UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"

Sean Keuroghlian-Eaton

How do different fire regimes affect anuran taxonomic and functional diversity in the Pantanal?

São José do Rio Preto
2023

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Dissertação apresentada no dia 13/10/2023 como parte dos requisitos para obtenção do título de Mestre em Biodiversidade, junto ao Programa de Pós-Graduação em Biodiversidade, do Instituto de Biociências, Letras e Ciências Exatas da Universidade Estadual Paulista “Júlio de Mesquita Filho”, Câmpus de São José do Rio Preto.

Financiadora: CAPES – Processo: 001

Orientador: Prof. Dr. Diego José Santana Silva

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K43

Keuroghlian-Eaton, Sean
How do different fire regimes affect anuran taxonomic and functional diversity in the Pantanal? / Sean Keuroghlian-Eaton. -- SãoJosé do Rio Preto, 2023
39 p. : il., tabs., mapas

Dissertação (mestrado profissional) - Universidade Estadual Paulista (Unesp), Instituto de Biociências Letras e Ciências Exatas,São José do Rio Preto
Orientador: Diego José Santana Silva

1. Fogo. 2. Ecologia. 3. Anura. 4. Diversidade funcional. 5.

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13 de outubro de 2023

Agradecimentos

Ao meu orientador, Diego José Santana Silva, agradeço pela sua paciência, amizade e orientação durante o meu mestrado. Além disso, por criar um ambiente de laboratório incrível com colegas maravilhosos que tornaram possível a realização do meu sonho de pesquisar herpetofauna.

Obrigado a todos que auxiliaram no campo durante a coleta e processamento de dados do meu mestrado.

À Karol Ceron, agradeço por me ensinar, ajudar e sugerir várias análises que tornaram este projeto muito melhor.

À Priscila Carvalho, agradeço por me auxiliar em muitas burocracias, fornecer ideias e dicas quando eu estava enfrentando dificuldades para avançar, e por ser uma grande amiga durante todo esse processo.

A Juan Carrillo e Hugo Cabral, agradeço por revisarem a escrita e o script em R da minha dissertação, e por me fazerem rir constantemente durante todo o processo.

Aos membros do laboratório Mapinguari, Diego é em grande parte a razão pela qual esse espaço é tão incrível. No entanto, não posso negar que todas as pessoas neste lugar são incríveis. Seja no campo, no laboratório ou nas festas, não importa o quão estressado eu esteja, todo dia vou para o trabalho animado porque é um ambiente divertido onde todos ajudam o outro. Além disso, nunca imaginei que encontraria tantas pessoas com uma paixão tão intensa pela herpetologia.

À banca, por aceitar e interessar nesse projeto, e pelos seus comentários e sugestões que elevou a qualidade desse projeto.

Aos meus pais por além de me ensinar tanto na área de biologia, também sugerir ideias para meus projetos, e recomendar eu falar com o Diego para iniciar meu mestrado.

Aos meus amigos não biólogos que me ajudam a relaxar e recarregar completamente para voltar ao meu trabalho com energia cheia.

Por liderarem as queimadas, selecionarem as áreas para queima, fornecerem recursos de campo e tornarem tudo isso possível, quero agradecer às pessoas incríveis do PELD, IBAMA Prev Fogo, Nefau, IMASUL e PPBio Rede Pantanal envolvidas nesses projetos, que trabalham para entender e minimizar o impacto do fogo em nosso Pantanal. A ciência não é feita individualmente, e ao ver tantos projetos associados a esta única pesquisa, prova isso.

Ao IBILCE pelo suporte burocrático e técnico.

O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código de Financiamento 001*, à qual agradeço.

Resumo

O fogo representa uma perturbação frequente em muitos ecossistemas, e o maior fator na modificação de habitats afeta as espécies de maneiras diferentes. Neste estudo, temos como objetivo desvendar quais são os impactos de diferentes tratamentos de incêndio na diversidade de anuros no Pantanal brasileiro, e se os traços da diversidade são afetados de maneira diferente pelos tratamentos de incêndio. Armadilhas de queda foram instaladas para amostrar populações de anuros em locais onde incêndios controlados foram realizados, juntamente com um número igual de locais de controle não queimados. Os incêndios foram divididos em dois tipos: incêndio na metade da estação seca (a partir de agora conhecido como modal-MDS) e incêndio no final da estação seca (a partir de agora conhecido como tratamento tardio-LDS). Não houve diferença estatisticamente significativa entre o controle, o incêndio modal e o incêndio tardio em relação à diversidade ou abundância de anuros. No entanto, a diversidade funcional mostrou que o controle era o mais diverso, com o incêndio tardio apresentando maior diversidade quando comparado ao incêndio modal. Diferentes tratamentos de incêndio afetam os anuros de forma negativa em diferentes níveis em sua diversidade funcional, ao observar o tamanho, massa, deposição de ovos e uso do habitat dos anuros. Entre os dois tratamentos de incêndio, o incêndio tardio teve um impacto significativamente menor em sua diversidade funcional quando comparado ao incêndio modal. Nossa pesquisa sugere que o uso da diversidade funcional pode ser uma abordagem mais eficaz para avaliar os impactos da escala do fogo sobre os anuros em comparação com a diversidade taxonômica. Essas descobertas podem potencialmente informar futuras estratégias de queimadas controladas, recomendando queimadas no final da estação seca para mitigar o impacto de incêndios futuros.

Palavras-Chave: Fogo. Ecologia. Anura. Diversidade. Funcionalidade. Escala. Pantanal.

Abstract

Fire represents a frequent disturbance in many ecosystems, and the biggest factor in habitat conversion affects species in different ways. In this study we aim to disentangle what impacts different fire regimes have on anuran diversity in the Brazilian Pantanal, and if diversity facets are affected differently by the fire regimes. Pitfall traps were installed to sample anurans at sites where controlled fires were set at, along with an equal number of unburned control sites. The fires were divided into two types: middle dry season fire (from here on known as MDS), and late dry season fire (from here on known as LDS). There was no statistically significant difference between the control, MDS and LDS fire for anuran diversity or abundance. Functional diversity on the other hand showed that the control was the healthiest collection site with LDS fire having higher diversity when compared to MDS fire. Different regimes of fire affect anurans negatively at different levels in their functional diversity, when looking at size, mass, egg deposition, and habitat use of anurans. Among the two fire regimes LDS fire had a significantly lessened impact on their functional diversity when compared to MDS fire. Our research suggests that using functional diversity may be a more effective approach for assessing the impacts of fire scale on anurans compared to taxonomic diversity. These findings could potentially inform future controlled burn strategies, recommending late dry season burns to mitigate the impact of future fires.

Key Words: Fire. Ecology. Anuran. Diversity. Functionality. Scale. Pantanal.

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MDS – middle of dry season fire

LDS – late dry season fire

SUMÁRIO

How do different fire regimes affect anuran taxonomic and functional diversity in the Pantanal?

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Abstract. Fire is a disturbance that homogenizes habitats more than any other disturbance, altering them significantly.. In this study we aim to disentangle what impacts different fire regimes have on anuran diversity in the Brazilian Pantanal, and if diversity facets are affected differently by the fire regimes. Pitfall traps were installed to sample anurans at sites where controlled fires were set at, along with an equal number of unburned control sites. The fires were divided into two types: middle dry season fire (from here on known as MDS), and late dry season fire (from here on known as LDS). There was no statistically significant difference between the control, MDS and LDS fire for anuran diversity or abundance. Functional diversity on the other hand showed that the control was the healthiest collection site with LDS fire having higher diversity when compared to MDS fire. Different regimes of fire affect anurans negatively at different levels in their functional diversity, when looking at size, mass, egg deposition, and habitat use of anurans. Among the two fire regimes LDS fire had a significantly lessened impact on their functional diversity when compared to MDS fire. Our research suggests that using functional diversity may be a more effective approach for assessing

the impacts of fire scale on anurans compared to taxonomic diversity. These findings could potentially inform future controlled burn strategies, recommending late dry season burns to mitigate the impact of future fire.

1. Introduction

Fire represents a frequent disturbance in many ecosystems and is the primary factor in habitat conversion, impacting various species interactions around the world (Peralta et al., 2017). Fire disturbances harbor the potential to diminish both the taxonomic and functional diversity within neotropical seasonal flooded forests (Meza et al., 2023). Taxonomic diversity observes the abundance and quantity of species in a community (Moore, 2013), while functional diversity pertains to the distribution of species within a functional space, where the axes represent the functional traits of species in their environment (Rosenfeld, 2002; Hutchinson, 1957). Impacts such as fire can lead to a prevalence of fire-resistant species and homogenizing the animal-plant dispersion, as well as the plant and soil characteristics (Da Silva, 2008)). In ecosystems, fire exerts a significant influence on the species composition, biodiversity, and operation by profoundly altering their physical, chemical, and biological characteristics (Buscardo et al., 2015). The effect of fire can be beneficial or detrimental depending on the organism (Bixby et al., 2015). For instance, the carandá palm (*Copernicia alba*), indigenous to the Pantanal, exhibits improved seed germination in response to fire (Fabri, 2018). This is why when discussing ecosystems impacted by fire, functional diversity should be assessed by examining the traits that assist species in surviving either during or after a fire (Pausas, 2019). In Brazil, biomes such as the Amazon, Cerrado and the Pantanal are under great threat of intensive agriculture, which regularly uses illegal fire to clear native habitat (de Oliveira, 2021).

The Pantanal encompasses over 190,000km² and ranks as the world's largest temporary wetland, extending across Bolivia, Brazil, and Paraguay (Fraser et al., 2005). The temporary nature of the Pantanals' wetlands imparts distinct wet and dry seasons experienced annually by species inhabiting the region (Junk et al., 1989; Junk & Wantzen, 2004). The occurrence of fire in the Pantanal predates human habitation (Power et al., 2016; Junk et al., 2006). Naturally ignited fires typically happen in between seasons, such as the beginning or ending of the rainy season, usually caused by lightning strikes on the dry vegetation (Pivello et al., 2021). These fires are rapid, low intensity surface burns that are extinguished by subsequent rainfall, typically occurring every three to six years (Ramos-Neto & Pivello, 2000; Medeiros & Fiedler, 2004). However, recent data reveals that only around 3% of the fires in the Pantanal are non-human-induced (Marengo et al., 2016; Pivello et al., 2021). Alarming statistics further indicate that, throughout the past four decades, the Pantanal has witnessed the highest incidence of wildfires among all Brazilian biomes (MapBiomas, 2022). In the years 2020 and 2021 specifically, fires were record breaking in quantity and intensity (Garcia, 2021; INPE, 2022). These recent fires have directly killed millions of vertebrates, and among one of the most impacted groups was amphibians (Tomas et al., 2021).

Amphibian populations worldwide are declining (Luedke et al. 2023), and current estimates show that 41% of amphibians in the world are endangered (IUCN 2020; Luedke et al. 2023). Climate change, pollution, disease, and habitat loss are the main factors contributing to declining amphibian populations (da Costa Araujo et al., 2020; Zhang et al., 2018; Luedke et al. 2023). Despite the considerable data on how fire affects climate, vegetation (Veldman et al. 2015), animals (Gibb, 2003), and mutualistic interactions (Peralta et al., 2017), very little is known about how different fire levels affect anuran populations. Depending on the scale, fire can affect amphibians directly (by killing the individuals), or indirectly (by altering their habitats) (Pilliod et al. 2003). The majority of habitat modifications affecting anurans are associated with vegetation and water dynamics (Gonçalves et al., 2015; Gangenova et al., 2018). Amphibians are particularly susceptible to the adverse effects of habitat alteration because of many characteristics, such as permeable skin, unshelled eggs and limited capacity of dispersal, for example (Green, 2003). On a larger scale, fire can cause the local extinction of amphibian species in isolated bodies of water (Pilliod et al. 2003), these can trigger cascading effects over a broader metapopulation (Marsh & Trenham, 2001). While on a smaller scale, the increase of solar radiation, loss of vegetation, elevated water temperature, altered hydroperiods reduces functional characteristics related to reproduction, increasing tadpole death, and affecting amphibian metamorphosis (Pilliod et al., 2003; Newman, 1998; Häkkinen et al., 2001; Russell et al., 1999).

Functional diversity has long served as an alternative approach for quantifying the level of diversity within a habitat, enabling the examination of the diverse array of functions performed by species within that particular environment (Tilman, 2001). Functional traits that can include habitat preferences (such as fossorial, arboreal, terrestrial or aquatic tendencies (Neves et al., 2020) or egg deposition strategies (such as in water, in a basin, arboreally, on the ground, in burrows or into foam (Neves et al., 2020). These are possible impacts that could emerge from fire and cannot be examined through taxonomic diversity or species richness alone, yet they should be considered when looking at fire impacts on any species (Westgate et al., 2012).

Our objective is to investigate the effects of different fire regimes on anuran diversity. The fire regimes were classified as the middle of dry season fire treatment (MDS) and the late dry season fire treatment (LDS). We hypothesize that the control group will exhibit higher levels of both taxonomic and functional diversity compared to the two fire regimes. We anticipate that the LDS fire treatments will have a lesser impact due to the increased moisture content in the organic material towards the end of the dry season and the onset of the rainy season, which would more closely mimic natural fires in the Pantanal (Ramos- Neto & Pivello, 2000; Medeiros & Fiedler, 2004). This higher moisture content may result in a less intense fire and subsequently lead to a reduced degree of environment modification.

2. Methods

2.1. Study area

The study site is located in the southern Pantanal, state of Mato Grosso do Sul, Brazil near a long stretch of the Miranda river in the type of Pantanal known as"Abobral".

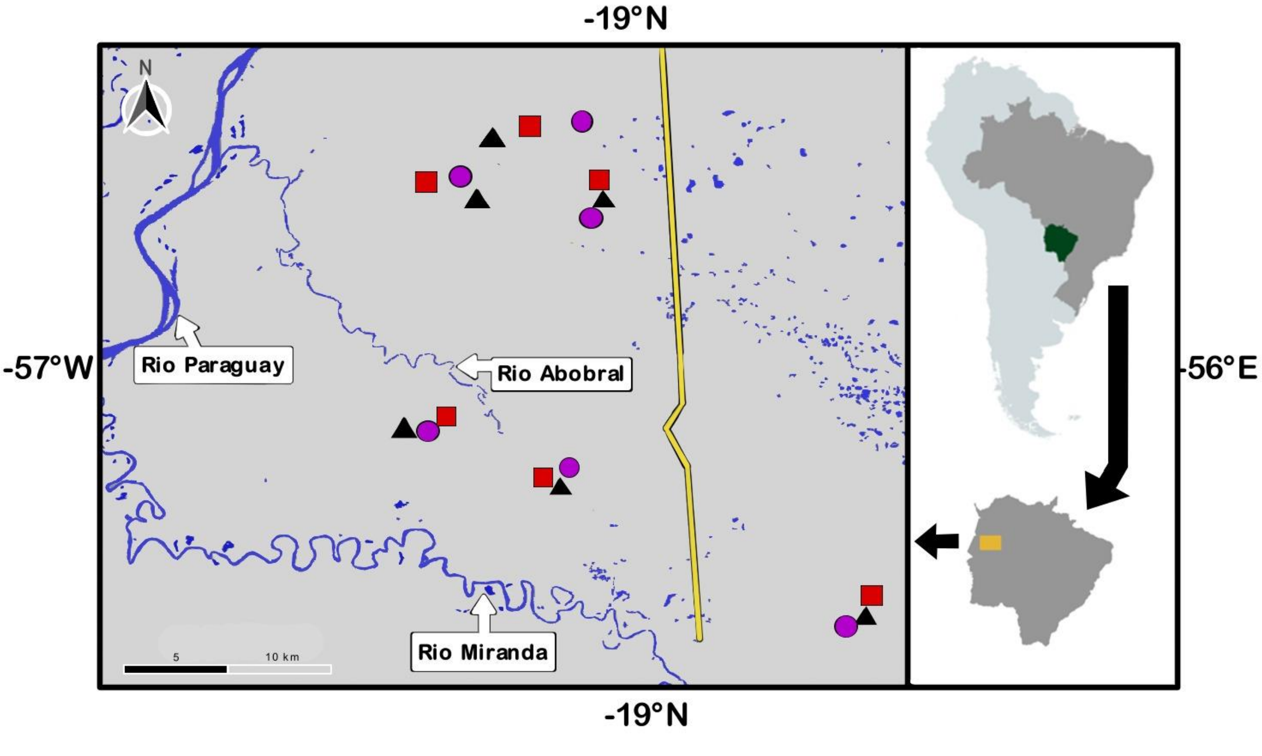

Figure 1. Burn plots were selected based on satellite data, identifying areas that had not experienced any burning since 2001. The yellow line represents the "Estrada parque" road in the Abobral region of the Pantanal. Purple circles represent control plots, red squares show plots burned in the middle of the dry season (MDS), and black triangles indicate plots burned in the late dry season (LDS). Each plot point, burned or control,

was $100m^2$, and at least 1 km apart. The burning of the MDS fire points took place between the 14th and 17th of September 2021, while the LDS fire points were set ablaze between the 2nd and 5th of November 2021. In total, there were six control points, six MDS fire points, and six LDS fire points, amounting to a total of 18 plot points that were sampled.

The study areas were mapped in direct correlation with fire occurrence and intensity from the last 20 years and habitat richness in terms of floodplain gradients. The climate is humid to sub-humid, and tropical sub- warm, according to the Köppen classification (Alvares et al., 2013) with medium annual temperatures between 22 and 26°C and maximum temperatures between 35 and 40°C. Annual rainfall ranges from 1,500 to 1,750 mm, with a warmer wet season occurring between October and March, and a cooler dry season occurring between May and August (SEMAC, 2011). The study plots were grouped into three treatments; one control and two fire regimes. In total, there were 18 sampling stations; six control plots, and 12 burn plots divided into the two different fire regimes (Figure 1). Both the burned and unburned control plots were $100m^2$ and at least 1km apart from each other.

2.2. Fire setting, and levels

To determine the fire regime used in the project, we used historical satellite fire data from the study plots. We used burn area maps provided by the ALARMES system (Alerta de área queimada com monitoramento estimado por satélite), images from VIIRS sensors (Visible Infrared Imaging Radiometer Suite), MODIS (Moderate Resolution Imaging Spectroradiometer) (Pinto et al., 2020), and images from the Landsat and Sentinel series (Pereira et al., 2017). The first set of burned area data, derived from the VIIRS sensor, allowed us to analyze how the burn areas changed each day with a resolution of 100-500m. Mapping burned areas with LANDSAT sensors allowed a better spatial detailing of the fire scars (with resolution between 30 and 20m) once every 16 days. We derived fire intensity data from satellites, mainly the FRP (Fire Radiative Power) product of MODIS sensors and VIIRS for the same period of years. After analyzing the occurrence of fires between 2001 and 2020 along with their intensity, we made maps of recurrence/intensity from the last two decades using QGIS (QGIS, 2021). This long series of data allowed us to map out areas that had remained fire-free from 2001 to 2020. This ensured that the locations where we conducted our prescribed burns and selected control sites for comparison were not affected by any other fires that could potentially influence our data.

Fires were set by the professional firefighting teams of IBAMA/PREVFOGO, using controlled techniques such as setting fires in a circle shape, “U" shape, or stripes. These techniques are usually used for fire suppression, by burning the fuel (available flammable vegetation) in the region. The fires were divided into two regimes: middle dry season fire (from here on known as MDS), and late dry season fire (from here on known as LDS). As the names of the fire regimes suggest, the MDS fire points were set between the 14th and 17th of September 2021, and the LDS fire points were set between the 2nd and 5th of November 2021. Through historical fire data obtained by satellite imagery, we also chose areas where there hadn’t been any fire for the last 20 years and would act as a control in our research.

2.3. Anuran sampling

We collected data on anurans in December 2021 during the wet season, which is the main breeding period for most anurans in the region (Prado et al., 2005). To sample anurans, we used pitfall traps, which have been shown to be effective at capturing a large proportion of terrestrial anuran species (Cechin & Martins et al., 2000). During the sampling period, we set up pitfall trap stations for each treatment, one in the control, one in the MDS burn area, and one in the LDS burn area. The pitfall traps had four 30-liter bucket pitfalls spaced along three 5m long and 1m high drift fences arranged in the shape of a “Y”.

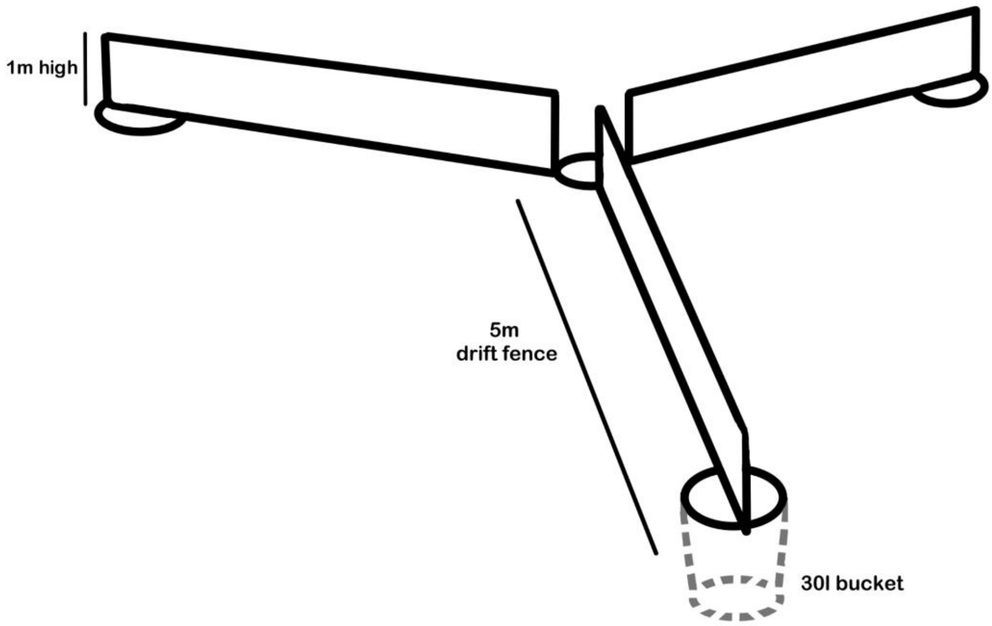

Figure 2. Pitfall trap representation one used in each plot point. The pitfall traps had four 30-liter bucket pitfalls spaced along three 5m long and 1m high drift fences arranged in the shape of a “Y”.

During trapping periods, all pitfalls were open for five days, a total of 120 hours, and checked daily in the morning. Each captured anuran was identified at the species level, and killed using topic lidocaine. Functional trait measurements, such as body size measured as snout-vent length (SVL), were obtained using a pachymeter after collection.

2.4. Data analysis

For the following analyses, we grouped all data collected from 18 stations into three categories; Control, MDS, and LDS

Species Collected	Control	MDS	LDS
Adenomera diptyx	1	1	0
Elachistocleis matogrosso	1	4	8
Leptodactylus luctator	0	0	0
Leptodactylus macrosternum	0	1	1
Leptodactylus podicipinus	1	0	0
Physalaemus albonotatus	11	6	52
Physalaemus biligonigerus	0	4	23
Physalaemus cuvieri	2	1	4
Pseudopaludicola motorzinho	1	5	1
Rhinella bergi	3	4	2
Rhinella diptycha	0	0	1
Rhinella major	0	0	2

Table 1. This table depicts the quantities of species and individuals that were collected and killed within each plot type during December of 2021.

Giving each category 6 sampling stations total. To compare the composition of the anuran community in each regime, we employed a permutational multivariate analysis of variance (PERMANOVA) using the Bray-Curtis similarity index. Homogeneous dispersion is crucial for accurate PERMANOVA testing, as heterogeneity within the groups can lead to a Type 1 error (Anderson & Walsh, 2013). Therefore, we conducted an ANOVA test to assess the homogeneity of dispersion, necessitating a normality test for our data. Our data was not normal, as indicated by all values being below 0.05 in both the Shapiro-Wilk W and Anderson-Darling A tests, thus non-parametric alternatives were used for the ANOVA tests of homogeneity, specifically the Kruskal-Wallis test followed by Dunn's post hoc tests. All results from our ANOVA tests yielded *P*-values above 0.05, confirming that the groups being modeled exhibit homogeneous dispersion and mitigating the aforementioned Type 1 error in PERMANOVA tests (Anderson & Walsh, 2013). We ran the PERMANOVA test with 9999 permutations using PAST 4.03 software.

We calculated the taxonomic diversity in each quadrant (MDS, LDS, and control). We used Simpson's and Shannon's diversity index to analyze the anuran communities in these sites. These two diversity indices can help us cover a wider range of variables; Simpson takes into account the number of species in the sample, while Shannon looks at the randomness in a site considering not just the number, but also the abundance of even distribution in a species (Kim et al., 2017). While the Simpson and Shannon indexes account well for diversity and abundance, we also seek to investigate species richness within our sampling plots. For this purpose, we decided to employ the Chao1 index, which takes into consideration that rare species provide important information about a population's species richness (Chao et al., 2005). Utilizing all three metrics, will give us a comprehensive understanding of the diversity and species richness among our control, MDS, and LDS plots. The aforementioned calculations were done using the software PAST 4.03.

To investigate the taxonomic differentiation and similarity among sites, we conducted a beta diversity analysis over the presence or absence of species within each site type. We utilized an R software script as suggested by Da Silva et al. (2022) to calculate the overall beta diversity among the sites using a Sorensen similarity test. Additionally, we generated a Venn diagram (Ruskey & Weston, 2012) depicting the distribution of species across each site, along with the site-to-site similarities.

We computed the pairwise functional distances between all functional entities using the mixed-variables coefficient of distance (i.e., a generalization of Gower's distance), which quantifies the functional dissimilarity between all species pairs based on the suite of assessed traits (Pavoine et al. 2009). Snout-vent length measurements were obtained from measuring each individual, while average mass (g) traits, egg deposition strategies (water, basin, and burrow), and habitat use preferences (fossorial, terrestrial or aquatic) were obtained from literature to calculate functional diversity indices (Prado & Haddad, 2005; Oliveira et al., 2017; Neves et al., 2020; Alves et al., 2022). The functional traits we investigated are anuran traits closely associated with specific niches related to vegetation and varied bodies of water in an ecosystem (Ribeiro et al. 2017). A functional distance matrix was obtained using ktab.list.df and dist.ktab functions of ade4 R package (Dray et al., 2007). After, we performed Principal coordinates analysis (PCoA) using the functional distance for each treatment. We retained the first three PCoA axes (cumulatively explaining 90% of the total variance) to construct hypervolumes, using the Gaussian method and an optimal bandwidth for each axis as estimated via the estimate_bandwidth (Blonder, 2018; Mammola & Cardoso, 2020). We then estimated the functional richness of each community with kernel.alpha and the functional similarity between treatments with kernel.similarity function of the R package BAT (Cardoso et al. 2015). Then, we used the function traits.faxes.cor to test for correlations between anuran traits to PCoA axes (Magneville et al. 2022).

3. Results

In total, we registered 12 species of anurans belonging to three families: Leptodactylidae (8), Microhylidae (1), and Bufonidae (3) (Table 1). Nine species observed in both the MDS and LDS fire treatments, and seven species recorded in the control plots. The control plots had a total of 20 individuals across all species, while the MDS plots contained 27 individuals, and the LDS plots had a total of 94 individuals.

Our Bray Curtis similarity index PERMANOVA test showed no statistically significant difference between the control, MDS fire and LDS fire ($P > 0.05$).

3.1. Diversity and Abundance

In both Shannon and Simpson indexes MDS fire had the highest amount of diversity with Control in second and LDS fire in third place.

Diversity index	Control	MDS fire	LDS fire
Number of Species	7	9	9
Simpson_1-D	0.655	0.845	0.6238
Shannon_H	1.443	1.983	1.325
Chao 1	10	15	10

Table 2. Simpson and Shannon diversity results, as well as the Chao1 species richness results, were compared among the Control sites, MDS (middle of dry season) fire sites, and LDS (late dry season) fire sites.

Simpson, which takes the number of species as well as how many of each species there is, was higher in MDS (0.845), followed by Control (0.655), and LDS (0.6238) in last. Shannon takes into account the number of species and their relative abundance. Highest again was MDS (1.983) with Control (1.443) in second and LDS (1.325) last. Chao 1 revealed equal levels of species richness in the Control plots (10) and LDS plots (10), whereas MDS plots exhibited a higher species richness of 15 among our three groups.

Our taxonomic beta diversity analysis showed the least amount of difference between Control and MDS (0.22), most difference between Control and LDS (0.29), and a medium difference between MDS and LDS (0.26).

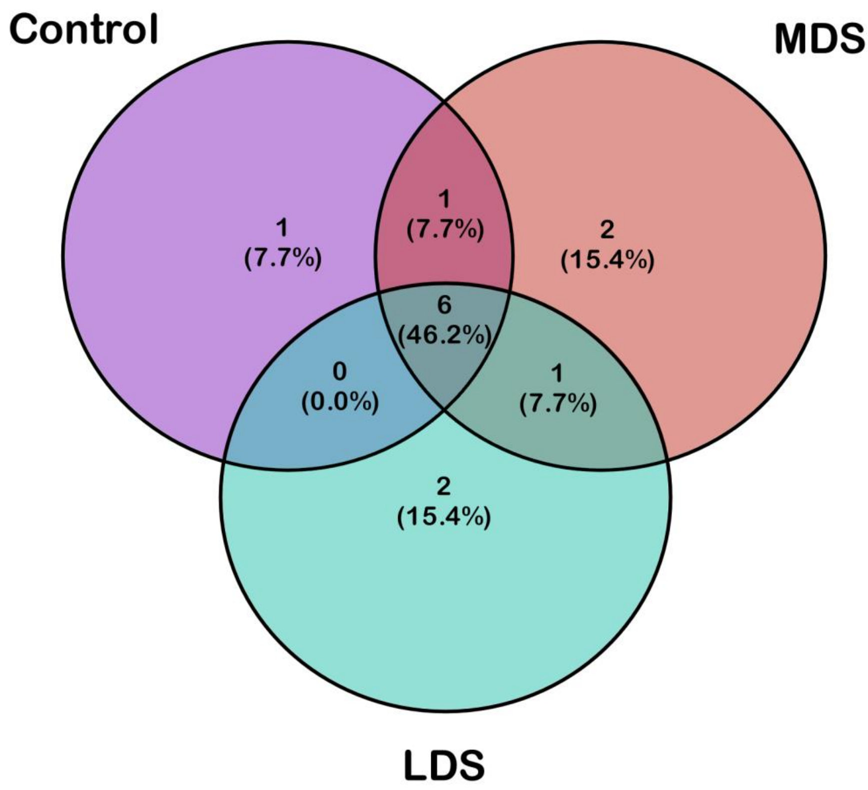

Figure 3. Venn diagram representing the results of our beta diversity analysis. Each number within the diagram indicates the count of species exclusive to a specific site, as well as the count of species exclusive to certain combinations of sites, within the control, MDS fire, and LDS fire groups.

3.2. Functional Diversity, Richness, and Similarity

Based on our kernel.alpha estimate combining our selected functional traits, functional diversity was higher in the control plots (0.3630036) and LDS fire plots (0.325644) were higher when compared to MDS fire plots (0.269821).

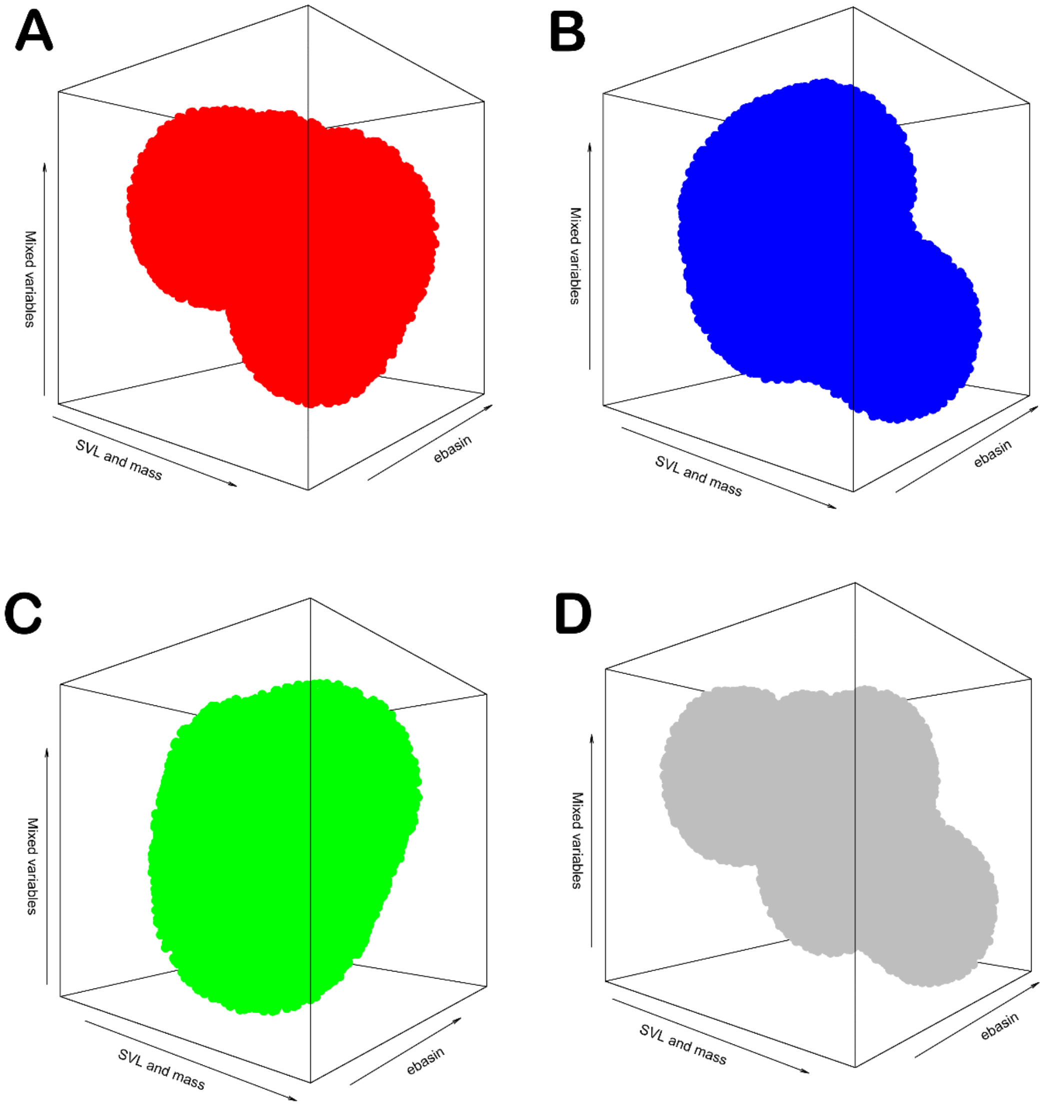

Figure 4. Functional space along three axes of PCoA: the "ebasin" axis represents egg deposition strategies (water, basin and burrow), the "SVL and mass" axis represents snout-vent length variation and average species mass, and the "Mixed Variables" includes habitat preferences (fossorial, terrestrial or aquatic) as well as a combination of the previously mentioned functional traits. Each color represents a different kind of plot (A, red) Control, (B, blue) LDS fire treatments, (C, green) MDS fire treatments, and (D, grey) Control, MDS, and LDS combined. Proximity to the center of the cube indicates lower functional diversity, whereas distance from the extremities signifies greater functional diversity with respect to the axes on the matrix.

Functional richness presented a similar result, with LDS fire plots showing higher similarity to the control plots than MDS fire plots. Furthermore, MDS and LDS fire regimes exhibited differences between them, as indicated in Table 3 showcasing the Jaccard similarity index.

Jaccard Similarity Index	Control	MDS
MDS	0.68998	
LDS	0.585767	0.767313

Table 3. This table compares the functional diversity results in the control, MDS (middle of dry season) fire, and LDS (late dry season) fire in our Jaccard similarity between treatments using kernel.similarity.

4. Discussion

Our objective was to investigate the potential differences between fire regimes on anuran diversity. Contrary to our hypothesis, the control group did not exhibit higher levels of species diversity compared to the two fire regimes. Instead, the MDS fire regime displayed higher diversity and species richness in comparison to both the LDS fire regime and the control group. Beta diversity analysis similarly revealed that the control points and MDS fire sites had the lowest degree of dissimilarity between them, while the most notable dissimilarity was observed between the control and LDS fire sites. Community composition was unexpectedly unaffected between both fire regimes and the control plots. Functional diversity however aligned with our hypothesis, with the control group exhibiting the highest level of functional diversity. The LDS fire treatment showed a relatively lower impact on functional diversity compared to the MDS fire treatments.

Despite being contrary to what we hypothesized, the higher diversity and species richness in MDS fire may be due to fire resistant species taking advantage of the opportunity a burned area can provide for some species. The most abundant species found were in the genus *Physalaemus*, which have a tendency of explosive breeding behavior, coming out in massive numbers to reproduce and feed during a short window of time (Bokermann, 1962; Cardoso, 1981; Wogel et al. 2002, Giaretta and Menin, 2004). The other factor is that many *Physalaemus* and other species from the Leptodactylidae family are burrowing frogs (Neves et al. 2020), which can be expected in burned sites, as burrowing species have a tendency of being fire-resistant (Friend, 1993). As for what a burn site could provide, there are food opportunities, such as invertebrate prey for anurans in some cases have been found to be the same in unburned and burned areas (Bamford, 1992). Insects may invade post burn areas, and the lack of vegetation cover could increase the ease of more fire-resistant anurans, such as *Physalaemus* species to feast (Pilliod et al., 2003). How anurans react to a post burned area is very species specific (dos Anjos et al., 2021), but can also provide some insight into why there are increases in species abundance and richness.

An increasing number of studies examining the impacts of fire on vertebrates and plants have turned their attention to functional diversity such as Westgate et al. (2012), dos Anjos et al. (2021), and Meza et al. (2023). The absence of impact and in some cases increased taxonomic diversity on burned sites in our results could suggest that taxonomic diversity and abundance are important metrics to have but should not be the only diversity metrics used for understanding how anuran populations are impacted by fire. This approach can aid us in generating multiple results based on our observations, providing us with a more precise understanding of how fire specifically affects anurans, which in our case was only in their functional diversity. Westgate et al. (2012) even suggests that comprehending anuran responses to fire should involve the utilization of information concerning animal behavior and species' ecological requirements, similar to the functional traits we have selected, such as nesting behavior and habitat preference. Species traits in anurans such as being fossorial or terrestrial affect how anurans respond to fire (dos Anjos et al. 2021). Therefore, assessing functional diversity linked to niches within fire affected environments may present a more comprehensive approach for evaluating the impact of fire on anuran communities, as opposed to relying solely on taxonomic diversity and richness.

Fire is a disturbance that significantly alters an ecosystem's plants and soil, often resulting in environmental homogenization and posing a threat to persistence (Da silva & Batalha, 2008; Meza et al. 2023). As mentioned earlier, the functional traits we examined are anuran traits closely tied to ecological niches related to vegetation and different water bodies within an ecosystem (Ribeiro et al., 2017).This connection might explain why anuran functional diversity was impacted in the burn sites. One noteworthy observation is that MDS fire had a higher negative impact than LDS fire, despite the MDS fire sites having a two-month head start to recover when compared to the LDS fire sites, which only had one month before collection commenced. This strongly suggests that fires in the middle of the Pantanal’s dry season are more jeopardizing to the anuran functional diversity than fires later on in the year. This difference may be explained by the likely higher moisture content within the organic fuel of the LDS plot points towards the end of the dry season (Ramos-Neto and Pivello, 2000; Medeiros and Fiedler, 2004). This increased moisture content likely contributed to a less intense occurrence of fire in these areas, consequently leading to a less homogenized post-burn environment.

The Brazilian Pantanal went through some of the worst fires in its history from 2019-2021 mainly due to illegal forest clearance done by farmers setting illegal fires to clear more land for cattle pasture (CIMI, 2020) and being one of the worst droughts of the century (Libonati et al. 2022). Studies like these can help us have an idea of fire impacts in different seasons, animal responses to fire has been a research gap for some time, especially in the Pantanal (Driscoll et al. 2010b; Pivello et al., 2021). So having information such as how late dry season-controlled burns have less impact on anuran functional diversity when compared to the middle of the dry season can help make better policies for controlled burns done not just by IBAMA and PREVfogo here in Brazil, but possibly other tropical wetlands with human made fire impacts. As mentioned before natural fires have a tendency of being low intensity and quick, naturally occurring towards the end of the dry season or end of the wet season. Our results suggest that to reduce impact on these controlled burns at least between the middle and end of the dry season, the more ideal fire regime for preserving anuran functional diversity would be towards the end of the dry season.

5. Conclusions

Different controlled fire regimes affect anurans negatively at different levels, but not in the way we initially expected such as species abundance, diversity or richness. It did affect anurans negatively through functional diversity, when looking at size, mass, egg deposition, and preferred habitat use of anurans. Among the two fire regimes LDS fire had a significantly lessened impact on their functional diversity when compared to MDS fire. This may be due to the MDS fire regime having a longer lasting and more intense fire, possibly homogenizing the environment more than the LDS regime, which simulates a more naturally occurring fire in the Pantanal. Results like these can aid fire brigades in setting less impactful controlled burned in floodplains like the Pantanal as well as floodplains in other tropical climates.

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