

Division - Soil Processes and Properties | Commission - Soil Biology

# Diversity and abundance of soil macrofauna in three land use systems in eastern Amazonia

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**ABSTRACT:** Given the influence of edaphic macrofauna in the physical, chemical, and biological processes that sustain the organic matter cycle in the soil of tropical ecosystems, this study aimed to evaluate the effect of the sequence: Secondary Forest – Pasture – Eucalyptus monoculture on the macrofauna structure in Southeast of Pará State, Brazil. In each land use system, two 350 m transect were taken. The data was collected in 8 sampling sites, which were 50 m apart in each transect at 0.10 and 0.20 m depths. Correlations between the community structure Family Richness (S), Shannon-Wiener diversity index (H'), Pielou equitability (J), and macrofauna density (ind. m<sup>-2</sup>) were tested with soil pH(H<sub>2</sub>O), Al<sup>3+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, P, SOC, N, Fe, Zn, and Mn and the litter dry matter total content of Ca, Mg, K, P, TOC, N, Fe, Zn. The land use has affected the macrofauna community parameters S, H', and J (p<0.05). The macrofauna density did not differ between land use systems Pasture and Secondary Forest (p>0.05). The evaluated indexes were highly correlated with the disturbance level, increasing gradually from the Pasture, where the lowest levels were found, to the Secondary Forest with the best indexes in this study, with 29 families exclusive to this land use system. Correlations between the community structure and soil and litter chemical parameters were not detected.

**Keywords:** soil biology, soil fertility, land use systems, edaphic fauna.

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## INTRODUCTION

Soil fauna, also known as edaphic fauna, is a term that encompasses all organisms that spend a significant portion of their life cycle within a soil profile, or at the soil-litter interface (Dionísio et al., 2016). The different sizes and metabolisms of these organisms allow them to be agents in interdependent processes that occur in the soil at different times and space scales (Frouz et al., 2015). Due to their relationship with edaphic properties, these processes range from filtering and cleaning toxic materials, selective activation of various functional groups of the microflora (Brown et al., 2015), biogeochemical flow of nutrients and water, and biological control of pests to the aggregation of soil particles (Marichal et al., 2017).

Agricultural practices can alter the composition and diversity of edaphic organisms at different intensity degrees, interfering in their ecological services (Camara et al., 2018). Overall, the increase in land use intensity leads to a reduction in the density and diversity of the edaphic macrofauna due to changes in habitat, food supply, creation of microenvironments, and intraspecific and interspecific competition (Bedano et al., 2016; Marichal et al., 2017). Furthermore, it reduces the possibility of a given process being mediated by different edaphic groups, which has been identified as the main cause of physical and chemical degradation of the soil (Marichal et al., 2014).

Therefore, the study of soil invertebrate communities is important to monitor changes in environments, providing information on the conservation and maintenance of balance in agroecosystems (Souza et al., 2016; Martins et al., 2017). For example, in Brazil, the state of Pará accumulates the largest deforested land area in the Brazilian Amazon (Barlow et al., 2016), totaling 164,800.55 km<sup>2</sup>, with 3,716.15 km<sup>2</sup> of open areas. This is mostly associated with the production of commodities in the livestock and mining sectors (Inpe, 2020).

In this sense, considering the importance of soil fauna biodiversity for soil quality and the constant changes in soil use, this study aimed: (a) to evaluate the density and diversity of the soil macrofauna and their relationship with soil chemical properties; and (b) to evaluate the functional groups of the edaphic macrofauna that are more representative in the following use sequence: Secondary Forest (40 years), Pasture (20 years), and Eucalyptus cultivation (10 years), in Marabá, state of Pará, Brazil.

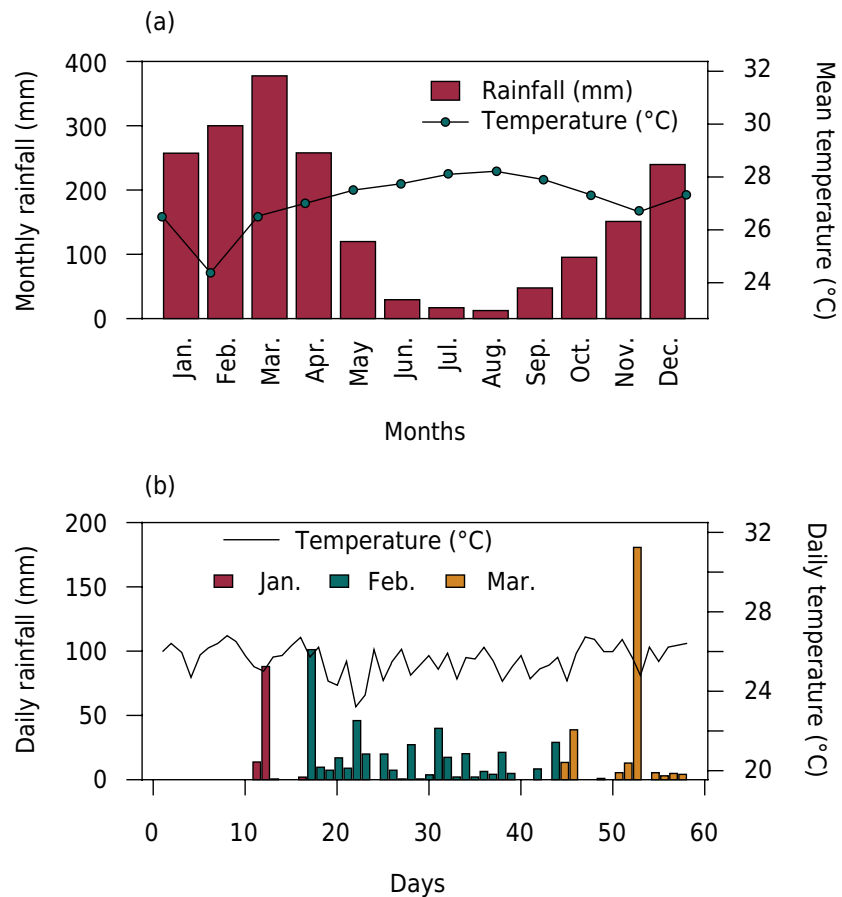
## MATERIALS AND METHODS

### Localization and characterization of the study area

The study area has 30.6 km<sup>2</sup> and it is located in Marabá municipality, state of Pará, Brazil. The municipality limits are between 05° 00' and 06° 00' latitude south and 48° 00' and 49° 30' longitude west. It is placed in the transition between Aw and Am Koppen climate regions (Inmet, 2018) with its mean annual temperature around 26 °C, and high rainfall, close to 2,200 mm annually (Figure 1).

Three land use systems (LUS) across a time sequence were evaluated, namely: Secondary Forest fragment (SF, 5° 26' 42.01" S and 49° 3' 18.15" W), pasture (PAS, 5° 25' 16.75" S and 49° 3' 39.81" W) and *Eucalyptus* sp. monoculture (EUC, 5° 26' 21.23" S and 49° 1' 45.94" W). The land use history and the identification of the agricultural practices that characterize the LUS were obtained from semi structured interviews.

In 1976, the study area was cleared with the *correntão* technique (this technique consists of the quick removal of native vegetation through the use of chains attached to tractors) followed by a slash and burn; then, the area was cultivated for two years and subsequently abandoned, originating a Secondary Forest (FS). In the same area, in 1998, the slash and burn technique was made again to introduce the pastures. A plot from the pasture



**Figure 1.** Climatological normal of Marabá-PA: 1981-2010 (a), with temperature distribution and precipitation during the data collection period (b). Source: Adapted from Inmet data (2018).

was later on converted into a *Eucalyptus* monoculture by October 2008 with the clone I - 144 [*Eucalyptus grandis* (W. Mill ex Maiden) and *E. urophylla* (S. T. Blake)] spaced in a 3.5 × 2.60 m grid. Since the beginning of the planting, no management or logging was performed in the area.

Between 2015 and 2018, there was no soil tillage and plough, but pesticides were annually applied for froghoppers (Hemiptera, Cercopidae) and weeds in this time frame. In the last year of the pasture renovation, the planting was made by throwing with Poaceae MG-5 [*Brachiaria brizantha* (A. Rich.) Stapf], hardgrass [*Elymandra lithophila* (Trin.) Clayton], and signalgrass (*Brachiaria decumbens* Stapf.). In the pasture area, babassu palm (*Attalea speciosa* Mart.), banana (*Musa* sp.), beard grass (*Andropogon bicornis* L.), and ant nests (Formicidae: Hymenoptera) were recorded. One month before sampling, aerial spraying of herbicides (glyphosate) was carried out in the area. Nowadays, the rotational pasture system is managed in the area, with 120 beef cattle in rotation with eight days grazing and thirty days resting.

### Sampling and statistical analysis

Data collection was conducted over February/March 2018. In each LUS, macrofauna individuals were collected in two parallel transects (350 m). Each transect presented eight sampling sites 50 m apart, 48 monoliths totaled were dug in this study. The method of soil monoliths “Tropical Soil Biology and Fertility” (TSBF) was used to sample the edaphic macrofauna and litter (Dionísio et al., 2016). In each transect sampling site, a wooden box of 0.25 × 0.25 m was used to shape the soil monolith, which was dug in two layers (0.00-0.10 and 0.10-0.20 m) in the PAS and three layers (soil-litter, 0.00-0.10, and 0.10-0.20 m) in the EUC and the SF. All samples for a single LUS were collected

on the same day. Macrofauna was picked manually, followed by preservation in 70 % ethanol. For Oligochaeta individuals, they were first preserved in 4 % formaldehyde for one month before moving to flasks containing 42 % ethanol.

Macrofauna identification was made to the family level (subfamily to Formicidae, Hymenoptera) according to Adis (2002) and Rafael et al. (2012) descriptions. Identified individuals were later classified into the following functional groups: detritivores/decomposers, predators/parasites, geophagous/bioturbators, phytophagous/parasites (Brown et al., 2015). Oligochaeta individuals were classified into microdriles (<10 mm in length) and megadriles (>10 mm in length) (Righi, 1997). The community structure of the edaphic invertebrates was compared at the family level between the LUS and expressed by density (individuals m<sup>-2</sup>), richness (S), Shannon (H'), and Pielou equitability index (J).

To evaluate the soil chemical properties, samples from two layers (0.00-0.10 and 0.10-0.20 m) were collected at the same sampling sites of the macrofauna within a radius of 6 m from the monoliths. Twelve samples were taken around each soil monolith (Franco et al., 2016). The procedures of soil preparation, chemical extraction, and determination were performed following Silva (2009). The soil parameters evaluated were: pH(H<sub>2</sub>O), Al<sup>3+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and K<sup>+</sup> (cmol<sub>c</sub> kg<sup>-1</sup>), C, N, and P (g kg<sup>-1</sup>), Fe, Zn, and Mn (mg kg<sup>-1</sup>). The litter samples after the macrofauna picking were air-dried and cleaned with brushes, then taken to a drying oven (60 °C) during 72 h for dry matter determination. Macro and micronutrients contents evaluated in the litter dry matter are presented in g kg<sup>-1</sup>, and the estimation of litter stocks in kg ha<sup>-1</sup>.

Homogeneity (Cochran and Bartlett, 5 %) and normality (Lilliefors, 5 %) tests were performed in the soil and macrofauna structure data. The macrofauna structure indexes (S, J, and H') were calculated with the BiodiversityR package (Kindt and Coe, 2005). For soil chemical properties and invertebrate density in different layers comparisons, the paired Wilcoxon test was performed. For the LUS effects on the community structure assessment, the generalized additive mixed model (GAMM) were performed, with the fixed effects as SF, PAS, and EUC and the nested factor as the transects, using mgcv package (Wood, 2011). The community structure was considered as the response variable and the soil chemical properties, litter dry matter and its total mineral contents as the predictor variables. Data analysis were performed using the software R Development Core Team (2018).

## RESULTS

A total of 11,234 specimens were collected from an area of 17.6 m<sup>2</sup> of soil, which were distributed in 85 families, with an average general density of 1,852 (±146) individuals per m<sup>2</sup>. A total of 24 families were found only in the Secondary Forest, while five families were found in the Pasture area, and six families in the Eucalyptus area (Table 1). The density of functional groups differed between SUS (p<0.05) (Figure 2), with a dominance of groups G\_B and D\_D in all SUS.

Due to the greater abundance of Microdrils in the Eucalyptus area, the relative abundance of D\_D between this SUS and FS did not differ (p>0.05). Myrmecinae corresponded to 96.5 % of the total pasture density. The land use systems have affected the edaphic macrofauna in S, J, and H' (p<0.05) parameters; however, total density did not differ between SF and PAS. The assessed indexes were highly correlated with land use intensity, gradually decreasing from pastures, where the lowest indexes have been found, to the Secondary Forest, with the higher ecological indexes found in this study (Table 1).

**Table 1.** Mean density of the edaphic macrofauna in the 40-year Secondary Forest (FS), 20-year Pasture (PAS), and 10-year *Eucalyptus* (EUC) in Marabá - Pará, Brazil

Táxon	G_T	FS	PAS	EUC	Mean	%
					ind. m <sup>-2</sup>	
Microdrilos	D_D	150 ± 1.5 a	13.61 ± 0.48 c	1113 b	425.82	23.00
Megadrilos	G_B	3.32 ± 0.07	0 ± 0	5.78 ± 0.28	3.03	0.16
Dipluridae	P_P	1.36 ± 1.36	0 ± 0	0 ± 0	0.45	0.02
Anapidae	P_P	1.07 ± 0.02	0 ± 0	2.43 ± 0.03	1.17	0.06
Ooconidae	P_P	1.07 ± 0.02	0 ± 0	2.13 ± 0.03	1.07	0.06
Orsolobidae	P_P	0 ± 0	0 ± 0	1.07 ± 0.02	0.36	0.02
Symphytognathidae	P_P	5.65 ± 0.07	0 ± 0	0 ± 0	1.88	0.10
Zodariidae	P_P	1.07 ± 0.02	0 ± 0	0 ± 0	0.36	0.02
Caponiidae	P_P	0.30 ± 0.02	0 ± 0	0 ± 0	0.10	0.01
Eremobatidae	P_P	4.27 ± 0.04	0 ± 0	0 ± 0	1.42	0.08
Agaristenidae	P_P	4.13 ± 0.05	0 ± 0	8.88 ± 0.13	4.34	0.23
Cranidae	P_P	1.07 ± 0.02	0 ± 0	0 ± 0	0.36	0.02
Stygnommatidae	P_P	1.07 ± 0.02	0 ± 0	0 ± 0	0.36	0.02
Palpigradi	P_P	4.27 ± 0.06	0 ± 0	0 ± 0	1.42	0.08
Argasidae	P_P	0 ± 0	0.28 ± 0.03	0.28 ± 0.03	0.19	0.01
Ixodidae	P_P	0 ± 0	0.56 ± 0.02	0.30 ± 0.05	0.64	0.01
Oplioacaridae	P_P	1.07 ± 0.02	0 ± 0	1.34 ± 0.05	0.80	0.04
Chthoniidae	P_P	1.70 ± 0.06	0 ± 0	2.13 ± 0.03	1.28	0.07
Lechtyiidae	P_P	2.13 ± 0.03	0 ± 0	0 ± 0	0.71	0.04
Olpidae	P_P	0.32 ± 0.02	0 ± 0	1.07 ± 0.02	0.46	0.02
Oniscidae	D_D	18.77 ± 0.13 a	0.28 ± 0.02	2.13 ± 0.04	7.06	0.38
Scutigereidae	D_D	3.20 ± 0.04	0 ± 0	1.07 ± 0.02	1.42	0.08
Ballophilidae	D_D	1.07 ± 0.02	0.28 ± 0.02	2.43 ± 0.04	1.26	0.07
Geophilidae	D_D	1.07 ± 0.02	0 ± 0	0.30 ± 0.02	0.45	0.02
Macronicophilidae	D_D	4.73 ± 0.10	0 ± 0	1.48 ± 0.07	2.07	0.11
Mecistocephalidae	D_D	0.30 ± 0.02	0 ± 0	0 ± 0	0.10	0.01
Oryidae	D_D	0.32 ± 0.02	0 ± 0	0 ± 0	0.11	0.01
Scolopendridae	D_D	1.07 ± 0.02	0 ± 0	0.30 ± 0.02	0.45	0.02
Hypogexenidae	D_D	7.47 ± 0.18	0 ± 0	0 ± 0	2.49	0.13
Siphoniulidae	D_D	1.36 ± 0.03	0 ± 0	8.91 ± 0.35	3.42	0.18
Siphonophoridae	D_D	2.43 ± 0.05	0 ± 0	3.89 ± 0.89	2.11	0.11
Stemmiulidae	D_D	0.59 ± 0.03	0 ± 0	1.07 ± 0.29	0.55	0.03
Paradoxomatidae	D_D	1.07 ± 0.02	0.56 ± 0.15	0 ± 0	0.54	0.03
Pyrgodesmidae	D_D	17.23 ± 0.14	0.28 ± 0.11	5 ± 0.25	7.50	0.40
Pseudonannolenidae	D_D	3.02 ± 0.06	0 ± 0	1.76 ± 0.11	1.59	0.09
Blaniulidae	D_D	0.30 ± 0.02	0 ± 0	0 ± 0	0.10	0.01
Parajulidae	D_D	2.13 ± 0.03	0 ± 0	0 ± 0	0.71	0.04
Japygidae	D_D	4.57 ± 0.10	0 ± 0	6.62 ± 0.09	3.73	0.20
Meinertellidae	F_H	0 ± 0	0 ± 0	1.07 ± 0.02	0.36	0.02
Gryllidae	F_H	0 ± 0	0.28 ± 0.02	0 ± 0	0.09	0.00
Imat. Orthop.	F_H	1.07 ± 0.02	0 ± 0	0 ± 0	0.36	0.02
Labiduridae	D_D	1.66 ± 0.03	0.28 ± 0.02	0 ± 0	0.65	0.04
Zorapytidae	P_P	0 ± 0	0 ± 0	1.07 ± 0.02	0.36	0.02
Mantoididae	P_P	1.07 ± 0.02	0 ± 0	0 ± 0	0.36	0.02
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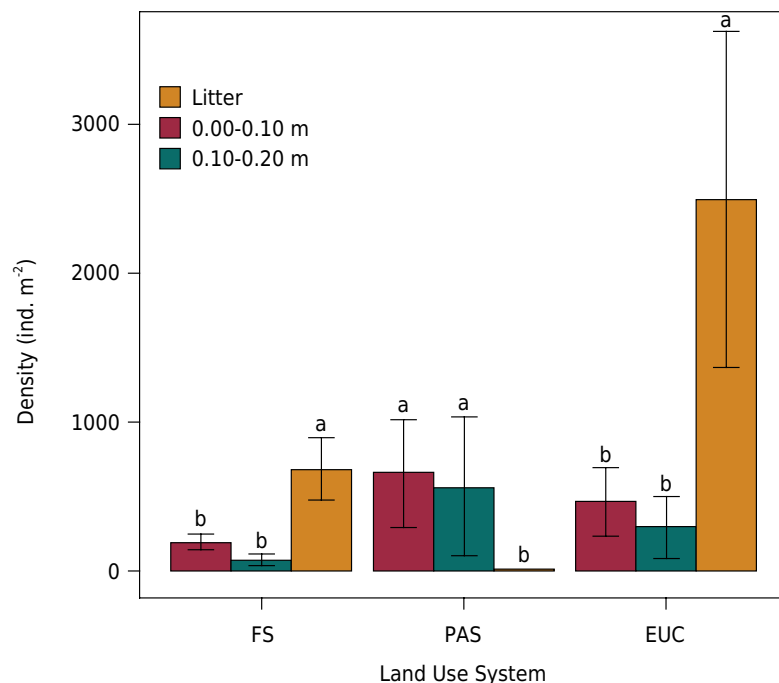
Corydiidae	D_D	3.20 ± 0.03	0 ± 0	0 ± 0	1.07	0.06
Termitidae	G_B	21.33 ± 0.34 a	0 ± 0 c	1.48 ± 0.11 b	7.60	0.41
Imat. Blatt.	F_H	0 ± 0	0 ± 0	0.59 ± 0.04	0.20	0.01
Cicadidae	F_H	1.07 ± 0.02	0 ± 0	1.07 ± 0.02	0.71	0.04
Delphacidae	F_H	3.20 ± 0.06	0 ± 0	1.66 ± 0.05	1.62	0.09
Hebridae	F_H	2.13 ± 0.04	0 ± 0	1.07 ± 0.02	1.07	0.06
Miridae	F_H	0 ± 0	0 ± 0	0.59 ± 0.03	0.20	0.01
Reduviidae	F_H	0.30 ± 0.02	0 ± 0	1.07 ± 0.02	0.45	0.02
Aradidae	F_H	0.30 ± 0.02	0.28 ± 0.02	0 ± 0	0.19	0.01
Cydnidae	F_H	0.30 ± 0.03	0 ± 0	1.07 ± 0.02	0.45	0.02
Pentatomidae	P_P	0 ± 0	0 ± 0	1.07 ± 0.02	0.36	0.02
Lygaeidea	P_P	3.20 ± 0.03	0 ± 0	0 ± 0	1.07	0.06
Phlaeothripidae	F_H	2.77 ± 0.05	0.56 ± 0.30	14.93 ± 3.83	6.09	0.33
Thripidae	F_H	0.93 ± 0.03	0 ± 0	4.56 ± 0.05	1.83	0.10
Psocidae	D_D	0.59 ± 0.03	0 ± 0	0 ± 0	0.20	0.01
Imat. Lep.	F_H	1.96 ± 0.05	1.39 ± 0.11	0.59 ± 0.05	1.31	0.07
Micromalthidae	F_H	0.30 ± 0.02	0.56 ± 0.09	2.83 ± 0.09	1.23	0.07
Torrindincolidae	F_H	0.55 ± 0.04	0.56 ± 0.09	0 ± 0	0.19	0.01
Noteridae	P_P	0.30 ± 0.02	0.28 ± 0.02	0 ± 0	0.09	0.00
Dystiscidae	P_P	1.98 ± 0.05	0.56 ± 0.02	0 ± 0	0.84	0.05
Carabidae	P_P	29.63 ± 0.38	1.39 ± 0.50	4.19 ± 0.50	11.74	0.63
Hydraenidae	F_H	0.59 ± 0.04	0 ± 0	0 ± 0	0.20	0.01
Leiodidae	D_D	0.30 ± 0.02	0 ± 0	0 ± 0	0.09	0.00
Staphylinidae	P_P	32.99 ± 0.27	0.83 ± 0.38	34.49 ± 0.38	22.77	1.23
Silphidae	D_D	1.07 ± 0.03	0 ± 0	0 ± 0	0.54	0.03
Bostrichidae	D_D	0.30 ± 0.02	0.28 ± 0.02	0.28 ± 0.02	0.19	0.01
Nitidulidae	D_D	1.66 ± 0.03	0.28 ± 0.02	0.30 ± 0.02	0.74	0.04
Tenebrionidae	D_D	0 ± 0	0.28 ± 0.02	0 ± 0	0.09	0.00
Salpingidae	P_P	0 ± 0	0.28 ± 0.02	0 ± 0	0.09	0.00
Brentidae	F_H	0 ± 0	0.56 ± 0.04	0 ± 0	0.19	0.01
Curculionidae	F_H	0.59 ± 0.03	0 ± 0	1.07 ± 0.02	0.55	0.03
Lucanidae	D_D	0.32 ± 0.02	0 ± 0	0 ± 0	0.11	0.01
Passalidae	D_D	0.30 ± 0.02	1.11 ± 0.11	1.07 ± 0.02	0.82	0.04
Scarabaeidae	D_D	0.61 ± 0.03	0.28 ± 0.02	0.28 ± 0.02	0.39	0.02
Psephenidae	P_P	0 ± 0	0.28 ± 0.02	0 ± 0	0.09	0.00
Throscidae	P_P	0.30 ± 0.03	0.28 ± 0.02	0 ± 0	0.19	0.01
Imat. Coleop.	F_H	28.91 ± 0.21 a	2.78 ± 2.31 b	19.12 ± 0.31 c	16.94	0.91
Siricidae	P_P	0 ± 0	0.28 ± 0.03	0.28 ± 0.02	0.37	0.02
Aulacidae	P_P	7.47 ± 0.15	0.83 ± 0.06	1.34 ± 0.06	3.21	0.17
Dryinidae	P_P	0.30 ± 0.02	0 ± 0	0.28 ± 0.02	0.19	0.01
Myrmicinae	G_B	410 ± 4.68 c	1139 ± 45 b	2007 ± 37.5 a	1.185	63.95
Ponerinae	G_B	38.48 ± 0.60	7.22 ± 0.02	2.25 ± 0.02	46.45	2.51
Formicinae	G_B	4.03 ± 0.61	0 ± 0	21.57 ± 0.18	11.22	0.61
Amblyoponinae	G_B	13.69 ± 0.03	0 ± 0	10.96 ± 0	17.34	0.94
Scelionidae	P_P	0 ± 0	0 ± 0	0.30 ± 0.03	0.10	0.01
Fitigidae	P_P	0.30 ± 0.02	0 ± 0	0.59 ± 0.02	0.49	0.03

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Mymarommatidae	P_P	2.96 ± 0.03	0.56 ± 0.02	0.30 ± 0.02	3.62	0.20
Vespidae	P_P	0.21 ± 0.02	0 ± 0	0 ± 0	0.07	0.00
Ascalaphidae	P_P	1.36 ± 0.02	0 ± 0	0 ± 0	0.45	0.02
Culicidae	P_P	1.36 ± 0.03	0 ± 0	0.55 ± 0.03	0.62	0.03
Aasteiidae	P_P	2.13 ± 0.03	0 ± 0	0.55 ± 0.03	2.47	0.13
Imat.Dip.	D_D	9.48 ± 0.11	0.55 ± 0.03	5.83 ± 0.16	13.31	0.72
Imat.Thys.	D_D	4.27 ± 0.05	0 ± 0	0 ± 0	1.42	0.08
Total		899 ± 94 b	1180 ± 122 b	3345 ± 226 a	1852 ± 146	100
H'		1.86 ± 0.3 a	0.13 ± 0.10 c	0.51 ± 0.37 b	3.34 ± 0.2	
S		74 ± 4.45 a	29 ± 2.22 c	50 ± 4.72 b	94.00 ± 3.7	
J		0.44 ± 0.1 a	0.03 ± 0.02 c	0.12 ± 0.1 b	0.74 ± 0.07	
F_H		43 ± 12 a	7 ± 3 c	51 ± 10 b		
G_B		491 ± 46 c	1146 ± 310 b	2049 ± 472 a		
P_P		116 ± 3 a	6 ± 3 c	78 ± 5.3 b		
D_D		244 ± 12 a	18 ± 13 c	1167 ± 5 b		

Mean ± standard error. Imat.: Imaturo; Orthop.: Orthoptera; Blatt.: Blattodea; Hemip.: Hemiptera; Lep.: Lepdoptera; Dip.: Diptera; Tricop.: Tricoptera; Thys.: Thysanura; G\_F: functional groups; D\_D: detritivores/decomposers; P\_P: predators/parasites; F\_H: phytophagous/herivores; G\_B: geophagous/bioturbators. n = 16. Means followed by the same letters in the lines do not have a significant difference by the Wilcoxon test at 5 % of probability.



**Figure 2.** Macrofauna total density (ind. m<sup>-2</sup>) in the different LUS and respective layers in Marabá-PA, Brazil. Mean and standard error (line bars). SF: Secondary Forest; PAS: Pasture; EUC: Eucalyptus. Means followed by the same letters in the same LUS do not have significant difference by Wilcoxon test at 5 % of probability.

In every LUS studied, the soil exchangeable content of K<sup>+</sup>, Ca<sup>2+</sup>, and P were classified as low, Zn as average, and Fe and Mn as high. In the SF, the low content of soil organic matter (SOM) and Mg was observed, whereas in the EUC, SOM, and Mg have presented an average content. Only the SF have presented high content of Al<sup>3+</sup> (Table 2), based on soil fertility index of Pará State (Cravo et al., 2007).

**Table 2.** Chemical properties in the soil layer of 0.00-0.20 m collected in the Secondary Forest (SF), Pasture (PAS), and Eucalyptus (EUC) in Marabá-PA, Brazil

Land use	pH(H <sub>2</sub> O)	g kg <sup>-1</sup>			cmol <sub>c</sub> kg <sup>-1</sup>			mg kg <sup>-1</sup>			
		S.O.M	N	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Al <sup>3+</sup>	P	Fe	Zn	Mn
FS	4.49 a	18.70 a	1.25 a	0.34 a	0.36 a	0.14 a	3.77 a	1.04 a	264 a	1.02 a	41.22 a
PAS	5.43 b	27.35 b	1.17 a	1.28 b	0.37 a	0.13 a	0.49 b	1.13 a	490 b	1.13 a	26.85 b
EUC	5.35 b	26.36 b	1.20 a	1.48 b	0.93 b	0.21 b	0.43 b	1.56 b	297 a	1.56 a	39.34 a

SOM: Walkley-Black (1934); N: Kjeldahl method; pH in water at a ratio of 1:2.5 soil:solution; P, K, Fe, Zn, and Mn were extracted with Mehlich-1 (H<sub>2</sub>SO<sub>4</sub> 0.05 mol L<sup>-1</sup> + HCl 0.125 mol L<sup>-1</sup>); Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Al<sup>3+</sup> were extracted by KCl 1 mol L<sup>-1</sup>. Values followed by the same letter in the columns indicate absence of statistical difference. Median. n = 16.

## DISCUSSION

The results of the chemical properties of the soil in this study are consistent with many other that studied the soil fertility in the Amazon region for secondary forests (Salim et al., 2017; Villani et al., 2017). Santos et al. (2018) observed low contents of soil organic matter, associated with soil acidity, low sum of exchangeable bases, and low extractable P ( $5.12 \pm 1.13$ ,  $7.29 \pm 1.72$  mg kg<sup>-1</sup> of P), when studying a pasture area (8 years) and a secondary forest (30 years). In the same study, the Al<sup>3+</sup> and the potential acidity were higher in secondary forest soil and lower in cultivated soils. However, regarding the land management systems (shifting cultivation, pasture, mixed fallow, and secondary forest), no significant influences were detected regarding the chemical properties of the soil.

Pastures with an average age of 17.6 years presented soil organic carbon stocks slightly higher than the primary forest ( $+6.8 \pm 3.1\%$ ) (Fujisaki et al., 2015). In a long-term study, Durigan et al. (2017) did not find significant values in the C and N stocks of the soil regarding the conversion of the Brazilian Amazon forest to pasture after the tenth year of implantation (pasture of 5, 10, and 20 years). According to the authors, the C stock in the soil is due to additional inputs of grasses, as well as the combination of silt and clay.

In the present study, the amounts of litter in the Eucalyptus and Secondary Forest areas are similar to the values found in the Eastern Amazon (Barlow et al., 2007), in which no significant differences were found between the Secondary forest ( $6.8 \text{ Mg ha}^{-1} \text{ year}^{-1}$ ) and the Eucalyptus area ( $4.5 \text{ Mg ha}^{-1} \text{ year}^{-1}$ ). The eucalyptus litter has a high concentration of lignin as well as high C/N, C/P, and C/S ratios, which contributed to slow decomposition (Silva et al., 2018; Laird-Hopkins et al., 2017) and accumulation of material above the ground. Furthermore, the increases in the stocks of total organic carbon and total nitrogen in the most superficial layers also play a important role (Vieira et al., 2014). As a consequence, there is reduction in the mineralization of plant nutrients (Martins et al., 2017), which can be verified by the higher total values of macronutrients in the Eucalyptus area in the present study, with the exception of N and P. Correlations between litter mineral contents (Table 3) and the community structure were not found, possibly because the litter biomass was not separated into fractions (branches, leaves, and detritus), this is why each fraction has a different turnover time scale thus, having different contents of minerals (Vieira et al., 2014). Moreover, the polyphenol contents (not assessed in this study) are highlighted as the main feature that influences the macrofauna palatability (Laird-Hopkins et al., 2017; Boenoa et al., 2019).

The diversity of families (H') had a reduction of 92 % from Secondary Forest (72) to Pasture (30). The taxa that most contributed to this percentage reduction were individuals from the Arachnida group (eliminated from the agroecosystem - Dipluridae, Anapidae, Ooponidae, Orsolobidae, Symphytognathidae, Zoderiidae, Caponiidae, Eremobatidae, Agaristenidae, Cranidae, Stygnommatidae, Palpigradi, Chthoniidae, Lechytiidae, and Olpiidae) and Myriápoda (79 % reduction from the Second Forest Pasture area - Dipluridae, Anapidae,



**Table 3.** Dry matter and litter total nutrient contents in the 40-year Secondary Forest (SF) and 10-year Eucalyptus monoculture (EUC) (clone I-144) in Marabá-PA, Brazil

Land use	M.S	Fe	Zn	Mn	Ca	Mg	K	C	N	P
	kg ha <sup>-1</sup>	mg kg <sup>-1</sup>			g kg <sup>-1</sup>					
FS	1,884.48 a	404.97 a	46.18 a	136.91 b	8.15 a	2.40 b	4.57 a	454 a	9.84 a	0.34 a
EUC	2,028.16 a	166.00 b	26.90 b	399.55 a	8.61 a	3.24 a	6.74 a	314 b	8.46 a	0.29 a

C: extracted and determined by the Walkley-Black method adapted using 250 g of crushed soil and HNO<sub>3</sub> (65 %) and H<sub>2</sub>O<sub>2</sub> (30 %) as reagents; N: Kjeldahl method; total of macro (Ca, Mg, K, and P) and micronutrients (Fe, Zn, and Mn) digestion by nitric-perchloric method. Values followed by the same letter in the columns indicate absence of statistical difference. n = 16.

Ooconidae, Orsolobidae, Symphytognathidae, Zoderiidae, Caponiidae, Eremobatidae, Agaristenidae, Cranidae, Stygnommatidae, Palpigridi, Chthoniidae, Lechtyidae, and Oplidae). The taxa Diplura, Pseudoscorpionida, Araneae, Chilopoda, and Gastropoda are associated with preserved areas (Suárez et al., 2018), which makes these organisms bioindicators of agroecosystem sustainability.

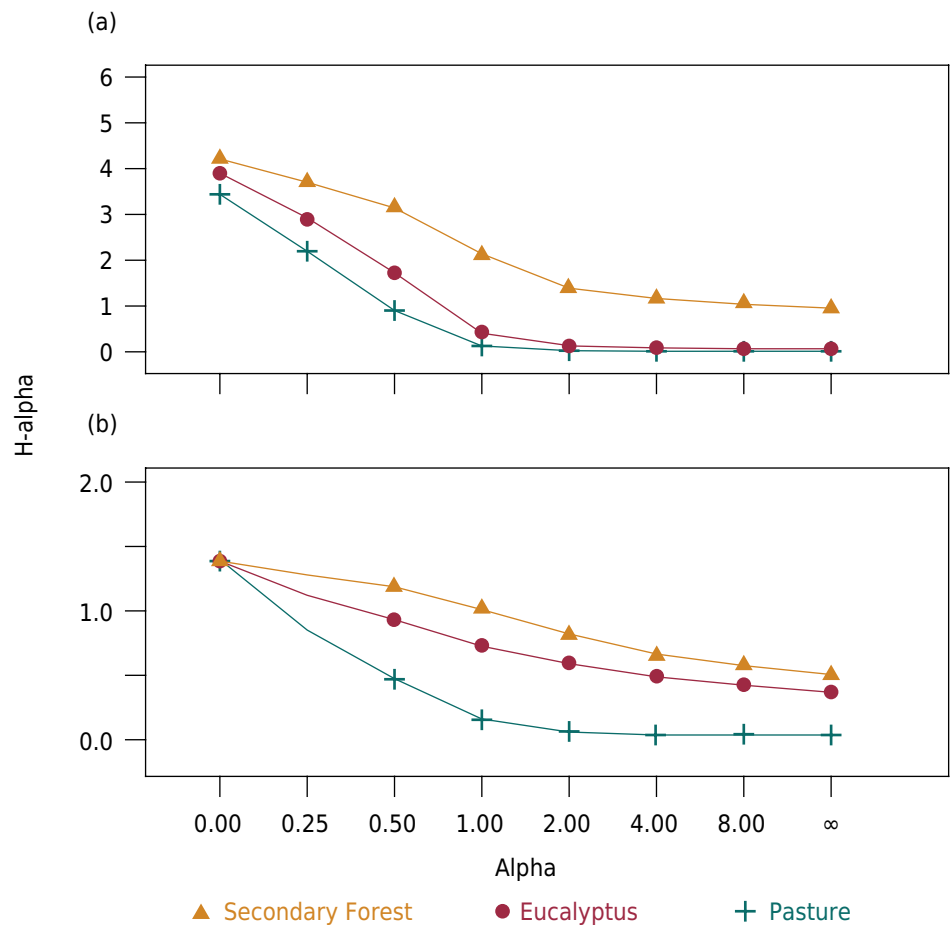
This reduction is related to the lower structural complexity of the Pasture area due to: the absence of litter (Ferrenberg et al., 2016; Rodrigues et al., 2016), unstable microclimate determined by the greater variation in soil temperature (Gullan and Craston, 2017) and less functional structural and complexity of the vegetation, which reduce the quantity and quality of nesting sites (Lo Sardo and Lima, 2019). In pasture areas in the state of Pará in the presence of Poaceae tufts, the morphospecies richness was twice as high (9-10 species per monolith) when compared with the surrounding areas (4-5 morphospecies). When this effect was extended to the total density (768 ind. m<sup>-2</sup> in the first case, and 274 ind. m<sup>-2</sup> in the second case) (Mathieu, 2004), it showed the importance of microclimate conditions in the abundance of edaphic invertebrates. This effect extends up to 100 m in areas nearby the forest. Marichal et al. (2014) found greater density and diversity of soil macrofauna at points located on pastures 100 m away from the forest when compared with pastures with no forest in the surrounding area, which was mainly related to soil moisture conditions ( $r^2 = 0.38$ ,  $p < 0.01$ ).

The results of the present study support the hypothesis that the structure and composition of the edaphic macrofauna changes as well as vegetation alterations, which formed a gradient of complexity (Secondary Forest > Eucalyptus > Pasture). The higher values of diversity indexes in the Secondary Forest compared with the Eucalyptus area (Table 1) indicated a greater uniformity between the abundance of families for the Secondary Forest, which represents greater structural integrity of the community and expresses the presence of rare organisms (Lo Sardo and Lima, 2019). The implantation of the tree component in the evaluated area in 2008, with consequent contribution and accumulation of litter, resulted in an increase in the number of families from the Pasture area (30 families) to the Eucalyptus area (50 families), which was expressed by the increase in the abundance of individuals in the groups Arachnida and Myriápoda at the Eucalyptus area. However, the mean D<sub>D</sub> and P<sub>P</sub> values found in the Eucalyptus area are lower than those found in the Secondary Forest ( $p < 0.05$ ). This result is in accordance with the theoretical expectation, in which a greater structural diversity of the environment implies greater species diversity (Amazonas et al., 2018). The possibility of specific organisms to find food and increase the supply of food for generalist organisms allows the association with different niches and food resources (Lo Sardo and Lima, 2019). Therefore, a greater diversity of taxonomic and trophic groups is advantageous, since in a situation of disruption if a group is compromised, the other groups prevailing can compensate it, playing the same ecological role (Correia et al., 2018; Quadros and Zimmer, 2018).

In general, there is a reduction in the total abundance of edaphic fauna over the years in more diversified agroecosystems, in which richness indexes tend to stabilize, on average, after seven years under crop-free managements (Mathieu, 2004; Correia et al., 2018). This

can be explained by the process of retrogression, in which plant succession is no longer complex after a few decades of succession (Rousseau et al., 2014). A similar pattern of colonization by the edaphic macrofauna was found in Itupiranga, state of Pará, in a seven-year - primary forest - pasture- secondary vegetation" sequence (Mathieu, 2004). In the present study, from the age of seven, the secondary vegetation management system already showed similar results when compared with the primary forest for earthworms, termites, ants, coleopterans, spiders, millipedes, and centipedes. Moreover, individuals from the Arachnida and Diplopoda group were found to have significantly greater abundances in the Secondary Forest area when compared with six-year Pasture area (Mathieu, 2004).

An indicative of this colonization process is given by the family richness diversity profiles (Figure 3a) and functional groups richness (Figure 3b) which follow the order SF > EUC > PAS. The SF highest alpha (infinite), indicates that is more diverse and its families distribution and abundance are more equitable. Two aspects have to be considered: if the profiles are crossed, it is possible that a location has more richness while the other has more equitability, although this does not mean to be a necessary condition, moreover, as the abundance between families are changing the equitability decreases whereas the trend line becomes steeper (Kindt and Coe, 2005). The results of the present study are similar to that of Rousseau et al. (2014), who worked with a chronosequence of secondary vegetation areas, forests and pastures in Eastern Amazon. The authors showed that the effect of history is similar to the effect of agricultural intensification because, as the use increases in intensity, the community of predators



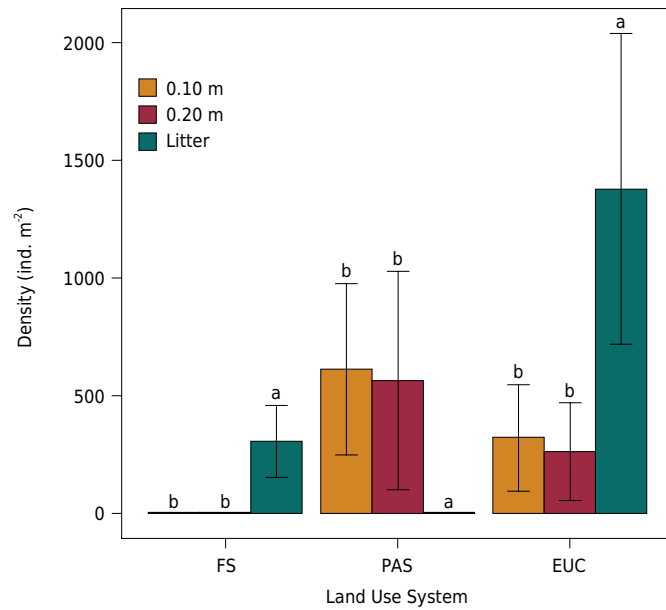
**Figure 3.** Rényi diversity profiles in the different LUS in Marabá-PA. Family diversity profile (a), functional groups (b) diversity profiles.  $\alpha = 0$ : Family richness;  $\alpha = 1$ : Shannon-wiener index;  $\alpha = 2$ : Simpson index;  $\alpha = \infty$  (infinite): Berger-Parker index.

decreases in abundance and diversity. In this study, despite 10 years more recent than Pasture, the use of more conservation soil in the Eucalyptus area presents better results in ecological index. The Diplura, Pseudoscorpionida, Araneae, Chilopoda, and Gastropoda taxa are highly sensitive to management practice, being associated with preserved sites, which allow their populations to serve as bioindicators of soil quality and environmental recovery (Rodrigues et al., 2016; Kamau et al., 2017; Suárez et al., 2018; Sánchez-Bayo et al., 2019).

In monoculture systems, the recovery of the community structure of the edaphic fauna after the disturbance is expressed differently when compared to more complex systems. Studies show that despite the increase in density and diversity in abandoned eucalyptus areas, the composition of the edaphic fauna tends to be different from natural ecosystems. Boenoa et al. (2019), studied the edaphic mesofauna in an area composed of *Eucalyptus grandis* with eight years of implantation and found the recovery of the biological quality of the soil expressed by the population of springtails, with a significant increase in the population of Cryptostigmata mites after six years of eucalyptus implantation. However, both densities (total and relative) of the two groups were higher than those found in the native forest. This pattern was also observed by Souza et al. (2016) in a secondary forest area, where land use systems change the composition of soil macrofauna, with less diversity in an area with greater intensification of land use, showing the following: sequence native forest > eucalyptus plantation > pasture. In both studies, eucalyptus cultivation inhibited the presence of several groups of soil macroinvertebrates, which is a result showed by other authors (Souza et al., 2016; Amazonas et al., 2018; Camara et al., 2018). In agroecosystems where there is a simplification of the environment, the deposited litter presents different characteristics, such as low concentration of nutrients and high levels of total polyphenols, among others, resulting in a decrease in the taxonomic groups of soil invertebrate communities (Baretta et al., 2014). In these areas, monoculture management systems, reductions in the abundance and the diversity of more specific organisms are observed, favoring the abundance of competitively more capable organisms, such as the Formicidae family, which can colonize environments with scarce resources (Gutiérrez et al., 2017a).

Studies show that conditions provided by anthropic activity, such as greater incidence of sunlight in the nests and greater supply of plant resources of spontaneous plants are favorable to the establishment of the family in the environment (Mathieu, 2004; Gullan and Cranston, 2017). This fact is corroborated by the number of individuals in the generalist subfamily Myrmicinae, which approximately triples the density from the Secondary Forest to the Pasture area in the present study (1,139 ind. m<sup>-2</sup>), favoring its relative abundance (45.2 %) (Figure 4). Similarly, Gutiérrez et al. (2017a,b), using different sampling methods, also registered the subfamily Myrmicinae as the dominant taxonomic group in tropical agroecosystems.

The ecological fitness of the Myrmicinae with regards to feeding habits, nidification, and competition mechanisms seems to explain the significant total and relative abundance within and between the SUS (Gutiérrez et al., 2017a). From the SF to the PAS, the reduction of nidification and foraging sites favor both abundance metrics. Since this subfamily feeding habits are generalist, they can play different roles in the trophic chain, acting as predators or primary consumers (Gutiérrez et al., 2017b). On the other hand, with the increasing of diversity, there is an increase of the trophic interactions such as competition and predation, pointed out by the larger abundance of predators in the EUC when compared to the PAS ( $p < 0.05$ ), simultaneously, the suppression of specific species and sensitive species to secondary metabolites may occur (Souza et al., 2016; Laird-Hopkins et al., 2017). Chilopoda and Araneae are predominantly predators and their presence in the EUC indicate greater prey diversity in this environment compared to the PAS, which can be related to the reduction in the relative abundance of Myrmicinae when compared to the PAS ( $p < 0.05$ ).



**Figure 4.** Total density of the Myrmicinae subfamilie in the different LUS and depths in Marabá-PA, Brazil. Mean and standard error. SF: Secondary Forest; PAS: Pasture; EUC: Eucalyptus. Means followed by the same letters in the same LUS do not have a significant difference by the Wilcoxon Signed Rank Test at 5 % of probability.





Studies regarding the ecology and biology of the Enchytraeidae family in the tropics or subtropics are still incipient. These organisms are often correlated with high levels of moisture and substrates in the form of partially decomposed organic matter (Römbke et al., 2017). This pattern observed by Martins et al. (2017), in which the family was found in the cultivation of sugar cane (*Saccharum officinarum* L.) with higher density than in the area of primary forest, which was related to positive values of humidity and P levels ( $13 \text{ mg dm}^{-3}$ ). Franco et al. (2016) found similar results, relating it to percentages of humidity and soil organic matter rather than land use and cover. In the present study, the Eucalyptus area is the one with the highest percentage of soil organic matter combined with better microclimate conditions, which might explain the significantly higher density of the taxon in the area ( $1,113 \text{ ind. m}^{-2}$ ) when compared with the Secondary Forest ( $150 \pm 1.5 \text{ ind. m}^{-2}$ ). The organisms often react very sensitively to microclimate humidity conditions due to their close contact with the soil pore water, as well as their high intake rate capacities and their fine cuticle (Römbke et al., 2017).





## CONCLUSIONS





The community structure of the edaphic macrofauna was influenced by the land use systems. The best structure indexes of the edaphic macrofauna were found in the secondary forest, followed by the eucalyptus monoculture and the pasture. The edaphic macrofauna groups were efficient bioindicators for each land use. However, in tropical degraded areas, such as pastures and eucalyptus monocultures, the abundance of well-adapted organisms tend to be favored, which makes the total density of the edaphic macrofauna alone does not appear to be a reliable soil bioindicator.





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**Software:**  Werica Larissa Farias de Vasconcelos (equal),  Diego de Macedo Rodrigues (equal),  Rafael Oliveira Carvalho Silva (supporting), and  Sônia Sena Alfaia (equal, supporting).



**Validation:**  Werica Larissa Farias de Vasconcelos (equal),  Diego de Macedo Rodrigues (equal),  Rafael Oliveira Carvalho Silva (equal), and  Sônia Sena Alfaia (equal).





**Formal analysis:**  Werica Larissa Farias de Vasconcelos (equal),  Diego de Macedo Rodrigues (supporting),  Rafael Oliveira Carvalho Silva (supporting), and  Sônia Sena Alfaia (supporting).





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