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Impact of fire on soil macrofauna in a Cerrado area in the municipality of São João do Sóter, Maranhão State, Brazil

Impacto do fogo sobre a macrofauna edáfica em área de cerrado no município de São João do Sóter – MA

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Abstract: The study of soil macrofauna serves as a tool for monitoring environmental disturbances and degraded areas. Fire is among the agents with the greatest potential to drastically modify the environment and landscape, causing environmental and economic damage. This study aimed to analyze the effect of fire on the soil macrofauna community in a Cerrado area. The biological material was collected in the rainy season (March 2021) in the Serra do Cajuí village, municipality of São João do Sóter, Maranhão State, Brazil. Specimens were collected using pitfall traps at 15 points spaced 450 m from each other. Sampling points were marked in a burned area (Area 1), a slightly burned area (Area 2), and an unburned area (Area 3). A total of 3,876 individuals were collected, belonging to 11 orders, including 8 orders from Area 1, 10 orders from Area 2, and 9 orders from Area 3. Area 2 showed the greatest abundance. The order Hymenoptera was the most abundant, dominant, and frequent in the three sampling areas. Area 1 had the highest diversity and evenness indices, whereas Area 2 showed the highest richness index. The richness estimator suggested the need for a greater sampling effort.

Keywords: Abundance; Monitoring; Soil Fauna.

Resumo: O estudo da macrofauna edáfica é utilizado no monitoramento de perturbações ambientais e de áreas degradadas. O fogo é um dos agentes com maior potencialidade de modificar drasticamente o ambiente e a paisagem, podendo gerar danos ambientais e econômicos. O trabalho tem como objetivo analisar o efeito do fogo sobre a comunidade da macrofauna edáfica em área de cerrado. O material foi coletado no período chuvoso (março de 2021) no Povoado Serra do Cajuí município de São João do Sóter – Caxias MA. Para coleta dos espécimes utilizou-se armadilhas do tipo *pitfall*. Foram delimitados 15 pontos com distância de 450m entre si. Estes pontos foram demarcados em Área queimada (Área 1), pouco queimada (Área 2) e não queimada (Área 3). Foram encontrados um total de 3.876 indivíduos distribuídos em 11 ordens, sendo que foram encontradas 8 ordens na Área 1, 10 ordens na Área 2 e 9 ordens na Área 3. A Área 2 apresentou a maior abundância, sendo entre as três Áreas, a ordem Hymenoptera a mais abundante, dominante e frequente. A Área 1 apresentou o maior índice de Diversidade e Uniformidade e a Área 2 apresentou o maior índice de Riqueza. O estimador de riqueza sugere maior esforço amostral.

Palavras-chave: Abundância; Monitoramento; Fauna do Solo.

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1. Introduction

Bioindicators are organisms with a narrow range of tolerance for one or more ecological factors, which allows their presence to serve as an indicator of particular environmental conditions. Insects are the most commonly used environmental bioindicators, given their great diversity and sensitivity to environmental changes (WINK *et al.*, 2005; BARETTA *et al.*, 2010). The invertebrate soil macrofauna comprises numerous well-known organisms, such as earthworms, ants, termites, beetles, centipedes, millipedes, cockroaches, earwigs, crickets, grasshoppers, spiders, harvestmen, and pseudoscorpions (KORASAKI *et al.*, 2017).

Soil invertebrates play an important role in structuring processes of terrestrial ecosystems, particularly in tropical regions. These organisms display different levels of sensitivity to soil management practices, depending on the effects on habitat changes, food supply, microenvironment creation, and intra- and interspecific competition. Other factors influencing soil vertebrates include anthropogenic activities and agroecosystem properties, such as climate, soil, and vegetation (TERRY *et al.*, 2015), which makes them efficient indicators of environmental quality.

In Maranhão State, Brazil, forest fires have become a major problem, reaching all biomes, including environmental protection and conservation areas. Fire is among the agents with the greatest potential to cause drastic changes to the environment and landscape, leading to irreparable damage to flora and fauna from an economic and environmental perspective (SILVA *et al.*, 2017). As such, the frequency of forest fires is considered a major determinant of the abundance and richness of soil biota (FRIZZO *et al.*, 2011).

There is a scarcity of studies assessing the effects of fire on soil macrofauna in Maranhão, particularly in the Serra do Cajuí village, São João do Sóter. Conducting a survey of the soil macrofauna in this area could enhance the regional database. In view of the foregoing, this study aimed to analyze fire effects on the soil macrofauna community in a Cerrado area in São João do Sóter, Maranhão State, Brazil. The relevance of this research lies in its contribution to the preservation of soil and all organisms that inhabit it, with findings expected to shed light on the impacts of fires and inform the development and review of public policies aimed at environmental conservation.

2. Methods

The study was conducted in the Serra do Cajuí village, São João do Sóter, on the left side of the MA-127 highway (−5.12073; −43.82683) (Figure 1). São João do Sóter is located approximately 58 km southwest of Caxias and 487 km from the state capital São Luís. It is crossed by MA-127 and comprises a territory of 1,438,067 km^2, with an estimated population of 18,746 inhabitants (IBGE, 2022).

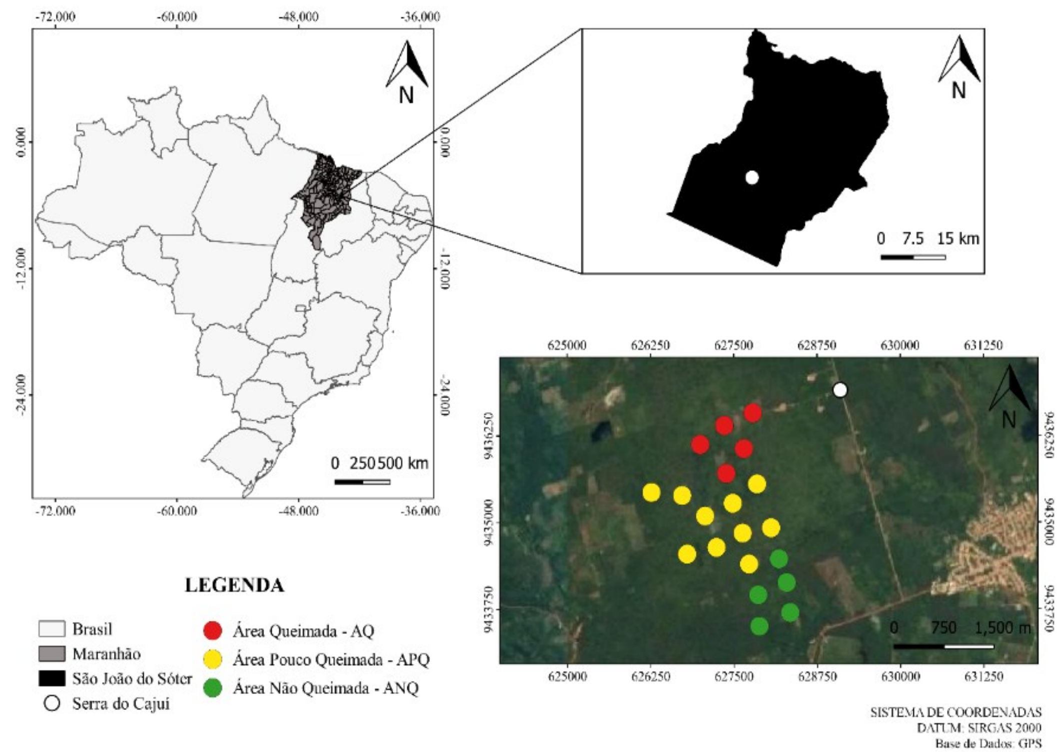

Figure 1 – Location map showing São João do Sóter, Maranhão State, Brazil, and satellite image of the Serra do Cajuí village with sampling points in burned, slightly burned, and unburned areas (red, yellow, and green, respectively). Source: Conceição (2022).

São João do Sóter has two well-defined seasons, a rainy one between November and April, with higher rainfall volumes in March, and a dry season between May and October (VIEIRA et al., 2017). The region encompasses concentrated forest areas belonging to the Cerrado phytogeographic domain and accumulating invaluable biodiversity, as well as anthropized environments with secondary vegetation of babaçu palm forests (VELOZO et al., 2019; SILVA Of, 2017).

This study analyzed three areas of Cerrado with different phytophysiognomies. Area 1 (Figure 2A) is located in an environment frequently affected by fires, hence its lack of dense vegetation and predominance of small shoots in the collection period, which occurred during the rainy season. Area 2 (Figure 2B) is slightly affected by fires but undergoing ecological succession, characterized by numerous shoots and denser vegetation. Area 3 (Figure 2C) is characterized by a dominant landscape of trees and shrubs interspersed with subshrubs and lianas. The ground vegetation is less dense than in grasslands, likely due to its more compact canopy (MALHEIROS, 2016). The selection of study areas was based on local observation of vegetation characteristics, fire damage, soil cover, and floristic composition, as well as satellite imagery data on fire hotspots over the past 10 years (INPE, 2020).

Figure 2 – Sampling areas in São João do Sóter, Maranhão State, Brazil, in March 2021. (A) burned area. (B) Slightly burned area. (C) Unburned area.
Source: Conceição (2022).

Collections were performed in March 2021, during the rainy season. The biological material was deposited in the collection of the Soil Fauna Laboratory (LAFS), Caxias Higher Education Center (CESC), Maranhão State University (UEMA), Brazil. A legal permit was obtained from ICMBio/IBAMA for sample collection (Permit No. 583781). A total of 15 sampling points were marked at a spacing of 450 m (points P1 to P5 in the burned Area, P6 to P10 in the slightly burned area, and P11 to P15 in the unburned area). Five pitfall traps were distributed at each sampling point, with a spacing of 20 m, totaling 75 traps. Each pitfall trap consisted of a disposable plastic cup (300 mL) buried in the soil with the opening at ground level. Cups contained 5% detergent in water (Araújo, 2010) to break the surface tension and prevent captured individuals from escaping.

Traps remained in the field for 48 h. After this period, the specimens were collected, sent to LAFS, and stored in labeled flasks containing 70% alcohol as preservative. Specimens were counted and identified at the order level following the identification key proposed by Triplehorn and Jonnson (2011). Identification was carried out using a magnifying glass, entomological forceps, and a Zeiss Stemi DV4 stereomicroscope.

For statistical analysis, a dataset was constructed using Microsoft Excel. Invertebrate soil macrofauna data were analyzed for frequency, constancy, and dominance, and predominant orders (i.e., those with higher faunal indices) were identified (SILVEIRA-NETO *et al.*, 1976). Shannon–Weaver diversity (*H*'), Pielou evenness (*J*), and Margalef richness indices were calculated using Anafau software (MORAES *et al.*, 2003). Richness analysis was carried out using Statistical Estimation of Species Richness and Share Species from Samples (EstimateS) software version 9.1.0 (COLWELL, 2004).

3. Results and discussion

A total of 3,876 soil macrofaunal individuals were collected, belonging to 11 orders (Coleoptera, Araneae, Diptera, Orthoptera, Isoptera, Diplopoda, Blattaria, Hemiptera, Hymenoptera, Pseudoscorpiones, and Mantodea). Of these, 855 individuals from 8 orders were collected from Area 1 (burned), 2,276 individuals belonging to 10 orders were sampled from Area 2 (slightly burned), and 742 individuals distributed in 9 orders were captured from Area 3 (unburned) (Table 1).

In Area 1 (burned), the order Hymenoptera (554 individuals, 64.79%) was categorized as abundant, super dominant, super frequent, and accessory. Additionally, Coleoptera (115 individuals, 13.45%) and Diptera (109 individuals, 12.74%) were considered very abundant, dominant, very frequent, and accessory. In Area 2 (slightly burned), the orders Hymenoptera (1,582 individuals, 69.5%), Diptera (364 individuals, 15.9%), and Coleoptera (215 individuals, 9.4%) were found to be superabundant, super dominant, super frequent, and constant. In Area 3 (unburned), the orders Hymenoptera (300 individuals, 40.4 %) and Diptera (213 individuals, 28.7%) were considered very abundant, dominant, very frequent, and constant. Furthermore, Coleoptera (174 individuals, 23.4%) was classified as abundant, dominant, very frequent, and constant. The order Mantodea was exclusive to Area 3.

Hymenoptera was considered superabundant in Areas 1, 2, and 3, encompassing the largest number of sampled individuals. These results are in agreement with the findings of Kitamura *et al.* (2008), who noted that members of the order Hymenoptera (ants) are indicators of environmental stress, as they colonize areas unsuitable for the survival of other groups. Previous studies assessing different biomes, such as the Caatinga and Atlantic Forest, for example, also found that Hymenoptera was the dominant group (MACHADO *et al.*, 2015). This group is considered to have high species richness due to its specialized taxa, high sensitivity to environmental changes, and ease of sampling (SOUZA *et al.*, 2019). Hymenopterans play an important role in the energy flow pyramid. These insects act in nutrient cycling and the control of other invertebrates, through predation. Ants are the main predators of other insects, in addition to acting as seed dispersers (ALMEIDA *et al.*, 2015). Forest fires remove above-ground biomass, favoring canopy opening and the growth of grasses. Thus, the exposure of vegetation to intense light and temperature conditions (VEIGA *et al.*, 2015) may contribute to the development of ant colonies (ALMEIDA *et al.*, 2007), providing favorable sites for ant nesting. These sites may represent important substitute niches for local diversity (LASSAU; HOCHULI, 2004). Some ant species are directly linked to degraded areas.

The order Coleoptera was sampled in all environments, probably because its members are highly adaptable to various soil, vegetation, and seasonal conditions. Beetles, the primary representatives of this order, have the potential to offer valuable ecological services in terrestrial ecosystems by preying on invertebrate pests and consuming weed seeds, thereby promoting ecological balance (KULKARNI *et al.*, 2017). The greater abundance of Coleoptera in Areas 2 and 3 is noteworthy. Kulkarni *et al.* (2017) reported that some elements influence the adaptability of beetles to different environments, such as plant canopy structure, vegetation density, and abiotic factors (e.g., temperature, humidity, and luminosity). These elements influence habitat selection and population distribution of beetles throughout the soil profile. Chávez-Suárez *et al.* (2016) reported that the Coleoptera is an important order, as it participates in the breakdown of plant residues, being considered an indicator of biomass and organic matter accumulation. In view of the above, the humidity, vegetation density, and organic matter content of the analyzed environments may have influenced the collection of this taxon.

Another super dominant group in Area 2 was Diptera. Bartrons *et al.* (2018) stated that the order Diptera increases soil fertility, improves pedological formation, and acts as a catalyst for plant growth, altering the stoichiometry of plants in the early stages of development. These effects may be mainly attributed to the presence of dipterans, influencing food composition and the concentration of specific soil taxa. Such aspects conditioned the presence of this taxon in anthropogenic and natural environments (LIMA *et al.*, 2020).

The higher occurrence of Orthoptera individuals in Areas 1 and 2 may be related to the constant changes caused by humans, such as agricultural practices and fires. Area 1 was the most affected by anthropogenic actions in comparison to Area 2, which was less subject to environmental changes. According to Nunes-Gutjahr and Braga (2010), some locust species are more frequently found in anthropogenic areas or those with numerous shoots.

The largest number of Diplopoda individuals was recorded in Area 3. In more preserved environments, vegetation cover promotes the accumulation of decomposing litter, increasing fungal populations, which serve as food for Diplopoda individuals (COSTA NETO, 2007).

Table 1 – Taxonomic groups recorded in Area 1 (burned), Area 2 (slightly burned), and Area 3 (unburned). São João do Sóter, Maranhão State, Brazil.

Order	Area 1							Area 2							Area 3						
	NI	%	NC	A	Do	Fr	C	NI	%	NC	A	Do	Fr	C	NI	%	NC	A	Do	Fr	C
Araneae	27	3.15	5	c	D	F	Y	35	1.53	5	a	D	VF	W	15	2.02	5	c	D	F	W
Blattaria	7	0.81	4	c	D	F	Y	10	0.43	3	c	D	F	Y	2	0.26	1	d	ND	IF	Z
Coleoptera	115	13.45	5	va	D	VF	Y	215	9.44	5	sa	SD	SF	W	174	23.45	5	a	D	VF	W
Diplopoda	6	0.70	4	d	D	IF	Y	5	0.21	3	c	ND	F	Y	9	1.21	4	c	D	F	Y
Diptera	109	12.74	5	va	D	VF	Y	364	15.99	5	sa	SD	SF	W	213	28.70	5	va	D	VF	W
Hymenoptera	554	64.79	5	a	SD	SF	Y	1,582	69.5	5	sa	SD	SF	W	300	40.43	5	va	D	VF	W
Hemiptera	-	-	-	-	-	-	-	8	0.35	4	c	D	F	Y	5	0.67	3	d	ND	IF	Y
Isoptera	1	0.11	1	d	ND	IF	Z	1	0.04	1	d	ND	IF	Z	-	-	-	-	-	-	-
Mantodea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.13	1	d	ND	IF	Z
Orthoptera	36	4.21	5	c	D	F	Y	55	2.41	5	va	D	VF	W	23	3.09	4	c	D	F	Y
Pseudoscorpiones	-	-	-	-	-	-	-	1	0.04	1	d	ND	IF	Z	-	-	-	-	-	-	-
TOTAL	855	100						2,276	100						742	100					

Source: Authors (2021).

Abbreviations: NI, number of individuals; NC, number of collections. Do, dominance; SD, super dominant; D, dominant; ND, non-dominant. A, abundance; sa, superabundant; va, very abundant; c, common; d, dispersed. Fr, frequency; SF, super frequent; VF, very frequent; F, frequent; IF, infrequent. C, constancy; W, constant; Y, accessory; Z, accidental.

The order Hemiptera was recorded in Areas 2 and 3 only. This finding can be attributed to the presence of plantations in these areas. Some representatives of the order are closely related to such environments. Hemipterans have a preference for areas with plants, shoots, new leaves, and flower buds; these insects feed on the sap of plants and may even cause plant death due to widespread weakening (RAFAEL *et al.*, 2012; MARTINS, *et al.*, 2021).

The order Araneae was considered dominant in Area 3, although it was recorded in all environments, both natural and anthropogenic. This order comprises generalist predators, which feed on various types of prey. Spiders are important because they participate in the maintenance of food webs, across several environments. They consume prey from various food chains and promote energy cycling in soil biota (PERKINS *et al.*, 2018; MURPHY *et al.*, 2020).

3.1 Margalef richness, Shannon diversity (*H′*), and Pielou evenness (*J*) indices

The Margalef richness, Shannon diversity, and Pielou evenness indices of the orders found in Areas 1, 2, and 3 are described in Table 2. The Margalef richness index was 1.05, 1.26, and 1.21 in Areas 1, 2, and 3, respectively. The Shannon diversity index was 1.39, 1.33, and 1.36 in Areas 1, 2, and 3, respectively. Finally, the Pielou evenness index was 0.71, 0.68, and 0.62 in Areas 1, 2, and 3, respectively.

Table 2 – Margalef richness, Shannon–Wiener diversity, and Pielou evenness indices of Area 1 (burned), Area 2 (slightly burned), and Area 3 (unburned). São João do Sóter, Maranhão State, Brazil.

Area	Richness index (Margalef)	Shannon diversity (*H′*)	Pielou evenness (*J*)
1	1.05	1.39	0.71
2	1.26	1.33	0.68
3	1.21	1.36	0.62

Source: Authors (2021).

In general, it was observed that Area 1 had the highest diversity and evenness indices but the lowest richness index. The findings indicate that some taxonomic groups can colonize areas even under suboptimal conditions for development, indicating stress. The lower diversity index of Area 2 might be related to the superabundance of Hymenoptera in comparison with the other areas. Begon *et al.* (1996) showed that reduced diversity may be due to the dominance of a specific group in relation to the others. Thus, the higher diversity indices of Areas 1 and 3 may reflect a greater distribution of groups.

The highest richness index was observed in Area 2, characterized by ecological succession with a considerable amount of plant material in the soil. Furthermore, the environment has a large quantity of plants that serve as food for several groups, such as beetles, which are indicators of organic matter and biomass accumulation (CHÁVEZ-SUÁREZ *et al.*, 2016). Climatic variables can act as environmental filters and may have negatively influenced richness, in view of the sampling period of the study (SILVA, 2020).

3.2 Estimated and observed richness

The observed richness of Areas 1, 2, and 3 was 8, 10, and 9, respectively. The richness estimator (Jackknife 1) of Areas 1, 2, and 3 was 9, 12, and 11, respectively.

Table 3 – Observed and estimated richness of Area 1 (burned), Area 2 (slightly burned), and Area 3 (unburned). São João do Sóter, Maranhão State, Brazil.

Index	Area 1	Area 2	Area 3
Observed richness	8	10	9
Jackknife 1 estimator	9	12	11

Source: Authors (2021).

Table 3 shows the observed and estimated richness values. The Jackknife 1 estimator was higher than the observed parameter, suggesting that a greater sampling effort is required for the curve to reach the asymptote. Although capture success is correlated with sampling effort, intrinsic factors of the study site can influence collection (SRBEK-ARAUJO;

CHIARELO, 2007), such as the type of area and amount of litter. Therefore, more collections are necessary to achieve a better result, as these groups are very diverse in terms of both species and habitats.

According to Colwell (2004), estimators become more accurate as the number of collections increases, resulting in more extensive sampling. In studies involving animal groups with numerous species, such as arthropods, diversity is best evaluated using richness estimators (DIAS, 2004). All data regarding richness and diversity are essential to subsidize conservation policies (CODDINGTON *et al*., 1991).

4. Final considerations

Among the three study areas, 11 orders were sampled, namely 8 in Area 1, 10 in Area 2, and 9 in Area 3. Area 2 had the highest abundance of soil macrofauna. The order Hymenoptera was the most abundant, dominant, and frequent in all areas. Area 1 had the highest diversity and evenness indices, and Area 2 had the highest richness index. The richness estimator suggested the need for a greater sampling effort.

This study provides a foundation for developing projects focused on conservation and soil integrity. Further research is needed to expand the database on the topic, support biodiversity knowledge across diverse areas, and facilitate the design and analysis of scientific research.

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