

Article

The Response of Dung Beetle Communities to Land Use Change in the Brazilian Cerrado

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Abstract: The transformation of the Cerrado biome into areas with different levels of activity and anthropic pressure negatively impacts biodiversity. This study evaluated the response of the dung beetle community to changes in land use systems: forests, rubber trees, pastures, and soybeans. Five areas were sampled in each system with a minimum distance of 2 km between them. Dung beetles were collected using pitfall traps, and both local (vegetation density, basal area of wooded vegetation, fractal dimension, litter height, electrical conductance (mV), water content in the soil (%), and soil resistance (kPa)) and landscape-related environmental variables (land use and overall composition and configuration of the landscape surrounding the sampling areas) were measured. In total, 2294 specimens were collected and distributed among 34 species and 18 genera. There was no significant difference in abundance between the systems, but differences in the number of species and biomass were observed between forest and soybean systems, as well as a separation of communities between the tree-covered (forest and rubber tree) and open (pasture and soybean) systems. Density and arboreal basal area were the main predictive variables for the diversity of the dung beetle community, reinforcing the importance of vegetation cover for maintaining diversity, whereas local and landscape-related variables influenced community composition.

Keywords: bioindicator; biodiversity; coprophagous beetle; habitat shift; Scarabaeinae; land use intensification



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1. Introduction

Anthropogenic activities are leading to changes in land use systems that result in massive habitat and biodiversity loss [1], threatening the maintenance of ecosystem balance [2,3] and posing a threat to human health and well-being [3]. One of the most visible changes in the landscape is habitat fragmentation, a process that alters the environment and landscape and also creates the edge effect, which affects the physical and chemical parameters of the environment [4–6]. These changes favor the establishment of exotic species and consequently alter the structures of plant and animal communities [7,8] and

also affect the flow of fauna [9]. Although some synanthropic species can benefit from these environmental changes, others are more sensitive and do not tolerate them [10,11]. Therefore, ecological studies on the effects (e.g., biological and functional diversity, ecosystem services, community resilience, habitats, and microhabitats) of different land uses are fundamental to understanding these dynamics, as the assessment of habitat changes and their consequences for natural communities is a major challenge in ecology [11,12].

The Cerrado, Brazil's second largest biome, extends over ten Brazilian states (Bahia, Goiás, Tocantins, Mato Grosso, Mato Grosso do Sul, Maranhão, Piauí, São Paulo, Minas Gerais, Rondônia, Paraná, and the Federal District) [13] and originally covered an area of approximately 198 million hectares (23.3%) of the Brazilian territory [14]. Its diversity of phytophysiognomies, including Cerrado Stricto-Sensu, Campo Sujo, Campo Limpo, Veredas, Gallery Forests, High-Altitude Grasslands, and Cerradão, gives the biome great structural heterogeneity [15]. However, the Cerrado is under strong pressure from human activities and is considered a biodiversity hotspot due to the high biodiversity and threats that it faces [16]. Despite its ecological importance, public action to protect this biome is limited, making it highly vulnerable to degradation [13,17]. Currently, only 3.1% of the total area of the Cerrado is protected by permanently protected areas, such as national parks, while 5.5% is categorized as sustainable use [14]. About 50% of the original area of the biome has already been converted to other land use systems [14], with the expansion of agricultural frontiers being one of the main threats, mainly driven by agribusiness-related projects [14,18].

Agricultural expansion in the Cerrado has led to the replacement of native vegetation with monocultures of soybeans, maize, pastures for intensive livestock farming, and commercial eucalyptus and pine plantations [19–21]. These different land uses alter the local environmental characteristics and landscape, modifying the availability of resources and microclimatic conditions and factors that directly affect fauna [2,22,23]. To understand the impact of these changes on ecosystems, it is important to use bioindicators that are able to reflect environmental change and habitat degradation [24].

Dung beetles (Scarabaeidae: Scarabaeinae) are widely used as bioindicators of environmental quality as they have a large species diversity, are well known from a taxonomic, biological, and ecological point of view, and fulfill basic ecological functions such as nutrient cycling, soil bioturbation, fertility enhancement, secondary seed dispersal, population control and dispersal of flies and gastrointestinal parasites of cattle, trophic regulation, and pollination [25–28]. In addition, they can be easily sampled using standardized, low-cost, and highly efficient methods [29–32]. The sensitivity of dung beetles to environmental change makes them ideal for assessing [11] the impact of land use change [10,11,22].

Several mechanisms make dung beetles sensitive to environmental changes, the main one being the availability of resources. During the process of replacing natural systems with anthropized environments, certain species of dung beetles were more abundant in natural vegetation compared to agricultural environments such as pastures and soybean fields, where the availability of dung from wild mammals is reduced [30]. Similarly, the conversion of landscapes into agricultural land leads to a decline in the species richness of dung beetles, mainly due to the reduction in mammal populations, which are essential for dung production [30].

In addition to direct impacts on the availability of resources and habitat structure, land use change can also influence dung beetle communities through indirect pathways, such as climate change [4,12], soil compaction [20], and the introduction of pollutants (e.g., crop protection products) [31]. The conversion of native savannas into grasslands affects not only species diversity but also the physiological condition of dung beetles, indicating that land use change can have cascading effects on beetle health [31]. This highlights the complex

interaction between anthropogenic practices and the ecology of the dung beetles. Given this scenario, the aim of this study was to evaluate the response of beetle communities to changes in land use systems (LUSs) in the Cerrado, to compare community parameters between different systems, and to test the influence of local environmental and landscape variables. We tested the following hypotheses:

- (i) The abundance, richness, biomass, and uniformity of beetle communities decrease with increasing land use intensity due to resource reduction and habitat degradation.
- (ii) The composition of the beetle community varies according to the type of land use, with forested areas serving as a reference. This pattern reflects the loss or replacement of species that are more sensitive to environmental changes.
- (iii) Local environmental and landscape changes influence the composition of the beetle community due to changes in habitat structure and resource availability.
- (iv) Different beetle species act as indicators for each land use system, as each system provides specific ecological conditions that favor different species.

2. Materials and Methods

2.1. Study Area and Dung Beetle Sampling

The study was conducted in the municipality of Frutal, Minas Gerais (20°1'11" S, 48°55'10" W), which has an area of 2526 km² and 60,012 inhabitants, with a demographic density of 22 inhabitants per km² [33]. The municipality is part of the Cerrado biome and presents a fragmented matrix formed by pastures and areas of perennial, semi-perennial, and annual crops, with few forest fragments. The agribusiness sector moves large amounts of resources into this region [33]. The climate in Frutal is defined as Aw according to the classification of Köppen–Geiger, tropical with a dry and cold season during winter, while the summer period is characterized by higher rainfall indices [34], with a mean temperature and rainfall of 23.8 °C and 1626.9 mm, respectively [33,35].

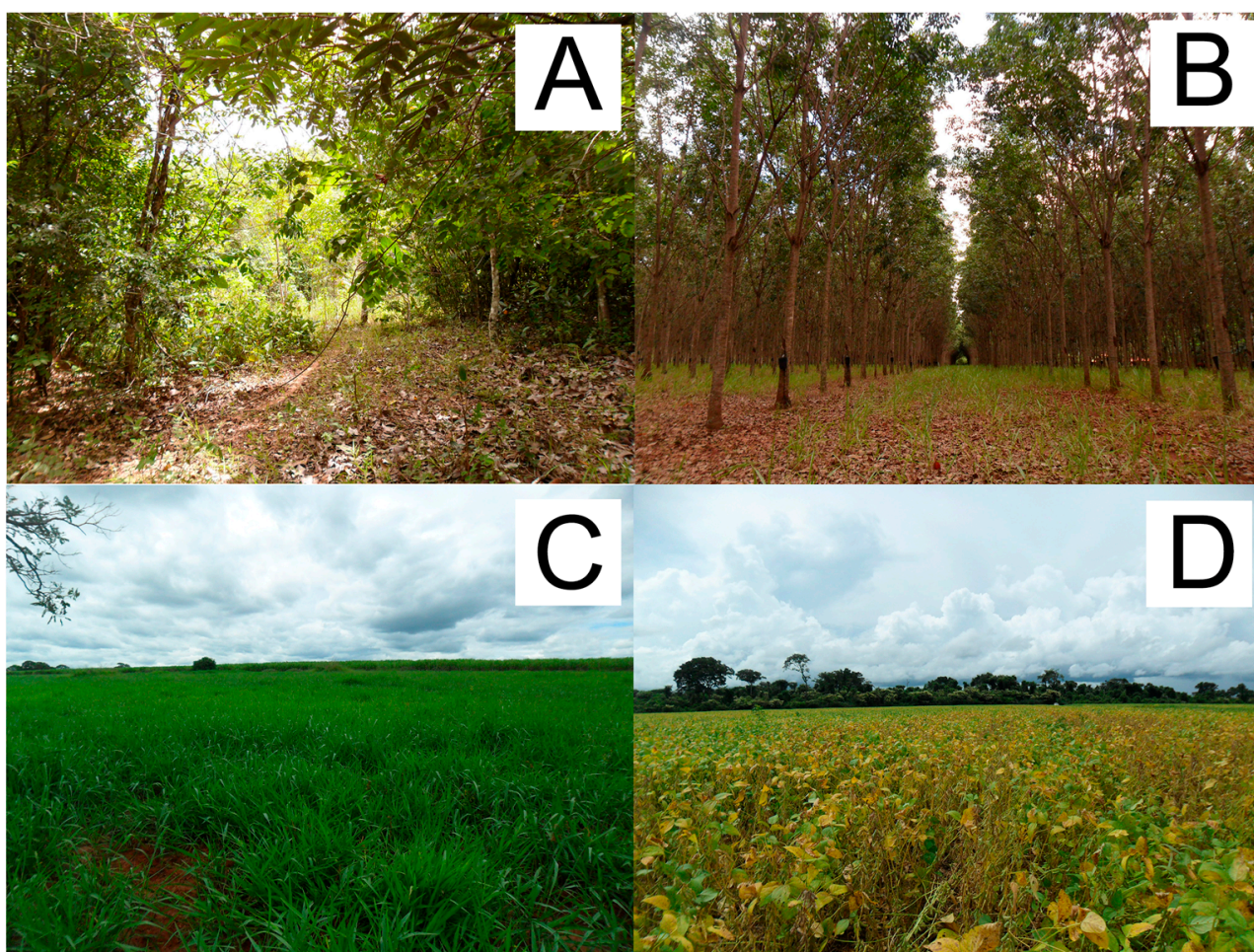
Dung beetles were collected in four different land use systems (from five areas of each system), totaling twenty areas: forest, rubber trees, pasture, and soybean (Table 1; Figure 1), and separated by at least 2 km [32]. The selected systems are economically important for the municipality and were chosen to form a gradient of intensity of land use.

The beetles were collected using pitfall traps (19 cm diameter and 11 cm depth), with human feces (25 g) as bait (in previous studies conducted in the same region, human feces proved to be more attractive, drawing a greater diversity of dung beetles [32]). Traps were installed throughout a 300 m transect containing five traps placed 50 m from each other and at the edges of the area. The traps remained in the study area for 48 h; after this period, they were collected and stored in plastic bags containing 70% (*v/v*) alcohol, and the source data were sent to the Laboratory of Environmental Research of the Minas Gerais State University (UEMG). In the laboratory, beetles were sorted using a stereomicroscope, packed in entomological blankets, and dried in an oven at 40 °C until a constant weight was achieved. All individuals were weighed on an analytical scale (precision, 0.0001 g).

The insects were morphologically identified and compared with specimens from the reference collection of the Laboratory of Ecology of Social Insects (LEIS) of the Federal University of Uberlândia (UFU). For some species, confirmation was performed by the taxonomist Prof. Dr. Fernando Z. Vaz-de-Mello. The voucher specimens were deposited in the collections of UEMG and the Entomological Section of the Zoological Collection of the Federal University of Mato Grosso (UFMT).

Table 1. Description of each land use system located in the municipality of Frutal.

Land Use	Characterization
Forest (A)	Areas with a predominance of tree species cover, with no history of cutting and felling.
Rubber tree (B)	Plantations of <i>Hevea brasiliensis</i> L. (rubber tree), the main management carried out consists of the following: land clearing and straw maintenance to control the growth of the herbaceous stratum and the understory.
Pasture (C)	Consisting of areas intended for livestock production, formed by exotic pastures, with a predominance of <i>Urochloa</i> spp. (Syn. <i>Brachiaria</i> spp.).
Soybean (D)	Consisting of conventional soybean monocultures (<i>Glycine max</i> (L.) Merr.).

**Figure 1.** Profile of the sites evaluated in this study. Legend: (A) forest, (B) rubber tree, (C) pasture, and (D) soybean.

2.2. Sampling of Environmental Variables

A survey of the understory density and fractal dimension was carried out according to the methodology proposed by [36], which consists of an analysis of photographs of the understory using a standardized procedure. Next to each trap, a black cloth of 1 m² was vertically stretched close to the soil, and four photographs perpendicular to the cloth were obtained in each of the four quadrants surrounding the pitfall trap at 3 m from the cloth, totaling 20 photographs per area.

The photographs were analyzed using the software SideLook 1.1.01 [36], which calculates the density and fractal dimension of the herbaceous vegetation by means of dichromatic image contrast (percentage of black and white pixels) available in the software. The vegetation density was calculated using the following equation [36]:

$$DV = \frac{(height \times width) \times \left(\frac{black\ pixels}{white\ pixels} \right)}{width}$$

where DV refers to the vegetation density, and the height and width are derived from the black cloth used as the background for the photos. Both fractal dimension and vegetation density were used as proxies for the complexity of the vegetation. The quadrant point method was used to estimate the density and basal area of tree vegetation. At each sampling point around the pitfall trap, four quadrants were randomly defined [36]. The circumference perimeter of the nearest tree in each direction was measured with the aid of a measuring tape at chest height (P); thus, based on this value, the measurement of the basal area (AB) was performed according to the equation below [37].

$$AB = P^2 / 4\pi$$

Here, AB is the basal area of the trees, and P is the perimeter [37].

The density of tree vegetation was calculated from the distance of the central point of the pitfall traps in the four quadrants around the transect's central point (north, south, east, and west) using the following equation [37]:

$$D = \frac{4(n-1)}{\pi \sum_{i=1}^n \sum_{j=1}^4 R_{ij}^2}$$

where D (trees/m²) is the estimated density, R is the measured distance, n is the number of pitfall traps, i is the number of sampling points, and j is the number of quadrants [38].

The density and basal area were used as proxies for tree vegetation. Trees located > 800 m from the central point of each pitfall were considered zero. The depth of the plant litter was measured around each pitfall using a digital caliper.

A portable meter that provides the electrical conductance (mV) and water content in the soil (%) was used. Soil resistance (kPa) was determined using a conical manual penetrometer. Before data collection, the plant layer surrounding each pitfall trap was removed, totaling five sampling points per area. Soil resistance was determined at each 2.5 cm, up to a depth of 60 cm.

The spatial data of the sampling units were registered and processed using ArcGIS 10.5 [39]. Land use coverage was classified using the databank of the Annual Project of Brazilian Soil Use and Mapping (MapBiomass)—Collection 4.1, with a collection on a scale of 1:250,000 and the standard RGB legend [14]. The platform aims to map land use systems in Brazil based on satellite data, such as Landsat (5-TM, 7-ETM + and 8-OLI). Altogether, nine classes of land use were defined: forest formation, savanna formation, rural formation, another non-forest formation, pasture, annual or perennial crops, semi-perennial crops, mosaic between agriculture and pasture, urban infrastructure, mining, and water bodies [14]. A buffer of 2 km was delimited around the central pitfall of each sampled area and all soil coverage was classified.

The variables analyzed in the study were divided into two categories: local variables and landscape variables. Local variables included basal area, vegetation density, fractal size, soil conductivity and moisture, and its resistance to 2.5, 30, and 60 cm litter height.

In turn, the landscape variables were considered as the amount of each land use system (9 possible classes described above) present and classified in the 2 km buffer.

2.3. Data Analysis

For all analyses, the sampling points were considered replicates to avoid the spatial pseudo-replicate effect. To verify the sampling coverage, rarefaction curves were calculated based on the number of captured individuals in the interpolation and extrapolation, together with the confidence interval of 95%, by means of the R package “iNext”. Additionally, normality and homogeneity of variance were assessed before applying the statistical tests. The Shapiro–Wilk test indicated that the data did not meet the normality assumption, and Levene’s test revealed the absence of homoscedasticity in the variances. Consequently, the authors chose to use non-parametric tests, such as Kruskal–Wallis and Dunn’s post hoc test, as they are more suitable for data that do not meet normality and homogeneity of variance assumptions. The post hoc test was carried out with the adjustment of Bonferroni correction, with the land use system considered a response variable and richness, biomass, and abundance as determinant variables. These analyses were performed with the aid of the software R 4.0.3 [40]. A Venn diagram was made to graphically indicate the number of exclusive species shared among distinct systems.

To visualize the ordering of the composition of the dung beetle community, principal coordinate analysis (PCO) was based on a similarity matrix constructed using the Bray–Curtis index calculated on standardized, square-root transformation data. The data were standardized and transformed into square roots for this analysis. Subsequently, we applied a permutational multivariate analysis of dispersion (PERMDISP) to test for heterogeneity in multivariate dispersions between LUSs [41]. The differences in community composition among land use systems were analyzed by means of a Permutational Analysis of Variance (PERMANOVA) [42]. These analyses were performed using PRIMER v6 PERMANOVA + software [43].

The distribution of abundance was performed with the aim of verifying species’ evenness according to the land use system. The curves ordered the species from most abundant to least abundant. Ranks were constructed for different land use systems. For this analysis, the data were transformed into logarithms ($\log + 1$).

To identify bioindicator species in each land use system, Indicator Species Analysis was performed, which considers the occurrence of species in samples within each system. This analysis was performed using PC-ORD 4.10 [44]. The species were categorized with an Indication Value (IV), and when above 70% ($p < 0.05$), were considered as indicators, while the species found with values between 45 and 70% ($p < 0.05$) were considered as detectors [44–46].

The relationship between the community composition of dung beetles and environmental variables was evaluated using distance-based linear models (DistLMs) [47,48]. Correlation analysis was previously performed, and those with an r -value above 70 were excluded from the model. The variables used after exclusion were the fractal dimension and density of the understory, tree distance, tree basal area, density of vegetation, plant litter depth, soil humidity, resistance at depths of 7.5, 30, and 60 cm, quantity of forest, savanna and field, pasture, and other cover formations. We used a stepwise procedure for selection and adjusted the R^2 as the criterion for selection. The DistLM was illustrated using distance-based redundancy analysis (dbRDA) [45]. These analyses were performed using PRIMER v6 PERMANOVA + software [44]. Both the DistLM and dbRDA were constructed with the dissimilarity matrix based on the Bray–Curtis index, with data being standardized and transformed into square roots with 999 permutations. These analyses were carried out using Primer v. 6 software with PERMANOVA+ [49].

3. Results

This study provides information about the response of dung beetle communities to the intensification of land use in the city of Frutal, Minas Gerais, a region with high agricultural intensity [33] that has not yet been studied. Significant differences in species richness and biomass were observed between the extremes of land use systems (forest and pasture). The forest system exhibited higher values of species richness and biomass compared to both rubber tree and pasture systems. The dung beetle community composition was clustered into two distinct groups: one formed by tree-based systems (forest and rubber tree) and the other by open systems (pasture and soybean). The results of this study demonstrate that the soybean system is the most adverse to the dung beetle community.

We collected 2294 beetles that were distributed among 34 species, 18 genera, and 5 Neotropical tribes, including 207 individuals from 3 species of the Ateuchini tribe, 192 individuals from 6 species of the Deltochilini tribe, 1339 from 15 species of the Coprini tribe, 145 from 3 species of the Onthophagini tribe, and 411 individuals belonging to 7 species of the Phanaeini tribe. There were 25 species in the forest system, with 17, 19, and 17 in the pasture, rubber tree, and soybean systems (Table 2).

Table 2. Number of individuals per species captured in four land use systems in Frutal, Minas Gerais.

Tribe/Species	System				Total
	Forest	Pasture	Rubber Tree	Soybean	
Ateuchini					
<i>Agamopus viridis</i> (Boucomont, 1928)	-	15	-	-	15
<i>Genieridium bidens</i> (Balthasar, 1938)	-	101	1	73	184
<i>Ateuchus</i> sp. 1	-	2	-	1	3
Coprini					
<i>Canthidium refulgens</i> (Boucomont, 1928)	62	15	86	8	171
<i>Canthidium</i> sp. 1	3	-	3	-	6
<i>Canthidium</i> sp. 2	1	-	3	-	4
<i>Canthidium</i> sp. 3	6	11	26	-	43
<i>Canthidium</i> sp. 4	2	-	1	-	3
<i>Canthidium</i> sp. 5	14	-	5	63	82
<i>Dichotomius bos</i> (Blanchard, 1843)	2	6	-	4	12
<i>Dichotomius</i> aff. <i>carbonarius</i> (Mannerhein, 1829)	60	-	33	44	137
<i>Dichotomius glaucus</i> (Harold, 1869)	8	-	-	-	8
<i>Dichotomius nisus</i> (Oliver, 1789)	240	116	77	80	513
<i>Isocopris inhatus</i> (German, 1824)	-	-	1	1	2
<i>Ontherus appendiculatus</i> (Mannerheim, 1829)	16	-	31	-	47
<i>Ontherus</i> sp. 1	26	11	13	18	68
<i>Ontherus</i> sp. 2	18	12	6	10	46
<i>Ontherus</i> sp. 3	21	-	12	-	33
Deltochilini					
<i>Anomiopus</i> sp. 1	3	-	-	-	3
<i>Canthon conformis</i> (Harold, 1868)	77	-	60	6	77
<i>Canthon lituratus</i> (Germar, 1824)	4	-	-	4	8
<i>Canthon ornatus</i> (Redtennbacher, 1868)	-	6	-	-	6
<i>Deltochilum</i> aff. <i>guyanense</i> (Paulian, 1938)	1	-	-	-	1
<i>Pseudocanthon</i> sp. 1	4	14	-	-	28
Onthophagini					
<i>Onthophagus buculus</i> (Mannerheim, 1829)	25	13	-	3	41
<i>Onthophagus hircus</i> (Billberg, 1815)	87	-	-	-	87
<i>Onthophagus ptox</i> (Erichson, 1847)	-	-	14	1	15

Table 2. Cont.

Tribe/Species	System				Total
	Forest	Pasture	Rubber Tree	Soybean	
Phanaeini					
<i>Coprophanaeus cyanescens</i> (d’Olsoufieff, 1924)	17	-	2	-	19
<i>Coprophanaeus spitzzi</i> (Pessôa, 1935)	4	5	1	1	11
<i>Dendropaemon nitidicollis</i> (d’Olsoufieff, 1924)	-	1	-	-	1
<i>Diabroctis mimas</i> (Linnaeus, 1758)	-	1	-	-	1
<i>Gromphas inermis</i> (Harold, 1869)	-	-	-	2	2
<i>Phanaeus palaeno</i> (Blanchard and Brullé, 1845)	5	12	-	-	17
<i>Trichillum externepunctatum</i> (Borre, 1886)	52	146	76	86	360
Number of Species	25	17	19	17	34
Number of Individuals	758	679	751	406	2101

In the study area, 17.64% (six species) were shared among all LUSs. Four species (11.76%) were exclusive to the forest system and four other species occurred only in the pasture system, whereas soybean systems presented a single exclusive species, and the rubber tree system did not present any exclusive species (Figure 2).

The species rarefaction curve by interpolation and extrapolation revealed that all areas approached the asymptote, with a tendency for the curve to stabilize, indicating sufficient sampling [50]. The accumulated richness of species in the forest was superior to that in the other land use systems (Figure 3).

Dichotomius nesus (Hope, 1838) was the most dominant species in terms of abundance in the forest system and was also represented as one of the main species in other systems (Figure 4i). The species *Canthidium refugens* was the most abundant in the rubber tree system, while *Trichillum externepunctatum* was the most dominant in pasture and soybean systems; however, its relative dominance extended to all land use systems (Figure 4i). Regarding the biomass of the dung beetles, *D. nesus* was dominant in all systems (Figure 4ii).

The number of individuals did not vary among the land use systems investigated in this study (Figure 5i, KW, $X^2(3) = 7.6615$, $p = 0.05355$), but both species richness and biomass differed between the forest and soybean systems (Figure 5ii,iii) (KW; $X^2(3) = 10.115$; $p = 0.01762$; KW; $X^2(3) = 12.957$; $p = 0.00473$, respectively). The forest system presented a greater richness in relation to soybeans (Figure 5ii, KW = 2.74; $p_{adj} = 0.0365$), whereas rubber trees and pastures did not show any significant differences among LUSs. The biomass of dung beetles presented the same pattern for species richness, differing only between the forest and pasture (Figure 5iii, KW = 3.54; $p_{adj} = 0.00241$).

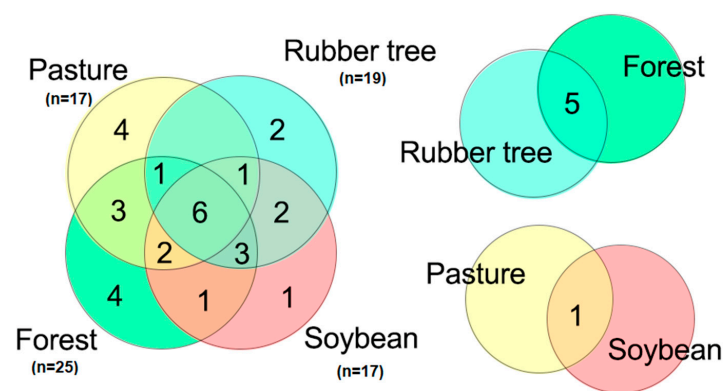


Figure 2. Venn diagram indicating multiple occurrences of species among different land use systems.

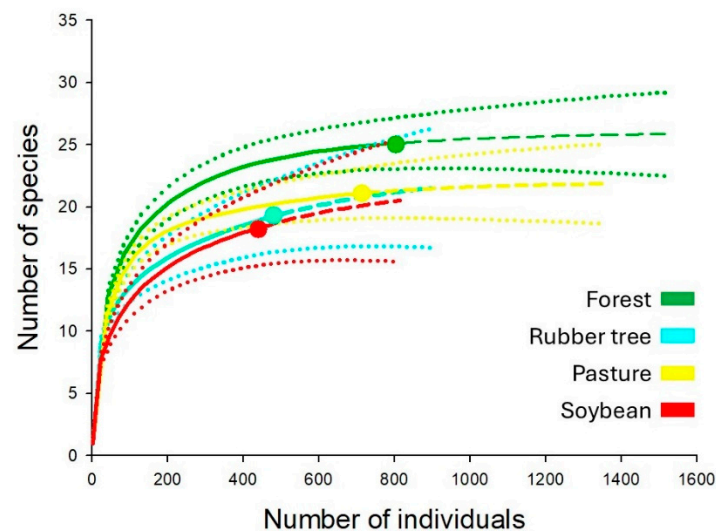


Figure 3. Species rarefaction curve based on the number of individuals collected, by interpolation (solid line) and extrapolation (dashed line) for four land use systems collected in Frutal, Minas Gerais, Brazil. Dotted lines represent 95% confidence intervals. Closed circle indicates the richness observed in each system.

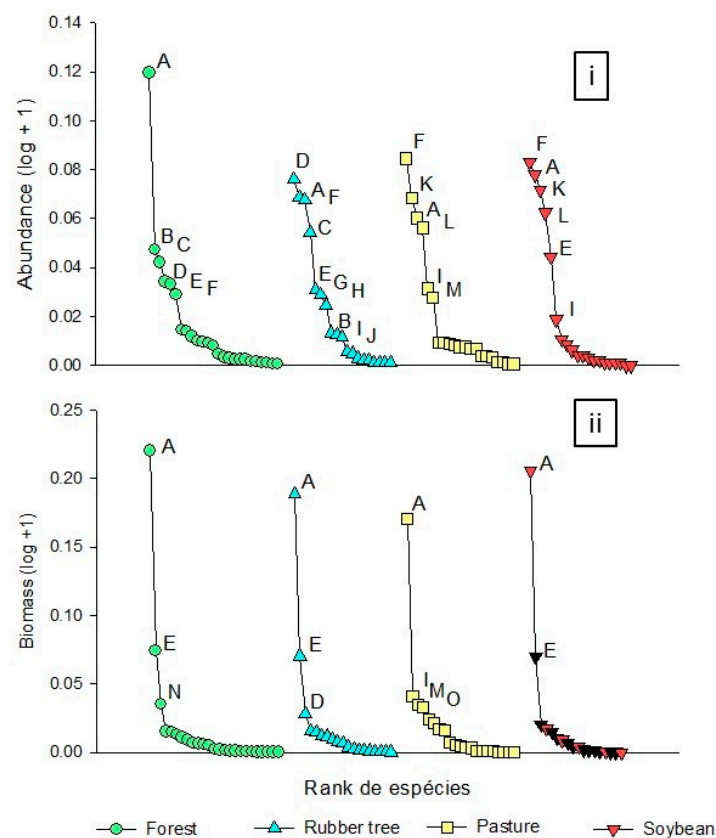


Figure 4. Abundance (A) and biomass (B) ranking of Scarabaeinae beetles in four land use systems, Frutal, Minas Gerais. Ranking of (i) species and (ii) biomass of Scarabaeinae beetles in four land use systems, Frutal, Minas Gerais, Brazil. A. *Dichotomius nesus*; B. *Onthophagus hirculus*; C. *Canthon conformis*; D. *Canthidium refugens*; E. *Dichotomius carbonarius*; F. *Trichilium externepunctatum*; G. *Ontherus appendiculatus*; H. *Canthidium* sp. 3; I. *Ontherus* sp. 1; J. *Ontherus* sp. 3; K. *Genieridium bidens*; L. *Canthidium* sp. 5; M. *Ontherus* sp. 2; N. *Coprophanaeus cyanescens*; O. *Coprophanaeus sptizi*.

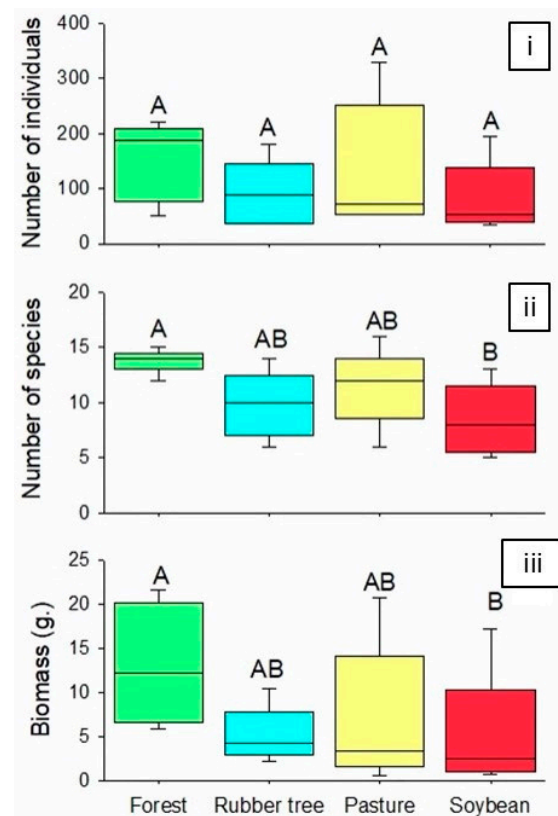


Figure 5. Representation of community parameters in different land use systems in Frutal, Minas Gerais. (i). Abundance, (ii) wealth, and (iii) biomass. Different letters above the bars represent statistical differences ($p < 0.05$, Kruskal–Wallis test followed by Dunn’s test with Bonferroni correction).

The composition of the dung beetle community differed among the land use systems (PERMANOVA, Pseudo- $F = 2.8982$; $p = 0.002$). In the paired-PERMANOVA test, the two open systems (soybean and pasture) did not differ from each other, similar to the closed systems (forest and rubber trees) (Figure 6; Table 3). These differences occurred because of the alteration in the community composition, instead of data dispersion (PERMDISP, $F = 0.4278$; $p = 0.83$) (Table 3) or the homogeneity of variance of data.

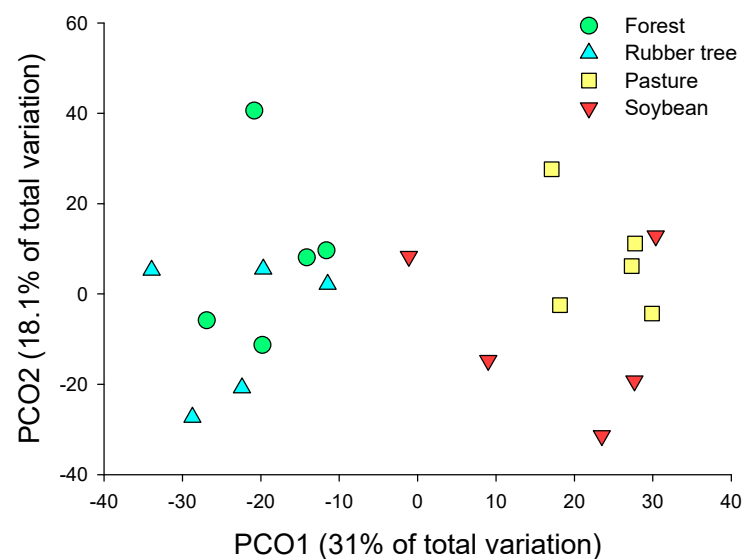


Figure 6. Ordering of Main Components (PCO) of land use systems scaled by the composition of the dung beetle community.

Table 3. Results of PERMANOVA analysis (differences between groups) and PERMDISP (differences in dispersion of groups) comparing pairs of land use systems scaled by the composition of the dung beetle community in Frutal, Minas Gerais. T: Test statistics, which indicate the magnitude of the difference between the groups (PERMANOVA) or in the dispersion of the data (PERMDISP). p (Perm.): Permutational probability value, which indicates the statistical significance of the observed difference. Values of p(Perm.) < 0.05 indicate statistically significant differences.

GROUP	PERMANOVA		PERMDISP	
	T	p (Perm.)	T	p (Perm.)
Soybean X Forest	1.761	0.007	0.29698	0.888
Soybean X Pasture	1.0752	0.344	0.6901	0.6
Soybean vs. Rubber Tree	1.8527	0.011	1.094	0.282
Forest vs. Pasture	1.9018	0.011	0.70553	0.616
Forest X Rubber Tree	0.90103	0.628	0.84589	0.619
Pasture X Rubber Tree	2.34	0.005	0.02549	0.984

Agamopus viridis presented an indication value of 60.0% ($p = 0.0332$), and *Ontherus* sp. 3 displayed an indication value of 50.9% ($p = 0.0384$), both in the pasture system, while all other species did not present significant values for this variable. Both values of IV were lower than 70%, which indicates that the species are classified as environmental detectors in pasture systems [45].

The complete DistLM was visualized using dbRDA (Figure 7).

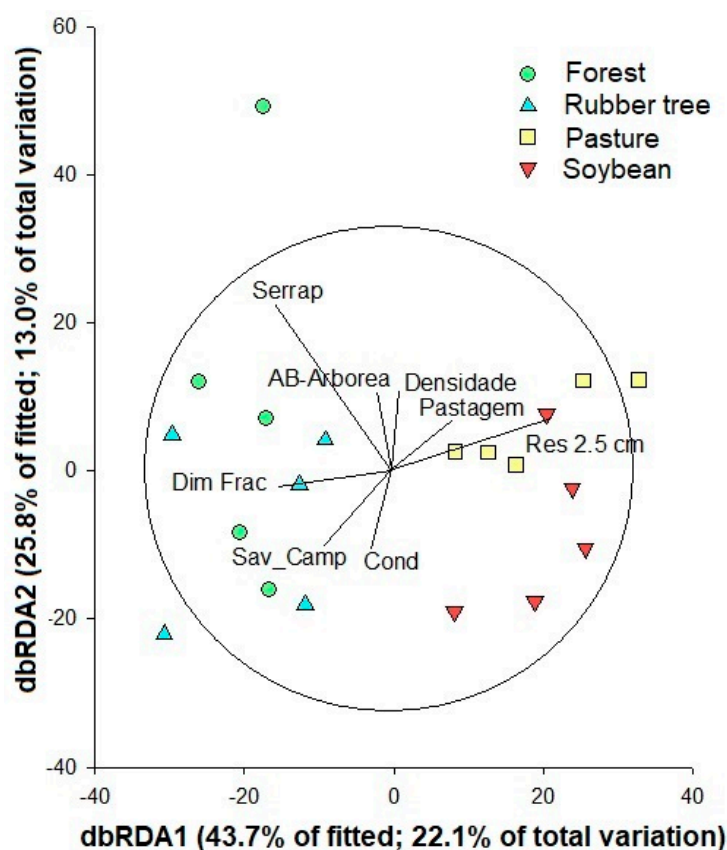


Figure 7. Distance-based redundancy analysis (dbRDA) relationships between the ordering of collections based on the composition of scarab beetles and the environmental variables analyzed. Frac Dim: fractal dimension; Serrap: litter; AB- Tree: arboreal basal area; Density: arboreal density; Cond: soil conductivity; Res 2.5 cm: soil resistance to 2.5 cm; pasture; Sav_Camp: grassland savanna formation.

The first two axes of dbRDA captured almost 69.5% of the variability in the adjusted model, which was approximately 35.1% of the total variation in the dung beetle community data cloud. The vector overlap revealed that the first dbRDA axis is strongly related to the soil resistance at 2.5 cm, while the height of plant litter, density, tree basal area, and soil resistance at 2.5 cm are related to the second axis of dbRDA (Figure 7). These four variables were statistically significant (marginal test; Table 4) to explain community composition. In the sequential test, the best model included eight variables (basal area, density of vegetation, fractal dimension, savanna and pasture formations, soil resistance at 2.5 cm, plant litter, and soil humidity) that together explained about 60% of the variation (Table 4).

Table 4. Result of the distance-based linear model (DistLM) tested for the relationship between the environmental variables (understory, litter, arboreal, soil moisture, geographic coordinate (“x” and “y” axis), and vegetation density) and the composition of the scarab beetle community in the marginal test (variation explained by a single variable) and sequential test (variation explained by adding a new variable each time to obtain the ideal fit criterion) based on the fit selection criterion R^2 .

Marginal Tests						
Variables		SS (Traço)	Pseudo-F	<i>p</i>	Prop.	
Fractal dimension		2767.5	1.6478	0.106	0.083866	
Understory density		2440.8	1.4377	0.174	0.073964	
Litter		5337.2	3.473	0.001	0.16174	
Arboreal Density		4160.5	2.5968	0.01	0.12608	
Tree basal area		3777.3	2.3267	0.024	0.11447	
Soil conductivity		1946	1.128	0.335	0.05897	
Soil penetration resistance 2.5 cm		3648.1	2.2373	0.033	0.11055	
Soil penetration resistance 30 cm		1206.5	0.68308	0.728	0.036562	
Soil penetration resistance 60 cm		1903	1.1016	0.359	0.057668	
Forest formations		1632.5	0.93683	0.522	0.049471	
Savanna formations		1527.7	0.87373	0.585	0.046294	
Pasture		2836.8	1.6929	0.099	0.085964	
Others		1363.5	0.77581	0.614	0.041319	
Sequential Test						
Variables	Adj R^2	SS (traço)	Pseudo-F	<i>p</i>	Prop.	Cumul.
+Litter	0.11517	5337.2	3.473	0.001	0.16174	0.16174
+R_2.5	0.16474	3000.5	2.0683	0.048	0.090926	0.25266
+Frac Dim	0.22865	3226.5	2.4084	0.018	0.097775	0.35044
+Pasture	0.27414	2524.9	2.0028	0.037	0.076512	0.42695
+Conduct_mv	0.27797	1354	1.0797	0.366	0.041031	0.46798
+Tree Basal Area	0.28259	1358.3	1.0901	0.359	0.041162	0.50914
+Tree Density	0.29517	1508.2	1.232	0.335	0.045704	0.55485
+Savanna Formation	0.30434	1399.2	1.1581	0.351	0.042101	0.59725

Legend: Frac Dim: fractal dimension; Conduct_mv: Electrical Conductivity of Soil; R_2.5: Soil penetration resistance 2.5 cm.

4. Discussion

As expected, abundance, species richness, biomass, and species evenness tended to decrease with increasing land use intensity. Differences in community composition were expected in all land use systems and followed a gradient from lower values in forests to higher values in soybean fields.

However, significant differences were only found between the two extremes of this gradient (forest and soybean) in terms of biomass and species richness (Figure 5). Fragmentation, degradation, and conversion of natural habitats to intensive and extensive agricultural systems consistently affected the abundance, richness, and composition of dung beetle communities [22,23,51,52]. These changes may be related to the loss of forest areas and the associated animal and plant resources [22,23].

The PCO analysis (Figure 6) revealed two distinct groups: open systems (soybean and pasture) and closed systems (forest and rubber tree). Environmental data supported this grouping as they indicated that dung beetle communities respond to habitat changes, food availability [53], and macro/microclimatic conditions [54]. Human activities often convert closed systems into open systems by clearing vegetation and intensifying land use, particularly through monocultures, which have been associated with a decline in mammal diversity [26]. As dung beetles are dependent on mammal feces, their diversity is affected accordingly. In general, beetles thrive in forested areas, where denser vegetation provides more shade and stability of humidity and temperature [54,55].

The similarities observed between the land use systems analyzed in this study are mainly due to the characteristics of the Cerrado biome where this study was conducted. In pastures used for livestock production, there is a greater amount of feces from a single mammal species, which causes soil compaction that can negatively affect the dung beetle community [20,56,57]. Therefore, a reduction in community parameters was expected, but this was not observed in terms of the number of individuals in different systems. This biome has evolved over millions of years as an open system with wide plain areas of pasture and savannah [13] and therefore has species that are adapted to open areas and can colonize open and closed environments; however, this subtle change affects dung beetles [58].

The conversion of the Cerrado into other land use systems drastically alters the landscape, affecting the structure and complexity of vegetation [58]. Although dung beetles colonize modified environments, natural vegetation usually provides a greater variety of resources and habitats for survival [59]. However, there are indications that vegetation-related parameters are more important than food resources available for dung beetles in this biome [58]. Several studies have indicated that vegetation plays a major role as a predictor of the abundance and richness of this group of beetles [22,23,58,60]. In addition, the species present in this biome may be persistent if there is sufficient time and the habitat has a structure similar to that of the original matrix [60], including exotic systems [56].

The species of dung beetles present in field phytophysiognomies can be numerically and qualitatively different between native and exotic fields [56]; thus, it might be possible that this is true for the soybean systems evaluated in this study. In addition, larger beetles tend to become extinct more frequently during the LUS shift [10], even though this is not a universal trend [61]. When such changes occur, abiotic factors also shift, such as temperature, which seems to be the main factor in the replacement of large-sized beetles by smaller-sized species [10]. This might explain some of the obtained data, where the biomass and species of the forest and soybean systems were different, while the number of individuals was similar, possibly because of functional compensation. Hypothetically, the parameter biomass should present intense differences among LUSs, which vary according to the other evaluated components in these systems, such as resource availability, changes in the soil structure, vegetation, and land use intensity [22,53].

The differences found between the dung beetle communities of the forest and soybean systems could be due to the intensity of land use. The traditional cultivation of soybeans presents a strong need for the application of inputs for its maintenance [62], which intensifies land use, especially in monocultures that alternate production cycles (sugarcane

and soybean). Therefore, the conversion of native forest areas into soybean crops leads to higher losses in the number of species and biomass of dung beetles, but there was no loss in the number of individuals (Figure 7). In addition, shifts in land use systems result in the formation of mosaics, causing the appearance of different-sized fragments that cohabitate with areas used for other LUSs with greater intensification of human action [63]. The distribution of environmental data is related to the responses of dung beetles to available habitats and food [53], as well as macro- and microclimatic conditions [53]. Presumably, dung beetles are more successful in colonizing forested areas, where the coverage provided by the vegetation is denser, ensuring higher shading, humidity, and temperature retention [54], compared to open areas [55]. However, human action tends to transform closed systems into open systems by suppressing vegetation, causing a rapid and immediate impact on the community.

Forest production systems may have a positive effect on dung beetle communities [54] compared to monocultures such as soybean crops. The areas destined for agricultural production tend to exclude a large part of mammals that support dung beetles [64], reducing the diversity and abundance of the mammal fauna and impacting the community-related parameters of dung beetles [25,26]. Thus, the increased variety of habitats can be considered an important factor for the maintenance of the diversity of dung beetle species and the critical maintenance of the ecosystem services provided [25,28,64].

In this study, a wide occurrence of the genus *Dichotomius* (Hope, 1838) was verified, represented by the species *D. nesus*, *D. bos*, *D. aff. carbonarius*, and *D. glaucus*, which have the highest biomass among the Scarabaeinae, with 170 valid species being representative of field areas and other open systems [65]. *D. nesus* presented a high abundance and biomass in all land use systems evaluated in this study (Figure 4). *D. nesus* and *D. bos* are frequently found in Brazilian pastures [66–68], but the abundance of *D. bos* in this study was low in relation to other species of the genus *Dichotomius*, especially in comparison to other studies carried out in the Brazilian Cerrado, which reported this species as one of the most representative in abundance and biomass [27,66–69]. The species *D. bos*, *D. nesus*, *T. externepunctatum*, and *O. appendiculatus* are regularly found in pasture environments, and their importance in this land use system is recognized by the wide increase in biomass, distribution, and incorporation of manure into the soil [68].

The genus *Deltochilum*, represented in this study by *D. aff. guyanense* (Paulian, 1938), can be considered a relevant finding, showing that this genus is sensitive to anthropic action [70]. Its occurrence is limited to a single individual in a forest system. The literature suggests that its occurrence is related to less disturbed environments that have constant increments of organic matter [71]. Therefore, this finding raises the hypothesis that changes in the environmental quality of forests in the study area may have occurred, corroborated by means of the low occurrence of the genus *Canthon* (limited to three species), which is also an indicator of good environmental quality [72,73].

In addition, *A. viridis* and *Ontherus* sp. 3 were identified as IVs in pastures and were considered detector species in this land use system. A relationship was identified for both species with the time of exposure to fecal resources; that is, there is apparently a preference for places with abundant and frequent deposition of resources, as observed in the pastures used for livestock production [74,75]. Although the 70% threshold is often used for the strict classification of species as indicators, species with IVs below this value can still provide valuable information about environmental conditions and changes in the community. These species, referred to as “detector species”, are sensitive to variations in habitat conditions and generally respond in a predictable way to environmental changes, even if they do not reach the 70% IV threshold.

Intermediate values, generally ranging between 50% and 70%, suggest a moderate association with the environment. These species can still indicate environmental conditions but with less specificity than those with higher IVs ($IV > 70\%$). This allows for a broader interpretation of their habitat preferences [76]. This range of values allows ecologists to identify species that may be more adaptable or generalist in their habitat requirements, which can be particularly useful in dynamic environments where conditions fluctuate [76]. The presence and abundance of these species can indicate subtle changes in the environment, such as modifications in the availability of resources, microclimatic conditions, or predation pressure. For example, the observation of *A. viridis* and *Ontherus* sp. 3 in certain habitats may suggest the presence of resources or favorable microclimate conditions that may not be captured by higher-IV species.

Therefore, significant aspects regarding the conservation of the Cerrado can be observed, as a recent study demonstrated that although changes in land use impact community structure, there was no direct impact on the ecosystem services provided by these insects in this biome [30]. This suggests that, despite potential changes in species composition, the essential functions performed by beetles may persist, highlighting the resilience of these communities under certain conditions, likely due to the replacement of species specialized in specific resources or interactions with other organisms by generalist species [77].

Our study indicates that heterogeneous systems varying in habitats provide a more favorable environment and harbor a greater number of species. In a broader sense, at the landscape scale, the landscape also plays a significant role in the recovery of dung beetle diversity. González-Tokman et al. observed that local conditions, including edge effects from surrounding areas, can limit the movement of dung beetles and impede their recovery in restored areas [78]. Thus, the establishment of interconnected habitats and the minimization of edge effects through strategic landscape planning are essential to facilitate the movement of these beetles and enhance their diversity in restored or recovering areas. In agricultural landscapes within the Cerrado (e.g., rubber tree, soybean, and pasture systems), there is a necessity to preserve fragments of natural vegetation, even if small, to increase diversity among dung beetle assemblages [79]. This finding reinforces the significance of maintaining habitat heterogeneity, which can provide essential resources and microhabitats for beetles, supporting their populations and the ecological functions they perform.

5. Conclusions

The parameters evaluated for the dung beetle communities in the four land use systems presented differences only in relation to species richness and biomass between the forest and soybean systems. This fact indicates that managements that include forest systems are less impacting for this group of insects, seeing that the current world scenario tends towards environmental degradation and fragmentation; therefore, studies like the present one are needed to evaluate the impacts of these processes on animal communities.

The use of bioindicator species, such as members of the Scarabaeidae family, is an important diagnostic tool, with a separation between closed (forest and rubber tree) and open (pasture and soybean crops) systems, indicating that forest coverage is an important parameter for the separation of communities that occur in each LUS. Forest cover influences a few environmental factors, such as solar incidence, temperature, and humidity, which can directly or indirectly influence the food resources used by beetles and consequently their community.

In summary, our findings indicate the important role of environmental variables in determining the dung beetle community [31,65], since there are varied responses for multiple taxonomic groups, as well as local factors [22,27,55]. In addition, it was possible

to verify the importance of systems other than natural ones, as they have been shown to host a similar community of dung beetles in relation to natural environments. Thus, local variables (basal area, density of vegetation, fractal dimension, soil resistance at 2.5 cm, plant litter, and soil moisture), together with landscape variables (pasture and savanna formation), proved to be a main predictor of the diversity of dung beetles in the studied land use systems.

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Abbreviations

The following abbreviations are used in this manuscript:

dbRDA	Distance-based redundancy analysis
distLM	Distance-based linear model
g	Gram
PCO	Ordering of main components
LUSs	Land use systems
v/v	Volume/volume
IV	Indicator Value

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