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Dung beetles (Coleoptera: Scarabaeoidea) population patterns in three environments in the Midwest of Brazil

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Abstract. Scarabaeids are economically very important due to their provision of several environmental services, in particular to cattle rearing, because they are highly active in the decomposition of cattle feces in pasture environments. The objectives of this research were to evaluate the season of dung beetle occurrence, and the effect of weather on their abundance and species richness in different environments. A total of 44,355 adults were captured: 105 samples in each of three different environments (agroecosystem, pasture and native forest), adding 315 samples for two consecutive years (November 2005 to November 2007). Fifty-three species were found in that three environments, being 51 of Scarabaeidae, including two subspecies of *Dichotomius*, and two of Hybosoridae: *Coilodes humeralis* (Mannerheim) and *Coilodes* sp.1. We verified a correlation between temperature and rainfall and the occurrence of Scarabaeidae species associated with bovine feces. The species with highest population levels were: *Labarrus pseudolividus* Balthasar in the pasture, and *Ataenius platensis* (Blanchard) in both: agroecosystem and native semi-deciduous forest. There was a positive correlation between higher temperature and rainfall with an increase in the abundance of adult dung beetles in the environments. The number of adults caught and species richness of dung beetles was significantly greater in the pasture when temperature and rainfall were higher. The combined analysis of the three environments showed that from Oct to Dec, when temperature and precipitation were highest, there was a significant increase in the capture of dung beetles in the traps in comparison to the period from Apr to Jul (coldest season).

Keywords: Biodiversity; Coprophagous beetles; Environments; Neotropics; Seasonality.

Padrões populacionais dos escaravelhos (Coleoptera: Scarabaeoidea) em três ambientes no Centro-Oeste do Brasil

Resumo. Scarabeídeos são economicamente muito importantes devido à pestação de vários serviços ambientais, em especial para bovinocultura, porque atuam fortemente na decomposição de fezes bovinas em ambientes de pastagem. Os objetivos desta pesquisa foram avaliar as épocas de ocorrência das espécies de besouros "rola bosta" e o efeito do clima sobre a abundância e riqueza de suas espécies em diferentes ambientes. Um total de 44.355 adultos foram capturados: 105 amostras em cada um dos diferentes ambientes (agroecossistema, pastagem e floresta nativa), somando 315 amostras durante dois anos consecutivos (novembro de 2005 a novembro de 2007). Cinquenta e três espécies foram encontradas nos três ambientes durante dois anos de amostragem, 51 de Scarabaeidae (incluindo duas subespécies de *Dichotomius*) e duas espécies de Hybosoridae: *Coilodes humeralis* (Mannerheim) e *Coilodes* sp.1. Houve correlação entre a temperatura e as chuvas com as épocas de ocorrência das espécies Scarabaeidae associadas com fezes bovinas. As espécies com níveis populacionais mais elevados foram: *Labarrus pseudolividus* Balthasar na pastagem e *Ataenius platensis* (Blanchard) em ambos: agroecossistema e floresta nativa semidecídua. Existe uma correlação positiva entre temperaturas mais elevadas e chuvas com aumento na captura dos "rola bosta" em armadilhas. O número de adultos capturados e a riqueza em espécies dos "rola bosta" capturados foi significativamente superior quando a temperatura e a pluviosidade foram mais altas. A análise combinada dos três ambientes mostrou que de outubro a dezembro, quando a temperatura e a precipitação foram mais elevadas, houve um aumento significativo na captura destes besouros nas armadilhas em comparação com o período de abril a julho (estação mais fria).

Palavras-chave: Ambientes; Biodiversidade; Região Neotropical; Sazonalidade; "Rola-bosta".

Scarabaeids are economically very important due to their provision of several environmental services, in particular to livestock rearing, because of their strong impact on the decomposition of cattle feces in pasture environments (Koller *et al.* 2007), cycling organic matter in nature, making substrates and nutrients available to the biota.

In Brazil, cattle production was very successful from the beginning. According to Primo (1992), cattle (*Bos taurus* L.; Bovidae) was first introduced in São Vicente, São Paulo state in 1534, by Mr. Martim Afonso de Sousa, and his wife, Ana Pimentel, from Portugal and Spain. At least in part, the success of Brazilian cattle production could be attributed to the high natural diversity of dung beetles that occurs from north to south Brazil. Herein, when cattle arrived in 1534, dung beetles soon began to feed and breed in their fecal masses, because they already were evolutionarily adapted to living in feces of big native

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mammals, such as: tapir, *Tapirus terrestris* (L.) (Tapiridae); capybara, *Hydrochoerus hydrochaeris* (L.) (Caviidae); wild hogs or 'queixada' *Tayassu pecari* (Link), and 'cateto,' *Pecari tajacu* (L.) (Tayassuidae); multiple species of some Cervidae genera: *Blastocerus* spp., *Mazama* spp., *Odocoileus* spp., and *Ozotoceros* spp., and other ungulates. On other hand, cattle was for the first time introduced in Australia by 1778, but in contrast to Brazil, within a few years ranchers faced problems due to bovine excreta accumulation. In Australia, due to a lack of efficient decomposers, year by year the areas available for cattle pastures decreased. Australian entomologists discovered that the problem was due to the fact that native dung beetle species from there were not adapted to feed and breed in bovine fecal masses (Bornemissza 1976). Prior to the introduction of bovines, the largest native mammals were kangaroos, *Macropus* (Macropodidae), which are phylogenetically distant from the genus *Bos* L. (Bovidae). The Australian problem was solved with the introduction of Scarabaeidae species that feed and breed in bovine feces, already established in Hawaii (USA), but native to Africa and Europe (Bornemissza 1976; Losey & Vaughan 2006).

Several factors have been hypothesized to explain variations in the abundance of dung beetles, including weather, source of food, and nesting sites (Howden & Nealis 1975; Gaston & Chown 1999). Discover which factors are positively or negatively affecting animal, plant, and microorganism populations, is a central issue in ecology. According to Nichols *et al.* (2007), more than one factor may be simultaneously acting positively or negatively on populations of Scarabaeidae in their natural habitats.

In the tropics there are variations in dung beetle populations, depending on the degree of modification of the environment, the type of forest (intact or fragmented), the mode of land use, and weather (Nichols *et al.* 2007). The weather plays an important role in the seasons of adult dung beetle occurrence (Halffter *et al.* 1992; Ronqui & Lopes 2006). There is evidence that higher temperatures and rainfall events contribute positively to the abundance of dung beetle populations (Koller *et al.* 2007; Nichols *et al.* 2007; Silva *et al.* 2007).

The modification and fragmentation of environments are the most common landscape patterns found worldwide in ecosystems with anthropogenic activities. In addition to the direct changes on the landscape, alter the local microclimate (Nichols *et al.* 2007). Knowledge of the population dynamics of dung beetles communities is very useful in the development of strategies for their conservation, to employ them as indicators of environmental degradation, and for their use in biological control programs against pestiferous invertebrates (e.g., nematodes and insects) that cause economic damage in agriculture and pasture environments.

Our hypothesis was that a higher species richness of dung beetles occurs in native forest in comparison with areas occupied by agriculture and pasture. In this context, the objectives of this research were: to evaluate the seasons of dung beetle species occurrence in three different environments (i.e., pasture, native semi-deciduous forest, and agroecosystem), and to determine the influence of temperature and rainfall on the species richness and abundance of Scarabaeoidea in these environments.

MATERIAL AND METHODS

Place of study. Samples of dung beetles were collected in three different ecosystems: a pasture with a monoculture of signal grass, *Urochloa decumbens* (Stapf) R.D. Webster (Poaceae); an agroecosystem with annual cultures of corn, *Zea mays* L. (Poaceae), in the fall (Mar to Jun), wheat (*Triticum aestivum* L.; Poaceae), in the winter (May to Aug), and soybean, *Glycine max* (L.) Merr. (Fabaceae), in the summer (Dec to Feb), and a native semi-deciduous forest from the region of Dourados-MS, Midwest Brazil, from Nov 2005 to Nov 2007.

The environment with pasture (21.9900000°S, 55.3225556°W), was at 420 m altitude, and about 75 km from the Dourados downtown area, Mato Grosso do Sul state. This area (22 ha) is planted with *U. decumbens*, and is part of a total area of 4,800 hectares of rural settlement. The pasture is surrounded by a dense wooded 'cerrado' (i.e., Brazilian savannah) environment, and the soil is a dystrophic red latosoil of medium texture (Projeto Radambrasil 1982).

The agroecosystem (22.1445000°S, 55.0260278°W) was at an altitude of 447 m, and is 40 km from the Dourados downtown. It is 35 km away from the pasture area and 20 km away from the native semi-deciduous forest. In total 2,470 hectares is occupied annually with a soybean, corn, and wheat rotation. There are some spots with natural vegetation including: swamps, springs, small streams, and riparian vegetation. The phyto-ecological formation is similar to that of the pasture area, but with clay soil (Projeto Radambrasil 1982).

The native semi-deciduous forest (22.9902500°S, 54.9156111°W) was at 434 m altitude. It is a natural heritage forest reserve of the old Fazenda Coqueiro, with 35 hectares, bordered by pastures, and around 20 km away from the Dourados downtown. Vegetation is of typical semi-deciduous forest type, and is considered a remnant of the Atlantic forest. The soil type is oxisol with clay. The weather is humid mesothermal (Cwa), according to Koppen's classification (Projeto Radambrasil 1982).

Sampling method. Samples were taken weekly, when the baits of the traps were exchanged. Exactly 315 samples were collected, comprised of 105 samples from each of the three environments. A set of three pitfall traps (i.e., one sample) per environment per week were baited with cattle dung according to the methodology by Koller *et al.* (2007). Traps were installed at a minimum distance of 200 m from each other, checked from 5 Nov 2005 to 3 Nov 2007, and weather data were obtained from Empresa Brasileira de Pesquisa Agropecuária, Centro de Pesquisas Agropecuária do Oeste (EMBRAPA-CPAO), Dourados-MS, Brazil.

The dung beetles caught were kept in vials with 70% ethanol and subsequently mounted on entomological pins, labeled and identified by Dr. S. Ide (Instituto Biológico de São Paulo). Voucher specimens were deposited in the Museu da Biodiversidade (MuBio), Faculdade de Ciências Biológicas e Ambientais (FCBA), Universidade Federal da Grande Dourados (UFGD), Dourados-MS, Brazil.

Data analysis. The seasons of occurrence of the predominant species were determined by taking in to account the monthly average of the number of individuals of each species caught in the three traps in each environment. For the calculations, the beetles captured weekly in the three traps from each environment were summed. We considered the species that were very abundant and very constant in each environment to be dominant.

To verify the influence of weather on the species sampled in the traps of each of the three ecosystems: pasture, agroecosystem, and native semi-deciduous forest, we applied the Pearson correlation index. To determine if means were significantly different we applied the non-parametric Mann-Whitney test for multiple comparisons (Whittaker 1972) (P <0.05). For the latter test, the average number of individuals (both males and females) captured by month in the traps in each ecosystem was calculated. Only those traps that captured at least one individual (herein named 'positive traps') in each environment were included in the analysis to verify whether there were significant differences between the environments. Finally, the results obtained from the non-parametric Mann-Whitney test (Whittaker 1972) were compared with the weather data.

RESULTS

A total of 54 Scarabaeiodea (Coleoptera) taxa, including two subspecies of *Dichotomius*, were found in the three environments (i.e., pasture, agroecosystem, and native semi-deciduous forest), during 2 yrs with weekly sampling. The predominant species, in descending order, captured in the pasture were: *Labarrus pseudolividus* Balthasar (18.60%), *Genieridium bidens* (Balthasar) (18.04%), *Ontherus appendiculatus* Mannerheim (16.61%), *Trichillum externepunctatum* Preudhomme de Borre (9.38%), and *Ataenius platensis* (Blanchard) (9.24%). In the agroecosystem the predominant species were: *A. platensis* (73.91%) and *A. sculptilis* Harold (12.10%). In the native semi-deciduous forest the predominant species were: *Eurysternus caribaeus* (Herbst) (28.95%), and *Dichotomius carbonarius* Mannerheim (21.00%) (Table 1).

Twenty six species occurred in all three sampled environments, as follows: *Agamopus viridis* Boucomont, *L. pseudolividus*, *A. platensis*, *Ateuchus pygidialis* (Harold), *Ateuchus*

Table 1. Taxon richness and adult abundance of Scarabaeiodea (Coleoptera) in three different environments in Mato Grosso do Sul state, Midwest Brazil (Nov 2005 to Nov 2007).

Taxa and Species Richness	Abundance of Adult by Species in each Environment		
	Native Forest	Pasture	Agroecosystem
Scarabaeidae, Aphodinae			
Aphodius (*Nialus*) *nigritus* Fabricius	0	40	20
Ataenius platensis (Blanchard)	478	1,215	19,122
Ataenius sculptilis Harold	0	145	3,131
Blackburneus laxepunctatus (Schimidt)	0	63	57
Labarrus pseudolividus Balthasar	5	2,444	360
Scarabaeidae, Scarabaeinae			
Agamopus viridis Boucomont	5	605	9
Anomiopus virescens Westwood	2	0	4
Ateuchus pygidialis (Harold)	58	28	3
Ateuchus vividus Germar	4	47	8
Ateuchus sp. 1	1	20	23
Ateuchus sp. 2	16	3	0
Canthidium (*Canthidium*) *dispar* Harold	2	0	0
Canthidium (*Canthidium*) *sulcatum* (Perty)	0	0	1
Canthidium (*Canthidium*) *viride* (Lucas)	4	98	170
Canthidium (*Eucanthidium*) sp.2	5	0	0
Canthidium sp. 1	3	12	6
Canthidium sp. 2	5	0	1
Canthon (*Francmonrosia*) *dives* Harold	0	3	233
Canthon laminatus Balthasar 1939	1	1	67
Canthon (*Canthon*) *virens chalybaeus* Blanchard	3	0	0
Canthon (*Glaphyrocanthon*) *oliverioi* (Pereira & Martínez)	16	0	0
Canthon quinquemaculatus Castelnau	32	0	0
Canthon (*Canthon*) sp. 1	1	0	1
Canthon (*Canthon*) sp. 2	0	4	0
Coprophanaeus jasius (Olivier)	281	3	8
Coprophanaeus spitzi (Pessoa)	2	2	7
Coprophanaeus (*Metallophanaeus*) sp.1	0	1	28
Deltochilum (*Deltohyboma*) *aspericolle* Bates	430	11	6
Deltochilum (*Hybomidium*) *icarus* (Olivier)	0	0	2
Dichotomius bos (Blanchard)	16	459	145
Dichotomius (*Luederwaldtinia*) *carbonarius* (Mannerheim)	1,123	68	80
Dichotomius (*Luederwaldtinia*) *glaucus* (Harold)	0	35	17
Dichotomius melzeri (Luederwaldt)	330	12	1
Dichotomius (*Luederwaldtinia*) *nisus* (Olivier)	47	658	641
Dichotomius (*Dichotomius*) *semianeus* (Germar)	11	46	14
Dichotomius (*Selenocopris*) *ascanius piceus* (Luederwaldt)	1	0	0
Dichotomius (*Dichotomius*) sp. 1	0	0	1
Dichotomius (*Selenocopris*) *ascanius* (Harold)	0	12	0
Digitonthophagus gazella (Fabricius)	3	518	120
Eurysternus caribaeus (Herbst)	1,548	35	30
Eurysternus parallelus Castelnau	374	2	1
Genieridium bidens (Balthasar)	1	2,371	283
Gromphas inermis Harold	0	0	1
Isocopris inhiatus (Germar)	0	0	3
Malagoniella (*Megathopomima*) *puncticollis aeneicollis* (Waterhouse)	0	14	0
Ontherus digitatus Harold	0	14	10
Ontherus sulcator (Fabricius)	8	145	94
Ontherus appendiculatus (Mannerheim)	13	2,183	391
Onthophagus catharinensis Paulian	246	13	0
Onthophagus hirculus Mannerheim	13	103	31
Onthophagus ptox Erichson	115	470	124
Trichillum externepunctatum Preudhomme de Borre	11	1,233	617
Hybosoridae, Hybsorinae			
Coilodes humeralis (Mannerheim)	28	0	0
Coilodes sp.1	104	2	0
Subtotal	**5,346**	**13,138**	**25,871**
Total Species Richness (s) 53	**S = 39**	**S = 39**	**S = 41**
Total		**44,355**	

vividus (Germar), *Ateuchus* sp.1, *Canthidium viride* (Lucas), *Canthidium* sp.1, *Canthon laminatus* Balthasar, *Coprophanaeus jasius* (Olivier), *Coprophanaeus spitzi* (Pessoa), *Deltochilum* (*Deltohyboma*) *aspiricolle* Bates, *Dichotomius bos* (Blanchard), *Dichotomius* (*Luederwaldtinia*) *carbonarius*, *Dichotomius melzeri* (Leuderwaldt), *Dichotomius* (*Luederwaldtinia*) *nisus* (Olivier), *Dichotomius* (*Dichotomius*) *semianeus* (Germar), *Digitonthophagus gazella* (Fabricius), *E. caribaeus*, *Eurysternus* (*Eurysternus*) *parallelus* Castelnau, *Ontherus sulcator* (Fabricius), *O. appendiculatus*, *Onthophagus hirculus* Mannerheim, *Onthophagus ptox* (Erichson), *P. brasiliensis*, and *T. externepunctatum* (Table 1).

Seven species were exclusive to the native semi-deciduous forest: *Canthidium dispar* (Harold), *Canthidium* (*Eucanthidium*) sp.2, *Canthon (Canthon) virens chalybaeus* Blanchard, *Canthon* (*Glaphyrocanthon*) *oliverioi* (Pereira & Martínez), *Canthon quinquemaculatus* Castelnau, *Coilodes humeralis* (Mannerheim), and *Dichotomius* (*Selenocopris*) *ascanius piceus* (Leuderwaldt); three species to the pasture: *Canthon* (*Canthon*) sp.2, *Dichotomius* (*Selenocopris*) *ascanius* (Harold), and *Malagoniella* (*Megathopomima*) *puncticollis aeneicollis* (Waterhouse), and five species occurred only in the agroecosystem: *Canthidium sulcatum* (Perty), *Gromphas inermis* Harold, *Deltochilum* (*Hybomidium*) *icarus* (Olivier), *Dichotomius* (*Dichotomius*) sp.1, and *Isocopris inhiatus inhiatus* (Germar) (Table 1).

The following seven species occurred concomitantly in both anthropized environments (i.e., pasture and agroecosystem): *Blackburneus laxepunctatus* (Schmidt), *Aphodius* (*Nialus*) *nigritus* Fabricius, *A. sculptilis*, *Canthon* (*Francmonrosia*) *dives* (Harold), *Coprophanaeus* (*Metallophanaeus*) sp. 1, *Dichotomius* (*Luederwaldtinia*) *glaucus* (Harold), and *Ontherus digitatus* Harold (Table 1).

The agroecosystem supported significantly higher abundance and species richness of dung beetles than the native forest or pasture (Table 2). In this research the occurrence of the most abundant and dominant species of dung beetles differed between the three environments (Table 2). In all environments, populations were higher in the periods with higher temperature and rainfall. The abundance of dung beetles had a strong positive correlation with precipitation ($r = 0.237$, $P < 0.01$, $N = 391$), and with the monthly average temperature ($r = 0.373$, $P < 0.01$, $N = 391$).

The months with the highest abundances of dung beetles, in descending order of abundance, were: Oct 2006 (14.94%), Oct 2007 (14.57%), Nov 2006 (8.58%), and Dec 2006 (8.38%), in the pasture; Dec 2006 (35.13%), Dec 2007 (15.79%), Nov 2006 (11.93%), Dec 2005 (5.50%), and Oct 2006 (5.09%), in the agroecosystem, and Nov 2006 (15.22%), Dec 2006 (13.65%), Dec 2005 (11.78%), and Oct 2007 (8.90%), in the native forest (Figure 1).

In this study, the adults of the Scarabaeidae species with the following behaviors: endocoprid (i.e., digging galleries inside the cattle dung), paracoprid (i.e., burying portions of feces below the fecal mass), and telecoprid (i.e., burying portions of feces at a distance from the fecal mass), predominantly emerged in the late spring and early summer. They presented an increase in abundance during the seasons of higher rainfall and temperature (Figure 2).

Labarrus pseudolividus showed highest abundances in Nov 2005, Oct 2006, and Sep 2007. *Ontherus appendiculatus* was more abundant in the months of Feb and Oct 2006, and Mar and Oct 2007. In 2006, *P. brasiliensis* and *T. externepunctatum* had similar population outbreaks, with small increases in Jan, Feb, Oct, and Nov. Only *P. brasiliensis* had higher populations in Mar and Oct 2007, with low abundance in the remaining months during the 2 yrs evaluated (Figure 3). In the agroecosystem, the species *A. platensis* and *A. sculptilis* were collected all year, with high captures in Oct, Nov, and Dec in 2005, 2006, and 2007. *Ataenius sculptilis* also presented an increase in abundance in Mar 2006 (Figure 4). In the native forest, *D. carbonarius* presented higher populations in the months of Nov and Dec 2005 and 2006, Sep and Oct 2006, and Sep and Oct 2007. In this ecosystem, *D. carbonarius* was not captured in the months of Mar, Apr, May, Jun, Jul, or Aug. On the other hand, *E. caribaeus* occurred during the entire period of this study, having their major population peak in Oct (Figure 5).

DISCUSSION

In this research, in general, the abundance of 54 dung beetle taxa, were highest in summer (Oct, Nov, and Dec) (Table 1), overlapping with higher temperatures and rainfall. An early population increase occurred at the start of spring (Sep). In January, there was a population decline that continued until February (Figure 1). This population pattern may represent a reproductive strategy,

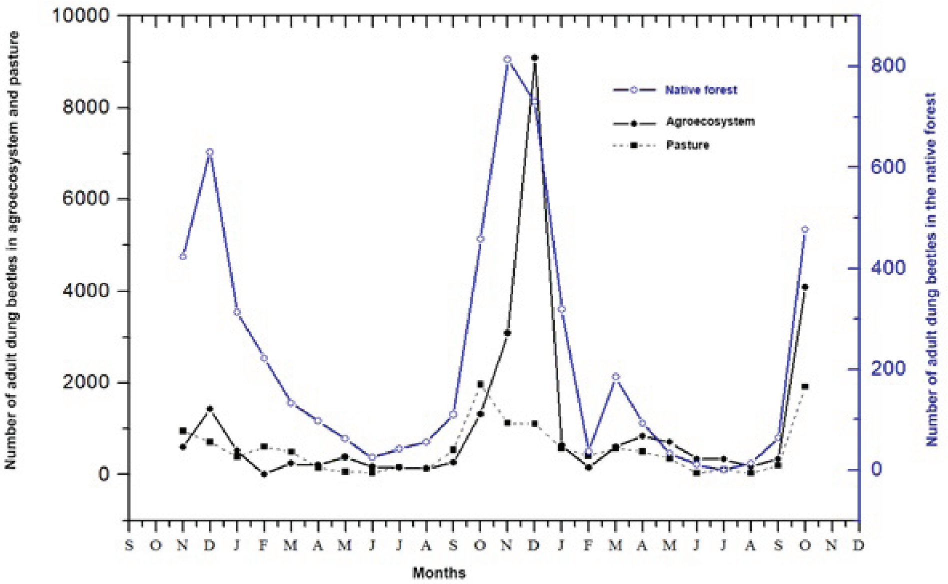

Figure 1. Abundance of coprophagous beetles (Coleoptera: Scarabaieidae) in three environments (i.e., native semi-deciduous forest, agroecosystem and pasture), and month of sampling in the municipality of Dourados, Mato Gosso do Sul state, Midwest Brazil (Nov 2005 to Nov 2007).

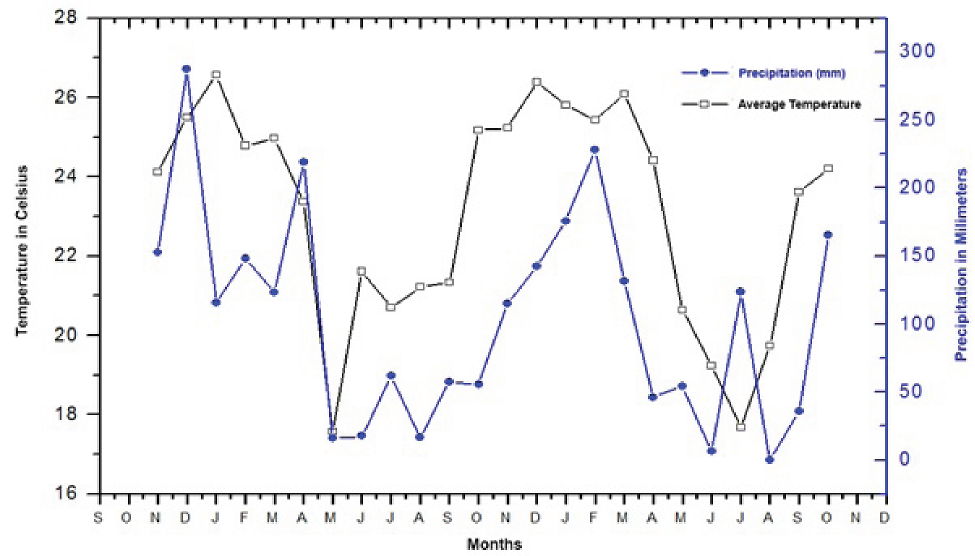

Figure 2. Average temperature (°C), and rainfall or precipitation (mm) in the municipality of Dourados, Mato Gosso do Sul state, Midwest Brazil, from Nov 2005 to Nov 2007.

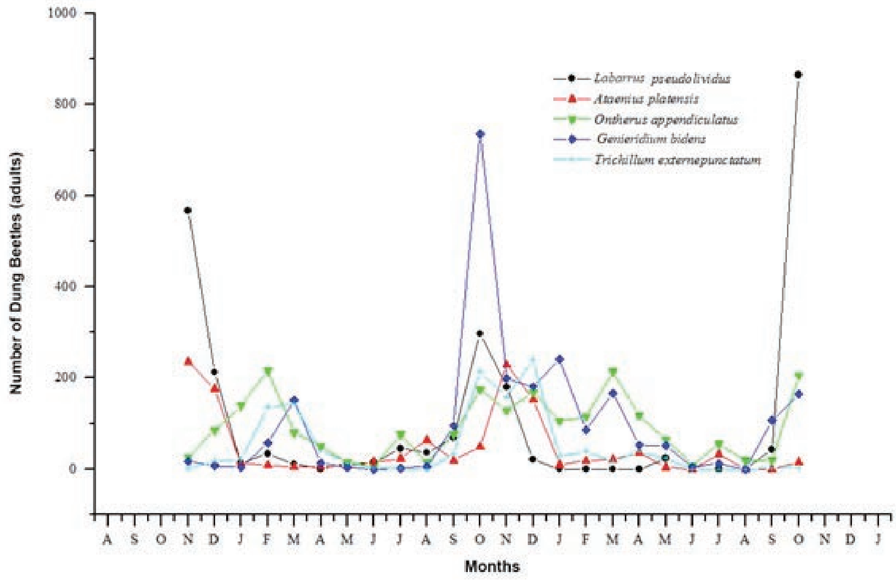

Figure 3. Population fluctuation of the top five most abundant dung beetle (Coleoptera: Scarabaeidae) species captured by month in pitfall traps in a pasture of signal grass, Urochloa decunbens, in the municipality of Dourados, Mato Gosso do Sul state, Midwest Brazil (Nov 2005 to Nov 2007)

especially for univoltine species, because in the summer higher precipitation makes the soil soft, facilitating synchronized adult emergence. This aspect was previously discussed by Koller *et al.* (2007). Overall, our results show a strong correlation between the abundance of dung beetle species with increasing temperature and rainfall, indicating that, despite differences in land use, anthropized, (i.e., agricultural and grazing areas) or intact soil (i.e. forested environment), the correlation remains.

Disproving our hypothesis, the native semi-deciduous forest supported lower species richness of dung beetles, in comparison with the agroecosystem, and presented no significant difference with the pasture (Table 1).

B. laxepunctatus, formerly *Aphodius* (*Blackburneus*) *laxepunctatus* (cited in Rodrigues *et al.* 2013 as *Aphodius* (*Blackburnium*) *lexepunctatus* Schimidt (error), occurred in both anthropized environments (pasture and agrosystem). This species occurs in Argentina, Bolivia, Brazil, Costa Rica, French Guiana, Paraguay, Peru, Suriname, Venezuela (Dellacasa *et al.* 2011). *G. inermis* Harold (formerly *G. lacordairei* Blanchard), occurred only a single specimen in the agroecosystem. This species is reported from Argentina, Brazil, Bolivia, Paraguay and Uruguay (Cupello & Vaz-de-Mello 2013) (Table 1).

Herein, the average number of Scarabaeidae collected in the positive traps (i.e., traps that captured at least one individual) as well the mean number of adults in the positive traps in the semi-deciduous forest was significantly lower than the averages in the pasture or agricultural environments. On the other hand, there was no significant difference in the capture of adults between the agroecosystem or pasture environments (Table 2).

We found that the abundance and species richness of dung beetles varied among the sampled environments, except for *A. platensis* and *A. sculptilis*, which were highly abundant in both anthropized environments: pasture and agroecosystem (Table 2). This result shows that the dominance of a species is related to its adaptability to a particular environment. As discussed by Howden & Nealis (1975), species of dung beetles have a close relationship with specific habitats. There are groups of dung beetle species adapted to open environments and others to

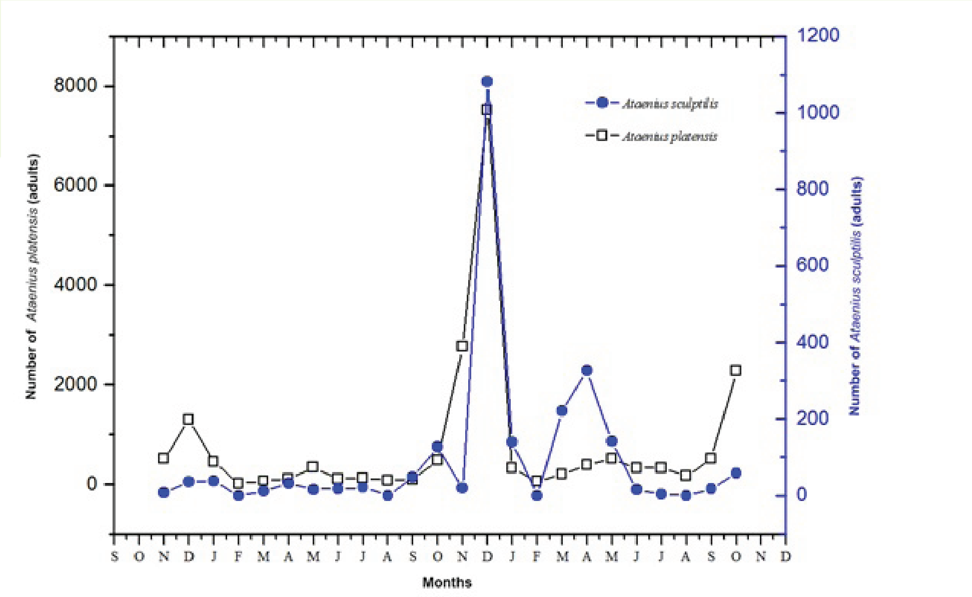

Figure 4. Population fluctuation of the top two most abundant dung beetle (Coleoptera: Scarabaeidae) species captured by month in pitfall traps in an agroecosystem in the municipality of Dourados, Mato Gosso do Sul state, Midwest Brazil (Nov 2005 to Nov 2007)

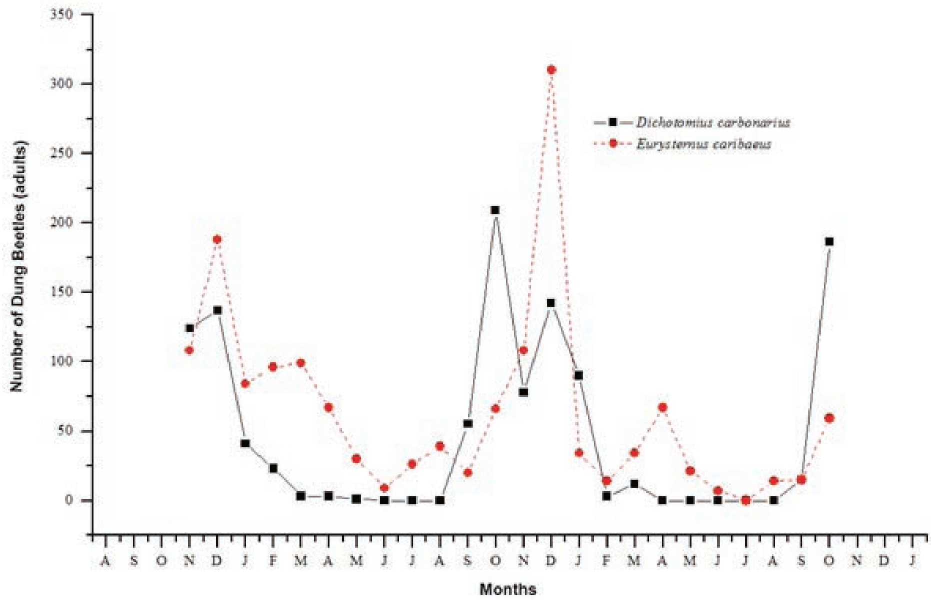

Figure 5. Population fluctuation of the top two most abundant dung beetle (Coleoptera: Scarabaeidae) species captured by month in pitfall traps in a semi-deciduous forest in the municipality of Dourados, Mato Gosso do Sul state, Midwest Brazil (Nov 2005 to Nov 2007)

Table 2. Number of dung beetle specimens caught in pitfall traps in 3 environments from the municipality of Dourados, Mato Grosso do Sul state, Midwest Brazil by weather variables and the type of environment (Nov 2005 to Nov 2007).

Environment	Mean, (standard deviation), and (N)		Mann-Whitney		Comparison
			Z	P	
Temperature	< 25°C	>25°C			
Pasture	20.58 (24.06) (78)	58.07 (54.93) (60)	–5.966	<0.001	a < b
Agroecosystem	23.96 (36.03) (78)	72.61 (72.11) (49)	–4.912	<0.001	a < b
Semi-deciduous forest	8.73 (8.31) (71)	34.96 (28.28) (55)	–6.181	<0.001	a < b
Total	**18.04 (26.50) (27)**	**54.66 (55.86) (164)**	**–9.623**	**<0.001**	**a < b**
Precipitation	< 25 mm	> 25 mm			
Pasture	28.61 (35.49) (84)	49.74 (53.39) (54)	–3.014	0.003	a < b
Agroecosystem	36.25 (51.32) (88)	57.36 (68.74) (39)	–1.182	0.237	ns
Semi-deciduous forest	18.68 (19.08) (84)	23.19 (30.66) (42)	–0.093	0.926	ns
Total	**27.98 (38.46) (256)**	**43.68 (54.37) (135)**	**–2.565**	**0.010**	**a < b**

Comparison indicates significant differences by the Mann-Whitney U test, p < 0.05, ns = not significant. Temperature: a < 25°C, b > 25°C, Precipitation: a < 25 mm, b > 25 mm.

forests. According to Howden & Nealis (1975), the abundance of dung beetles decreases in locations near deforested areas, where the sources of resources (animal feces) are suppressed as a result of vegetation removal. Hernández *et al.* (2003) reported that following an environmental disturbance, some species can explore the resources of substitution fauna (i.e., dung of small mammals and birds).

In this survey, a joint analysis of the 53 species collected (including two subspecies of *Dichotomius*) shows that there are greater abundance of adult dung beetles in the months with highest temperatures and rainfall, that occurs in Mato Grosso do Sul state from Oct to May (Figures 1-2). These results are in agreement with Flechtmann *et al.* (1995); Hilje (1996); Ronqui & Lopes (2006) and Koller *et al.* (2007), who all correlated the hottest and more humid months with the highest abundance of Scarabaeidae. These environmental conditions promote the acceleration of dung beetle metabolism and ensure greater flexibility of the soil, favoring the emergence of adults. However, in this study, the months of Jan and Feb 2007 were an exception: despite the high rainfall and high temperatures in the region, population levels were low.

In Feb 2006 and again in Feb 2007 in the agroecosystem, although there was relatively high rainfall and high temperatures, there was a decrease in the catch of the adults. This same pattern also was observed in the native forest, but the decrease was more pronounced from Dec to Feb 2007, with the population rising again in Mar (Figure 2). This fact can be attributed to the high occurrence of heavy rainfall during that season in the municipality of Dourados. As a consequence, soil flooding may have increased larval mortality. Another possibility is that the dung beetles were still in their larval stage at that time, with their emergence starting from Mar.

In the remaining months of the year, there was a low population level associated with lower precipitation and temperature. Apr, May, and Jun in 2006, and Jun and Aug in 2007, were the months with lower abundance of Scarabeiodea (Figure 1). In these seasons there was a rapid lowering of temperature and decreases in rainfall (Figure 2). Because of these weather conditions, the soil becomes dried and hardened, making it difficult for the adults to emerge. Additionally, according to Nation (2015), the decrease in temperature can cause lowering of biological reactions, decreasing the rate of larval development. Furthermore, adult reproduction can be impacted due to decreases in testicular and oogenesis activities, which in turn reduce oviposition.

The species *L. pseudolividus*, *A. platensis*, *P. brasiliensis,* and *T. externepunctatum* are multivoltine (Flechtmann *et al.* 1995) endocoprid dung beetles with a small body size (Doube 1990). In this study, these species were collected in almost all months in the pasture (Figure 3), being the predominant species for that ecosystem (Table 2). According to Nichols *et al.* (2007), dung beetles species with these characteristics, generally are hyper-abundant in open areas. Higher abundance in the agroecosystem was due to the presence of *A. platensis*, with many adults caught in the rainy season, i.e., end of fall and all summer (Oct to Mar). *Ataenius platensis* was most abundant and frequent during the months of Nov 2005 and Nov 2006 (Figure 4).

The dung beetle species with a small body size showed high abundance in this study, however, they provide minimal burial of bovine dung, because they require only a small amount of resources to feed and breed. On the other hand, these small body sized beetles contribute to internal aeration of fecal masses, facilitating draining and disintegration, mainly in the dry season (winter), when other species are not active. These species of dung beetle (i.e., with endocoprid behavior) are not dependent on habitat soil type and according to Flechtmann & Rodrigues (1995), are less affected by changes in weather.

Species such as *D. carbonarius* and *E. caribaeus* were frequently and constantly caught in the native semi-deciduous forest. *Dichotomius carbonarius* had higher abundance in Nov and Dec 2005 and 2006; Sep and Oct 2006, and Sep and Oct 2007. However, *D. carbonarius* was not captured in Mar, Apr, May, Jun, Jul, or Aug. On the other hand, *E. caribaeus* occurred throughout the entire 2 yr period of this study, having a population outbreak in Oct (Figure 5). According to Flechtmann & Rodrigues (1995) these two species are typical of forested ecosystems.

We found that for both univoltine species, with a long life cycle between 327-435 d, such as *Coprophanaeus spitzi*, *Coprophanaeus* (*Metallophanaeus*) sp.1, and *G. inermis* Harold, as well for multivoltine species, with a short life cycle of around 30 d, such as *A. platensis*, *C. dispar*, *P. brasiliensis,* and *T. externepunctatum*, the highest abundance was more related to environmental factors, than to their own reproduction and development rates. Probably, the weather indirectly influences reproduction and development. Our results are consistent with other studies carried out in Brazil (Honer *et al.* 1987; Flechtmann *et al.* 1995; Ronqui & Lopes 2006; Koller *et al.* 2007; Novais *et al.* 2016). In South Africa, Gaston & Chown (1999) concluded that the differences between dung beetles communities at altitude gradients are related to the weather differences between these environments. As reported by Davis *et al.* (1999), there was a strong influence of biogeographic factors on the Scarabaeidae communities. They act most notably at the genus and species levels, being correlated with the type of weather, especially in tropical regions with seasonal rainfall and temperature variations.

In conclusion, there are a strong positive correlation between high temperature and rainfall with an increase in abundance of dung beetles (Scarabaeidae). There are differences in the patterns of abundance of the dung beetle communities between the environments (native semi-deciduous forest, pasture and agroecosystem). Scarabaeids were most abundant and with highest species richness in the agroecosystem (41 species); with no significant differences between the native semi-deciduous forest and pasture, with 39 species in each environment.

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