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A SURVEY OF SOIL MACROFAUNA IN ENVIRONMENTAL PROTECTION AREAS IN MARANHÃO STATE, BRAZIL

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Abstract

Analysis of soil macrofaunal community structure can contribute to our understanding of soil dynamics and bioindicators. This study aimed to survey the biodiversity of soil macrofauna in two Environmental Protection Areas (EPA) in Maranhão State, Brazil. Experimental sites were as follows: site I, Buriti do Meio EPA; and site II, Inhamum EPA. Provid-type traps were used to sample soil macrofaunal individuals. A faunistic analysis was carried out, and diversity, evenness, and richness indices of orders were calculated using ANAFAU software. Overall, 6,695 individuals were collected, distributed in 15 orders. Hymenoptera was the most prominent order at both sites, being considered superdominant, superabundant, superfrequent, and constant. Rainfall may directly interfere with the abundance of soil macrofaunal individuals. Site II showed greater richness, diversity, and evenness. This study revealed that agricultural management practices interfere with the behavior of soil macrofauna, showing that soil organisms are more abundant in more preserved environments and may therefore serve as bioindicators of soil quality.

Palavras-chave: Abundance; Diversity; Soil insect..

LEVANTAMENTO DA MACROFAUA EDÁFICA EM ÁREAS DE PROTEÇÃO AMBIENTAL NO MARANHÃO

Resumo

O estudo da estrutura da comunidade da macrofauna edáfica é um meio de entender o funcionamento do solo e os possíveis bioindicadores de sua qualidade. Neste contexto, objetivou-se realizar um levantamento da biodiversidade da macrofauna do solo em duas áreas de Proteção Ambiental no Maranhão. As áreas experimentais consideradas no estudo foram: Área I (APA do Buriti do Meio) e Área II (APA do Inhamum). Para realização das coletas da macrofauna do solo utilizou-se armadilhas do tipo Provid. Foi realizada uma análise faunística, e calculados os índices de diversidade, equbilidade e riqueza das ordens no programa ANAFAU. No geral, foram contabilizados 6.695 indivíduos, distribuídos em 15 ordens. Aordem que mais se destacou dentre as duas áreas foi Hymenoptera, considerada superdominante, superabundante, superfrequente e constante. A precipitação pluvial pode interferir diretamente na abundância de indivíduos da macrofauna edáfica. O ambiente da Área II apresentou maior riqueza, diversidade e equabilidade. O trabalho relevou que as práticas de manejo de agricultura interferem no comportamento da fauna do solo, indicando que a mesma é mais abundante em ambientes mais conservados, confirmando que os organismos edáficos são bons bioindicadores da qualidade do solo.

Keywords: Abundância; Diversidade; Insetos do solo.

RELEVAMIENTO DEL MACROFAUA EDÁFICA EN ÁREAS PROTEGIDAS EN MARANHÃO

Resumen

El estudio de la estructura comunitaria de la macrofauna edáfica es un medio para comprender el funcionamiento del suelo y los posibles bioindicadores de su calidad. En este contexto, el objetivo fue realizar un estudio de la biodiversidad de la macrofauna del suelo en dos áreas de Protección en Maranhão. Las áreas experimentales consideradas en el estudio fueron Área I (APA de Buriti do Meio) y Área II (APA de Inhamum). Se utilizaron trampas provid para recolectar la macrofauna del suelo. Se realizó análisis de fauna y se calculó el índice de diversidad, equidad y riqueza de los pedidos en el programa ANAFAU. En total, se registraron 6.695 personas, distribuidas en 15 pedidos. El orden que más se destacó entre las dos áreas fue el orden Hymenoptera, considerado superdominante, superabundante, superfrecuente y constante. Las precipitaciones pueden interferir directamente con la abundancia de individuos en la macrofauna edáfica. El entorno del Área II mostró mayor riqueza, diversidad y equidad. El trabajo reveló que las prácticas de manejo agrícola interfieren en el comportamiento de la fauna del suelo, indicando que es más abundante en ambientes más conservados, confirmando que los organismos edáficos son buenos bioindicadores de la calidad del suelo.

Palabras-clave: Abundancia; Diversidad; Insectos del suelo.

1. INTRODUCTION

Soil plays a crucial role in the production of the vast majority of consumed products, as practically all foods are grown in soil. Soil is a natural environment in which many organisms develop, generating important benefits to humans (RENNER et al., 2017) and other soil inhabitants. Brazil has one of the world's largest biodiversity, and soil fauna is an important component of the country's ecosystems (MELO et al., 2009). The soil is a fauna reservoir composed of a great variety of organisms that are necessary for the functioning of not only the soil environment but also the entire biome (JACOBS et al., 2007). Soil nutrient levels depend on complex interactions between roots, microorganisms, and edaphic fauna (GESTEL et al., 2003).

Soil fauna is divided into three groups: microfauna, mesofauna, and macrofauna. These organisms act together, preserving soil physical, chemical, and biological integrity, contributing to nutrient cycling, and promoting gas exchange between soil and the atmosphere (RENNER et al., 2017). Macrofaunal communities are influenced by the quantity and quality of plant material present in soil, which is why they serve as indicators of the ecological conditions of soil environments (CARRILLO et al., 2011). Indicator organisms are groups or communities whose presence, absence, density, diversity, or functional role reveal the possibility of adverse effects caused by natural or anthropogenic factors (BARETTA et al., 2010). The study of soil macrofaunal communities is a means of understanding soil functioning and quality (AQUINO et al., 2008).

Soil macrofauna consists of all invertebrates (animals that lack a vertebral column) larger than 2 mm living in the soil for at least one phase of the life cycle, whether in the adult or immature phase. Because of their large size, it is possible to visualize macrofauna with the naked eye, obviating the need for a magnifying glass or microscope. Macrofaunal individuals are represented by more than 20 taxonomic groups distributed across various classes, orders, and families. Soil invertebrate macrofaunae are well known by farmers and greatly studied by researchers. The group includes earthworms, ants, termites, beetles, centipedes, millipedes, cockroaches, earwigs, crickets, locusts, snails, bed bugs, woodlice, cicadas, caterpillars, spiders, harvesters, pseudoscorpions, and others (KORASAKI et al., 2017).

The main macrofaunal activities in soil include organic matter decomposition, humus production, and nutrient and energy cycling (HOFFMAN et al., 2009). Macrofaunal organisms are generally found in 0–10 cm depth soil. This layer is greatly affected by crop management practices, such as tillage, fertilization, and organic waste decomposition (BARETTA et., 2006).

This study investigated two sites, the Inhamum Municipal Environmental Protection Area (EPA) and the Buriti do Meio EPA, both part of the Cerrado biome in Maranhão State, Brazil. Anthropogenic activities, such as deforestation and, especially, fire events, have been reported in the study sites. Stubble burning can have catastrophic effects, compromising faunal and floral integrity. Studies investigating the environmental impacts of human activities in Inhamum and Buriti do Meio EPAs have aimed to promote awareness among the local population. The results of such studies can contribute to the development of public policies aimed at protecting conservation areas. In view of the above, this study aimed to conduct a survey of soil macrofauna biodiversity in two EPAs in Maranhão.

2. METHODS

The experiment was carried out at two sites located within EPAs in Caxias, Maranhão State, Brazil. Site I is located in the Buriti do Meio Municipal Environmental Protection Area (Buriti do Meio and Santa Rosa Settlement Project, Second District). The site is 35 km away from the urban perimeter of Caxias. It is covered by secondary vegetation resulting from crop cultivation, deforestation, and fire events. The climate is dry sub-humid, with mean annual temperatures of 26–27 °C and mean annual rainfall of 1,600–2,000 mm. There is a dry season from June to November and a rainy season from December to May (MONTES et al., 1997).

Site II is located on the left side of the BR-316 highway in the Inhamum Municipal Environmental Preservation Area, close to the urban perimeter of Caxias. It is covered by typical Cerrado vegetation, varying from open fields to *cerradão* (drought-resistant forest). Because it is located between the semi-arid Northeast and the middle-North, this region has hot and wet equatorial climate, with two distinct seasons (rainy summers and dry winters). The mean annual temperature is above 24 °C, with 1,600–1,800 mm of rainfall well-distributed throughout the year (ARAÚJO, 2012).

Four parallel transects were placed about 10 m apart at each site. Within each transect, five equidistant sampling points (10 × 10 m) were identified, totaling 20 points per treatment (site).

Soil macrofaunal individuals were sampled by using Provid-type pitfall traps. Each trap consisted of a 2 L PET bottle with four holes measuring 2 × 2 cm (ARAUJO, 2010) at 20 cm from the base filled with 200 mL of a 5% detergent solution containing 5 drops of formaldehyde p.a. Traps were buried with the holes at soil level and were kept in the same place during all collections. At each collection, the traps remained in the field for 96 h. Four collections were performed, two in the dry season (September and October 2018) and two in the rainy season (February and March 2019).

After 96 h, traps were removed from the field and identified with the collection date, sampling point, and experimental site. Then, they were transported to the laboratory, their contents washed under running water through a 0.25 mm sieve, and the collected individuals transferred to plastic pots containing 70% ethyl alcohol. Individuals were placed on Petri dishes, examined using a pair of tweezers and a magnifying glass, counted, and identified at the class, order, and/or taxonomic group level. Identification was performed using the key proposed by Triplehorn and Jonnson (2011).

Soil macrofauna data were subjected to faunistic analysis for determination of frequency, constancy, and dominance indices and identification of the predominant orders (that is, those with the highest ecological indices) (SILVEIRA NETO et al., 1976). Shannon–Weaver diversity (*H′*), Pielou's evenness (*J′*), and Margalef richness (*I*) indices were calculated using ANAFAU software (MORAES et al., 2003).

The frequency (*f*) of taxonomic orders was determined from the percentage share of the number of individuals from each order in relation to the total number of individuals collected. Frequency values were categorized according to the confidence interval (CI) of arithmetic means at the 5% level (SILVEIRA NETO et al., 1976), as follows: infrequent, frequency lower than the lower CI; frequent, frequency within the CI; and very frequent, frequency higher than the upper CI.

Constancy was calculated from the percentage occurrence of each order. Taxa were then categorized according to the classification of Bodenheiner (1955), as described by Silveira Neto et al. (1976): constant, found in more than 50% of collections; accessory, found in 20–50% of collections; accidental, found in less than 20% of collections.

Dominance refers to the ability of a taxon to modify the environment for its own benefit, which may lead to the appearance or disappearance of other organisms (SILVEIRA NETO et al., 1976). Orders were classified into the following dominance categories: dominant, orders with frequency values above the dominance index; and non-dominant, orders with frequency values below the dominance index.

Soil temperature was measured at a depth of 10 cm at each collection point using a digital stick thermometer (model K29-5030, Kasvi). Rainfall data were collected monthly from the Caxias Meteorological Station. The same rainfall data were used for both sites, as they are located in the same city.

3. RESULTS AND DISCUSSION

3.1. Abundance, frequency, constancy, and dominance of taxonomic groups

Macrofaunal communities differed between the investigated EPAs. Overall, 6,695 individuals were collected, 3,496 from site I (Buriti do Meio EPA) and 3,199 from site II (Inhamum EPA), distributed in 15 orders (Table 1).

At site I, the following orders were identified (in descending order of number of individuals): Hymenoptera, classified as superdominant, superabundant, superfrequent, and constant; Coleoptera, classified as superabundant, superfrequent, and constant; Diptera (n = 159 individuals), classified as dominant, very abundant, very frequent, and constant; Orthoptera (n = 136 individuals), classified as dominant, very abundant, very frequent, and accessory; and Araneae (n = 106 individuals), classified as dominant, very abundant, very frequent, and accessory.

The orders Embioptera, Hemiptera, and Scorpiones were exclusive to site I (Table 1). Individuals of the order Embioptera, occur in soil (up to 30 cm depth), under trunks, under stones, under tree barks, and at the base of trees, shrubs, and cacti, regardless of the climatic region (ROSS, 2000). There was no determining factor for the appearance of these individuals at site I. The exclusivity of Hemiptera individuals at site I may be due to the presence of crops. Many hemipteran representatives are closely related to crop environments, as they feed on plant shoots, new leaves, and flower buds. These organisms suck on plant sap, leading to plant yellowing, wrinkling, deformation, withering, and, sometimes, death by generalized weakening (RAFAEL et al., 2012). Scorpiones was also exclusive to site I. The vast majority of scorpion species have specific habitat and microhabitat requirements, with predictable, local ecological and biogeographic patterns (LOURENÇO; EICKSTEDT, 2009). However, some species of the genera *Centruroides*, *Isometrus*, *Tityus*, *Euscorpius*, and *Bothriurus* exhibit high ecological plasticity and irregular distribution patterns, occurring even in areas disturbed or modified by humans.

At site II, the following orders were identified: Hymenoptera (n = 2,523 individuals), Coleoptera (n = 314 individuals), Diptera (n = 195 individuals), and Araneae (n = 99 individuals). These orders were classified as superdominant, superabundant, superfrequent, and constant. The order Orthoptera, represented by

16 individuals, was classified as dominant, abundant, very frequent, and accessory.

Table 1. Abundance, frequency, constancy, and dominance of taxonomic groups identified in the Buriti do Meio Environmental Protection Area (EPA) and the Inhamum EPA, Caxias, Maranhão State, Brazil. Source: the authors (2019).

			Site I							**Site II**						
Phylum	**Class**	**Order**	**NI**	**%**	**NC**	**D**	**A**	**F**	**C**	**NI**	**%**	**NC**	**D**	**A**	**F**	**C**
Arthropoda	Arachnida	Araneae	106	3.03	53	d	va	vf	W	99	3.09	46	sd	sa	sf	W
	Insecta	Archaeognatha	-	-	-	-	-	-	-	1	0.03	1	nd	s	if	Z
		Blattaria	13	0.37	12	d	c	f	Y	26	0.81	15	d	va	vf	Y
		Coleoptera	590	16.88	50	sd	sa	sf	W	314	9.82	45	sd	sa	sf	W
		Diptera	159	4.55	46	d	va	vf	W	195	6.10	47	sd	sa	sf	W
		Embioptera	1	0.03	1	nd	s	if	Z	-	-	-	-	-	-	-
		Hemiptera	9	0.26	8	d	c	f	Z	-	-	-	-	-	-	-
		Hymenoptera	2.472	70.71	74	sd	sa	sf	W	2523	78.87	67	sd	sa	sf	W
		Isoptera	-	-	-	-	-	-	-	2	0.06	2	nd	c	f	Z
		Lepidoptera	1	0.03	1	nd	d	if	Z	1	0.03	1	nd	s	if	Z
	Chilopoda	Lithobiomorpha	-	-	-	-	-	-	-	1	0.03	1	nd	s	if	Z
	Insecta	Orthoptera	136	3.89	40	d	va	vf	Y	16	0.50	8	d	c	vf	Y
	Arachnida	Pseudoscorpiones	6	0.17	6	d	c	f	Z	20	0.63	15	d	va	vf	Y
		Scorpiones	3	0.09	2	nd	s	if	Z	-	-	-	-	-	-	-
	Chilopoda	Scutigeromorpha	-	-	-	-	-	-	-	1	0.03	1	nd	s	if	Z
		Total	3496	100						3199	100					

NI, number of individuals; NC, number of collections; D, dominance; d, dominant; sd, superdominant; nd, non-dominant; A, abundance; sa, superabundant; va, very abundant; c, common; s, sparse; F, frequency; sf, superfrequent; vf, very frequent; f, frequent; if, infrequent; C, constancy, W, constant; Y, accessory; Z, accidental.

Archaeognatha, Isoptera, Lithobiomorpha, and Scutigeromorpha were exclusive to site II (Table 1). Individuals of the orders Archaeognatha, Lithobiomorpha, and Scutigeromorpha prefer humid environments and are found under tree barks in soil and near decomposing litterfall and tree trunks (RAFAEL et al., 2012; GREGORY; GIRIBERT, 2007). The exclusivity of these orders can be explained by the high presence of decomposing plant litter, organic material, and tree barks at site II. Isoptera individuals can also be related to the presence of organic material and, particularly, to high amounts of plant litter. Organic materials serve as food for soil fauna, promoting faunal stability. High organic matter levels also favor the presence of active predators, as some species of earthworms, ants, and termites are more generalist and require soil with good physical properties (ROSA et al., 2015).

Overall, Hymenoptera was the predominant order. Our results agree with those of previous studies on soil macrofauna in Cerrado regions using the same sampling method (BUSSINGUER, 2018; ARAÚJO et al., 2010). Studies carried out in the Caatinga (SANTOS et al., 2018; SANTOS, 2014) and Atlantic Forest (MACHADO et al., 2015) reported that Hymenoptera was the most dominant group. In the current study, the predominance of Hymenoptera can be attributed to the high presence of Formicidae individuals. Formicidae is a group with high species richness, composed of highly specialized taxa that are sensitive to environmental changes and relatively easy to collect (SOUZA et al., 2018).

Individuals of the order Coleoptera were found at both sites, but their occurrence was higher at site I. This finding might be related to presence of crop fields (bean, maize, and cassava, among others) at site I. Collection traps were located within crop fields, likely favoring the sampling of beetles that benefit from these environments, such as adults of the family Meloidae. According to Marinone and Ganho (2003), members of this family are defoliators and, thus, classified as pests of cultivated plants. Coleoptera is the largest order within the class Insecta, comprising a large number of species that occupy the most diverse ecological niches. Agricultural pests with various eating habits are also part of this group (AUDINO et al., 2007).

The higher occurrence of Orthoptera individuals (e.g., grasshoppers) at site I compared with site II can be attributed to constant anthropogenic activities, such as agricultural farming. Site I was more anthropized than site II, which has not undergone such environmental changes. It is interesting to note that, according to Nunes-Gutjahr and Braga (2010), some grasshopper species (Acrididae) are more commonly found in anthropized areas.

3.2. Effects of temperature and rainfall on soil macrofaunal organisms

Rainfall levels might have influenced the abundance of soil macrofauna. Table 2 shows the distribution of individuals sampled at sites I and II over the experimental period.

Table 2. Climatic variables and number of macrofaunal individuals collected in the Buriti do Meio Environmental Protection Area (EPA) (site I) and the Inhamum EPA (site II), Caxias, Maranhão State, Brazil. Source: the authors (2019).

Period	Site I	*T* (°C)	Site II	*T* (°C)	Rainfall (mm)
September 2018	1192	29	415	27	13.5
October 2018	1046	32	1658	28	42.5
February 2019	884	28	625	27	182.2
March 2019	395	27	516	28	3739

T, soil temperature.

At site I, a higher number of individuals was sampled in the dry season (September and October 2018) and a lower number in the rainy season (February and March 2019). Only 395 individuals were collected in March 2019. The soil temperature remained constant at site I (28 °C in February and 27 °C in March 2018). At site II, abundance was considerably higher in October 2018.

The results suggest that macrofaunal populations were influenced by rainfall. Seasonal variations in soil temperature and humidity are known to have a direct influence on faunal density (SOARES; COSTA, 2001; FERNANDES et al., 2011). Pinheiro et al. (2014) evaluated soil macrofauna occurring at the soil–plant litter interface at a Caatinga site and observed similar results: macrofaunal individuals were more abundant in the dry period. Marques and Del-Claro (2010) reported that Hymenoptera and Coleoptera were the most abundant in the dry season in *vereda* vegetation at a Cerrado site. These results can be attributed mainly to the presence of ants because, in the dry season, ants have greater food availability and lower competition (Vasconcellos et al. 2013). As discussed by Collison et al. (2013), in dry periods, the activity of macroinvertebrates may decrease, favoring communities that are better adapted to low humidity conditions.

According to Thomas (2017), litterfall increases in the dry period, given that plants lose a large part of their foliage. Accumulated litterfall provides favorable microclimate conditions for hypogeal species, that is, species that forage in the soil (SILVA et al., 2015). Plant litter helps maintain soil temperatures and provides nesting and foraging sites for ants (ROCHA, 2012).

3.3. Margalef richness (*I*), Shannon–Weaver diversity (*H′*), and Pielou’s evenness (*J′*) indices

The richness (*I*), diversity (*H′*), and evenness (*J′*) of macrofaunal orders identified at sites I and II are described in Table 3.

Table 3. Margalef richness (I), Shannon–Weaver diversity (H'), and Pielou's evenness (J') indices of the soil macrofaunal community in the Buriti do Meio Environmental Protection Area (EPA) (site I) and the Inhamum EPA (site II), Caxias, Maranhão State, Brazil. Source: the authors (2019).

Site	*I*	*H′*	*J′*
I	1.32	1.38	0.63
II	1.66	1.42	0.68

Site II had greater richness, diversity, and evenness. This result may be directly related to the higher environmental stability of site II compared with site I. Site I was at an advanced stage of secondary succession, as the area is constantly subjected to burning by farmers, causing an imbalance in faunal and floral communities. In general, preserved, stable, or recovering areas exhibit high soil invertebrate diversity and evenness because of the greater environmental stability (NUNES et al., 2008; HOFFAMANN et al., 2009). Silva et al. (2014) reported that agricultural management systems directly influence soil fauna diversity, as cropping practices can cause physical, chemical, and biological changes to soil. The greater the diversity, the better the ecological conditions of a given area. Ecosystem degradation alters the distribution of soil fauna by limiting or eliminating food resources and modifying ecological interactions, thereby affecting the sustainability of production systems (GOMIDE et al., 2011).

Table 4 shows the diversity and evenness indices of sites I and II in each collection period. At site I, the highest diversity and evenness values were observed in March 2019 and the lowest in September 2018.

Table 4. Shannon–Wiener diversity (H') and Pielou's evenness (J') indices of the soil macrofaunal community in the Buriti do Meio Environmental Protection Area (EPA) (site I) and the Inhamum EPA (site II), Caxias, Maranhão State, Brazil, according to collection period. Source: the authors (2019).

Site	Period	*H′*	*J′*
I	September 2018	0.30	0.14
	October 2018	0.49	0.22
	February 2019	1.22	0.59
	March 2019	1.41	0.64
II	September 2018	0.38	0.19
	October 2018	0.33	0.17
	February 2019	1.26	0.58
	March 2019	1.27	0.58

At site II, the highest diversity and evenness indices were recorded in February and March 2019 and the lowest in October 2018. Such a variation in diversity is an indication of soil resilience. Soil organisms generally respond differently to soil management practices, and species diversity is directly linked to climate conditions and irrigation regimes, thereby serving as a sensitive biological indicator (PELOSI; RÖMBKE, 2016).

Diversity and evenness were lower in the dry season (September and October) at both sites. This result may be attributed to the presence of groups that are better adapted to dry conditions, as is the case of individuals of the order Hymenoptera. According to Bianchi et al. (2017), the predominance of hymenopterans, especially ants, leads to differences in Shannon's diversity and Pielou's evenness indices. The relationship between density and group richness, as expressed by these indices, shows that, in the rainy season, the sites had a more diverse community. Taxa occurred in a more representative manner and were better distributed; however, this does not imply higher total abundance. Baretta et al. (2003) argued that a loss of diversity is caused by the presence of dominant species, favored by the environment or by greater availability of specific food resources.

4. FINAL CONSIDERATIONS

✓ During the four months of sample collection, 15 taxonomic orders were identified at the two studied sites.

✓ The order Hymenoptera was superdominant, superabundant, superfrequent, and constant at both sites.

✓ Rainfall can directly interfere with the abundance of soil macrofaunal individuals.

✓ Site II showed greater richness, diversity, and evenness of taxonomic groups, as revealed by Margalef, Shannon, and Pielou's indices.

✓ Agricultural management practices interfere with the behavior of soil fauna, showing that soil organisms are more abundant in better preserved environments and serve as good bioindicators of soil quality.

✓ The findings reported here can be used as a starting point for the development of management and conservation strategies or as a tool for environmental monitoring. This faunistic study contributed to the knowledge of biodiversity in protected areas and may guide future research and environmental impact reports.

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