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Dung beetle (Coleoptera, Scarabaeidae) assemblage of a highly fragmented landscape of Atlantic forest: from small to the largest fragments of northeastern Brazilian region

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ABSTRACT

Human activities in tropical forests are the main causes of forest fragmentation. According to historical factor in deforestation processes, forest remnants exhibit different sizes and shapes. The aim of the present study was to evaluate the dung beetle assemblage on fragments of different degree of sizes. Sampling was performed during rainy and dry season of 2010 in six fragments of Atlantic forest, using pitfall traps baited with excrement and carrion. Also, we used two larger fragments as control. We used General Linear Models to determine whether the fragments presented distinguished dung beetle abundance and richness. Analysis of Similarities and Non-Metric Multidimensional Scaling were used to determine whether the dung beetle assemblage was grouped according to species composition. A total of 3352 individuals were collected and 19 species were identified in the six fragments sampled. Dung beetle abundance exhibited a shift according to fragment size; however, richness did not change among fragments evaluated. Also, fragments sampled and the two controls exhibited distinct species composition. The distinction on abundance of dung beetles among fragments may be related to different amount of resource available in each one. It is likely that the dung beetle richness did not distinguish among the different fragments due to the even distribution of the mammal communities in these patches, and consequent equal dung diversity. We conclude that larger fragments encompass higher abundance of dung beetle and distinct species. However, for a clearer understanding of effects of fragmentation on dung beetles in Atlantic forest, studies evaluating narrower variations of larger fragments should be conducted.

Introduction

The economic cycles of agricultural and logging have been the major causes of environmental degradation for the last 500 years in Brazil (Fiszon et al., 2003; Santos et al., 2008). In the northeast region of the country, the sugarcane monoculture has led to huge changes in natural areas of the Atlantic forest, which is currently almost completely fragmented (Tabarelli et al., 2006). The majority of the remnants of the Atlantic forest in northeastern Brazil are small (<10 ha) and irregular in shape (Ranta et al., 1998), although the present forest remnants exhibit different sizes and shapes, depending upon the intensity of the deforestation process, acting as either constraints or facilitators to the natural communities (Tabarelli et al., 2006). Some factors, as fragment size, history and disturbance effects of a landscape are important structural parameters to the establishment of natural communities over disturbed areas (Bevers and Flather, 1999; Metzger, 2000; Cook et al., 2002). Small fragments experience a higher intensity of edge effect, mainly due to the smaller core area (Ranta et al., 1998), resulting in a less complex community (Herrmann et al., 2005). The edge area of fragments is subjected to a variety of ecological effects, such as greater light intensity, lower moisture and higher temperature (Gehlhausen et al., 2000). These effects alter soil dynamics, such as the nitrogen cycle (Paul and Clark, 1996), thereby affecting forest regeneration and nutrient recycling processes (Chen et al., 1995; Hagerman et al., 1999).

Habitat modification has important consequences, especially with regard to biodiversity (Naeem et al., 1999). Sensitive groups are more quickly affected by such modifications and suffer resource shortages and are unable to occupy disturbed areas (Jankielsohn et al., 2001; Halffter and Arellano, 2002). The dung beetles represent a group sensible to habitat disturbances, in such a way that the diversity of their assemblages are affected by fragment parameters, as isolation degree, size, tree species richness and canopy

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structure (Nichols et al., 2007; Díaz et al., 2010; Shahabuddin, 2010; Filgueiras et al., 2011). Disturbed habitats exhibit a quantitative impoverishment of vertebrates, which are the main providers of resources for the dung beetle assemblage, resulting in an inability to maintain more specialized groups (Asfora and Pontes, 2009; Filgueiras et al., 2009).

Although natural, the seasonality presents another influencing factor over dung beetle assemblages (Gill, 1991; Hernández and Vaz-de-Mello, 2009; Neves et al., 2010). In the tropics, seasonality exerts a considerable influence on the set of factors that contribute to the feeding and nesting of dung beetles (Gill, 1991; Filgueiras et al., 2009). In the dry season, food resources, which generally have a dough texture, dry out quickly, which hampers their use (Gill, 1991). Likewise, the soil in this period is drier, thereby inhibiting tunneling activities for the construction of nests and storage of resources (Doube, 1991).

The aim of the present study was to evaluate how the degree of size of fragments from the Atlantic forest affects the dung beetle assemblage. Our hypothesis is that larger fragments are less restrictive to dung beetles assemblage.

Material and methods

Study site

This study was conducted in forest fragments located in the Trapiche sugar processing plant located in the city of Sirinhaém (08°35′27″ S; 35°06′58″ O), state of Pernambuco, Brazil. The region has a mean annual precipitation of 2400 mm and mean temperature of 25 °C (Silva et al., 2010). This region is inserted in the Pernambuco Endemism Center ("Centro de Endemismo Pernambuco – CEPE"). The Trapiche plant owns fragments of dense ombrophilous forest situated on the tops of hills inferior than 100 m above sea level. Six fragments with different size attributes and separated by at least 1 km were selected: Ubaca (8°32′31″ S, 35°10′5″ W), Canto Escuro (8°33′13″ S, 35°8′46″ W), Mata das Cobras (8°33′18″ S, 35°8′40″ W), Tauá (8°33′15″ S, 35°9′23″ W), Xanguá (8°38′58″ S, 35°10′21″ W) and Xanguazinho (8°39′23″ S, 35°10′27″ W) (Fig. 1) (Table 1). The fragments were grouped into two size classes according to Filgueiras et al. (2011), as this study presents a landscape similar to the one found in Trapiche. Tauá and Xanguá were considered the large fragments, and the other four were considered small. In this way, the smallest fragment was Ubaca, with 8 ha, and the largest fragment was Xanguá, with 469 ha.

Table 1
Fragments of Atlantic forest situated around Trapiche property, city of Sirinhaém, Pernambuco, and respective size (ha) and size classes.

Fragment	Size (ha)	Size class	Number on the map (Fig. 1)
Ubaca	8.12	Small	4
Mata das Cobras	40.03	Small	1
Canto Escuro	75.80	Small	2
Xanguazinho	100.57	Small	6
Tauá	288.33	Large	3
Xanguá	469.76	Large	5

Additionally, two larger fragments outside Trapiche where the dung beetle assemblage has already been sampled were selected as control (Filgueiras et al., 2011; Costa et al., 2013). These data were utilized to compare dung beetle assemblages of fragments sampled in Trapiche and larger fragments, being 3500 ha the fragment of Coimbra (Filgueiras et al., 2011) and 7324 ha the fragment of CIMNC (Costa et al., 2013). These fragments are located near to Trapiche region, presenting a similar vegetal composition, also surrounded by a sugarcane matrix. Sampling methodology (trap spacing, type and weight of baits used, time of traps kept in field) applied on both fragments was similar to the samplings of fragments of Trapiche.

Dung beetle sampling

Sampling was performed in July and December 2010, corresponding to the rainy and dry seasons, respectively (LAMEPE, 2011).

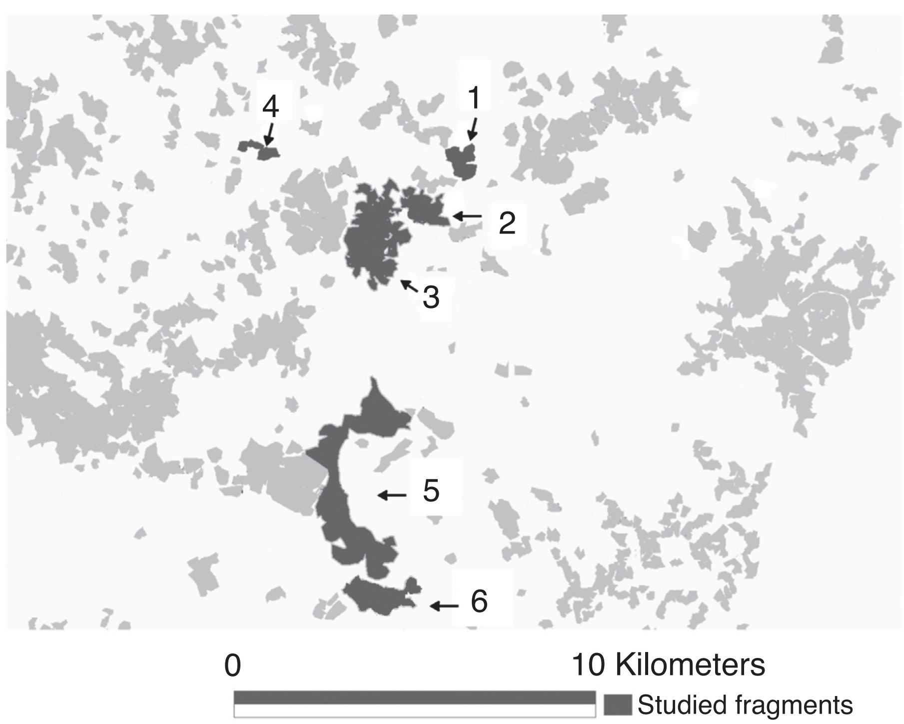

Fig. 1. Map showing forest fragments evaluated of the Trapiche property (Oliveira, unpublished data); 1: Mata das Cobas; 2: Canto Escuro; 3: Tauá; 4: Ubaca; 5: Xanguá; 6: Xanguazinho. Sirinhaém, Pernambuco, Brazil, 2010.

In each fragment of Trapiche two sampling sites separated by 150 m were determined. Eight pitfall traps were installed per site, separated from each other by 20 m were deployed – four baited with human excrement (25 g per trap) and four baited with carrion (rotten bovine spleen) (25 g per trap). The trap consisted of a plastic bottle measuring 13 cm × 15 cm with a total volume of 1000 mL, and was filled with 200 mL of water with salt and detergent. A plastic disk was placed over the trap to avoid the accumulation of leaves, twigs and rainwater. Forty-eight hours after deployment, the dung beetles were removed and mounted on entomological pins.

The identification of the dung beetles collected was done with assistance of the specialist Fernando Zagury Vaz-de-Mello. The specimens were deposited in the "Coleção Entomológica da UFPE" (CE – UFPE, Brazil).

Data analysis

General Linear Models (GLM) were used to compare the abundance and richness of dung beetle species between Trapiche and CIMNC fragments. Abundance and richness were the dependent variables; the Trapiche and CIMNC fragments were the categorical predictor variables; and fragment sizes were the continuous predictor variables. To compare samples equally between these areas, we only selected the data from the rainy season, due to the different sampling effort between CIMNC and Trapiche during the dry season. Each fragment was considered one sample unit. This analysis was performed using the STATISTICA 7.0 program. Although the sampling methodology in Coimbra was similar to those realized in Trapiche and CIMNC, the number of traps installed differed, resulting in distinct sampling effort. As abundance and richness of dung beetles tend to be connected with number of pitfalls installed, we opted to do not include Coimbra in this analysis to avoid sampling bias.

Non-Metric Multidimensional Scaling (NMDS) was used to determine overall differences in species composition between Trapiche, CIMNC and Coimbra fragments. Ordination was performed for abundance and composition using the Bray–Curtis index. Analysis of Similarities (ANOSIM) was used to test differences in species composition between the fragments. These analyzes were performed using the PRIMER 6.0 program.

Results

A total of 3352 dung beetles were captured and 19 species were identified in the forest fragments of Trapiche. *Dichotomius* aff. *sericeus*, *Canthon sulcatus* and *Canthon nigripennis* were the most abundant species, with 2648, 397 and 169 individuals sampled, respectively (Table 2).

A total of 2210 dung beetles were sampled in the rainy season and 1142 were sampled in the dry season. Two species had predominant distribution in the rainy season: *Dichotomius* aff. *sericeus* ($N = 1966$; 74% of total) and *Coprophanaeus dardanus* ($N = 56$; 96% of total). *C. nigripennis* and *C. sulcatus* were obtained mainly in dry season (59% and 81% of total, respectively), particularly with a dry/rainy ratio of 4.36/1 individuals for *C. sulcatus* (Table 2).

From the six fragments sampled in Trapiche, two were classified as large (Xanguá and Tauá) and the remaining four fragments were classified as small. A total of 1389 individuals from 11 species were collected from the large fragments of Trapiche, with an average of 694 dung beetles per fragment (Table 2). In the fragment of Xanguá (the largest fragment of Trapiche), we collected 601 individuals from six species. In the second larger fragment, Tauá, we collected 1035 individuals from nine species. A total of 1716 individuals from 16 species were collected from the small fragments, with an average of 429 dung beetles per fragment. The richness exhibited a variation between 7 and 12 species, and the abundance exhibited a variation between 255 and 822 individuals in the small fragments.

Three species exhibited a wide distribution, being collected in all fragments of Trapiche, also being collected in CIMNC and Coimbra: *Dichotomius* aff. *sericeus*, *C. nigripennis* and *C. dardanus*. On the other hand, *Eurysternus hirtellus* was collected only in CIMNC and Coimbra, and *C. sulcatus* was the only species caught exclusively in Trapiche, occurring in four of the six fragments. The fragment of CIMNC presented 13 exclusive species, while Coimbra presented nine (Table 3).

The dung beetle abundance showed difference among fragments of Trapiche and CIMNC ($F = 7.54$; DF = 1; $P = 0.006$). Also, dung beetle abundance was influenced by the size of the fragments of Trapiche and CIMNC ($F = 7.00$; DF = 1; $P = 0.008$). However, richness did not exhibited difference between fragments of Trapiche and

Table 2
Abundance of dung beetle species in six fragments of Atlantic forest on the Trapiche property, city of Sirinhaém, Pernambuco, 2010. 1 = Ubaca; 2 = Mata das Cobras; 3 = Canto Escuro; 4 = Xanguazinho; 5 = Tauá; 6 = Xanguá; R = Rainy; D = Dry.

Taxon	Fragments and periods												Total
	1 (8 ha)		2 (40 ha)		3 (75 ha)		4 (100 ha)		5 (288 ha)		6 (469 ha)		
	R	D	R	D	R	D	R	D	R	D	R	D	
Ateuchus sp. 1	1	0	0	0	0	0	2	2	0	0	0	0	5
Ateuchus sp. 2	0	0	0	0	0	0	2	3	0	0	0	0	2
Canthidium sp.	0	6	0	0	1	1	7	0	0	0	4	1	23
Canthon chalybaeus Blanchard, 1843	0	0	0	0	0	0	1	0	0	0	0	0	1
Canthon nigripennis Lansberge, 1874	7	27	10	19	12	12	23	11	7	15	9	17	169
Canthon aff. *oliveriori* (Pereira and Martínez, 1956)	0	0	0	0	0	0	0	0	0	1	0	0	1
Canthon simulans (Martínez, 1950)	0	0	0	1	0	0	0	0	0	0	0	0	1
Canthon staigi (Pereira, 1953)	0	0	1	0	1	0	0	0	0	0	0	0	2
Canthon sulcatus Laporte, 1840	0	0	36	82	22	109	0	0	14	131	2	1	397
Canthonella aff. *silphoides* (Harold, 1867)	5	7	0	0	7	2	5	2	0	1	0	0	29
Coprophanaeus sp.	0	0	0	0	0	0	0	0	1	0	0	0	1
Coprophanaeus dardanus (MacLeay, 1819)	9	0	5	0	6	0	22	2	4	0	10	0	58
Coprophanaeus aff. *ensifer* (Germar, 1824)	0	0	0	0	0	0	1	0	0	0	0	0	1
Coprophanaeus punctatus (d'Olsoufieff, 1924)	1	0	0	0	1	0	0	0	1	0	0	0	3
Deltochilum irroratum (Laporte, 1840)	0	0	0	1	0	0	0	3	0	3	0	0	7
Dichotomius sp.	0	0	0	0	0	0	1	0	0	0	0	0	1
Dichotomius depressicollis (Harold, 1867)	0	0	0	0	0	0	0	0	0	0	1	0	1
Dichotomius aff. *sericeus* (Harold, 1867)	132	68	79	21	391	257	238	49	653	204	473	83	2648
Sylvicanthon sp.	0	0	0	0	0	0	2	0	0	0	0	0	2
Total	155	108	131	124	441	381	304	72	680	355	499	102	3352

Table 3
List of species of dung beetle sampled in fragments of Trapiche (Tra), CIMNC (Cim) and Coimbra (Coi).

Species	Area
Agamopus convexus Balthasar, 1965	Coi
Canthon chalybaeus Blanchard, 1843	Tra, Cim
Canthon nigripennis Lansberge, 1874	Tra, Cim, Coi
Canthon scrutator Balthasar, 1939	Cim
Canthon histrio (Serville, 1828)	Cim
Canthon mutabilis Lucas, 1857	Cim
Canthon aff. *oliveriori* (Pereira & Martínez, 1956)	Tra, Cim
Canthon simulans (Martínez, 1950)	Tra, Cim
Canthon smaragdulus (Fabricius, 1781)	Coi
Canthon staigi (Pereira, 1953)	Tra, Cim
Canthon sulcatus Laporte, 1840	Tra
Canthonella barrerai (Halffter e Martínez, 1968)	Coi
Canthonella aff. *silphoides* (Harold, 1867)	Tra, Cim
Coprophanaeus acrisius (MacLeay, 1819)	Cim
Coprophanaeus cyanescens (Olsoufieff, 1924)	Cim
Coprophanaeus dardanus (MacLeay, 1819)	Tra, Cim, Coi
Coprophanaeus telamon (Erichson, 1847)	Cim
Coprophanaeus aff. *ensifer* (Germar, 1824)	Tra, Cim
Coprophanaeus punctatus (d'Olsoufieff, 1924)	Tra, Cim
Coprophanaeus bellicosus (Olivier, 1789)	Coi
Deltochilum irroratum (Laporte, 1840)	Tra, Cim
Deltochilum calcaratum Bates, 1870	Coi
Deltochilum pseudoicarus Balthasar, 1939	Cim
Dichotomius depressicolis (Harold, 1867)	Tra, Cim, Coi
Dichotomius mormon (Ljungh, 1799)	Coi
Dichotomius nisus (Olivier, 1789)	Cim
Dichotomius aff. *sericeus* (Harold, 1867)	Tra, Cim, Coi
Dichotomius ascanius (Harold, 1869)	Cim
Eurysternus caribaeus (Herbst, 1789)	Cim
Eurysternus hirtellus Dalman, 1824	Cim, Coi
Ontherus erosus Harold, 1875	Coi
Onthophagus clypeatus Blanchard, 1846	Coi
Onthophagus ranunculus Arrow, 1913	Cim
Pseudocanthon xanthurus (Blanchard, 1843)	Cim
Sylvicanthon foveiventris (Schmidt, 1920)	Cim
Uroxys batesi Harold, 1868	Coi

CIMNC ($F = 0.28$; DF = 1; $P = 0.597$), neither was influenced by the size of the fragments ($F = 0.29$; DF = 1; $P = 0.663$).

When we compared the species composition between fragments in Trapiche and fragments of CIMNC and Coimbra, we verified a segregation of the dung beetle assemblage (R: 0.875; p: 0.03). NMDS showed this pattern, grouping samples from the fragments of Trapiche apart from Coimbra and CIMNC, which segregated one from another (Fig. 2).

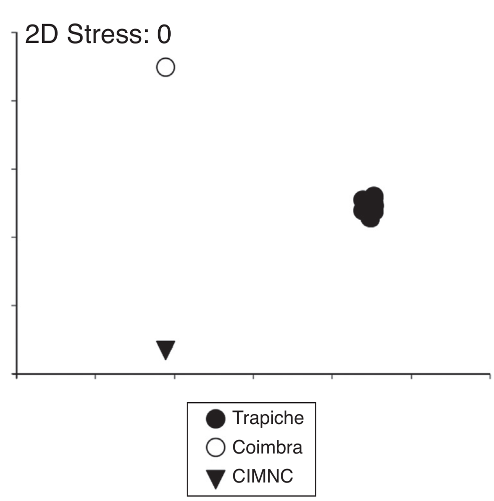

Fig. 2. Non-Metric Multidimensional Scaling (NMDS) ordination of fragments of Trapiche, CIMNC and Coimbra, based on dung beetle species composition.

Discussion

On the present study, the assemblage of dung beetle was dominated essentially by *Dichotomius* aff. *sericeus*. Also, this species is notably the most abundant in other tropical rainforests of northeastern Brazil, exhibiting competitive success in the region (Endres et al., 2007; Costa et al., 2009). This success is probably associated to low biological constrains, as this species is known to exhibit a wider trophic habit compared to other dung beetle species that co-occurs with it, allowing it to overcome resource scarcity and competitive barriers (Salomão et al., 2014). Although not studied in *D.* aff. *sericeus*, the high success of dung beetle species may also be related to a successful brood, with elevated number of eggs laid and high number of adults successfully developed from them (Halffter and Matthews, 1966; Halffter and Edmonds, 1982). However, the strong dominance of this species is geographically restricted, as *D.* aff. *sericeus* is reported to have low representativeness in the dung beetle assemblages of other areas near the fragments studied herein, such as the rainforest enclaves in the state of Pernambuco and forest remnants to the south of the Pernambuco Endemism Center (Schiffler et al., 2003; Silva et al., 2007). An important factor associated with the high occurrence of this species regards on adaptation to disturbed habitats. Human disturbances are found in most Atlantic forest remnants in the region and generally lead to a reduction in the abundance of dung beetles in forested areas (Costa et al., 2009; Filgueiras et al., 2011). However, *D.* aff. *sericeus* populations are highly successful in these modified remnants, dominating the dung beetle assemblage of forests that have undergone human disturbance episodes (Costa et al., 2009, 2013; Filgueiras et al., 2011).

Dichotomius aff. *sericeus* exhibited a higher abundance during the rainy season, with two thirds of the total caught during it. The rainy season also exerted an influence on species of the genus *Coprophanaeus*, as three of the four species identified were only caught during this period. This pattern is in agreement with that described in previous studies on the seasonality of Neotropical dung beetles (Andresen and Laurence, 2007; Hernández and Vaz-de-Mello, 2009; Neves et al., 2010). In tropical regions, seasonality is regulated by the rainy and dry periods of the year, with little fluctuation in temperature (Wolda, 1988). In the rainy season, tropical forests have high moisture content, allowing the longer use of ephemeral resources by dung beetles for feeding and breeding (Gill, 1991; Hernández and Vaz-de-Mello, 2009).

Differing from the results usually found for tropical dung beetles, *C. nigripennis* and *C. sulcatus* were abundant mainly in the dry season. Dung beetles adapted to environments and seasons with elevated drought stress and limited resource availability tend to exhibit trophic adaptations to stand out in extremely competitive habitats (Ocampo and Philips, 2005; Halffter and Halffter, 2009). The greater abundance of both species in the dry season may be related to the wider trophic niche, as these species are not restricted to excrement and carrion. There are records that species of the genus *Canthon* use fruits of the families Annonaceae and Arecaceae, which are present in the Atlantic forest of northeastern Brazil (Halffter and Halffter, 2009). Also, wider trophic niche could be an adaptation to the stronger competition that occurs in episodes of scarcer dung availability, such as during the drier periods of the year. This evolutional adaptation results from the absence of large mammals in the region (Halffter and Matthews, 1966; Halffter and Halffter, 2009).

Although our trapping design did not follow the distance recommended by Larsen and Forsyth (2005) to avoid interference among traps (at least 50 m from each other), our results presented solid data, as the interference of attractively that the traps could cause among them was similar in each fragment due to the same distance employed in each fragment sampled. Besides that, the distance among traps that we used has already been proven respond well in another studies evaluating dung beetle assemblages of Atlantic forest (Filgueiras et al., 2011; Costa et al., 2013; Salomão et al., 2014). We verified that the size of forest fragments exerted an influence on the dung beetle abundance, confirming the hypothesis that larger fragments would favor the structure of dung beetle assemblage. However, this result was only observed when there was a broad range of fragments size, when we included fragment of CIMNC. We believe that fragment size variations between 8 and 470 ha that we sampled in Trapiche could not exhibit strong influence over dung beetle abundance. This shift on dung beetle abundance may be explained by the theory of island biogeography proposed by MacArthur and Wilson (1967), which points that larger occupation area shows a tendency to support a higher abundance and diversity. Although there are no great distinction on the dung providers of larger forest fragments of northeastern Atlantic forest, these habitat supports higher abundance of mammals when compared to smaller ones (Asfora and Pontes, 2009). As a consequence, more resource to dung beetles is expected to be available, allowing a higher abundance on larger fragments.

The size of the forest fragments did not exert an influence on the dung beetle richness. It was expected that larger, more conserved fragments would support a richer fauna (Nichols et al., 2007; Filgueiras et al., 2011), since such habitats supposedly house a diverse community of resource providers. However, mammals, major providers of resource for dung beetles, are unable to maintain stable populations in the majority of Atlantic forest remnants in Brazil (Asfora and Pontes, 2009). Therefore, larger patches do not have resource providers to support different dung beetle fauna in comparison to smaller patches (Harvey et al., 2006; Asfora and Pontes, 2009). Although there were not significant differences on richness, species composition of dung beetles showed a distinction among the fragments of different sizes. Atlantic forest was a continuous region of tropical wet forest, however, strongly disturbance and fragmentation episodes caused an isolation of native fauna and flora (Ranta et al., 1998; Myers et al., 2000). Due to the high diversity, it is expected that each remnant maintains a specific faunal community. *C. sulcatus*, for example, was only obtained in the fragments of Trapiche, and did not occur in CIMNC and Coimbra. This species is known to occur just in other isolated fragments from southernmost regions of Atlantic forest (Campos, unpublished data). The same scenario was verified in fragments of Coimbra and CIMNC, in such way that each one presented dung beetle species that did not occur in the other fragments. As dung beetles have the capacity to fly long distances, it would be expected that they could move between fragments of Trapiche, allowing the species to co-occur on them (Scholtz et al., 2009). However, as many dung beetle species from Tropical rainforest have strong limitations to occupy open unshaded areas, agricultural matrices usually acts as strong barriers, in such a way that dung beetles cannot trespass them (Díaz et al., 2010; Costa et al., 2013).

Differing from the results found for the majority of fragments of Trapiche, the fragment of Xanguazinho (classified as small) had the higher species richness (12) and lowest abundance (232 individuals), which are parameters of well-balanced habitats (Novelo et al., 2007; Neves et al., 2010). Xanguazinho was the fragment with greatest degree of environmental heterogeneity, as evidenced by the presence of large trees and watercourses, thereby supporting a greater abundance of mammals (Alves, unpublished data) and the consequent maintenance of the dung beetle assemblage (Andresen and Laurence, 2007).

The high degree of fragmentation that tropical forests have been suffering is reflected in the stability of the ecosystems. Since the present remnants have a reduced size and capacity to support the environment, the associated community continuously suffers simplification processes (Fahrig, 2003). The largest fragment of Trapiche owns 469 ha, which may not be adequate to support a significant portion of Atlantic forest. Comparatively, Coimbra is one of the largest patches of Atlantic forest in northeastern Brazil, measuring 3500 ha, in which 23 species of dung beetle have been identified (Filgueiras et al., 2011). In the present study, the richest fragment of Trapiche had 12 species. This difference in richness may be associated with the size of the fragment, such that larger fragments can provide higher sort of habitat and consequently higher richness (Filgueiras et al., 2011).

Based on the present findings, the patches larger than 470 ha exhibited shifts in the abundance and species composition of dung beetles. However, studies encompassing fragments ranging from 470 ha and 3500 ha are necessary for a narrower comprehension of the influence of this factor on the Atlantic forest. With the clearer understanding of fragmentation effects over dung beetles, more effective conservation strategies can be conducted on the Atlantic forest.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

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References

Andresen, E., Laurence, S.G.W., 2007. Possible indirect effects of mammal hunting on dung beetle assemblages in Panama. Biotropica 39, 141–146.
Asfora, P.H., Pontes, A.R.M., 2009. The small mammals of the highly impacted North-eastern Atlantic Forest of Brazil, Pernambuco Endemism Center. Biota Neotrop. 9, 31–35.
Bevers, M., Flather, C.H., 1999. Numerically exploring habitat fragmentation effects on populations using cell-based coupled map lattices. Theor. Popul. Biol. 55, 61–76.
Chen, J.Q., Franklin, J.F., Spies, T.A., 1995. Growing season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. Ecol. Appl. 5, 74–86.
Cook, W.M., Lane, K.T., Foster, B.L., Holt, R.D., 2002. Island theory, matrix effects and species richness patterns in habitat fragments. Ecol. Lett. 5, 619–623.
Costa, C.M.Q., Silva, F.A.B., Farias, A.I., Moura, R.C., 2009. Diversidade de Scarabaeinae (Coleoptera, Scarabaeidae) coletados com armadilha de interceptação de vôo no Refúgio Ecológico Charles Darwin, Igarassu-PE, Brasil. Rev. Bras. Entomol. 53, 88–94.
Costa, F.C., Pessoa, K.K.T., Liberal, C.N., Filgueiras, B.K.C., Salomão, R.P., Iannuzzi, L., 2013. What is the importance of open habitat in a predominantly closed forest area to the dung beetle (Coleoptera, Scarabaeinae) assemblage? Rev. Bras. Entomol. 57, 329–334.
Díaz, A., Galante, E., Favila, M.E., 2010. The effect of the landscape matrix on the distribution of dung and carrion beetles in a fragmented Tropical rain forest. J. Insect Sci. 10, 1–16.
Doube, B.M., 1991. Dung beetles of Southern Africa. In: Hanski, I., Cambefort, Y. (Eds.), Dung Beetle Ecology. Princeton University Press, Princeton, pp. 133–155.
Endres, A.A., Creão-Duarte, A.J., Hernández, M.I.M., 2007. Diversidade de Scarabaeidae *s. str.* (Coleoptera) da Reserva Biológica Guaribas, Mamanguape, Paraíba, Brasil: uma comparação entre Mata Atlântica e Tabuleiro Nordestino. Rev. Bras. Entomol. 51, 67–71.
Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Evol. Syst. 34, 487–515.
Filgueiras, B.K.C., Liberal, C.N., Aguiar, C.D.M., Hernández, M.I.M., Iannuzzi, L., 2009. Attractivity of omnivore, carnivore and herbivore mammalian dung to Scarabaeinae (Coleoptera, Scarabaeidae) in a tropical Atlantic rainforest remnant. Rev. Bras. Entomol. 53, 422–427.
Filgueiras, B.K.C., Iannuzzi, L., Leal, I.R., 2011. Habitat fragmentation alters the structure of dung beetle communities in the Atlantic Forest. Biol. Conserv. 144, 362–369.
Fiszon, J.T., Marchioro, N.P.X., Britez, R.M., Cabral, D.C., Camely, N.C., Canavesi, V., Castella, P.R., Castro, E.B.V., Cullen Jr., L., Cunha, M.B.S., Figueiredo, E.O., Franke, I.L., Gomes, H., Gomes, L.J., Hreisemnou, V.H.V., Landau, E.C., Lima, S.M.F., Lopes,

A.T.L., Neto, E.M., Mello, A.L., Oliveira, L.C., Ono, K.Y., Pereira, N.W.V., Rodrigues, A.S., Rodrigues, A.A.F., Ruiz, C.R., Santos, L.F.G.L., Smith, W.S., Souza, C.R., 2003. Causas antropicas. In: Rambaldi, D.M., Oliveira, D.A.S. (Eds.), Fragmentação de Ecossistemas: Causas, Efeitos Sobre a Biodiversidade e Recomendações de Políticas Públicas. Ministério do Meio Ambiente/Secretaria de Biodiversidade e Florestas, Brasília, pp. 65–99.

Gehlhausen, S.M., Schwartz, M.W., Augspurger, C.K., 2000. Vegetation and microclimatic edge effects in two mixed-mesophytic forest fragments. Plant Ecol. 147, 21–35.

Gill, B.D., 1991. Dung beetles in Tropical American Forest. In: Hanski, I., Cambefort, Y. (Eds.), Dung Beetle Ecology. Princeton University Press, Princeton, pp. 221–229.

Hagerman, S.M., Jones, M.D., Bradfield, G.E., Gillespie, M., Durall, D.M., 1999. Effects of clearcut logging on the diversity and persistence of ectomycorrhizae at a subalpine forest. Can. J. Forest Res. 29, 124–134.

Halffter, G., Edmonds, W.D., 1982. The Nesting Behavior of Dung Beetles (Scarabaeinae). An Ecological and Evolutive Approach. Instituto de Ecología, México, DF.

Halffter, G., Matthews, E.G., 1966. The natural history of dung beetles of the subfamily Scarabaeinae (Coleoptera: Scarabaeidae). Fol. Entomol. Mex. 12, 1–312.

Halffter, G., Arellano, L., 2002. Response of dung beetle diversity to human-induced changes in a tropical landscape. Biotropica 34, 144–154.

Halffter, G., Halffter, V., 2009. Why and where coprophagous beetles (Coleoptera: Scarabaeinae) eat seeds, fruits or vegetable detritus. Bol. Soc. Entomol. Aragon. 45, 1–22.

Harvey, C.A., Gonzalez, J., Somarriba, E., 2006. Dung beetle and terrestrial mammal diversity in forests, indigenous agroforestry systems and plantain monocultures in Talamanca, Costa Rica. Biodivers. Conserv. 15, 555–585.

Hernández, M.I.M., Vaz-de-Mello, F.Z., 2009. Seasonal and spatial species richness variation of dung beetle (Coleoptera, Scarabaeidae s. str.) in the Atlantic Forest of southeastern Brazil. Rev. Bras. Entomol. 53, 607–613.

Herrmann, B.C., Rodrigues, E., Lima, A., 2005. A paisagem como condicionador de fragmentos florestais. Floresta 35, 13–22.

Jankielsohn, A., Scholtz, C.H., Louw, S.V., 2001. Effect of habitat transformation on dung beetle assemblages: a comparison between a South African Nature Reserve and neighboring farms. Environ. Entomol. 30, 474–483.

LAMEPE, 2011. Laboratório de Meteorologia de Pernambuco, Available at: http://www.itep.br/LAMEPE.asp (accessed 15.08.11).

Larsen, T.H., Forsyth, A., 2005. Trap spacing and transect design for dung beetle biodiversity studies. Biotropica 37, 322–325.

MacArthur, R.H., Wilson, E.O., 1967. The Theory of Island Biogeography. Princeton University press, Princeton.

Metzger, J.P., 2000. Tree functional group richness and landscape structure in Brazilian tropical fragmented landscape. Ecol. Appl. 10, 1147–1161.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Naeem, S., Chapin, C.F.S., Costanza, R., Ehrlich, P.R., Golley, F.B., Hooper, D.U., Lawton, J.H., O'Neill, R.V., Mooney, H.A., Sala, O.E., Symstad, A.J., Tilman, D., 1999. Biodiversity and ecosystem functioning: maintaining natural life support Processes. Issues Ecol. 4, 1–11.

Neves, F.S., Oliveira, V.H.F., Espírito-Santo, M.M., Vaz-de-Mello, F.Z., Louzada, J., Sanchez-Azofeifa, A., Ferndandes, G.W., 2010. Successional and seasonal changes in a community of dung beetles (Coleoptera: Scarabaeinae) in a Brazilian Tropical Dry Forest. Nat. Conserv. 8, 160–164.

Nichols, E., Larsen, T., Spector, S., Davis, A.L., Escobar, F., Favila, M., Vullinec, K., The Scarabaeinae Research Network, 2007. Global dung beetle response to tropical forest modification and fragmentation: a quantitative literature review and meta-analysis. Biol. Conserv. 137, 1–19.

Novelo, E.R., Delfin-Golzález, H., Morón, M.A., 2007. Copro-necrophagous beetle (Coleoptera: Scarabaeidae) diversity in an agroecosystem in Yucatan, Mexico. Rev. Biol. Trop. 55, 83–99.

Ocampo, F.C., Philips, T.K., 2005. Food relocation and nesting behavior of the Argentinian dung beetle genus *Eucranium* and comparison with the southwest African *Scarabaeus* (*Pachysoma*) (Coleoptera: Scarabaeidae: Scarabaeinae). Rev. Soc. Entomol. Argent. 64, 53–59.

Paul, E.A., Clark, F.E., 1996. Soil Microbiology, and Biochemistry. Academic Press, San Diego.

Ranta, P., Blom, T., Niemelä, J., Joensuu, E., Siitonen, M., 1998. The fragmented Atlantic rain forest of Brazil: size, shape and distribution of forest fragments. Biodivers. Conserv. 7, 385–403.

Salomão, R.P.S., Lira, A.F.A., Iannuzzi, L., 2014. Dominant dung beetle (Coleoptera: Scarabaeidae: Scarabaeinae) species exhibit wider trophic niches on fruits, excrement, and carrion in Atlantic forest, Brazil. Coleopt. Bull. 68, 686–688.

Santos, A.L.S., Pereira, E.C.G., Andrade, L.H.C., 2008. Fragmentação florestal decorrente do uso do solo e do processo de degradação ambiental, no Município de Junqueiro (AL). Camin. Geogr. 9, 115–120.

Shahabuddin, 2010. Diversity and community structure of dung beetles (Coleoptera: Scarabaeidae) across a habitat disturbance gradient in Lore Lindu National Park, Central Sulawesi. Biodiversitas 11, 29–33.

Schiffler, G., Vaz-De-Mello, F.Z., Azevedo, C.O., 2003. Scarabaeidae *s. str.* (Coleoptera) do Delta do Rio Doce e Vale do Suruaca no município de Linhares, estado do Espírito Santo, Brasil. Rev. Bras. Zoociênc. 5, 205–211.

Scholtz, C.H., Davis, A.L.V., Kryger, U., 2009. Evolutionary Biology and Conservation of Dung Beetles. Pensoft Publishers.

Silva, F.A.B., Hernández, M.I.M., Ide, S., Moura, R.C., 2007. Comunidade de escarabeíneos (Coleoptera, Scarabaeidae) copronecrófagos da região de Brejo Novo, Caruaru, Pernambuco, Brasil. Rev. Bras. Entomol. 51, 228–233.

Silva, R.K.S., Feliciano, A.L.P., Marangon, L.C., Lima, R.B.A., 2010. Florística e sucessão ecológica da vegetação arbórea em área de nascente de um fragmento de Mata Atlântica, Pernambuco. Rev. Bras. Ciênc. Agrár. 5, 550–559.

Tabarelli, M., Melo, M.D.V.C., Lira, O.C., 2006. Os Estados da Mata Atlântica Nordeste. In: Campanili, M., Prochnow, M. (Eds.), Mata Atlântica – Uma Rede pela Floresta. Rede de Ongs da Mata Atlântica, Brasília, pp. 149–164.

Wolda, H., 1988. Insect seasonality: why? Ann. Rev. Ecol. Syst. 19, 1–18.