5	0.1538173046	**0.001**
B	2 vs 6	0.1682830602	**0.001**
B	2 vs 7	0.1797388454	**0.001**
B	2 vs 8	0.1831833500	**0.001**
B	2 vs 9	0.1855178080	**0.001**
B	2 vs 10	0.1858695865	**0.001**
B	2 vs 11	0.1984757701	**0.001**
B	3 vs 4	0.0505003773	0.606
B	3 vs 5	0.0926189358	**0.049**
B	3 vs 6	0.1110513041	**0.004**
B	3 vs 7	0.1245253875	**0.002**
B	3 vs 8	0.1302551839	**0.001**
B	3 vs 9	0.1340766857	**0.001**
B	3 vs 10	0.1361095435	**0.001**
B	3 vs 11	0.1496947553	**0.001**
B	4 vs 5	0.0119907714	0.996
B	4 vs 6	0.0256840170	0.961
B	4 vs 7	0.0378903974	0.863
B	4 vs 8	0.0436179196	0.752
B	4 vs 9	0.0478778370	0.685
B	4 vs 10	0.0523050733	0.614
B	4 vs 11	0.0640365773	0.336
B	5 vs 6	0.0048972283	0.993
B	5 vs 7	0.0114748451	0.982
B	5 vs 8	0.0163008758	0.989
B	5 vs 9	0.0221974156	0.981
B	5 vs 10	0.0257047726	0.959
B	5 vs 11	0.0353099138	0.840
B	6 vs 7	0.0008361961	0.997
B	6 vs 8	0.0052009739	0.988
B	6 vs 9	0.0124639844	0.989
B	6 vs 10	0.0156753798	0.992
B	6 vs 11	0.0201768848	0.985
B	7 vs 8	0.0014871712	0.993
B	7 vs 9	0.0072104903	0.987
B	7 vs 10	0.0088479980	0.990
B	7 vs 11	0.0111689901	0.990
B	8 vs 9	0.0020077081	0.993
B	8 vs 10	0.0049174078	0.992
B	8 vs 11	0.0075754573	0.983
B	9 vs 10	0.0014637718	0.992
B	9 vs 11	0.0064179390	0.987
B	10 vs 11	0.0013264970	0.993

* From the first to the fourth week, the readings were weekly, and from the 5th reading onwards, the readings were biweekly.

** Significant p-values are shown in bold.

3 CONSIDERAÇÕES FINAIS

O presente estudo analisou os efeitos do fogo antrópico sob as assembleias vegetais em Campos de Altitude do município de Poços de Caldas/MG. A partir das análises foi possível observar que o fogo afeta tanto a riqueza quanto a composição de espécies. A riqueza apresentou um aumento progressivo, seguido por uma leve estabilização, ao longo do tempo. Já a composição de espécies mudou ao longo do tempo, afetada tanto pelos transectos, quanto na interação com o tempo pós-fogo, mostrando a formação de diferentes micro-habitats. O principal mecanismo de mudança da composição foi o *turnover*.

Observou-se uma maior frequência das famílias Asteraceae e Poaceae, com predominância de espécies hemicriptófitas e caméfitas, táxons que apresentam formas de vida que favorecem a sobrevivência e o rápido desenvolvimento após a queima. Salienta-se que, embora algumas espécies vegetais apresentam mecanismos que permitem a rápida regeneração pós-fogo, a recorrência das queimadas deve ser evitada, visto que afeta o equilíbrio ecológico e a microbiota do solo.

Esse é o primeiro estudo a avaliar o processo pós-fogo de assembleias vegetais nos campos de altitude no município de Poços de Caldas/MG, e que em um curto recorte temporal já apresentou resultados bem significativos. Dessa forma, destaca-se a importância de outros estudos que auxiliem na compreensão dos processos sucessionais nos campos de altitude, ambientes considerados prioritários para conservação. Ademais, se faz necessário aplicar políticas públicas e requisitos legais para sua efetiva proteção, assim como o planejamento e a destinação orçamentária na gestão territorial, destinada à manutenção e conservação dos campos de altitude, fazendo jus ao apregoada na Lei da Mata Atlântica e normas complementares.

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