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The effects of cattle ranching on the communities of necrophagous flies (Diptera: Calliphoridae, Mesembrinellidae and Sarcophagidae) in Northeastern Brazil

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Abstract

Most of the ongoing decline in biodiversity, worldwide, is due to human activities, in particular, the expansion of agriculture. In this context, we highlight the need for studies of the taxonomic groups that can provide insights into the dynamics of the ecological communities facing anthropogenic impacts. For this, we evaluated the effects of the environmental changes caused by cattle ranching on five phytophysiognomies (Cerrado Savanna, Amazon Forest, Palm Forest, Marshland, and Mangrove) in the state of Maranhão, Brazil. We tested the hypothesis that the species composition, abundance, and richness of the families Calliphoridae, Mesembrinellidae, and Sarcophagidae (Diptera) are affected by ranching in each of the phytophysiognomies. Specimens were collected at 90 sites, including 45 anthropic sites (cattle ranches) and 45 preserved habitats, using traps baited with bovine lung. We collected 15,023 calliphorids (11 species), 10,772 sarcophagids (52 species), and 241 mesembrinellids (one species). The results indicated significant differences between anthropic and preserved habitats in the species composition, abundance, and richness of sarcophagids, in particular in the Amazon Forest, where the highest species richness was recorded in the anthropic environments. In the case of the calliphorids and mesembrinellids, by contrast, significant differences were found in species composition and abundance in only in four of the five phytophysiognomies analyzed (excluding the Cerrado Savanna), while species richness only varied in the palm forest and marshland. In all cases, lower values were recorded in the anthropic environments. These results indicate that the insects of the families Sarcophagidae, Calliphoridae, and Mesembrinellidae respond differentially to the anthropic activity (cattle ranching) and can be used to evaluate this type of anthropogenic impact systematically. In addition, the Amazon Forest was the phytophysiognomy most impacted by this activity in the Brazilian state of Maranhão.

Keywords Land use · Pasture · Neotropical region · Oestroidea

Introduction

The homogenized vegetation and high levels of habitat disturbance found in anthropogenic environments can limit the survival of many species (Forister et al. 2019; Sánchez-Bayo and Wyckhuys 2019). The homogenization of the vegetation, in particular, is known to have negative effects on biodiversity (Benton et al. 2003; Tavares et al. 2019). There is convincing evidence that the progressive intensification of agricultural activities is the principal factor determining the population decline observed in a wide variety of taxa, including birds, insectivorous mammals, and insects (Sánchez-Bayo and Wyckhuys 2019). In areas used to raise livestock, the changes in spatial heterogeneity caused by grazing have negative effects on the species composition, richness, and abundance of many types of organism, ranging from invertebrates to mammals (Dennis et al. 1998; Wallis-de-Vries et al. 2007). In the case of arthropod communities, environments with more structurally complex habitats tend to have higher species richness, which is probably due to both the variety of habitats and the greater availability of

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food resources (Tews et al. 2004). For insects, changes in the habitat or plant community can affect the distribution of species, especially of the more sensitive or specialized taxa (Brown 1997).

The flies (Diptera) of the families Calliphoridae, Mesembrinellidae, and Sarcophagidae are widely distributed and can be found in an ample range of environments (Guimaraes 1977; Shewell 1987a, b; Erzinçlioglu 1996; Pape 1996; Whitworth and Yusseff-Vanegas 2019). These flies have a high ecological value, given the role of their larvae in the decomposition of organic material (Guimarães and Papavero 1999; Furusawa and Cassino 2006). Given this, they are potential bioindicators for the assessment of impacts (Sousa et al. 2015), and can be used to monitor forest restoration programs, given their abundance, the diversity of the niches they occupy, and their multiple trophic interactions (Majer 1987). The anthropophilic habits of the sarcosaprophagous dipterans (Galante and Marcos-Garcia 2004) also make them ideal candidates for use as bioindicators (Majer 1987) and for the the assessment of short-and long-term environmental changes (Sousa et al. 2014).

Studies of calliphorids have detected considerable variation in their ecological requirements and tolerance of environmental impacts, with some species being adapted to anthropogenic environments, while others require preserved habitats (Gomes et al. 2000; Esposito et al. 2009, 2010; Ferraz et al. 2009, 2010; Sousa et al. 2010; Gonçalves et al. 2011; Koller 2011, Cabrini et al. 2013). Mesembrinellids are typical of humid habitats and are exclusive to the tropical forests of the Neotropical region (Guimarães 1977; Wolff and Kosmann 2016). These flies also tend to be associated with primary or preserved forest environments, and are classified as asynanthropic (Mello et al. 2007). The greatest concentrations of mesembrinellid species has been found in the most preserved areas of the Amazon (Esposito et al. 2010; Sousa et al. 2010) and Atlantic Forests (Gadelha et al. 2009; Ferraz et al. 2010; Cabrini et al 2013; Figueiredo et al. 2018). These dipterans may thus be potential bioindicators of environmental quality, responding to different types of environmental impact (Gadelha et al. 2009).

Sarcophagids, by contrast, appear to be more plastic, and tend to be more abundant in anthropogenic environments (Mulieri et al. 2008; Sousa et al. 2011a, b). In this context, a number of studies have focused on the variation in the degree of adaption of these flies to different levels of anthropogenic disturbance, including deforestation, farming, and urban development (Valverde-Castro et al. 2017; Dufek et al. 2019). However, few studies have evaluated the impact of grazing land on these flies. The few studies that do exist report a greater abundance of sarcophagids in areas of pasture in comparison with forest and changes in the characteristics of sarcophagid communities that may reflect the effects of the proximity of these environments to urban

areas (Mulieri et al. 2008). In the case of the Calliphoridae and Mesembrinellidae, the available studies have focused on changes in species composition related to human activities (Ferraz et al. 2010; Cabrini et al. 2013; Dufek et al. 2019), but have not investigated specifically the effects of cattle ranching on these flies.

In the Brazilian state of Maranhão, the suppression of the native forest cover is related primarily to the expansion of areas of farmland, principally for cattle pasture and monocultures, which has profound impacts on the local fauna and flora (Lemos 2001). Although cattle ranching is concentrated primarily on the northern lowland plain (Baixada Maranhense), the Cerrado savanna in the south of the state, and the palm forest (Cocais) of the central region, it is found throughout Maranhão, including the Amazon Forest, in the west (Barreto et al. 2008). This provides an opportunity to study the effects of cattle ranching on fly communities in the full range of natural environments found in the state, in order to detect and analyze the influence of this type of impact on community structure and ecosystem services.

The present study assesses the community structure of the necrophagous dipterans of the families Calliphoridae, Mesembrinellidae, and Sarcophagidae in well-preserved and anthropic (cattle ranches) environments in five natural phytophysiognomies (Amazon Forest, Cerrado Savanna, Palm Forest, marshland, and mangrove) in Maranhão state, northern Brazil. We tested the hypothesis that the species composition, richness, and abundance of the three dipteran families, in particular, the Calliphoridae + Mesembrinellidae (C + M) group, are impacted by the presence of grazing land in all five phytophysiognomies, especially in the more complex vegetation types (Amazon Forest, Cerrado Savanna, and Palm Forest), which have more habitable niches.

Material and methods

Study area

The present study was conducted at 90 sites, 45 located in preserved areas and 45 in neighboring anthropic environments, on cattle ranches, in 17 municipalities in the state of Maranhão, Brazil (Fig. 1, S1 Table). The 90 sites (sampling units) were distributed evenly among the five natural phytophysiognomies found in the state, that is, the Cerrado Savanna, Amazon Forest, Palm Forest, Marshland, and Mangrove.

The Cerrado Savanna can be divided into four habitat subgroups based on the stature and density of its trees and shrubs—savanna woodland (Cerradão), arboreal savanna, park savanna, and grassy-shrubby savanna (IBGE 2012). Areas of Cerradão were selected for the present study. This forest formation has a non-grassy herbaceous stratum
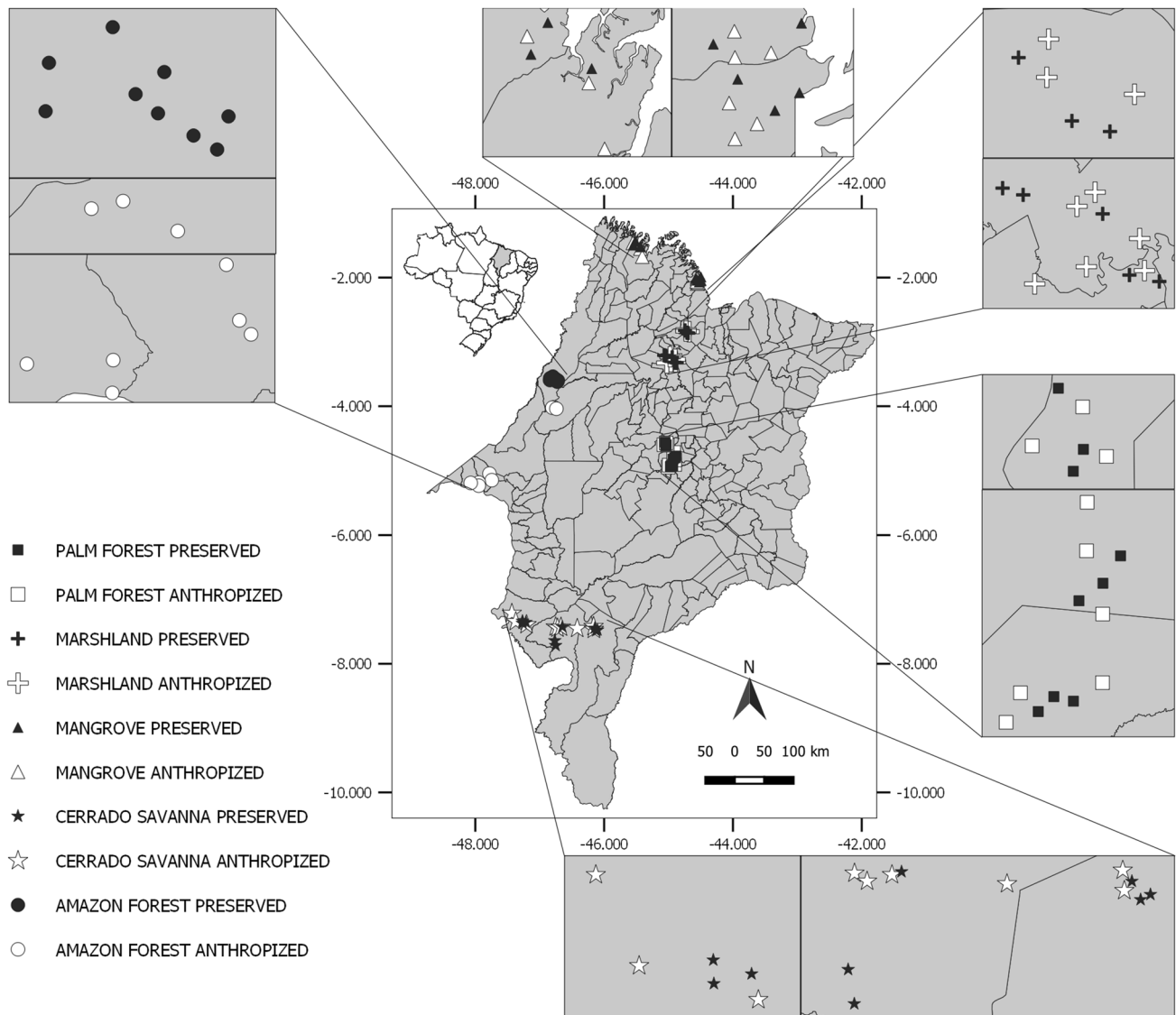
Fig. 1 Map of the 90 sites sampled in Maranhão state, northeastern Brazil, between 2010 and 2012

dominated by seedlings and shrubs, with relatively well-developed tree cover and taller trees than those found in the other savanna subtypes (Marinho-Filho et al. 2010) (S2 photographs of the five phytophysiognomies).

The Amazon Forest is dominated by vegetation of the dense rainforest type, with trees reaching a height of 20 m (IBGE 2012). Tropical forests are known for their high plant diversity (Svenning 1999), which is sustained in large part by niche differentiation (Svenning 2001), and is closely related to the spatial heterogeneity of the forest (S2 Photographs).

The Palm Forest (Cocais) is located between the Cerrado savanna and the Amazon Forest, and is characterized by a mixture of the plant species found in these two types of vegetation. The Cocais are evergreen forests dominated by the babassu palm (*Orbignya phalerata*), and trees of relatively

reduced height in comparison with the typical dense Amazon broadleaf forest (S2 Photographs).

The marshland zone is a large area formed by a series of lakes surrounded by extensive marshes, which are dry for approximately seven months of the year. These floodplains are dominated by open vegetation, with some taller trees and palms. The sites selected for the present study were open fields dominated by herbaceous vegetation, interspersed with a few trees and lianas (S2 Photographs).

The mangrove is a microphanerophyte community found in brackish environments, generally in estuaries and coastal channels, where the muddy substrates support this specialized vegetation adapted to highly saline conditions, including *Rhizophora mangle* L., *Avicennia* spp. (the local species depends on the latitude), and *Laguncularia racemosa* L.,

which grows on the highest terrain, which is only flooded at high tide (S2 Photographs).

We considered anthropic areas to be those in where the original vegetation had been impacted by cattle ranching, such as deforestation for the planting of pasture or the use of natural pastures as grazing land, a phenomenon typical of the marshland and mangrove. Sousa et al. (2016) provide a more detailed description of the five phytophysiognomies surveyed in the present study.

Data collection

Nine replicates of each phytophysiognomy were sampled, with a minimum distance of 2 km between each. In each area, two sites were sampled, one representing the natural vegetation and the other, representing the anthropic environment. Each site was sampled twice, with five traps per sample, and a total of 180 traps per phytophysiognomy, and 900 traps overall. The field campaigns for the collection of the dipteran specimens were conducted during the dry season in 2010 (August–October, 2011 (April–October), and 2012 (May–November).

The specimens were collected using traps designed specifically to capture saprophagous dipterans (Ferreira 1978) and used successfully by Sousa et al. (2010). The traps were baited with 50 g of cow lung (decomposed for 24 h) hung on tree branches 40 cm above the ground in shaded locations at 200-m intervals along a 1 km transect of 200 m, where they were left for 48 h.

The calliphorid and mesembrinellid specimens were identified using the taxonomic keys of Mello (2003), Carvalho and Mello-Patiu (2008), Kosmann et al. (2013), and Whitworth and Yusseff-Vanegas (2019). The sarcophagids were identified using the species keys available for the genera *Oxysarcodexia* Townsend (Lopes and Tibana 1987) and *Peckia* Robineau-Desvoidy (Buenaventura and Pape 2013) and other references, including Lopes (Lopes 1939, 1958, 1989), Tibana (1976, 1981), Tibana and Xerez (1985), and Guimarães (2004). As the taxonomic identification of the sarcophagids is based primarily on the male genitalia, only the males were identified in the present study. Part of the material collected was prepared in a dry medium and deposited in the Entomology Collection at the Goeldi Museum (Museu Paraense Emílio Goeldi: MPEG) and the Museum of Zoology at the Biological Sciences Institute of the Federal University of Pará (UFPA), which are both located in the city of Belém, Pará (Brazil). The remaining specimens were preserved in a liquid medium (70% ethanol) and included in the teaching collection of the Environmental Sciences and Biodiversity Laboratory at the São Luis campus of Maranhão State University (UEMA).

In the present study, we follow the arrangements of Marinho et al. (2017) and Whitworth and Yusseff-Vanegas

(2019), who consider the Mesembrinellidae to be a valid family, rather than a subfamily of the Calliphoridae. Even so, Rognes (1997) aligns the Mesembrinellidae closely with some other calliphorid subfamilies, such as the Auchmeromyinae, Bengaliinae, and Phumosiinae. Given the taxonomic proximity of these two families, and the identification of only one mesembrinellid species in the study area, the analyses of species richness, composition, and abundance conducted in the present study considered a single group containing the calliphorids and mesembrinellids (referred to here as the C + M group).

Data analysis

Species richness was estimated for each type of environment (preserved *vs.* anthropic) in each phytophysiognomy using the first-order jackknife estimator, with 1000 randomizations, considering the number of traps as the samples (Colwell et al. 2004). This analysis was run in EstimateS, the Statistical Estimation of Species Richness and Shared Species from Samples, version 9.0 (Colwell 2013).

Each occurrence of a species considered to be rare (Colwell 2013) increases the heterogeneity of the data set and the probability of encountering a new species. In this case, the first-order jackknife estimator is less strict than other estimators, with species occurring in only one sample ("unique species") being considered rare (Santos 2009). For this reason, we selected this estimator as the most appropriate for the present study. The sampling efficiency of the species of the C + M group and the family Sarcophagidae was calculated using the following formula: (observed richness/estimated richness) × 100. A confidence interval-based inference approach was used to test the hypothesis that the species richness of the two groups (C + M and Sarcophagidae) is affected by the anthropogenic impact of cattle ranching on each of the phytophysiognomies. This approach was also based on first-order jackknife estimates (Colwell et al. 2004), with the two types of environment (anthropic and preserved) being considered significantly different when the confidence interval of one environment did not overlap with the mean value of the other.

Species composition was analyzed using non-metric multidimensional scaling (NMDS) based on a Bray–Curtis dissimilarity matrix (Legendre and Legendre 1998; Clarke and Warwick, 2001). Prior to this, the abundance data were log (x + 1) transformed to reduce the effect of discrepant values. The present study tested only a single factor, that is, the presence/absence of cattle ranching. To test the hypothesis that cattle ranching has differential effects on the species composition and abundance of the two dipteran groups (C + M and Sarcophagidae) a nonparametric permutational analysis of variance (PERMANOVA), for models with multiple factors, was applied based on a Bray–Curtis similarity index,

with 9999 permutations (Andersen 2005). When significant results were obtained by the PERMANOVA, multiple pairwise a posteriori tests were applied to compare the two environments in each phytophysiognomy. All analyses were run in the R program of the R Development Core Team (2018), using the Vegan (Oksanen et al. 2007) and Mass packages (Ripley et al. 2013).

Results

A total of 15,023 calliphorid specimens were collected during the present study, representing seven genera and 11 species (S3 Table). Two species, *Chrysomya albiceps* and *Cochliomyia macellaria*, together accounted for nearly 71% of the total number of specimens collected in the two environments, although both species were more abundant at the anthropic sites. *Chloroprocta idioidea* and *Paralucilia paraensis* were more abundant in the preserved environments, by contrast (S3 Table).

The family Mesembrinellidae was represented by a single species, *Mesembrinella bicolor*, which was present only at one preserved Amazon forest site, where 241 specimens were collected (S3 Table). In the case of the sarcophagids, 10,772 specimens were collected in 15 genera and 52 species (S4 Table). *Tricharaea (Sarcophagula) occidua* and *Peckia (Sarcodexia) lambens* represented approximately 73% of the specimens, and while they were collected in the two environments, they were more abundant at the anthropic sites (S4 Table). *Oxysarcodexia intona* (Curran & Walley, 1934), *Peckia (Euboettcheria) collusor* (Curran & Walley, 1934) and *Peckia (Squamatodes) ingens* (Walker, 1849) were more abundant in the preserved environments.

Species richness

Sampling efficiency varied between 62 and 100% for the Calliphoridae and between 70 and 88% for the Sarcophagidae (Table 1), which indicates that the sampling effort employed in the present study was adequate to determine the diversity of these dipterans found in the different study areas.

The highest estimated species richness values for the C+M group were recorded in both environments (preserved and anthropic) of the Cerrado Savanna and Amazon Forest, and in the preserved Palm Forest (Table 1). When comparing this dipteran group between environments in each phytophysiognomy, significant differences were found only in the palm forest and marshland areas, where species richness was greater in the preserved environments. These differences are significant because the confidence intervals recorded for the two environments do not overlap (Fig. 2).

In the family Sarcophagidae, the highest estimated species richness values were recorded in both environments (preserved and anthropic) in the Cerrado Savanna and Palm Forest, and at the anthropic sites in the Amazon Forest (Table 1). Significant differences (non-overlapping confidence intervals) were only found in the Amazon Forest, however, where species richness was higher in the anthropic environments (Fig. 3).

Species composition and abundance

Dipteran species composition and abundance varied significant between environments (anthropic and preserved) in both the C+M group (pseudo-F = 43.87; df = 1; p < 0.001) and the Sarcophagidae, pseudo-F = 6.88; df = 1; p < 0.001 (Table 2). Multiple a posteriori comparisons indicate significant differences between environments (p < 0.001) in the C+M group in four of the five phytophysiognomies evaluated, i.e., Palm Forest, Amazon Forest, Marshland, and Mangrove (Table 3). In the sarcophagids, however, a significant difference (t = 2.16; p = 0.003) was found only in the case of the Amazon Forest (Table 3). The variation in the composition of the dipteran communities did not vary significantly between environments in the other phytophysiognomies analyzed (Table 3).

The NMDS ordination segregated the C+M communities into four groups (Fig. 4). One of these groups encompassed

Table 1 Observed and estimated species richness and the sampling efficiency (observed richness divided by estimated richness) of the two dipteran groups (Sarcophagidae and Calliphoridae + Mesembrinellidae) sampled in anthropic (cattle ranching) and preserved environments in the five phytophysiognomies of Maranhão state, Brazil, between 2010 and 2012. *A* Anthropic environments, *P* Preserved environments

	Cerrado Savanna		Palm forest		Amazon forest		Marshland		Mangrove	
	A	P	A	P	A	P	A	P	A	P
Calliphoridae + Mesembrinellidae										
Observed richness	10	11	6	9	9	9	3	4	4	5
Estimated richness	12	14	7	11	11	14	3	6	6	8
Sampling efficiency (%)	83	78	85	82	82	64	100	66	66	62
Family Sarcophagidae										
Observed richness	26	26	16	20	27	7	12	10	13	16
Estimated richness	34	35	22	27	36	10	15	12	15	18
Sampling efficiency (%)	76	74	72	74	75	70	80	83	86	88

Fig. 2 Estimated species richness of the Calliphoridae + Mesembrinellidae (C + M) group (Jackknife 1; mean ± confidence interval) per environment (anthropic and preserved) sampled in each phytophysiognomy in Maranhão state, Brazil (2010–2012). *C* Cerrado Savanna, *P* Palm Forest, *A* Amazon Forest, *M* Marshland, *ME* Mangrove, *a* anthropic, *p* preserved. Observation: the dotted rectangles highlight the phytophysiognomies with significant differences between environments
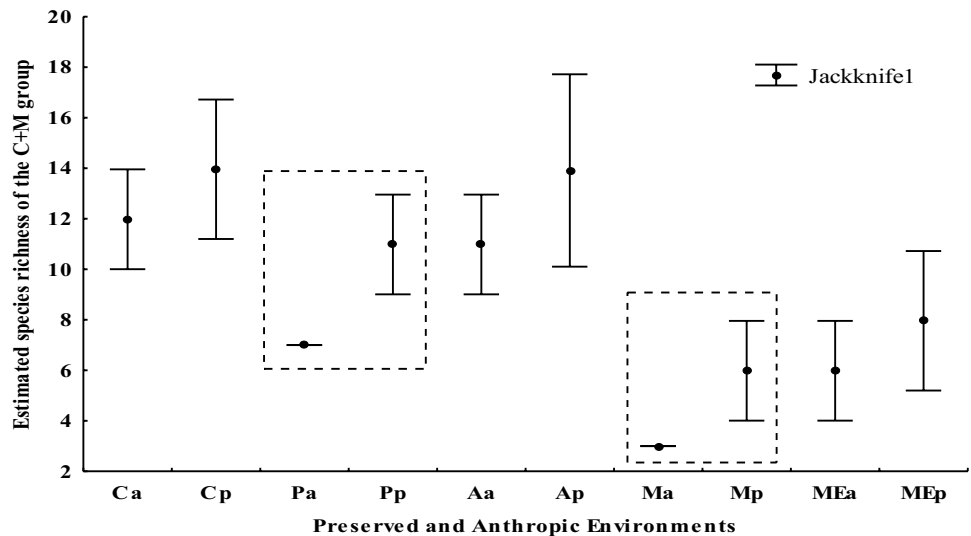
Fig. 3 Estimated species richness of the Sarcophagidae (Jackknife 1; mean ± confidence interval) per environment (anthropic and preserved) sampled in each phytophysiognomy in Maranhão state, Brazil (2010–2012). *C* Cerrado Savanna, *P* Palm Forest, *A* Amazon Forest, *M* Marshland, *ME* Mangrove, *a* anthropic, *p* preserved. Observation: the dotted rectangles highlight the phytophysiognomies with significant differences between environments
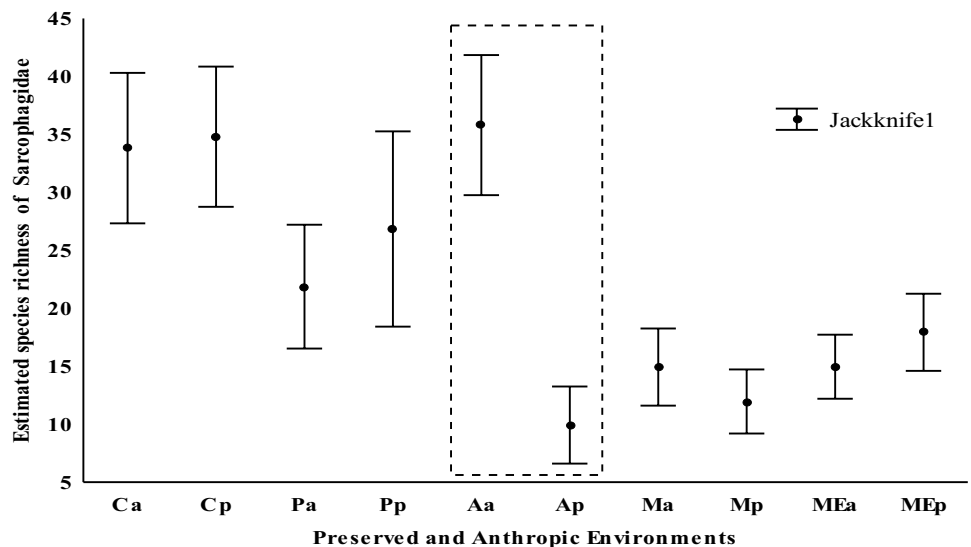
Table 2 Results of the permutational analysis of variance (PERMANOVA) applied to the community structure of the C + M and sarcophagid communities in the two environments (anthropic and preserved) of the five phytophysiognomies (Cerrado Savanna, Palm Forest, Amazon Forest, Marshland, and Mangrove) surveyed in Maranhão state, Brazil, in 2010–2012. *df* degrees of freedom

Treatment	d.f.	F	*p*	Contribution
PERMANOVA—group Calliphoridae + Mesembrinellidae				
Environments	1	43.87	0.0001	14.92
Residues	80			15.28
PERMANOVA—Sarcophagidae				
Environments	1	6.88	0.0001	13.85
Residues	77			37.78

the dipteran communities recorded in the preserved Amazon Forest (Ap), while a second group included the community

of both environments in the Cerrado Savanna (Ca and Cp) and Palm Forest, Pa and Pp (Fig. 4, Axis 1). A third group was formed by both Mangrove environments (MEa and MEp) and the fourth, by the two Marshland environments, Ma and Mp (Fig. 4, Axis 1).

With the exception of the Cerrado Savanna, the species composition of the C + M communities varied between the anthropic and preserved environments of each phytophysiognomy. A considerable difference was found between environments in the Amazon Forest, for example, which indicates that anthropogenic impacts determined a major shift in species composition in this phytophysiognomy (Fig. 4, Axis 1). Some C + M species were more associated with preserved environments, for example, in the Amazon Forest (*C. idioidea*, *M. bicolor*, and *Lucilia eximia*) and Palm Forest (*L. eximia*) (Fig. 4). The species *C. albiceps* was associated with the anthropic environments of the Amazon Forest and

Group Calliphoridae + Mesembrinellidae				Sarcophagidae			
Environments	t	P(perm)	perms	Environments	t	P(perm)	perms
Ca x Cp	1.02	0.4070	8169	Ca x Cp	0.84	0.6492	8154
Pa x Pp	4.31	0.0001*	8185	Pa x Pp	1.36	0.1267	8146
Aa x Ap	7.5	0.0001*	8147	Aa x Ap	2.16	0.0032*	4295
Ma x Mp	2.35	0.0002*	8161	Ma x Mp	1.44	0.0822	8149
MEa x MEp	2.81	0.0009*	8221	MEa x MEp	1.02	0.4050	8228

Fig. 4 Non-metric multidimensional scaling (NMDS) ordination of the data on the Calliphoridae + Mesembrinellidae community recorded at the 90 study sites surveyed in the present study in Maranhão state, Brazil, from 2010 to 2012. The sites are coded by phytophysiognomy (*C* Cerrado Savanna, *P* Palm Forest, *A* Amazon Forest, *M* Marshland, *ME* Mangrove) and environment (*a* anthropic, *p* preserved). Observations: the arrows indicate a species association, while the dotted lines delimit specific groups
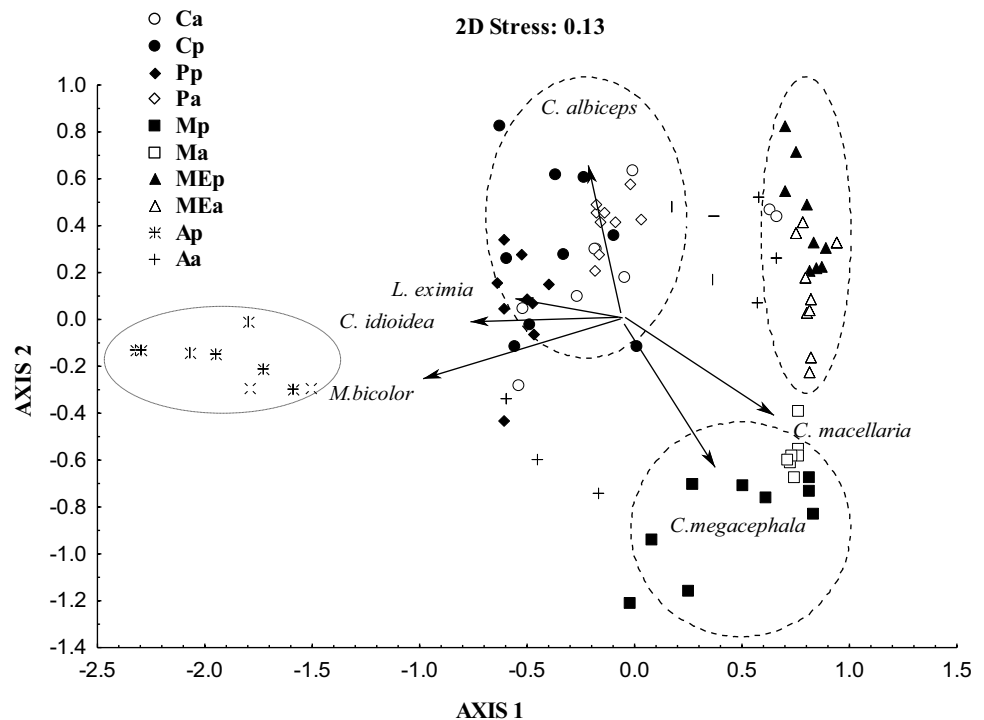
Palm Forest, as well as both environments in the Cerrado Savanna, while *C. macellaria* and *Chrysomya megacephala* were strongly associated with the two Mangrove environments (Fig. 4).

In the analysis of the sarcophagid, two groups were formed (Fig. 5), one encompassing the Cerrado Savanna, Palm Forest, and Amazon Forest sites, and the other, the Mangrove and Marshland sites (Fig. 5; Axis 1). In this analysis, the anthropic and preserved environments of the Amazon Forest were well-spaced, which indicates that their sarcophagid faunas were quite distinct (Fig. 5; Axis 2). There was no clear evidence of divergence between the communities in the anthropic and preserved environments in the other phytophysiognomies, however (Fig. 5). In this analysis, *P. (S.) lambens* was associated more with the anthropic environments of the Cerrado Savanna and Amazon Forest, whereas *T. (S.) occidua* was associated only with the anthropic environment of the Amazon Forest. One species, *O. intona*, was associated with both environments in the Marshland, while *P. (P.) chrysostoma* was associated with the two environments in the Mangrove.

Discussion

The results of the present study indicate that the changes in land use associated with cattle ranching in the Brazilian state of Maranhão have systematic impacts on the patterns of species richness, abundance, and composition of necrophagous dipteran communities (Calliphoridae + Mesembrinellidae (C + M) group, and Sarcophagidae) in the state's principal phytophysiognomies. In the Palm Forest and Marshland,

Fig. 5 Non-metric multidimensional scaling (NMDS) ordination of the data on the Sarcophagidae community recorded at the 90 study sites surveyed in the present study in Maranhão state, Brazil, from 2010 to 2012. The sites are coded by phytophysiognomy (*C* Cerrado Savanna, *P* Palm Forest, *A* Amazon Forest, *M* Marshland, *ME* Mangrove) and environment (*a* anthropic, *p* preserved). Observations: the arrows indicate a species association, while the dotted lines delimit specific groups
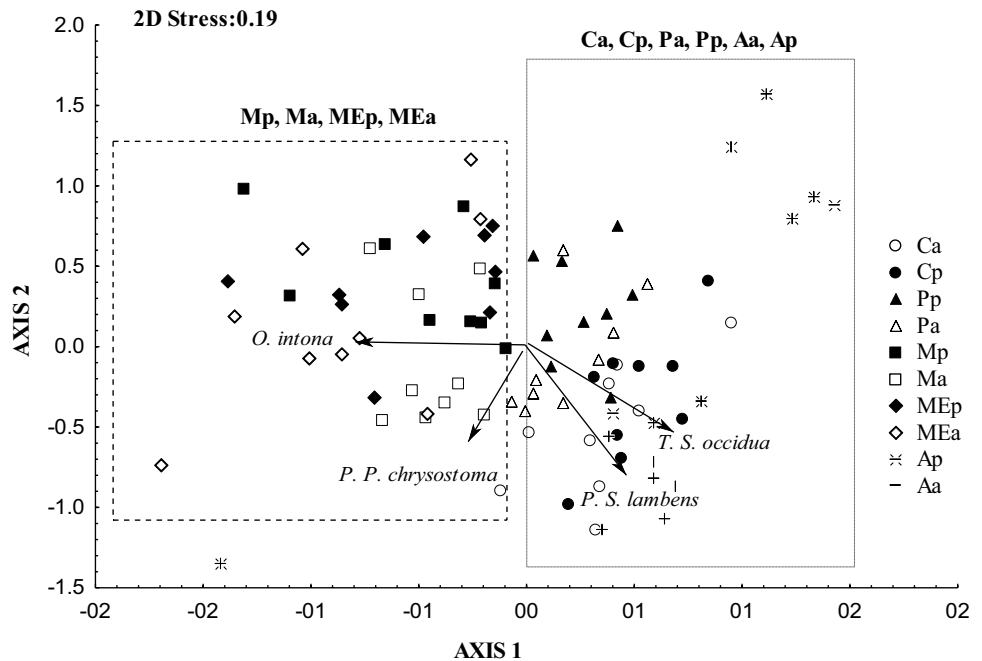
cattle ranching provoked a decline in the species richness of the Calliphoridae + Mesembrinellidae (C + M) group. A similar pattern of decreasing species richness in impacted environments has been observed in the C + M in a number of previous studies (Centeno et al. 2004; Sousa et al. 2010; Battan-Horenstein et al. 2016; Dufek et al. 2019), although some research has found a relatively high diversity in impacted habitats. Cabrini et al. (2013), for example, recorded a higher calliphorid species richness and diversity in areas with greater anthropogenic impact (grazing land and plantations) in the Brazilian Atlantic Forest in comparison with more preserved environments, such as forest fragments and secondary forest. In this study, *Mesembrinella bellardiana*, which is typical of preserved environments, was the most abundant species in all environments, with more than half of all the individuals collected.

Sarcophagid species richness was highest in the anthropic areas of the Amazon Forest. Sousa et al. (2011a) compared clearings opened for oil prospecting within the continuous forest in western Amazonia, and found that the sarcophagid fauna was richest in the clearings. The loss of forest cover may favor some sarcophagids due to their ecological characteristics, including their heliophilous behavior (Willmer 1982) and their ability to exploit the ephemeral resources that are typical of these environments (Sousa et al. 2011b). Some dipterans are able to colonize anthropogenic environments successfully, in particular, the more generalist species and those with less specific habitat preferences, which are more able to adapt to novel environments and niches, resulting in an increase in their abundance and species richness (Mulieri et al. 2011). Some sarcophagids are considered to

be biological invaders, that are even able to colonize different continents, as in the case of *Peckia* (*Sarcodexia*) *lambens* and *Peckia* (*Peckia*) *chrysostoma*, both native to the New World and introduced in Australia and the species *Sarcophaga ruficornis* which is Native to the Paleártica region and has been introduced in almost all continents (Pape 1996). Despite not being a consensus, some studies, e.g., Mulieri et al. (2008), Sousa et al. (2011a), Yepes-Gaurisas et al. (2013), and Valverde-Castro et al. (2017), have identified an association with anthropic environments in the subfamily Sarcophaginae.

Due to the distribution patterns of the calliphorids and mesembrinellids (Sousa et al. 2010, 2011a, b, 2014), the species richness of these families was expected to have been affected by the anthropogenic impacts in the more heterogeneous phytogeographic environments (Cerrado Savanna, Palm Forest, and Amazon Forest). These phytophysiognomies have a greater tree density and a taller canopy than the Marshland and Mangrove, which implies the loss of a greater amount of substrates and microhabitats following deforestation for cattle ranching. By contrast, the sarcophagid species richness varied significantly between environments only in the Amazon Forest, where it increased in the anthropic environment. Otherwise, little variation was found between environments (preserved and anthropic) in the more heterogeneous phytophysiognomies, although species richness did tend to be higher, in general, than in the Marshland and Mangrove. This pattern may also be related, at least in part, to spatial effects, given that most species tend to occur within a given phytophysiognomy (Blackburn and Gaston 1996; Rahbek 1997). In particular, the Cerrado,

Palm Forest and Amazon Forest together cover more than 70% of the study area, which may also determine higher overall levels of biodiversity in these phytophysiognomies.

The hypothesis that the anthropogenic impacts on the phytophysiognomies affect the composition and abundance patterns of the C + M group and the sarcophagids was corroborated. The anthropogenic process affected the species composition and abundance of the C + M group in most of the phytophysiognomies, although the Amazon Forest was the most affected. The greater abundance of *C. albiceps* and *C. macellaria* in the anthropic Amazon Forest environment (Aa), and of *M. bicolor* in the preserved Amazon Forest (Ap), was fundamental to the differentiation of the assemblages between these environments. *Mesembrinella bicolor* is asynanthropic and, like other mesembrinellids, is found in forest (Guimarães 1977; Whitworth and Yusseff-Vanegas 2019).

In the sarcophagids, species composition and abundance only varied significantly between the anthropic and preserved environments in the Amazon Forest. Even so, the patterns observed in the Cerrado Savanna, Palm Forest, and Amazon Forest were distinct from those recorded in the Mangrove and Marshland (considering both environments). The species *T.* (*S.*) *occidua*, *P.* (*S.*) *lambens*, *O. intona*, and *P.* (*P.*) *chrysostoma* contributed most to this dissimilarity. Anthropogenic impacts resulted in an increase in the abundance of *T.* (*S.*) *occidua*, *P.* (*S.*) *lambens*, and *P.* (*P.*) *chrysostoma*. *Tricharaea* (*S.*) *occidua* presents a strong preference for areas of human settlement and has high synanthropic indices (Yepes-Gaurisas et al. 2013), and in rural environments, it has been collected in pastures (Mulieri et al. 2008). *Peckia* (*S.*) *lambens* and *P.* (*P.*) *chrysostoma* also present affinities for habitats modified by humans, and are seen as species with positive synanthropic indices (Yepes-Gaurisas et al. 2013; Valverde-Castro et al. 2017).

Studies along an anthropogenic gradient (urban–rural-forest) have demonstrated systematic shifts in the composition of the calliphorid, mesembrinellid, and sarcophagid communities as a result of environmental change, in Colombia (Beltran et al. 2012; Yepes-Gaurisas et al. 2013; Valverde-Castro et al. 2017), Argentina (Mulieri et al. 2011; Patitucci et al. 2011), England (Hwang and Turner 2005) and Brazil (Linhares 1981; Gadelha et al. 2015). Clearly, the species composition and relative abundance of the dipterans of these three families are influenced strongly by human impacts on natural environments, as in the case of cattle ranching in the present study. The contradicting responses found among the different dipteran families in the present study reinforces the potential of this group as indicators of environmental conditions. The general lack of a clear relationship between species richness and anthropogenic impacts can be accounted for by the tradeoff between the local extinction of more specialized species and the arrival of more generalist taxa,

which tends to balance out the number of species in the community. The increase in species richness observed at moderate levels of anthropogenic impact may be related to the intermediate disturbance hypothesis (Connell 1978), which states that moderate levels of human disturbance promote the coexistence of several different types of species, including native pioneer species, as well as introduced taxa (McKinney 2008).

In addition to varying responses between the groups, we also detected variation in species associations, with some species being more closely associated with preserved environments, others with anthropic environments, and some with both types of environment. The calliphorids *C. idioidea* and *L. eximia* and the mesembrinellid, *M. bicolor*, were all associated with natural environments, as verified in previous studies (Esposito et al. 2009, 2010; Gadelha et al. 2009, 2015; Sousa et al. 2010). By contrast, whereas species such as *C. albiceps*, *C. macellaria* and *C. megacephala*, are more abundant in anthropic environments in some areas, they have also been recorded in more pristine areas (Gomes et al. 2000; Ferraz et al. 2010; Gonçalves et al. 2011, Koller 2011). A greater abundance of *C. albiceps* and *C. macellaria* in anthropized environments has already been found (Nuorteva 1963; Ferreira and Barbola 1998; Gomes et al. 2000; Ferraz et al. 2010; Koller 2011). These studies indicate that these species prefer areas inhabited by humans or those that have suffered some degree of anthropogenic change, such as forest margins and pastures.

The sarcophagids *P.* (*S.*) *lambens* and *T.* (*S.*) *occidua*, associated in this study with anthropic environments in the Cerrado Savanna and Amazon Forest, have also been recorded in open areas, such as pastures, in other studies (Almeida 1984; Mulieri et al. 2008). The species *O. intona* and *P.* (*P.*) *chrysostoma*, associated with both types of environment, are capable of adapting to different environments (Ferraz 1995; Sousa et al. 2011b; Vasconcelos et al. 2013), given that they have been recorded in both forest and open areas.

The results of the present study indicate that cattle ranching in natural phytophysiognomies affects the species richness, composition, and abundance of the calliphorids, mesembrinellids, and sarcophagids, in particular in the Amazon Forest, but also with differential responses. Reliable data on biodiversity are important to define public policies and ensure the economic development of a region or biome, such as criteria for regulating the use of an Ecological Economic Zone, and the integration of its economic, social, and environmental relationships. The results of the present study highlight the negative impacts of cattle ranching on the more forested areas such as the Amazon Forest and the Palm Forest, where it would be recommendable to avoid this activity in favor of more sustainable types of land use, such as the production of babassu oil or the extraction of other natural

forest products that do not require shifts in land use. The findings of the present study thus provide important insights for the regulation and planning of cattle ranching in Maranhão. If the conversion of natural habitats to cattle pasture continues, special attention should be given to the Amazon Forest, Palm Forest, Marshland, and Mangrove phytophysiognomies, where anthropogenic impacts cause significant shifts in the dipteran communities.

It is important to note here that, while the Cerrado is defined as a biodiversity hotspot (Myers 2000; Martinelli et al. 2014), the other phytophysiognomies surveyed in the present study may suffer similar or even greater pressures than the Cerrado Savanna, given their much smaller areas (except in the case of the Amazon Forest). The Palm Forest is especially interesting in this context, given that this natural system is used as a source of subsistence by many extractive communities, for the production of babassu oil, a practise that is being lost progressively with the advance of cattle ranching in the region. The Palm Forest is also an important transition zone between the Amazon Forest and the Cerrado Savanna, which contains a unique biodiversity that includes representatives of the Amazonian, Atlantic Forest, and Cerrado biomes, as shown in studies of other taxonomic groups (Martins et al. 2009). Furthermore, *C. idioidea, M. bicolor* and *Lucilia eximia* were associated strongly with preserved environments. If natural areas continue to be impacted on a large scale, then, these species should be monitored or included in management programs to prevent their extinction.

Conflict of interest

All the authors participated in (a) the conception and design of the study, or the analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content, and (c) the approval of the final version; This manuscript has not been submitted to, nor is under review at, at any other journal or other publishing venue. The authors have no affiliation with any organization that has a direct or indirect financial interest in the subject matter discussed in the manuscript.

Ethical approval

Please be advised that the specimens analyzed in the present study were collected according to Brazilian law. The permits for the collection and transportation of zoological specimens (necrophagous Diptera) were provided by the Chico Mendes Institute for the Conservation of Biodiversity (ICMBio)/Sisbio, in accordance with federal law and the regulations of the Brazilian Environmental Ministry,

through process number 1403-1 (for private properties) and 29342-1 (for the Gurupi Biological Reserve, a federal conservation unit in the state of Maranhão). At private properties, permission from the landowner or property manager was obtained prior to sampling. None of the study species are protected by Brazilian law or red-listed.

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