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What is the importance of open habitat in a predominantly closed forest area to the dung beetle (Coleoptera, Scarabaeinae) assemblage?

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ABSTRACT. What is the importance of open habitat in a predominantly closed forest to the dung beetle assemblage? The Atlantic Forest in Brazil is one of the most highly disturbed ecosystems and is mainly represented by fragmented areas. However, in places where human disturbances have ceased, certain areas are showing a natural regeneration pattern. The aim of the present study was to determine how the dung beetle assemblage responds to distinct habitat structures in a fragment of Atlantic Forest. For such, open and closed forest areas were sampled in a fragment of the Atlantic Forest in the northeastern region of Brazil. Pitfall traps baited with excrement and carrion were used to collect the beetles. A total of 7,267 individuals belonging to 35 species were captured. *Canthon chalybaeus* and *C. mutabilis* were restricted to open areas. Nearly 90% of the individuals of *C.* aff. *simulans* and *Deltochilum* aff. *irroratum* were identified in these areas. A higher percentage (> 50%) of *Canthon staigi*, *Dichotomius* aff. *depressicolis* and *D.* aff. *sericeus* occurred in closed areas. Abundance differed between areas, with higher values in closed areas. Richness was not influenced by the habitat structure. NMDS ordination exhibited the segregation of areas and ANOSIM confirmed that this variable explained the assemblage of dung beetle species. The findings of the present study validate that open areas are associated to more restrictive conditions, limiting a higher abundance of dung beetle. Although situated near preserved fragments, the studied open areas increase the heterogeneity of the general landscape.

KEYWORDS. CIMNC; distribution patterns; Insecta; spatial heterogeneity.

The agriculture cycles in northeastern Brazil, which started in the 16th century with sugarcane plantations, have altered the natural habitats of the Atlantic Forest, which currently has approximately only 7.8% of its original area (Tabarelli *et al.* 2006). This forest offers a broad diversity of environments with particular climatic and structural characteristics, supporting one of the most distinctive biogeographical units in the entire Neotropical region, the Pernambuco Centre (Prance 1987). Despite its ecological importance, fragments of the Atlantic Forest have a mean size of 10 ha, which is insufficient for the establishment of k-strategist organisms (Ranta *et al*. 1998). Besides the small size, the forest remnants have also been highly altered and are usually surrounded by the sugarcane matrix. However, regeneration strategies directed at altered sites and the conservation of undisturbed forests has allowed changes in this scenario (Ranta *et al*. 1998). In abandoned areas of sugarcane, for example, regeneration has occurred and different stages of plant succession and structural complexity are currently found (Ranta *et al*. 1998; Asfora & Pontes 2009). Regeneration activities as the establishment of ecological corridors, conservation units and reforestation techniques can contribute toward the recovery and/or maintenance of the Atlantic Forest and floristic and faunal communities (Henein & Merrian 1990; SCBD 2008).

Due to the high degree of deforestation of the remnants surrounded by modified habitats, the edge effect is very strong in comparison to preserved sites (Santos *et al.* 2010). Furthermore, altered environments often have a high number of clearings due to logging activities (Stone & Lefebvre 1998). Consequently, there is a tendency toward a simplification of the biota, resulting from the reduction in area and the homogenization of habitats (Murcia 1995; Rodrigues 1998; Bierregaard Jr. *et al*. 2001). On the other hand, natural open habitats show a tendency to be occupied by specialized taxa that requires conditions of less humidity and higher sunlight and temperature, characteristics that are common on these environments (Costa *et al*. 2009; Gossner 2009).

Habitat loss has a direct effect on biological diversity and species that are more resistant to environmental alterations exhibit faster recovery rates (Santos *et al.* 2010). Such is the case with some species of dung beetles (Pineda *et al*. 2005; Davis *et al*. 2012). Although they feed essentially on decaying matter, these insects are not particularly specialized with regard to the type of resource (Halffter & Matthews 1966; Gill 1991; Quintero & Roslin 2005; Halffter & Halffter 2009). Dung beetles are also excellent bioindicators, as their distribution is directly related to the composition of the flora and fauna (Nichols *et al*. 2007, 2009; Hernández & Vaz-de-Mello 2009).

Dung beetles respond differently to the variety of matrices in forest fragments and vegetal succession gradients, exhibiting variation with regard to abundance and species composition (Nichols *et al*. 2007; Noriega *et al*. 2007; Neves *et al*. 2010). The presence of medium-size to large vertebrates also influences dung beetle diversity, as these insects depend on such animals as resource providers (Andresen & Laurance 2007; Nichols *et al*. 2009). In the Neotropics, the greatest diversity of dung beetles occurs in closed forest areas, mainly due to the higher availability of food sources and nesting conditions (Hanski & Cambefort 1991).

The aims of the present study were to describe how the dung beetle assemblage is distributed among different habitats in a remnant of the northeastern Brazilian Atlantic Forest. More specifically, we tested the hypothesis that despite of the disturbance history, the recent secondary regeneration is already sufficient for a distinction in dung beetle assemblage between closed and open habitats.

MATERIAL AND METHODS

Study site. The study was conducted at *Campo de Instrução Marechal Newton Cavalcanti* (CIMNC), located in the state of Pernambuco, northeastern Brazil (07°50'S and 35°06'W). The CIMNC is a military unit established in 1944 through the expropriation of ten sugarcane plantations for the training of military troops. The camp still serves for training and military exercises. The CIMNC is located among the cities of Abreu e Lima, Araçoiaba, Igarassu, Paulista, Paudalho and Tracunhaém, with 7,324 ha covering both forested and urbanized areas. The mean annual minimum and maximum temperature is 20.4°C and 30.4°C, respectively, with a mean annual precipitation of 1,175 mm. The region has a rainy tropical climate with a dry summer, with the rainfall concentrated between February and October (LAMEPE 2010). The soil is composed of latosols and podzolics on the top of plateaus and residual tops; podzolics with fragipan, plinthic podzolics and podzols on the small depressions of the Tabuleiro; concretionary podzolics in dry areas and on cliffs; and gleysol and alluvial soils in meadow areas (Beltrão *et al*. 2005).

The CIMNC fragment is considered one of the largest continuous patches of the Atlantic Forest north of the São Francisco River, with lowland dense rainforest (IBGE 1992). The area was previously used for sugarcane cultivation. The cessation of monoculture activities following the use by the Brazilian Army over 60 years ago has led to its current state of secondary regeneration succession (Rego *et al*. 2004).

Data collection. Beetles were collected from 12 areas of the CIMNC at sites spaced at least 1,000 m apart – six open areas and six closed areas. Open areas were characterized by sparse plant cover and no canopy and essentially composed of grasses. Closed areas had canopy coverage ranging from 7 to 10 m and more closed plant coverage than the open areas. Both habitat types have undergone succession for the same amount of time after cessation of agricultural activities on them and were at least 100 m from the edge of the forest (Lucena 2009). Sampling was performed monthly from January to May 2010, using pitfall traps baited (see Filgueiras *et al*. 2011) with human excrement (30g) and bovine carrion spleen (30g). Each sampling unit was established for four traps (2 with excrement and 2 with carrion). The traps were distributed in two sets spaced 20 m apart, each with two types of bait (3 m between baits).

Statistical analysis. Abundance of species that predominated in a type of habitat (>50% of individuals) was compared between the two habitats (open and closed) using Generalized Linear Models with a Poisson error distribution. Whenever data exhibited statistical difference, their normality was checked through the Shapiro-Wilk test (W-test).

One-Factor ANOVA was used to compare the abundance and richness of dung beetles between the types of sites (open and closed). In an attempt to avoid the non normality and heteroscedasticity of variances, data of abundance were square-root transformed. These analyses were carried out with the aid of the STATISTICA 7.0 program.

Non-metric multidimensional scaling (NMDS) was used to determine overall differences in species abundance and composition between open and closed sites. Ordination was determined for abundance and composition using the Bray-Curtis index. Analysis of similarities (ANOSIM) was used to determine differences in species abundance and composition between sites. NMDS and ANOSIM analyses were carried out using the Primer 6 program.

The number of species present at sites was estimated using the non-parametric estimator Jack 1. Rarefaction curves for closed and open habitats were constructed using individual-based rarefaction.

RESULTS

A total of 7,267 beetles distributed among 13 genera and 35 species were captured. *Dichotomius* aff. *sericeus* and *Canthon staigi* were the most abundant species, corresponding to 38.7% and 26.4% of the overall sample, respectively. Among the most abundant species (more than 1% of total abundance), all of them were attracted to both baits. *Pseudocanthon* and *Sylvicanthon* species were exclusively attracted by excrement. Regarding abundance, carrion attracted the majority of individuals (58%) (Table I).

Among the most abundant species, the majority had a preference for some type of habitat. Nearly 90% of the individuals of *Canthon* aff. *simulans* and *Deltochilum* aff. *irroratum* were captured in open areas. Significant differences were found in abundance of the *Canthon* aff. *simulans* ($F = 95.4$, $df = 1$, $p < 0.0001$) and *D*. aff. *irroratum* ($F = 5.43$, $df = 1$, $p = 0.019$) between sites, although for both of them the data did not exhibit normal distribution (*C*. aff. *simulans*: $W = 0.704$, $p = 0.0068$; *D*.aff. *irroratum*: $W = 0.714$, $p = 0.008$) showing that they had a grouped distribution. A higher percentage (> 50%) of *C. staigi*, *Dichotomius* aff. *depressicolis* and *Dichotomius* aff. *sericeus* occurred in the closed areas of the fragment (Table I). Similarly, significant differences were found in abundance of *C. staigi* ($F = 247.18$, $df = 1$, $p = 0.001$), *D*. aff. *depressicolis* ($F = 17.29$, $df = 1$, $p = 0.001$) and *D*. aff. *sericeus* ($F = 1104.34$, $df = 1$, $p = 0.001$) between open and closed areas. On the other

Table I. Species of dung beetles, and respective abundance according to habitat and bait type, of an Atlantic Forest fragment (CIMNC), in Abreu e Lima, Pernambuco, Brazil.

Taxa	Habitat and bait type			
	Open		Closed	
	Carrion	Dung	Carrion	Dung
Ateuchus sp. 1	0	10	1	20
Ateuchus sp. 2	6	0	24	1
Canthidium sp. 1	7	20	1	60
Canthidium sp. 2	1	3	1	0
Canthidium sp. 3	3	1	1	0
Canthidium sp. 4	1	0	1	0
Canthidium sp. 5	1	0	1	0
Canthon aff. *scrutator* Balthasar, 1939	17	2	8	1
Canthon chalybaeus Blanchard, 1843	62	14	0	0
Canthon mutabilis Harold, 1867	426	71	0	0
Canthon nigripennis Lansberge, 1874	20	17	9	20
Canthon histrio LaPeletier and Serville, 1828	2	1	0	1
Canthon aff. *simulans* Martinez, 1950	66	140	0	33
Canthon staigi (Pereira, 1953)	176	309	770	667
Canthonella silphoides (Harold, 1867)	2	0	5	3
Coprophanaeus aff. *ensifer* (Germar, 1824)	4	0	15	1
Coprophanaeus acrisius (Macleay, 1819)	1	0	0	0
Coprophanaeus cyanescens (Olsoufieff, 1924)	3	0	0	0
Coprophanaeus punctatus (Olsoufieff, 1924)	2	0	11	1
Coprophaneus dardanus (MacLeay, 1819)	1	1	8	1
Deltochilum pseudocairus Balthasar,1939	0	0	1	0
Deltochilum aff. *irroratum* (Laporte, 1840)	72	12	8	0
Deltochilum sp.	128	17	371	66
Dichotomius sp.	0	0	0	1
Dichotomius aff. *bicuspis* Germar, 1824	1	0	0	0
Dichotomius aff. *depressicolis* (Harold, 1867)	1	0	66	0
Dichotomius aff. *sericeus* (Harold, 1867)	217	186	1,270	1,140
Dichotomius nisus (Olivier, 1789)	1	0	0	0
Eurysternus caribaeus (Herbst, 1789)	42	1	35	1
Eurysternus aff. *hirtellus* Dalman, 1824	201	97	132	115
Onthophagus ranunculus Arrow, 1913	2	0	0	0
Pseudocanthon aff. *xanthurus* (Blanchard, 1843)	0	6	0	0
Sylvicanthon sp.	0	1	0	0
Trichillum externepunctatum Borre, 1886	16	0	0	0
Uroxys sp.	0	0	0	2
Total abundance	1,482	909	2,743	2,134
Total richness	29	19	21	18

hand, *C. staigi* ($W = 0.87$, $p = 0.227$) and *D.* aff. *sericeus* ($W = 0.803$, $p = 0.062$) had normal distribution, but *D.* aff. *depressicolis* ($W = 0.532$, $p < 0.0001$) exhibited an aggregate distribution.

In the comparison of CIMNC areas, a significant difference was found in dung beetle abundance ($F_{1;58} = 20.753$, $p = 0.00003$) (Fig. 1), with greater abundance occurring in closed areas (n = 4,877) in comparison to open areas (n = 2,390). The richness values were not different between areas ($F_{1;58} = 1.2266$, $p = 0.27265$) although more species were captured in open habitats than closed habitats (Fig. 2). In this way, open habitats exhibited the highest value for Simpson's diversity index (1/D = 6.673). Estimation of total species number for both open and closed habitats indicated a high level of completeness (see Table II).

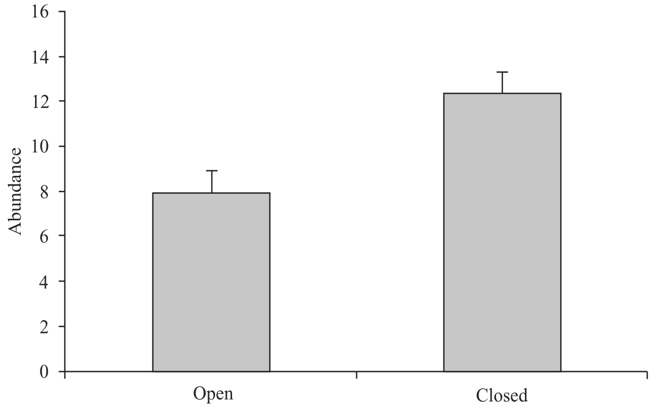

Fig. 1. Average and standard error (bar) of abundance of dung beetle community in open and closed habitats of an Atlantic Forest fragment (CIMNC), in Abreu e Lima, Pernambuco, Brazil.

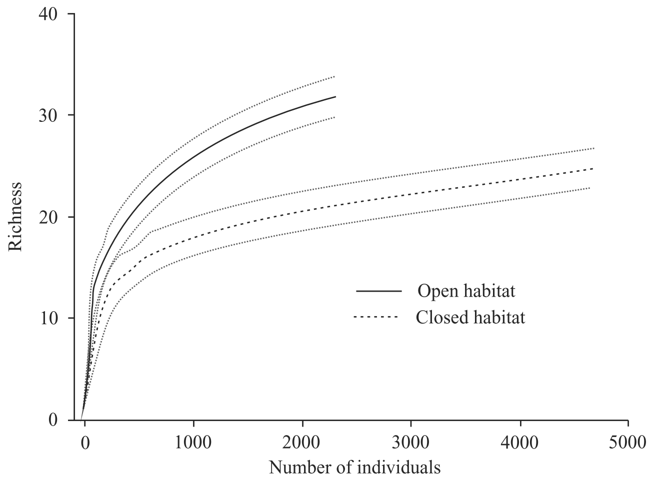

Fig. 2. Individual-based rarefaction curves for dung beetles in open and closed habitats of an Atlantic Forest fragment (CIMNC), in Abreu e Lima, Pernambuco, Brazil. Dotted-lines are 95% confidence intervals (CI).

Table II. Abundance, species richness, estimated species richness and diversity index for dung beetles in open and closed habitats of an Atlantic Forest fragment (CIMNC), in Abreu e Lima, Pernambuco, Brazil.

	Abundance	Richness	Estimated richness (Jack 1)	Completeness*	Simpson (1-λ)
Open habitat	2391	31	37.67	82.39	6.673
Closed habitat	4873	25	29.54	84.63	2.856

* Percentage of Jack 1 estimate in relation to observed richness.

The NMDS provided a good representation of the similarity matrices among the dung beetles in the areas sampled (stress = 0.06 – species composition; stress = 0.01 – abundance) (Fig. 3). The ordination exhibited the grouping of areas and ANOSIM confirmed that the variable "area" explained the species composition (global $R = 0.279$, $p = 0.009$, number of permutations = 999) and abundance (global $R = 0.433$, $p = 0.002$, number of permutations = 999).

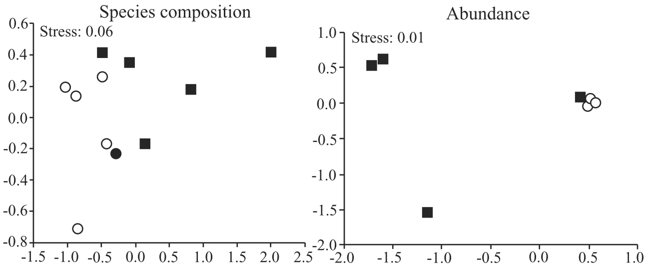

Fig. 3. NMDS ordination of dung beetle community (major groups) in open and closed habitats of an Atlantic Forest fragment (CIMNC), in Abreu e Lima, Pernambuco, Brazil. (■) Open habitat, (○) closed habitat.

DISCUSSION

The present study investigated the structural relationship between open and close habitats of a fragment of the Atlantic Forest and the dung beetle assemblage. The diversity of this group was similar to that reported in other studies carried out in northeastern Brazil (Costa *et al*. 2009; Silva *et al*. 2010). *Dichotomius* aff. *sericeus* and *C. staigi* were the most abundant species in the present study, distributed mainly in closed habitats. Members of the complex *D.* aff. *sericeus* and *C. staigi* have been shown to be predominant components at Atlantic Forest sites in northeastern Brazil, mostly associated with closed habitats (Endres *et al*. 2007; Costa *et al*. 2009; Silva *et al*. 2010; Filgueiras *et al*. 2011). The type of environment also played an important role in the distribution of other species. For instance, *Canthon mutabilis* and *C. chalybaeus* were restricted to open areas. *Canthon mutabilis* occurs throughout most of South America, always associated with dry savanna and open moist areas (Solís & Kohlmann 2002; Silva 2011). In Brazil, *C. chalybaeus* is more abundant on the edge of forests and in pastures used for cattle grazing than within forests (Lopes *et al*. 2011). Thus, the exposed conditions of open areas seem to benefit these species, which, in turn, constitute an indicator of this condition.

The established mosaic of the CIMNC fragment exerts an influence on the conservation of dung beetles. Most significantly, abundance was higher in areas where the plant structure was denser. In Neotropical rainforests, closed forests with a high degree of conservation constitute the most favorable condition for the establishment of assemblages of this beetle group (Howden & Nealis 1975; Gill 1991; Spector & Azayama 2003; Kohlmann *et al*. 2007). In these wetter habitats the availability of resources remains viable for longer periods (Halffter & Matthews 1966; Halffter 1991). On the other hand, some species of the dung beetle assemblage exhibited greater affinity to open areas, with higher abundance in these areas, in addition to those species that were found only in this type of habitat. This may explain the higher value of diversity index for open areas. The species composition of dung beetles over distinct areas may be explained by evolutionary traits. Species that occupy open areas show a tendency to use the resources quickly due to faster desiccation, avoiding the abiotic factors that limit the resource utilization (Larsen *et al*. 2006; Almeida & Louzada 2009). This proves the importance of open areas as much as closed areas.

On the other hand, the type of habitat (open or closed) did not exert an influence on the richness of dung beetle species. This finding does not lend support to the hypothesis put forth. In comparison to closed areas, open areas commonly display a tendency toward an increase in the number of species over time as the forest naturally regenerates (Quintero & Roslin 2005; Quintero & Halffter 2009). However, some disturbed environments in the regeneration process do not exhibit differences in the dung beetle communities between open and closed habitats (Silva *et al*. 2010). The distinct responses to regeneration in terms of dung beetle richness are related to the different kinds of disturbance, i.e., fire or logging (Hobbs & Huenneke 1992). In the fragment studied herein, despite extensive logging for decades, the area has been in a process of natural regeneration for over 60 years (Rego *et al*. 2004). In the present study it was observed a homogenization in both areas with regard to richness. Despite the lower abundance in comparison to closed forest areas, species from an earlier stage of regeneration can cross open areas, even if they have a decreased presence when compared with the closed forest (Nichols *et al*. 2007). Another factor could be the narrow forest contour of some open areas in the CIMNC, enabling the colonization of species that require some specific conditions (Davis *et al*. 2002).

Despite the low global R-values in both analysis (presence/absence and abundance), species composition was distinct between the two habitats. However, abundance nested most of the studied sites, except for three open sites that were distinct from the others in both analyses. In these sites, sandy soil is predominant and, associated to the distinct plant cover, composed mainly by grasses, may have contributed to the distinct distribution of dung beetles. Sandy areas make tunneling, reproduction and larval growth more difficult, and constitutes a restrictive habitat for the occurrence of some dung beetle species (Fincher 1973). Likewise, one closed site was separated from the others; it is located in the most preserved portion of the forest remnant, having suffered little, if any, deforestation (Davis *et al*. 2002).

The results of the present study suggest that distinct habitats act complementarily for the structure of the dung beetle assemblage in the Atlantic Forest. One may therefore conclude that the conservation of forest remnants contributes to regeneration and the consequent diversification and maintenance of dung beetle assemblage. These insects are effective bioindicators, exhibiting a well-established structure in preserved areas. This same pattern can be extrapolated to other components of biodiversity.

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