

# Successional and Seasonal Changes in a Community of Dung Beetles (Coleoptera: Scarabaeinae) in a Brazilian Tropical Dry Forest

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## Abstract

We tested the following hypotheses on the dynamics of a dung beetle community in a Brazilian Seasonally Dry Tropical Forest: (1) successional changes of dung beetle community, with species composition, richness and overall abundance increasing with the successional stages; (2) dung beetle community changes between dry and wet seasons, with species composition, richness and abundance decreasing in the dry season. Dung beetles were sampled in 15 plots from three different successional stages in both wet and dry seasons. We sampled a total of 2,752 individuals, representing 38 beetle species and 14 genera. The composition, richness, and abundance of dung beetles changed along the successional gradient and was strongly related to seasonal variation. The highest diversity of dung beetles was found in the intermediate aged forest fragments. These findings highlight the importance of secondary forests to biodiversity conservation and restoration programs in seasonally dry tropical ecosystems.

**Key words:** Biodiversity, Habitat Complexity, Resource Availability, Scarabaeidae, Secondary Succession.

## Introduction

The loss of tropical habitats due to anthropogenic activities is the major cause of decline in species diversity during recent decades (Balmford *et al.* 2005; Reid *et al.* 2005). Seasonally Dry Tropical Forests (SDTF) encompasses approximately 42% of all tropical habitats (Murphy & Lugo 1986) and harbors a unique range of biodiversity (Janzen 1988). SDTFs are among the least protected (Janzen 1988) and most threatened ecosystems in the world (Miles *et al.* 2006), yet they have generally been neglected by conservation efforts and fall behind other global initiatives aimed to protect tropical rainforests (Sanchez-Azofeifa *et al.* 2005). For instance, less than 1% of the original 500,000 km<sup>2</sup> of

SDTFs is under protection in Central America (Janzen 1988). In Brazil, only 3.9% of the remaining SDTFs are protected (Sevilha *et al.* 2004).

Human occupation of SDTF areas is usually followed by abandonment and the subsequent natural recover in secondary forest formations (Quesada *et al.* 2009). As such, SDTF landscapes are often a mosaic of remnants in a range of successional stages depending on the length of recovery time and the degree of the disturbance (Madeira *et al.* 2009; Quesada *et al.* 2009). These, in turn, affect the community structure and composition of several groups of plants and animals (Siemann *et al.* 1999; Neves *et al.* 2010). It is not yet clear, however, how arthropod communities change across successional gradients in tropical dry systems (see Neves *et al.* 2010).

In addition to forest successional status, seasonal variation in biotic and abiotic factors strongly influence SDTF structure

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and function (Murphy & Lugo 1986). SDTFs are usually characterized by a marked dry season (3-6 months) and concentrated rainfall during the wet season (Murphy & Lugo 1986). The seasonality of these forests affects the phenological patterns of plants and, consequently, the faunal abundance (Wolda 1978). Since insect abundance has often been correlated with rainfall (Wolda 1978), pronounced differences are expected for these organisms between dry and wet seasons in SDTFs (but see Neves *et al.* 2010).

Many groups of arthropods have been used as indicators of habitat quality due to their great sensitivity to environmental changes (Gardner *et al.* 2008). Particularly, Scarabaeinae dung beetles have been used to evaluate and monitor the relationship between habitat structure and degree of disturbance and community composition (Nichols *et al.* 2007; Gardner *et al.* 2008; Nichols *et al.* 2008). Dung beetles include a very diverse group of detritus-feeding insects in tropical rainforests (Hanski & Cambefort 1991). They are considered to be one of the most important insect components of terrestrial ecosystems, since they contribute to several ecological functions, such as secondary seed dispersal, nutrient cycling, bioturbation and biological control of pests and parasites (Nichols *et al.* 2008). Casual observations indicate that dung beetles are very common in SDTFs, but there is a lack of information about the responses of this insect group to forest disturbance.

A better understanding of the spatial and temporal distributions of the dung beetles across gradients of natural regeneration, and of the effects of habitat structure on this group's diversity may inform the management and conservation of threatened SDTFs. Therefore, the objectives of this study were to test two hypotheses on a dung beetle community in a Brazilian SDTF. The first hypothesis predicts changes in species composition, richness and overall abundance increasing along the successional gradient. The second predicts seasonal changes in the dung beetle community, with species composition, richness and overall abundance decreasing in the dry season.

## Material and Methods

### Study area

This study was carried out in the Parque Estadual da Mata Seca (PEMS), a conservation unit created in the area of four farms in 2000. The PEMS is located on 10,281.44 ha in the São Francisco river valley, Minas Gerais, Brazil (between 14° 48' 36" – 14° 56' 59" S and 43° 55' 12" – 44° 04' 12" W). The original vegetation is SDTF, growing on plain and nutrient-rich soils (Instituto Estadual de Florestas 2000) and dominated by deciduous trees, with 90-95% leaf loss during the May–September dry season (Madeira *et al.* 2009). The climate of the region is tropical semi-arid (Köppen's classification), characterized by a severe dry season during the winter months. The average temperature of the study region is 24 °C (Antunes 1994), with an average annual

precipitation of 818 ± 242 mm. (Madeira *et al.* 2009). The main land uses in the area before the establishment of the park were cattle ranching and cultivation of beans, tomato and corn in irrigated areas. Approximately 1,525 ha of the PEMS is covered with abandoned pasture where SDTF can be found in different stages of recovery, while the remaining area supports secondary and primary SDTF (Madeira *et al.* 2009).

Samples of dung beetles were conducted inside 15 randomly delimited plots of 50 × 20 m inside forest fragments classified as early, intermediate or late successional stages (five plots per stage). These plots were established in January 2006, and all plants with a diameter at breast height ≥ 5 cm were tagged and identified (see Madeira *et al.* 2009 for details). All plots were located along a 7 km transect inside the original area of a single farm, where management practices were similar for all pasturelands over the last 30 years. Plots from the same regeneration stage were located at least 0.2 km apart. The early successional plots were characterized by a forested area composed of sparse patches of woody vegetation, shrubs, herbs and grasses with a single stratum of tree crowns presenting a very open canopy approximately 4 m high. This area had been used as pasture for at least 20 years and abandoned in 2000. The intermediate successional plots were characterized by two vegetation layers: one composed by deciduous trees (10–12 m) and some emergent trees (up to 15 m), and a second layer of dense understory with many young trees and abundant lianas. This area was used as pasture for at least five years and abandoned in 1987. The late successional plots were also characterized by two strata: the first composed of taller deciduous trees forming a closed canopy 18–20 m high, and the second of a sparse understory with reduced light levels and low density of young trees and lianas. There are no records of clear-cutting in this area for the last 50 years. Site history was determined through interviews with the park manager and former farm employees. For a detailed description of plot structure and composition see Madeira *et al.* (2009).

### Dung beetle sampling

Dung beetles were sampled during two periods in 2007: February (wet season) and September (dry season). We placed four pairs (two alternative baits) of pitfall traps in each plot, totaling 120 traps. Traps consisted of a plastic container 14 cm in diameter and 9 cm deep buried with the opening level with the soil. In the inner compartment approximately 50 g of human feces or carrion (rotten chicken liver) was used as bait, and covered with a lid to protect from rain. We filled the surroundings of the inner pitfall compartment with 250 mL of a liquid detergent solution as a killing and preservative agent. After a period of 48 hours, all insects were collected, sorted and identified to the lowest taxonomic level possible. Voucher specimens were deposited at the Entomological Collection of the Laboratório de Biologia da Conservação (Unimontes) and in the FZVM collection at Universidade Federal do Mato Grosso (UFMT).

Data analyses

We used non-metric multidimensional scaling to search for overall differences in species abundance and composition between different successional stages. Ordination was undertaken for abundance and composition using the Bray-Curtis index. We used analysis of similarities (ANOSIM, Clarke 1993) to test the differences in species abundance and composition between successional stages. This is a non-parametric permutation procedure applied to rank similarity matrices underlying sample ordinations (Clarke 1993). The relative differences between *R*-values from the ANOSIM test were used to determine the patterns of similarity between dung beetle communities in the three successional stages. We used similarity percentage (SIMPER, Clarke 1993) to determine the individual species contribution in each successional stage. The analyses were performed using the software PAST (Hammer et al. 2001).

We used generalized linear models (GLMs) to identify the effects of successional stages (explanatory variable) on dung beetle richness and abundance (response variables). All GLMs were submitted to residual analyses to evaluate adequacy of the error distribution (Crawley 2002). Significant results for factor levels (stages) were compared using contrast analysis by aggregating levels and comparing deviance change (Crawley 2002). If the level of aggregation did not significantly alter the deviance explained by the model, the levels were pooled together (amalgamated), simplifying the model. Minimum adequate models were generated by stepwise omission of non-significant terms. The GLMs were performed with the software R (R Development Core Team 2008).

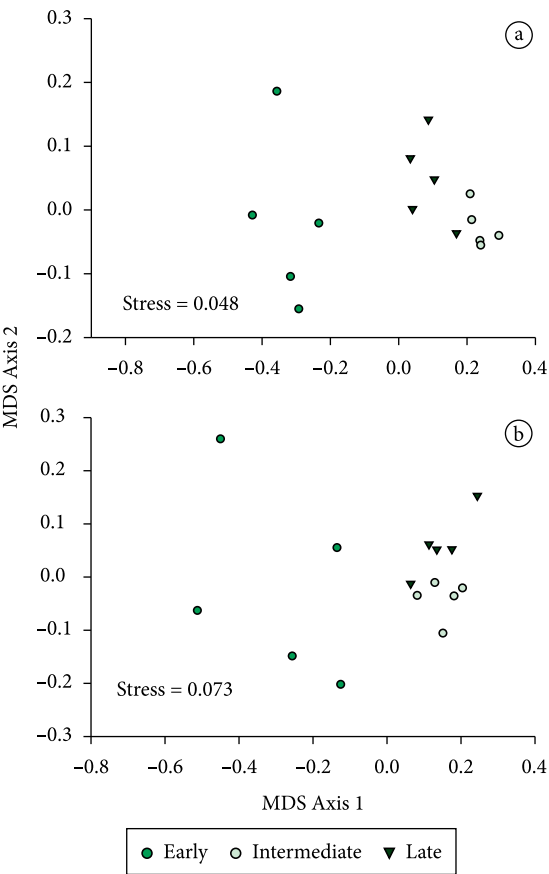
Results

We sampled 2,752 dung beetle individuals, belonging to 38 species from 14 genera. Among the identified species, 56% have a wide geographical distribution, 20% occur in the Caatinga, 12% in the Cerrado, and another 12% are common to both Biomes (Table S1). For all samples combined, the species accumulation curve was close to reaching an asymptote (Figure S1a), but this varied between successional stages (Figure S1b).

Strong changes were observed in the species abundance and composition of dung beetles across the successional gradient. We collected 41 individuals from 13 species in the early successional stage, with one species exclusive to this stage. In the intermediate stage, we found 32 species (2,010 individuals) from which ten were exclusive to this stage. In the late successional stage, 27 species were sampled (701 individuals), with five exclusive species. Among the collected species, 32% were found in all stages, whereas 58% were found only in intermediate and late stages (Table S1).

The MDS ordination showed clear differences in dung beetle species abundance (Figure 1a) and composition (Figure 1b) between successional stages (Table 1). However, these analyses showed that the early successional stage

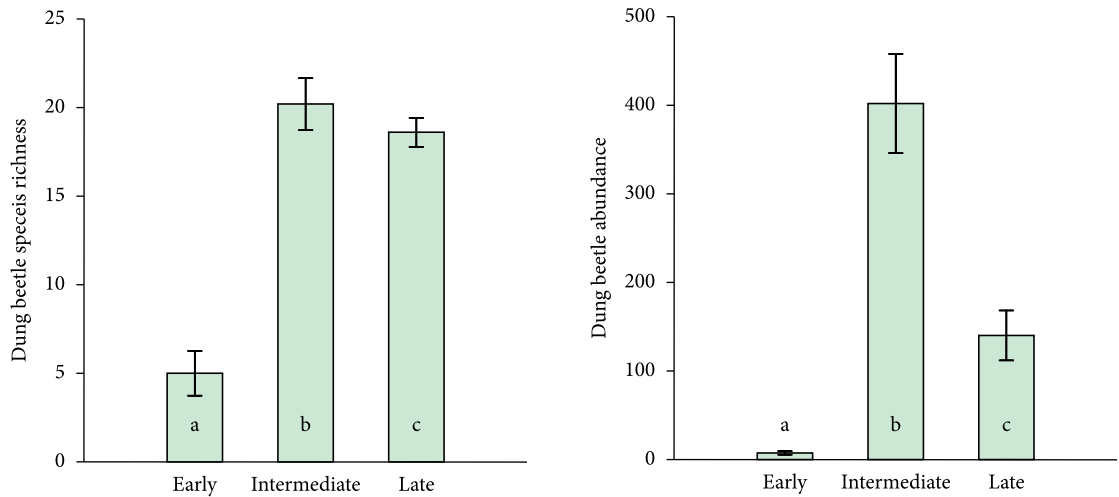
presented a more distinct dung beetle community compared to the advanced stages of regeneration (Figure 1, Table 1). Only four species (*C. histrio*, *Uroxys* sp.2, *Deltachilum verruciferum* and *Canthidium manni*) contributed more than 69% to the observed differences between stages. The dominant *Uroxys* sp.1 and *C. histrio* did not occur in the early successional stage, where the most common species was *Canthidium* sp.1. The species richness and total abundance of dung beetles were significantly higher in the intermediate stage, followed by the late stage (Figure 2, Table 2).



**Figure 1.** Non-metric multidimensional scaling (MDS) ordination of the dung beetle community in three successional stages as sampled by pitfalls traps. a) species abundance and b) species composition.

**Table 1.** Results of Non-parametric analyses of similarity (ANOSIM) testing for differences in the rank similarities for 15 sites in three successional stages (early, intermediate and late) grouped by dung beetles species abundance and composition. ANOSIMs were calculated based on Bray–Curtis similarity.

Parameter	Stage	R	p
Species abundance	early × intermediate	1	0.008
	early × late	0.984	0.0085
	intermediate × late	0.7	0.0074
Composition	early × intermediate	0.722	0.0081
	early × late	0.73	0.0074
	intermediate × late	0.294	0.0156



**Figure 2.** Dung beetle richness and abundance (Mean  $\pm$  SE) per plot in the wet season in three successional stages. Distinct letters in the bars represent statistical differences between successional stages detected by contrast analysis ( $p < 0.05$ ).

**Table 2.** Analyses of deviance of the minimal adequate models showing the effects of successional stage on dung beetle richness and abundance.

Response variable	Error distribution	d. f.	Deviance	p
Richness	Poisson	2	16.82	<0.001
Abundance	Quasipoisson	2	1476.49	<0.001

Dung beetle communities also showed a strong seasonal variation, with remarkable differences between the dry and wet seasons. During the wet season 2,748 individuals belonging to 38 species of dung beetles were collected, whereas only four *Uroxys* sp.1 individuals were sampled in the dry season.

Discussion

Dung beetle community changed along a successional gradient in the studied SDTF, with variation in species abundance and composition and increases in species richness and overall abundance from early to advanced stages. The differences between successional stages observed here are consistent with studies conducted on other organisms in the same plots (see Madeira *et al.* 2009; Quesada *et al.* 2009; Neves *et al.* 2010). After seven years of regeneration, only 31.6% of the species present in the early stage was shared with late forests. Additionally, of the five most abundant species in intermediate and late stages, three were not recorded in early stages: *C. histrio*, *Uroxys* sp.2 and *C. manni*. These species are therefore potential indicators of disturbance levels in Brazilian SDTFs, due to their marked responses to habitat conditions, though further studies are needed to validate this suggestion. *C. histrio* is commonly found in seasonal wooded areas of the Cerrado, Caatinga and Chaco biomes (and is also encountered in southern Amazonia), whereas *C. manni* is restricted to the Caatinga and northern Brazilian coastal vegetation complexes, apparently always

associated with less open habitats (Fernando Vaz-de-Mello, pers. obs.).

Though intermediate and late successional stages sustained more similar beetle communities, substantial differences were still observed. Of the 32 species recorded in intermediate plots, 22 were also found in late stage plots. All the exclusive species from both intermediate (10) and late (5) stages can be considered rare, and there is no clear explanation for this habitat segregation. It is possible that some beetle species were excluded in late succession plots due to a decreased habitat complexity caused by liana impoverishment (see Madeira *et al.* 2009; Sanchez-Azofeifa *et al.* 2009). Thus, it is possible that more structurally complex, liana-rich intermediate forest fragments attract and maintain potential seed dispersers, which in turn provide feeding and reproductive resources for dung beetles, increasing their diversity in these habitats. This explanation is in accordance with the intermediate disturbance hypothesis (Connell 1978), which predicts a higher organism diversity under moderate levels of disturbance. Similar results have been reported in a study of dung beetles by Nichols *et al.* (2007), who did not find differences in species richness between secondary and primary forests.

Dung beetle community changed between dry and wet seasons, with a dramatic decrease in species richness and abundance in the dry season. SDTFs probably have the most pronounced intra-annual differences in dung beetle communities among all tropical forested ecosystems, since these organisms all but cease activity during the dry season. The dry season in the PEMS region is very intense, with up to seven months without rain (typically from mid-April to mid-November). In this period, the superficial soil layer becomes desiccated and compacted, and plants lose up to 95% of their leaves (Pezzini *et al.* 2008). Though direct observations of dung-producing vertebrates are not currently available for the study site, it is very likely that they respond

negatively to the lack of water and to the absence of insects as a food resource, and probably migrate temporarily to the riparian forests nearby.

Habitat structural complexity and resource availability are important factors in determining the dung beetle community in this SDTF, as indicated by their high susceptibility to both spatial (across successional stages) and temporal (across seasons) environmental changes. These characteristics, combined with the relatively inexpensive sampling techniques necessary for dung beetle survey, strength the role of these insects as good ecological indicators in rapid diversity assessment programs. Usually, secondary forests are often ignored and their importance for conservation purposes is neglected or underestimated. The highest beetle diversity in intermediate forests also highlights the importance of secondary forests maintenance and restoration programs to tropical conservation strategies.

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