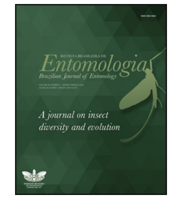
Revista Brasileira de Entomologia 66(4):e20220065, 2022

SOCIEDADE BRASILEIRA DE ENTOMOLOGIA
FUNDADA EM 1937

REVISTA BRASILEIRA DE
Entomologia
A Journal on Insect Diversity and Evolution



Seasonality and bait type driving the diversity of dung beetle (Scarabaeidae: Scarabaeinae) communities in urban remnants of the Atlantic Forest

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ARTICLE INFO

Article history
Received 11 August 2022
Accepted 01 November 2022
Available online 28 November 2022
Associate Editor: Gustavo Graciolli

Keywords:
Coleoptera
Fragmentation
Insect sampling
Millipede predators
Scarabaeoidea

ABSTRACT

Describing dung beetle communities in tropical forest remnants located in disturbed/urbanized and conserved areas can provide information about the functioning of these ecosystems and support conservation plans. This study aimed to verify the effect of seasons and bait type on dung beetle communities in remnants of the Atlantic Forest in order to describe their composition and diversity parameters. The study was carried out during both the rainy and dry seasons in periurban and urban remnants. Eighteen pitfall traps baited with feces, carrion, and injured millipedes were established in each site. A total of 3501 individuals and 23 species were recorded. Urban remnant presented higher abundance of individuals in the dry season. On the other hand, in periurban remnant the higher abundance was verified in the rainy season. The diversity was higher in the rainy season in both sites. In urban remnant, *Coprophanaeus ensifer* was found to be generalist regarding its choice of bait (feces and carrion). The use of injured millipedes as bait allowed the record of the predatory species *Deltochilum alpercata*. Among the types of bait used, the injured millipedes proved to be very effective, capturing a greater diversity of dung beetles during the rainy season in both remnants, and allowed the collection of specialized, necrophages, and generalists species. Therefore, we propose the use of mixed-bait sampling designs in inventories and surveys to increase the chances of sampling species with different traits or dietary preferences, which are often rare in collections.

Introduction

The Atlantic Forest is a biodiversity hotspot which has suffered drastic reductions in native forest cover due to the urbanization that has occurred throughout the region (Myers et al., 2000). High-resolution remote sensing imagery has revealed that the Atlantic Forest has only 28% of its area covered by native vegetation (Rezende et al., 2018). At present, the Atlantic Forest is surrounded/influenced by populous cities throughout its original distribution, leading to reductions in forest cover and increasing isolation of remnants in urban and periurban landscapes (Weller et al., 2019). This in turn generates conflicts with biodiversity and leads to losses in the provision of ecosystem services (Ferreira et al., 2019). The conservation status of the Pernambuco Endemism Center is critical. This endemism center covers an area of 39,567 km^2, but only 4.82% of its extent is covered by native vegetation, distributed across small and isolated remnants surrounded by a matrix of either sugarcane or urban areas (Silva and Casteleti, 2005; Tabarelli et al., 2006).

Beetles of the subfamily Scarabaeinae, known as dung beetles, are representatives of the Atlantic Forest entomofauna, commonly used as environmental indicators because they are sensitive to anthropogenic disturbances, are easy to collect, have well-known taxonomy and biology, and have well-defined functional guilds (Favila and Halffter, 1997; Gardner et al., 2008; Otavo et al., 2013). Currently in Brazil, 780 species of dung beetle across 66 genera have been recorded (Vaz-de-Mello, 2022). These beetles are strongly associated with periods of higher rainfall in the Neotropics (Filgueiras et al., 2009; Damborsky et al., 2015; Salomão and Iannuzzi, 2015; Novais et al., 2016; Correa et al., 2021), mainly because the humidity in the environment prevents the

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https://doi.org/10.1590/1806-9665-RBENT-2022-0065

dehydration of food resources and facilitates the excavation of the soil, affecting the development of these organisms (Halffter and Matthews, 1966; Hanski and Cambefort, 1991).

Due to their behavior of rolling and burying balls of fecal matter for feeding and nesting, these beetles perform important environmental services such as organic matter recycling, secondary seed dispersal, soil aeration, and biological pest control (Flechtmann et al., 1995; Nichols et al., 2008). Additionally, species of dung beetle are detritivores but may have different eating habits, including necrophagy, myrmecophily, saprophagy, carpophagy, and predation (Halffter and Matthews, 1966; Bedoussac et al., 2007; Forti et al., 2012). Among the predatory dung beetles, species of the genus *Deltochilum* Eschscholtz, subgenus *Aganhyboma* Kolbe, are known to prey on millipedes (Larsen et al., 2009; Silva et al., 2012), attracted by compounds released in the defenses of these organisms (Bedoussac et al., 2007).

In studies of dung beetle inventories, passive collection methods have been used, with pitfall traps baited with feces or carrion, and in some studies with decaying fruits (Filgueiras et al., 2009; Salomão et al., 2014; Noriega, 2015; Salomão and Iannuzzi, 2015). However, predators of millipedes of the subgenus *Deltochilum* (*Aganhyboma*) are usually recorded through casual encounters, flight interception traps, light traps, or pitfall traps baited with formalin solution and injured millipedes (Silva et al., 2015). This group of predatory beetles is considered rare in collections and some species have only the holotype known because traps with injured millipedes are not commonly used in entomofauna surveys (Silva et al., 2015). Thus, dung beetle surveys that employ multiple baits in urban and periurban remnants of the Atlantic Forest can contribute to our knowledge of the biodiversity and organization of dung beetle assemblages in disturbed and degraded habitats.

This study aims to verify the effect of seasons and bait type on dung beetle communities in two remnants of the Atlantic Forest in order to describe their composition and diversity parameters, comparing the attractiveness of different food resources (feces, carrion, and millipedes) in different seasons (rainy and dry). Here, the following hypotheses were tested: (a) the rainy season directly influences and increases the diversity and abundance of dung beetles, since the foraging activity of these beetles is related to seasonality (Halffter and Matthews, 1966; Hanski and Cambefort, 1991); (b) dung beetle specializing in millipedes predation will only be recorded in traps baited with injured millipedes, since this is a specific and unusual resource in dung beetle surveys (Silva et al., 2012).

Materials and methods

Study areas

This study was carried out in two sites of Atlantic Forest in the Metropolitan Region of Recife, Pernambuco, Brazil. The first collection site was at the Mata de Jaguarana Urban Forest Reserve (FURB Jaguarana) (7º55'13"S and 34º53'06"W, 57 m a.s.l.), a remnant of coastal Atlantic Forest located on the margins of the state highway PE-015 in the neighborhood of Jaguarana, adjacent to the urban center of the city of Paulista (Fig. 1). The remnant currently has an area of approximately 332 ha of Dense Ombrophilous Forest (CPRH, 2003), having lost an area almost twice its current extent over a period of 22 years (from 1985 to 2007) (Pessoa et al., 2014). The second collection site was a periurban remnant within the Aldeia-Beberibe Environmental Protection Area (APA Aldeia-Beberibe), located in Chã de Peroba (7º57'11"S and 34º59'13"W, 79 m a.s.l.), Aldeia dos Camarás, Camaragibe (Fig. 1). This

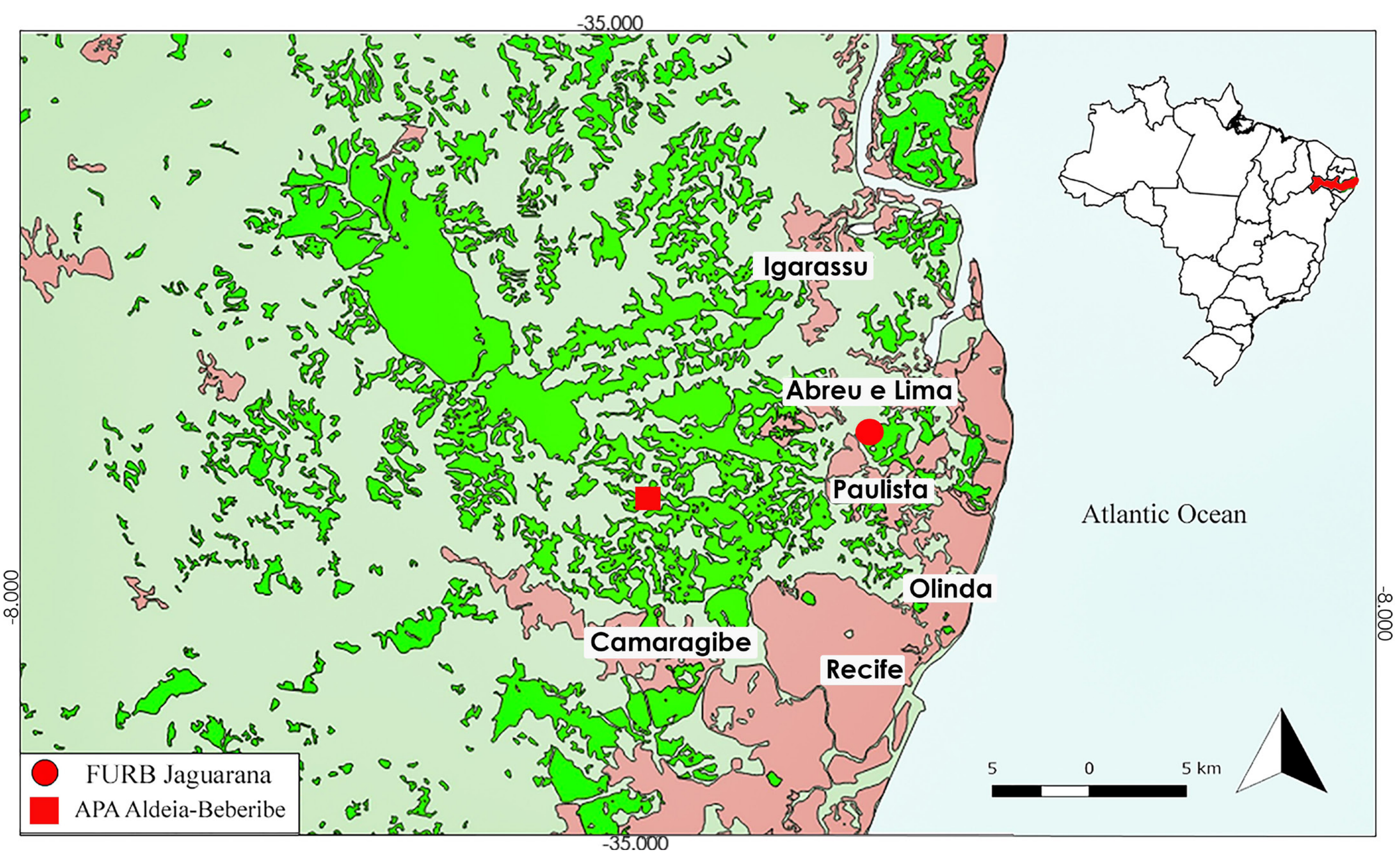

Figure 1. Partial map of the state of Pernambuco, with emphasis on the remnants of the Atlantic Forest (Green) and the urban area (Pink) located on the outskirts of FURB Jaguarana in the municipality of Paulista and APA Aldeia-Beberibe in the municipality of Camaragibe, PE, Brazil.

is a remnant of Secondary Forest that has approximately 166 ha of Dense Ombrophilous Forest that is in a highly fragmented landscape.

Sampling method

The collections at the FURB Jaguarana site were carried out from April to July (rainy season) and September to December (dry season) of 2018, while collections at the APA Aldeia-Beberibe site were carried out from September to December (dry season) of 2018 and March to June (rainy season) of 2019. At each month a total of 18 pitfall traps were installed at each site, distributed equally between three transects (*i.e.*, six per transect). Transects were separated by 100 m and each one contained six pitfall traps (50 m apart) with only one bait type (*i.e.*, human feces, carrion, or injured millipedes). In total, 144 pitfall traps were set at each site.

Pitfall traps were constructed with polyethylene terephthalate (PET) bottles of 2 liters, with wire fixed in the upper edges to support a bait holder for either human feces or carrion (putrefying beef). For those baited with injured millipedes (Diplopoda: Spirobolida), the base of the trap was used to hold the bait. Traps were retrieved after 48 hours and the dung beetles were collected and transported to the Laboratory of Biodiversity and Insect Genetics (LBGI), at the University of Pernambuco (UPE). The specimens are deposited in the Entomological Collection of the University of Pernambuco (CEUPE). Species identification were confirmed by Fernando A. B. Silva, specialist in taxonomy of dung beetles. The collections were carried out with the authorization of IBAMA/SISBIO, permanent zoological material license of Class Insecta (nº 16278-1).

Data analysis

Diversity was estimated using the iNEXT online program (Hsieh et al., 2016), using the q0, q1, and q2 diversity indices, where the q-value indicates the sensitivity of the index in relation to the abundance of species. When q=0 the index considers species without considering their abundances, thus it is a species richness index (Chao and Jost, 2012). When q=1 the index is sensitive to the abundance of common species, and when q=2 it is sensitive to the abundance of dominant species (Chao and Jost, 2012). As the coverage of the samples was variable and lower for some samples (e.g. Aldeia: 0.97%-1%; Jaguarana: 0.80%-1%), we considered the extrapolated values at 95% coverage as the standard for all samples to calculate q0, q1, and q2. This extrapolation was also performed using the iNEXT online program (Hsieh et al., 2016).

The differences between the values of q0, q1, and q2 for the different baits (feces, millipedes, and carrion) and season (dry and rainy), as well as the interaction between type of bait and season, were tested using a two-factor ANOVA, which was followed up by Tukey's Post Hoc tests to check for differences between groups. The residuals of each test were checked for normality using the Shapiro-Wilk test. The Jaguarana q0 values were square-root transformed to normalize the residuals of the ANOVA model. To perform these tests, the 'oav', 'TukeyHSD', and 'shapiro.test' functions were used in version 4.0.3 of R (R Core Team, 2020).

Data about rainfall provided by APAC (Pernambucan Water and Climates Agency) were used to assess the change in species abundance due changes in rainfall. To verify the existence of species groups with the abundance related to precipitation and bait types, a canonical correspondence analysis (CCA) was performed using the 'vegan' package (Oksanen et al., 2022) also in version 4.0.3 of R (R Core Team, 2020).

Results

A total of 3501 individuals and 23 species were recorded (Table 1). In urban remnant FURB Jaguarana, 1857 individuals were collected, 752 in the rainy season and 1105 in the dry season. In total, 15 species belonging to nine genera were recorded in FURB Jaguarana. In the rainy season all 15 species were recorded, while only seven were recorded in the dry period in FURB Jaguarana. These species are distributed between the Ateuchini (1.1%), Coprini (0.5%), Dichotomiini (67.5%), Deltochilini (6.3%), Oniticellini (19.8%), and Phanaeini (4.8%) tribes. The most abundant species in FURB Jaguarana were *Dichotomius gilletti* Valois, Vaz-de-Mello, and Silva, 2017 (67.5% of all individuals), *Eurysternus caribaeus* (Herbst, 1789) (19.7%), and *Coprophanaeus ensifer* (Germar, 1824) (4.6%), which represented 91.8% of the individuals sampled (Table 1).

In the periurban remnant APA Aldeia-Beberibe site 1644 individuals were collected, 782 in the dry season and 862 in the rainy season (Table 1). In total, 19 species belonging to 11 genera were recorded, 12 species in the dry season and 18 in the rainy season, which were distributed between seven tribes: Ateuchini (0.2%), Coprini (7.4%), Dichotomiini (40.9%), Deltochilini (37.3%), Oniticellini (3.3%), Epilissini (0.1%), Onthophagini (8.1%), and Phanaeini (2.7%) (Table 1). The dominant species were *Canthon nigripennis* Van Lansberge, 1874 (27.7% of all individuals), *Dichotomius iannuzziae* Valois, Vaz-de-Mello, and Silva, 2017 (21.3%), and *D. gilletti* (19.4%) which represented 68.4% of the individuals sampled (Table 1). *Deltochilum* (*Aganhyboma*) *alpercata* Silva, Louzada, and Vaz-de-Mello, 2015 was recorded in both sites exclusively in traps baited with injurious millipedes (Table 1).

In FURB Jaguarana, season (rainy and dry) is an important predictor of dung beetle assemblages, increasing q0, q1, and q2 metrics in rainy season. Moreover, the effect of interaction between season and bait type was significant, with a higher diversity (q0, q1, and q2) in traps baited with millipedes in the rainy season (Table 2; Fig. 2A).

In the APA Aldeia-Beberibe, all the diversity metrics (q0, q1, and q2) were influenced by bait type and season, and the effects of the interaction between these factors were not only detected for q0 (Table 3). The richness of common species (q1) and dominant species (q2) was strongly influenced by all factors (Table 3), increasing in the rainy season (Fig. 2B). The interaction between bait and season had an influence on q1 and q2 in both remnants (Table 2; 3), being higher for carrion and millipedes baits in rainy season (Fig. 2B).

The first two axes of the CCA in the FURB Jaguarana site explained 54% and 12% of the variation in species abundance, respectively, with the axes and terms (precipitation and bait) significant ($p < 0.05$; Fig. 3A). The species of the genera *Coprophanaeus* and *Deltochilum* were associated with the periods of greater rainfall, while the opposite occurred in some coprophagous species, which were associated with drier periods (Fig. 3A). In addition to precipitation, some species were also correlated with bait type (Fig. 3A), while *C. ensifer* (Germar, 1824), *Deltochilum* sp. 1, and *C. nigripennis* Van Lansberge, 1874 were found to be generalists in this site (Fig. 3A).

In APA Aldeia-Beberibe, the first two axes of the CCA explained 72% and 16% of the variation in the distribution of species abundance, with the axes and terms (precipitation and bait) being statistically significant ($p < 0.05$; Fig. 3B). The species of the genera *Deltochilum*, *Coprophanaeus*, and *Onthophagus*, in addition to *Dichotomius depressicollis* (Harold, 1867) and *Eurysternus nigrovirens* Génier, 2009 were strongly associated with periods of higher rainfall (Fig. 3B). The other species had a similar distribution of abundance in the dry and rainy seasons or were strongly correlated with the dry season (Fig. 3B). The species, *Deltochilum* sp. 1, *Deltochilum* sp. 2, and *Coprophanaeus punctatus* (d'Olsoufieff, 1924) were found to be generalists in this site (Fig. 3B).

Table 1
Number of individuals per species and tribes of the subfamily Scarabaeinae collected in pitfall traps of feces (F), carrion (C) and millipedes (M) in the rainy and dry seasons of 2018 at FURB Jaguarana (JAG), Paulista, PE and in the dry season 2018 and 2019 rainy in Aldeia (ALD), APA Aldeia-Beberibe, Camaragibe, PE.

Tribes / Species	JAG						ALD						Total
	Rainy			Dry			Dry			Rainy			
Ateuchini	F	C	M	F	C	M	F	C	M	F	C	M	
Ateuchus sp.	1	0	0	19	0	0	1	0	0	2	0	0	23
Trichillum externepunctatum Borre, 1880	1	0	0	0	0	0	0	0	0	0	0	0	1
Coprini													
Canthidium sp. 1	0	0	5	0	0	2	78	0	0	41	1	0	127
Canthidium sp. 2	0	0	1	0	0	0	0	0	0	0	0	0	1
Ontherus appendiculatus (Mannerheim, 1829)	0	0	0	0	0	0	1	0	0	1	0	0	2
Ontherus azteca Harold, 1869	1	0	0	0	0	0	0	0	0	0	0	0	1
Dichotomiini													
Dichotomius bos (Blanchard, 1845)	1	0	0	0	0	0	0	0	0	0	0	0	1
Dichotomius depressicollis (Harold, 1867)	0	0	0	0	0	0	0	0	0	4	0	0	4
Dichotomius iannuzziae Valois, Vaz-de-Mello & Silva, 2017	0	0	0	0	0	0	169	11	0	117	50	3	350
Dichotomius gilletti Valois, Vaz-de-Mello & Silva, 2017	298	131	13	762	44	5	152	31	1	84	48	3	1572
Deltochilini													
Canthon nigripennis Van Lansberge, 1874	0	13	9	2	7	18	1	239	29	0	105	81	504
Deltochilum (Deltohyboma) sp. 1	0	25	12	2	6	6	1	8	0	4	72	29	165
D. (Deltohyboma) sp. 2	0	0	0	0	0	0	0	0	0	0	5	2	7
D. alpercata Silva, Louzada & Vaz-de-Mello, 2015	0	0	16	0	0	0	0	0	1	0	0	33	50
Sylvicanthon obscurus (Schmidt, 1920)	0	0	0	0	0	0	3	0	0	0	0	0	3
Oniticellini													
Eurysternus caribaeus (Herbst, 1789)	134	1	0	231	0	0	20	0	0	33	0	0	419
Eurysternus nigrovirens Génier, 2009	0	1	0	1	0	0	0	0	0	2	0	0	4
Epilissini													
Canthonella sp.	0	0	0	0	0	0	0	1	0	0	1	0	2
Onthophagini													
Onthophagus sp.	0	0	0	0	0	0	34	0	0	98	0	1	133
Phanaeini													
Coprophanaeus cyanescens (d'Olsoufieff, 1924)	0	2	0	0	0	0	0	0	0	0	2	0	4
Coprophanaeus dardanus (MacLeay, 1819)	0	0	0	0	0	0	0	1	0	2	33	0	36
Coprophanaeus ensifer (Germar, 1824)	49	37	0	0	0	0	0	0	0	2	0	0	88
Coprophanaeus punctatus (d'Olsoufieff, 1924)	0	1	0	0	0	0	0	0	0	0	2	1	4
Total individuals	**485**	**211**	**56**	**1017**	**57**	**31**	**460**	**291**	**31**	**390**	**319**	**153**	**3501**
Total species	**7**	**8**	**6**	**6**	**3**	**4**	**10**	**5**	**3**	**12**	**10**	**8**	**23**

Table 2
ANOVA results to verify the effect of bait type and season on diversity indices (q0, q1, q2) of dung beetles from FURB Jaguarana, Paulista, PE. Meaningfulness: <0.001'***'; <0.01'**'; <0.05'*'

		q0			
Factor	Df	Sum of sqrs	Mean square	F	p-value
Bait	2	0.196	0.0979	0.652	0.528
Season	1	2.516	2.5159	16.751	0.000 ***
Interaction	2	1.238	0.6192	4.123	0.026 *
		q1			
Factor	Df	Sum of sqrs	Mean square	F	p
Bait	2	10.878	5.439	6.661	0.005 **
Season	1	19.743	19.743	24.180	0.000 ***
Interaction	2	9.983	4.992	6.113	0.005 **
		q2			
Factor	Df	Sum of sqrs	Mean square	F	p
Bait	2	13.384	6.692	7.796	0.001 **
Season	1	14.402	14.402	16.777	0.000 ***
Interaction	2	9.991	4.995	5.819	0.007 **

Discussion

The urban remnant FURB Jaguarana and periurban remnant APA Aldeia-Beberibe presented higher dung beetle diversity in the rainy season, as is expected because this is the period of greatest activity of most species (Halffter and Matthews, 1966; Hanski and Cambefort, 1991). However, dung beetles were more abundant in urban remnants in the dry season, which is unusual, caused by the dominance of *D. gilletti* and *E. caribaeus*, corroborating with Filgueiras et al. (2009) that for omnivorous dung bait (human dung) and herbivorous dung

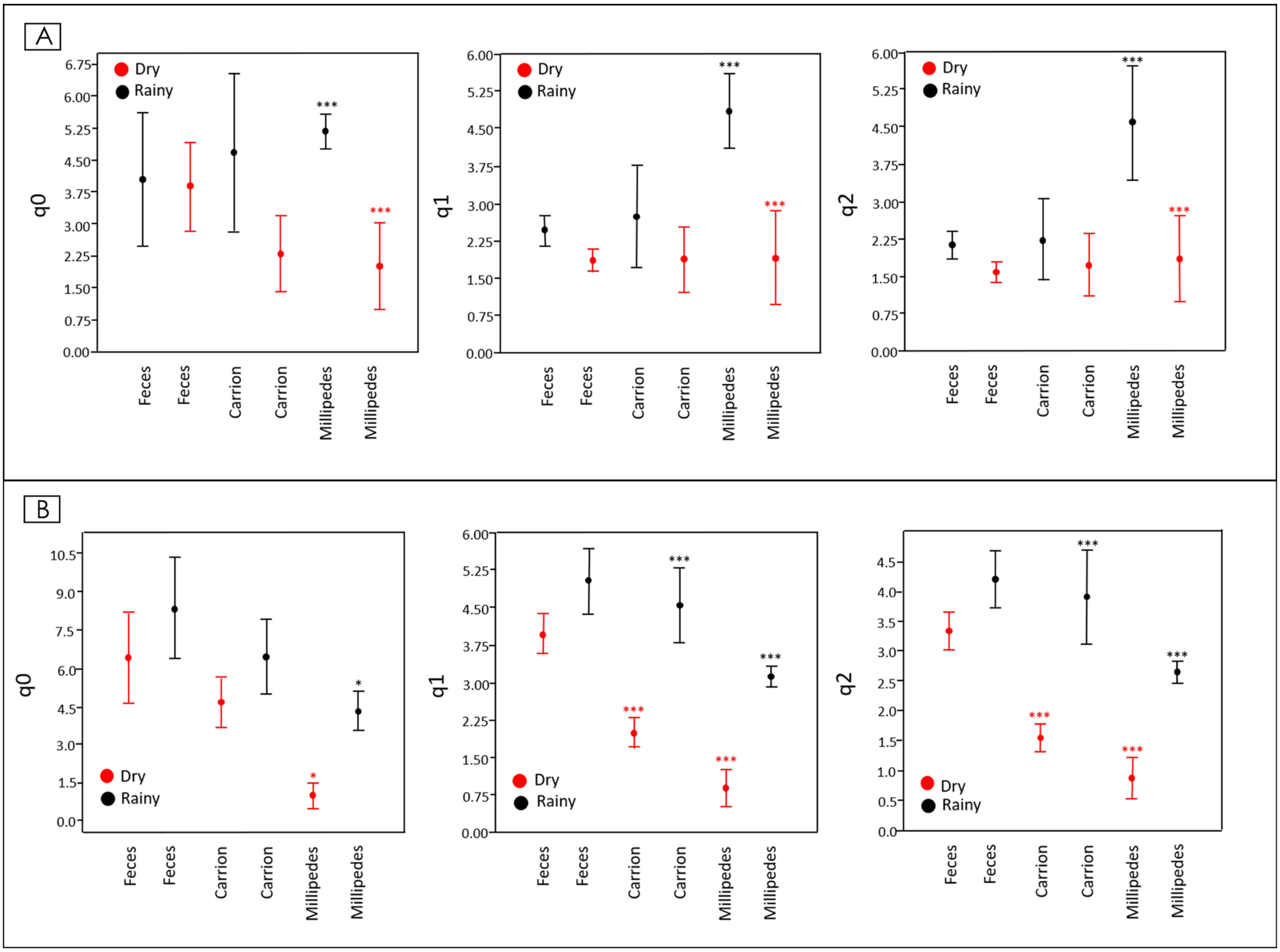

Figure 2. Differences between diversity index values (q0, q1, q2) for different types of baits (feces, carrion, millipedes) in the rainy and dry season at FURB Jaguarana (A) and APA Aldeia-Beberibe (B). Meaningfulness: <0.001‘***’; <0.01‘**’; <0.05‘*’.

Table 3
ANOVA results to verify the effect of bait type and season on diversity indices (q0, q1, q2) of dung beetles from APA Aldeia-Beberibe, Camaragibe, PE. Meaningfulness: <0.001‘***’; <0.01‘**’; <0.05‘*’

		q0			
Factor	Df	Sum of sqrs	Mean square	F	p-value
Bait	2	136.56	68.28	23.450	0.000 ***
Season	1	50.74	50.74	17.426	0.000 ***
Interaction	2	4.26	2.13	0.732	0.489
		q1			
Factor	Df	Sum of sqrs	Mean square	F	p
Bait	2	37.73	18.86	50.739	0.000 ***
Season	1	34.44	34.44	92.626	0.000 ***
Interaction	2	3.70	1.85	4.978	0.013 *
		q2			
Factor	Df	Sum of sqrs	Mean square	F	p
Bait	2	24.391	12.195	40.346	0.000 ***
Season	1	25.134	25.134	83.150	0.000 ***
Interaction	2	3.413	1.707	5.646	0.008 **

bait (waterbuck dung) obtained higher abundance in the period of lower precipitation. While in periurban remnant the highest abundance was recorded in the rainy season, corroborating with Halffter and Matthews (1966), Janzen (1983), Stumpf (1986), according to which, the abundance of dung beetles can increase after the beginning of the rainy season in tropical rainforests.

In this study, the injured millipedes were an important factor driving dung beetle diversity in the rainy and dry seasons, demonstrating that some food resources have a strong influence on the diversity of dung beetles during the year, being reported in some studies as an important factor for stability and fluctuation of dung beetle communities (Halffter and Edmonds, 1982; Hernández and Vaz-de-Mello, 2009). Other factors

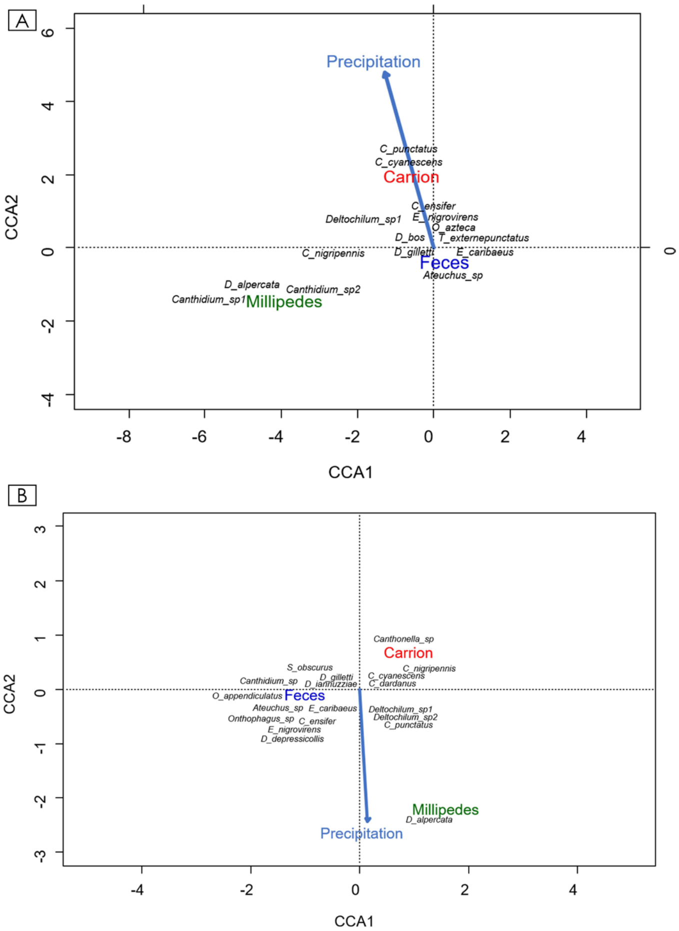

Figure 3. Canonical Correspondence Analysis (CCA) with group formations related to separation and types of baits used in the collection of dung beetles at FURB Jaguarana (A) and APA Aldeia-Beberibe (B).

can directly influence on attraction of dung beetles by a resource at different periods of the year, such as nutritional requirements due to reproductive factors, seasonal changes in the availability of resources that can be ephemeral in part of the year, and attractiveness of resources in severe climatic conditions (Halffter and Matthews, 1966; Wolda, 1988; Krell et al., 2003; Halffter and Halffter, 2009). Everything indicates that the resource of millipedes suffer influence of these and other factors throughout the year, influencing the diversity of dung beetles.

The predator of millipedes *D.* (*A.*) *alpercata* was recorded in both remnants exclusively in traps with injured millipedes during the rainy season. This species had recently only a specimen known, the holotype, which was collected in Murici, state of Alagoas (Silva et al., 2015). Its distribution was recently expanded to the state of Pernambuco (Araújo et al., 2020). In addition, *Canthidium* species were collected exclusively in pitfall traps baited with freshly killed millipedes in FURB Jaguarana. It is interesting that recently freshly killed millipedes also attract generalist species (Sánchez-Hernández et al., 2019), such as *C. nigripennis*, *Deltochilum* sp. 1, *Deltochilum* sp. 2, and *C. punctatus,* which likely exploited this bait type to decrease inter-specific competition for other resources, such as feces and carrion. *Coprophanaeus punctatus* is considered rare in collections, and was the only Phanaeini recorded in traps baited with millipedes.

Species of the genus *Dichotomius*, belonging to the "*sericeus*" group, were dominant in both remnants and recorded in both the rainy and dry seasons. In the forested areas of the region, the representatives of the "*sericeus*" group are dominant, most likely because they are generalists and well adapted to the biotic and abiotic conditions of this region (Silva et al., 2010; Costa et al., 2013; Salomão and Iannuzzi, 2015; Salomão et al., 2019). *Dichotomius bos* (Blanchard, 1845) was recorded in the FURB Jaguarana. This is a coprophagous species which inhabits open areas such as pastures (Tissiani et al., 2017). There are some pastures close to the northern portion of the FURB Jaguarana, so it was classified here as a tourist species. Tourist species (individuals) arrive from neighboring landscapes in a stochastic way and cannot maintain a stable population, remaining in these remnants for brief periods (Halffter and Moreno, 2005).

The urban remnant (FURB Jaguarana) presented dominant species distinct from the periurban remnant (APA Aldeia-Beberibe). In studies carried out in other remnants neighbor to FURB Jaguarana, *E. caribaeus* and *C. ensifer* have not presented a high dominance as in the urban remnant of FURB Jaguarana. (Endres et al., 2007; Silva et al., 2010; Costa et al., 2013;). The abundance of *E. caribaeus* in the dry season in the urban remnant is probably due to the vegetation structure of the remnant, mammal community, and the availability of feces within the remnant, since this species is strictly coprophagic. *Coprophanaeus ensifer* was classified here as a generalist species since it was attracted by both feces and carrion in urban remnant, while in periurban remnant this species was strictly coprophagic. This was contrary to our expectations, since this species is frequently cited as being necrophagous (Endres et al., 2005, 2007; Costa et al., 2013). Thus, the abundance of *C. ensifer* observed in the urban remnant suggests a plasticity in this species in terms of food preference.

The periurban remnant presented *C. nigripennis* as dominant species in both the dry and rainy seasons. According to Filgueiras et al. (2015) and Tissiani et al. (2017), this species benefits from the open habitats that can result from anthropogenic actions, such as grazing near forests and clearings, both present in the periurban remnant. Therefore, these differences in the dung beetle assemblages of urban and periurban remnants may be also explained by the consequences of fragmentation, urbanization, defaunation, and size of each studied remnant. The periurban remnant studied here is composed by a secondary forest connected with other remnants of different areas along the APA Aldeia-Beberibe. This region presents the largest forested area above the São Francisco River, which may explain the greater species richness in this remnant. The urban remnant is isolated from other remnants in the landscape and it is surrounded by an urban matrix that has been suffering from loss of territory by the growth of cities, besides hunting and burning (Pessoa et al., 2014). For instance, remnant size, matrix composition, and urbanization are predictor variables that cause reductions in dung beetles taxonomic diversity in tropical rainforests (Sánchez-de-Jesús et al., 2015; Salomão et al., 2019).

Changes in the composition of mammal communities and habitat structure are described as the main factors driving richness of dung beetles, since the richness of these beetles is greater in areas with greater resource availability and climate stability (Bogoni et al., 2016; Medina, 2019). In addition, this study highlights the role of seasonality as a driver of dung beetle diversity in urban and periurban remnants of the Atlantic Forest. However, due to the sampling and temporal limitation of this study, it was not possible to verify a wide dynamic of community structure, such as in atypical climatic conditions (intensity of rain and duration of dry seasons) along successive years (França et al., 2020). We suggest long-duration studies to better understand the role of different seasonal periods in the populational dynamics, in addition to increasing the accumulation curve of species with the use of a multi-bait approach in different years.

Conclusions

The importance of using millipede-baited traps to increase the representativeness of dung beetle surveys was shown, particularly in the rainy season, when we were able to sample generalist as well as specialist species. To our knowledge, this is the first study to compare the efficacy of pitfall traps baited with injured millipedes as compared with those baited with feces and carrion in distinct seasons. Using a multi-bait approach were recorded individuals of *Deltochilum* (*Aganhyboma*) *alpercata*, a predatory species of millipede which is apparently rare in dung beetle surveys due to a collection artifact. We recommend the use of varied pitfall trap baits in a mixed sampling design to increase the representativeness of dung beetle surveys.

Acknowledgements

We would like to thank those responsible for the reserves and the owners of the forest remnants for their support during the collections, in particular the FMA family for all their assistance with collections in Aldeia. We also thank the members of LBGI-ICB-UPE, especially Bruno Pereira and Júlio Silva for their contribution to the fieldwork. Finally, we thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for providing research grants for F.A.B.S. (444020/2014-4). F.A.B.S. is a Conselho Nacional de Desenvolvimento Científico e Tecnológico fellow (PQ2, 303035/2021-8).

Funding

This work was funded by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Conflicts of interest

The author declares no conflicts of interest.

Author contributions statement

JFA performed the collections, identified the specimens, performed the analyzes, and wrote the manuscript. EMSR contributes to statistical analyses. FMA contributed with the collections in Aldeia and with the statistical analyses. FABS confirmed the species identifications. RCM guided the work. EMSR, FMA, FABS, and RCM contributed with suggestions for the writing of the manuscript.

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