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Subtle Land-Use Change and Tropical Biodiversity: Dung Beetle Communities in Cerrado Grasslands and Exotic Pastures

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ABSTRACT

Although many tropical savannas are highly influenced by humans, the patterns of biodiversity loss in these systems remain poorly understood. In particular, the biodiversity consequences of replacing native grasslands with exotic pastures have not been studied. Here we examine how the conversion of the native savanna grasslands affects dung beetle communities. Our study was conducted in 14 native (grassland: *campo limpo*), and 21 exotic (*Urochloa* spp. monoculture) pastures in Carrancas, Minas Gerais, Brazil. We collected 4996 dung beetle individuals from 66 species: 3139 individuals from 50 species in native pastures and 1857 individuals from 55 species in the exotic pastures. Exotic pastures had lower dung beetle richness, abundance and biomass than native pastures. Species composition between the two pasture types was significantly different and exotic pastures were dominated by few abundant species. Indicator species analysis detected 16 species indicators of native pastures and three of exotic pastures, according to relative abundance and frequency in each pasture system. Our results show that the conversion of native pastures to exotic pastures leads to a predictable loss of local species richness, increasing dominance and changes in species composition. These results highlight the importance of maintaining native pastures in the Cerrado agro-pastoral landscape.

Abstract in Portuguese is available at http://www.blackwell-synergy.com/loi/btp.

Key words: agro-pastoral landscape; Brazil; Brazilian savanna; habitat conversion; native pasture; Scarabaeinae.

Like tropical forests, many tropical savannas have undergone considerable human-induced transformations. Unlike tropical forests though, the patterns of biodiversity loss in tropical savannas remain poorly understood (Lehmann *et al*. 2009). Specifically, few studies have addressed the conservation implications of converting native savannas to exotic pastures (Pivello *et al*. 1999). This is perhaps because the structural changes in grass-dominated ecosystems are less obvious and more difficult to detect (Houet *et al*. 2009).

One-fifth of the human population and most of the world's livestock lives in savanna ecosystems (Lehmann *et al*. 2009). The replacement of native grasslands and bush savanna by exotic pastures has being implemented in many different regions to increase the livestock carrying capacity (Pivello *et al*. 1999, Jepson 2005). These changes are particularly noticeable in the Brazilian savanna (hereafter referred to as Cerrado). This Neotropical ecosystem covers around 20 percent of Brazil, and is considered one of the world's 25 biodiversity hotspots due to high rate of conversion and the occurrence of thousands of endemic animals and plants (Myers *et al*. 2000). At the same time, Brazil has large bovine livestock populations, and around half of all Brazilian pastures are composed of exotic grasses, the majority located in the Cerrado (Martha & Vilela 2002).

Cerrado is a complex mosaic of native vegetation, including grassland (*campo limpo*), savanna (cerrado *sensu strictu*) and forest (Cerradão) (Oliveira & Marquis 2002). Most of the Cerrado vegetation was degraded or converted to agriculture in the 1960s. Recent estimates suggest that more than a half of the Cerrado is now occupied with agro-pastoral activities (Ratter *et al*. 1997, Bond & Parr 2010).

The conversion of the Cerrado vegetation to intensive monocultures, such as sugarcane for biofuel production, can have disastrous consequences for biodiversity (Scharlemann & Laurance 2008). We have a poor understanding, however, of the more subtle changes that occur when Cerrado grasslands are planted with exotic grass species. The consequences for the native fauna are particularly poorly known.

Our objective was to examine the biodiversity consequences of replacing native Cerrado grasslands currently used as extensive pastures, with pastures planted with exotic grass. We focused on dung beetles (Coleoptera: Scarabaeidae, Scarabaeinae) as they are considered effective indicators of disturbance (Halffter & Favila 1993, Nichols *et al*. 2009), and have a high degree of habitat specificity in the Cerrado (Almeida & Louzada 2009). Furthermore, dung beetles are closely linked to mammals because both adult and larvae use dung as a food resource (Hanski & Cambefort 1991). They also have important ecological functions such as secondary seed dispersal and nutrient cycling (Nichols *et al*. 2008). Most importantly from the perspective of cattle farmers, dung beetles bury livestock dung, reducing both forage fouling and the abundance of some common parasites that affect livestock (*e.g*., haematophagous flies).

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These ecological services have been valued at around US$380 million/yr in the United States alone (Losey & Vaughan 2006). Our specific hypotheses were: (1) exotic pasture systems have fewer species and individuals than native systems; (2) total dung beetle biomass is smaller in exotic pasture; and (3) there are differences in the dung beetle community structure and species composition between pasture systems.

METHODS

STUDY SITE.—The study was carried out in Carrancas, in the south of the state of Minas Gerais, southeast Brazil (21°28′24″ S, 44°39′05″ W), situated in the cerrado biome (Oliveira-Filho *et al.* 2004). The sample sites were between 900 and 1200 m in altitude, and receive 1480 mm of rainfall/yr with a mean annual temperature of 15°C (Oliveira-Filho *et al.* 2004). The study region is an important milk-producing region in Minas Gerais, and dairy farming is the main economic activity in many of the small cities, including Carrancas.

Almost all farmlands in Carrancas contain some native cerrado grasslands (*campo limpo*), and traditionally the farmers utilize these native grasslands to graze their cattle. These native pastures (*campo limpo*) are composed of several native species of grass (Poaceae). In the last 30 yr, exotic grasses have been introduced to increase the carrying capacity of cattle. These grasses include African *Urochloa* spp., which is highly tolerant of acidic soils characteristic of cerrado (Martha & Vilela 2002). The replacement process is associated with several technological changes in pasture management, such as ploughing and the use of fertilizers and lime, which are not used in native pastures (Martha & Vilela 2002).

We sampled dung beetles in 35 pasture sites that were a minimum of 300 m apart. Fourteen pastures were of native cerrado grassland and 21 were *Urochloa* spp. grasses. The pastures were distributed across seven medium to large dairy farms in Carrancas, all used for grazing cattle (Fig. S1). The farms varied in size from 43 to 457 ha, which reflected the typical range of farm sizes registered in Carrancas (Instituto Brasileiro de Geografia e Estatística [IBGE] 2006).

DUNG BEETLE SAMPLING.—All sampling was undertaken during the middle of the rainy season, in January 2008, in order to minimize the potential effect of seasonality in our comparisons across farming systems. The rainy season is recognized as the best period of the year to sample dung beetles in the seasonal tropics (Martínez & Vásquez 1995).

Our sampling unit was a baited pitfall trap composed of a plastic container (19 cm diam, 11 cm height) filled with 150 mL of a saline solution and detergent. The trap had a wire base in the shape of a hoop to accommodate a small plastic container (4 cm diam, 4 cm height) where the bait was placed. The wire was fixed in the soil to suspend the bait container in the center of the trap. We also used a small plastic cover (20 cm diam) sustained by three sticks to protect the trap from rain.

We placed six traps in each pasture site, and these were distributed in a rectangular design with 100 m between traps (Fig. S1). Traps were baited and left in the field for a 48-h period in each pasture. We placed a total of 210 traps in the study (six traps in each of the 35 pastures). Traps were baited with 20 g of human faeces in order to attract a wide range of species (Larsen & Forsyth 2005). Previous studies show that cow dung only attracts a limited range of species, underestimating dung beetle biodiversity (Dormont *et al.* 2004, Louzada & Silva 2009).

Dung beetles were identified to species by Dr. Fernando Z. Vaz-de-Mello or by using the reference collection of Invertebrate Ecology and Conservation Laboratory (IEC) at Universidade Federal de Lavras, Brazil. Voucher specimens were stored at the IEC and Universidade Federal do Mato Grosso (UFMT) collection. Whenever sample sizes permitted, we weighed 30 individuals of each species (approximately the same proportion of males and females), drying all specimens in a constant-temperature oven at 40°C for 1 wk before weighing on a precision scale (0.0001 g). The mean species weight was multiplied by the species abundance to obtain an estimate of biomass (Peck & Howden 1984) per trap in each pasture system. We also classified dung beetles in the following functional guilds relating to their nesting behavior: (i) rollers; (ii) tunnellers; and (iii) dwellers (Hanski & Cambefort 1991).

DATA ANALYSES.—We used individual-based rarefaction analysis to compare patterns of species richness and sample effort in native and exotic pastures (Gotelli & Colwell 2001). Comparisons among pasture systems were made by visual assessment of overlapping 95% CI of the rarefaction curves implemented in EstimateS7.5 (Colwell 2005).

We used generalized linear models (GLM) to examine differences in richness, abundance and total biomass between pasture systems. We used Poisson's error structure to richness and abundance, normal error structure to biomass and quasi-Poisson correction when overdispersion was detected (Crawley 2007, Zuur *et al.* 2009). Minimal models were adjusted by excluding nonsignificant variables and verifying effects on deviance (Crawley 2007). All values were converted to mean per pasture to reduce the overall variability and avoid spatial pseudoreplication. In addition, we used nonparametric Kruskal–Wallis tests to compare the abundance variation of each dung beetle species between both pasture systems due to nonnormal distribution of the data. We compared the average body weight of species in the different pasture systems using nonparametric Kruskal–Wallis tests. We used a nonparametric Pearson's correlation to relate abundance with total biomass. All above analyses were undertaken within the R environment (R Development Core Team 2008).

We plotted species rank-abundance distributions to visually compare patterns of species dominance in the two pasture systems. Species rank followed their mean relative abundance in the native pastures. We used nonmetric multidimensional scaling (NMDS) to explore differences in community structure and composition in the 35 pastures. The NMDS was based on a similarity matrix constructed using the Bray–Curtis index on log-transformed abundance and presence/absence matrix. We used the same NMDS method to test differences in dung beetle guild composition and community structure (abundance of individuals between the two pasture systems). The stress value is used to assess the robustness of the NMDS solution, with stress values above 0.2 indicating plots that could be unreliable (Clarke 1993). Analysis of similarity (ANOSIM; Clarke 1993) was used to test for significant differences in multivariate community structure. ANOSIM is a nonparametric permutations test for similarity matrices analogous to an ANOVA.

We used the Indicator Value (IndVal) analysis (Dufrene & Legendre 1997) to identify the species that were significant and reliable indicators of each pasture system. The method combines data on relative abundance and frequency to access the degree to which a given taxon is frequently associated with a particular habitat. Significant IndVal scores suggest that a given taxon is a faithful indicator of a certain habitat when contrasted with a distribution of indexes generated by Monte Carlo randomization procedure (5000 randomizations). IndVal analysis was implemented in PC-ORD5 (McCune & Mefford 2006).

RESULTS

RICHNESS AND ABUNDANCE ANALYSIS.—We collected 4996 individuals from 66 dung beetle species during the study, distributed across six tribes and 23 genera (Table S1): Ateuchini (22 species, eight genera), Canthonini (24 species, six genera), Coprini (ten species, three genera), Eurysternini (one species, one genera), Onthophagini (two species, one genera), Phanaeini (seven species, four genera). In the 14 native grassland pastures we collected 3139 individuals from 50 dung beetle species. In the 21 exotic pastures we collected 1857 individuals from 55 dung beetle species. Species accumulation curves indicated no significant difference in overall species richness between native and exotic system (Fig. 1). Mean species richness ($\chi^2 = 14.20$, $P < 0.001$) and number of individuals ($\chi^2 = 9.76$, $P < 0.001$; Fig. 2) per pasture was, however, higher in native than exotic pastures.

TOTAL BIOMASS AND BODY WEIGHT.—Total dung beetle biomass was higher in native pastures (mean ± SE = 9.70 ± 1.66 g) than in exotic (mean ± SE = 4.42 ± 0.79 g) pastures ($F_{1, 33} = 10.69$, $P < 0.05$). Additionally, there was a marginally significant correlation between biomass and abundance ($r = 0.31$, $N = 35$, $P = 0.06$) but no correlation between biomass and richness ($r = 0.10$, $N = 35$, $P = 0.56$). There was no significant difference between the average body weight of the dung beetle species captured in native (mean ± SE = 0.04 ± 0.006 g) and exotic (mean ± SE = 0.06 ± 0.01 g) pastures (Kruskal–Wallis; $\chi^2 = 0.09$, $P = 0.76$, df = 1).

SPECIES COMPOSITION.—Almost all species were more abundant in native pastures than in exotic pastures (Table S1). Exotic pastures

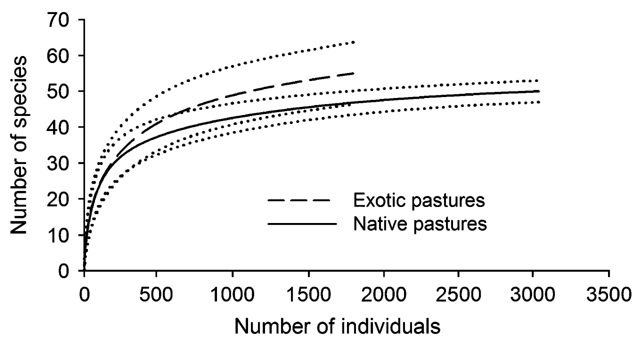

FIGURE 1. Individual-based species accumulation curves for dung beetle communities within different pasture systems. The dotted lines are 95% CI, illustrating that there was no significant difference between native and exotic pastures.

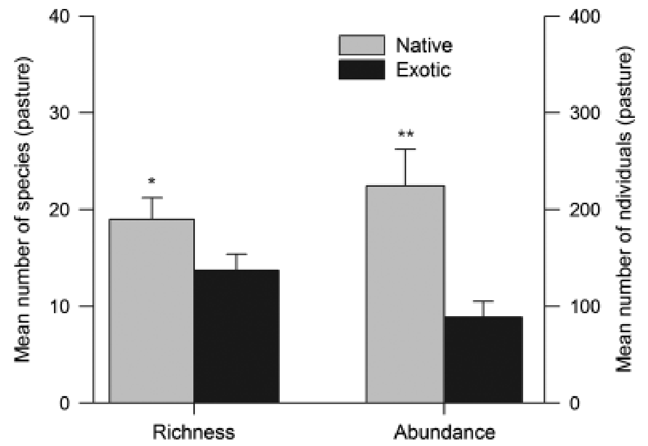

FIGURE 2. Observed mean richness and abundance of dung beetles (per pasture) in native ($N = 14$) and exotic ($N = 21$) pastures (*$P < 0.05$, **$P < 0.005$) based on Poisson's generalized linear model.

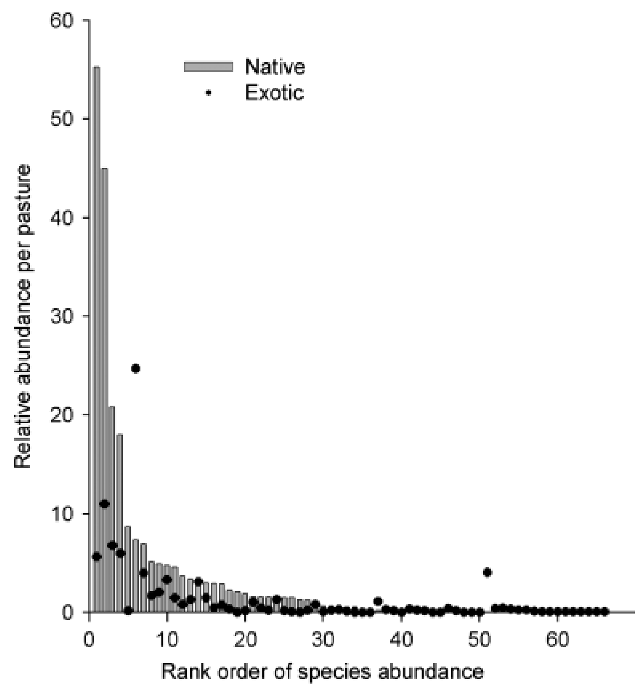

FIGURE 3. Rank-abundance distribution of dung beetles species in native and exotic pastures in the Carrancas farms in an agricultural landscape.

were dominated by few abundant species (Fig. 3). Four of the five most abundant species (*Trichillum adjunctum*, *Canthidium barbacenicum*, *Canthidium decoratum* and *Canthon virens)* were most abundant in native pastures (Table S1) but only three of these differences were significant: *C. barbacenicum* ($\chi^2 = 35.02$, $P < 0.001$), *C. decoratum* ($\chi^2 = 52.99$, $P < 0.001$) and *C. virens* ($\chi^2 = 27.79$, $P < 0.001$). Overall, the abundance of almost 40 percent of dung beetle species declined in response to exotic grasses, while just six percent increased with the replacement (Table S1). Of the 50 species captured in native pastures, 11 were only caught within that system. Of the 55 species recorded in exotic pastures, 16 were only collected in this pasture type and just one or two individuals of each species were collected (Table S1).

Dung beetle community composition and structure were different between native and exotic pastures, with each pasture system forming a distinct cluster on the NMDS plot (Fig. 4; ANOSIM, $R = 0.22$, $P < 0.001$ for composition, and $R = 0.10$, $P = 0.05$ for structure). IndVal analysis highlighted 19 species as indicator species (at $P < 0.05$), around 36 percent of recorded species. Of these, 16 were considered indicators of native grassland and just three were indicators of the exotic pasture (Table S2). According to functional guild, we found 1588 individuals of 24 species from the roller group, five individuals of one species (*Eurysternus paralellus*) from the dweller group and 3403 individuals of 41 species from the tunneller group (Table S1). There was no difference in the relative composition of the functional guilds between native and exotic pastures on NMDS plot (stress value = 0.01).

DISCUSSION

Land-use change has had an enormous impact on the Brazilian Cerrado over the past 30–50 yr (Silva 2000, Houet *et al.* 2009). Many of these changes are ongoing, but can often go unnoticed if they occur at a fine scale or are not detectable by remote sensing (Peterson 2008, Houet *et al.* 2009). By investigating the consequences of the replacement of native pastures by exotic pastures on dung beetles communities in the Brazilian grasslands (cerrado), we reveal the potential loss of biodiversity resulting from cryptic land-use change. This includes a marked decline in overall beetle abundance and species richness per pasture in the exotic system. We discuss these results, highlighting the importance of spatial scale and the conservation implications of the change of dung beetle community structure in exotic pastures.

Species richness at different spatial scales.—Human actions in managed landscapes can increase the regional diversity but have negative impacts on species richness at a local level (Estrada & Coates-Estrada 2002, Nichols *et al.* 2007). Although species richness per pasture (local scale) was much lower in the exotic pastures, this introduced system maintained a high overall species richness at the landscape level (regional scale). This result likely relates to the presence of only one or two individuals of some species in our samples, that could be transient species (Fagan *et al.* 1999) moving between the surrounding native vegetation, which remains the predominant land-cover in the region (IBGE 2006, Scolforo *et al.* 2008). These movements are well documented for several beetles groups, including dung beetles (*e.g.*, Grez & Prado 2000, French *et al.* 2001, Nichols *et al.* 2007). The higher percentage of species with only one or two individuals collected in the exotic pastures supports this possibility. It seems likely that these exotic pastures were often used as stepping stone habitats by dung beetles dispersing in their search for food, preferential habitats or as part of their reproductive strategy (Fagan *et al.* 1999, Estrada & Coates-Estrada 2002).

Dung beetle communities in cerrado pastures.—We recorded surprisingly few species typical of exotic pastures elsewhere in Brazil. For example, we found an overlap of only 16 species (29% of our samples) with exotic pastures in the cerrado regions studied by Louzada and Silva (2009), and an overlap of just 22 species (33% of

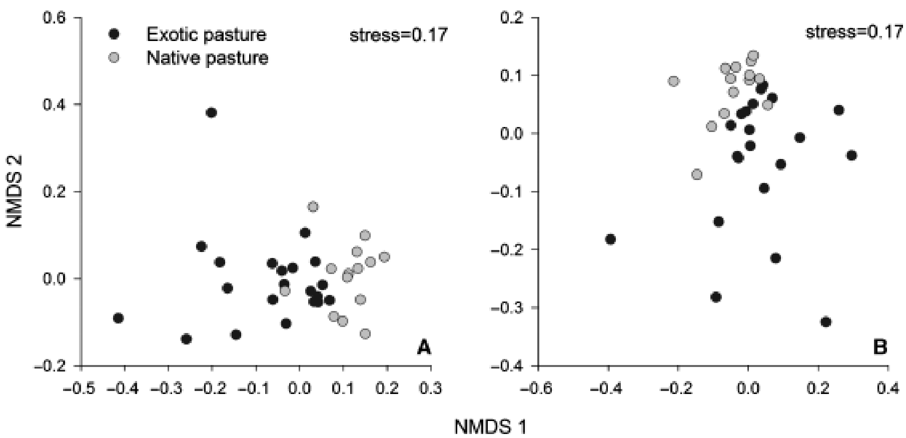

FIGURE 4. Nonmetric multidimensional scaling (NMDS) ordination based on a distance matrix computed with Bray-Curtis similarity index between pasture systems: native pasture and exotic pasture. NMDS (A) shows the difference in community composition (presence/absence species data) and NMDS (B) shows the difference based on community structure (abundance of individuals).

our samples) with the study of Almeida and Louzada (2009) in native habitats of cerrado, including native grasslands not used as pastures, in the same region. As in this study, both cited studies were conducted in January, and seasonality is unlikely to explain these results. Instead, the low degree of overlap could reflect a high β diversity in open-systems in cerrado (Almeida & Louzada 2009) or, most probably, the use of human faeces instead of cow dung in this study, as the latter has been commonly used in studies to evaluate dung beetles species composition in exotic pastures elsewhere (Koller *et al.* 1999, Aidar *et al.* 2000, Marchiori *et al.* 2003, Louzada & Silva 2009). Although we sampled pastures with a high availability of cow dung, we chose to use human faeces as bait to attract a wider range of beetle species dependent on the dung of native carnivores, herbivores and omnivores (Filgueiras *et al.* 2009).

It was surprising that no exotic dung beetles were found in this study. For example, *Digitonthophagus gazella* is an African dung beetle species exotic in Brazil, introduced during the 1980s to help control gastrointestinal helmiths and the horn fly *Haematobia irritans* (Miranda *et al.* 2000) and has already been observed in several exotic pastures in Brazil (Koller *et al.* 1999, Aidar *et al.* 2000, Marchiori *et al.* 2003), including the Amazon (Matavelli & Louzada 2008), but did not in southern Minas Gerais (Almeida & Louzada 2009, Louzada & Silva 2009). The reasons for its absence are not clear, but could relate to colonization time lags.

The effect of grassland conversion on the dung beetle community.—Deforestation and land-use change in forests landscapes often brings about dramatic changes in species composition and community structure (*e.g.*, Barlow *et al.* 2007). The more subtle grass-to-grass land-use change in savannas has received much less attention (Bond & Parr 2010); and could also have important consequences for the diverse and endemic biodiversity found in cerrado grasslands because the exotic grasses are able to invade and modify environmental conditions (Pivello *et al.* 1999).

Changes in dung beetle abundance can lead to a decrease of ecological functions important for pasture functioning, such as limiting the availability of some inorganic elements (N, P, K) in the soil and reducing the primary productivity (Borghesio 1999, Yamada *et al.* 2007). Our results consistently indicate that almost all species of dung beetles had much lower abundance in the exotic pastures and 11 species were not collected in exotic pastures. These results were supported by the 40 percent decline in dung beetle abundance in exotic pastures. There are three complementary mechanisms, which might explain the lower abundance of dung beetles in exotic pastures. First, savanna replacement would affect the availability and heterogeneity of food resources for dung beetles, as the disappearance of several plant species—including Leguminosae families (Ratter *et al.* 1997)—could affect the native mammal community activity on the area (Vieira & Baumgarten 1995, Vieira 1999). Also, a higher density of cattle suggests more herbivore dung, which could result in competitive advantages for a few species that can use this novel food resource (Louzada & Silva 2009). Second, the ploughing used before planting the exotic grass is likely to negatively affect dung beetles since most feeding galleries and nests are within the first 30 cm of the soil profile (Bang *et al.* 2005). Finally, the higher bovine densities at exotic pastures should result in soil compaction due to livestock trampling which might benefit the few species that are able to cope with the hardest soils (Halffter *et al.* 1992). Further studies are needed to examine the relative importance of these complementary hypotheses.

Dung beetle biomass and body weight.—Dung beetles with a large body size and body weight are often the most likely to go extinct following land-use change (Larsen *et al.* 2005, Gardner *et al.* 2008). Our study showed that biomass and species body weight were not different between pasture systems, despite the fact that biomass was higher in native pastures, suggesting the link between body size and extinction risk may not be universal (see also Larsen *et al.* 2005). If biomass is related to land-use intensity then dung beetle biomass is likely to vary depending on how land-use change alters factors important for dung beetles, including resource availability, changes in soils, vegetation structure and temperature (see also Verdú *et al.* 2006, Nichols *et al.* 2007).

Conservation implications.—Our results highlight a poorly understood threat to dung beetle biodiversity in Brazilian Cerrado. This is especially relevant as Brazilian government departments often provide incentives for converting native grasslands into exotic pastures, with the aim to increase the pasture carrying capacity (Martha & Vilela 2002). Furthermore, farmers require permission to use fire to manage their native pastures, but this permission can take a long time to be obtained from the State institution responsible for licensing and fire monitoring. The difficulty of obtaining permission provides an incentive to farmers to convert native pastures to exotic pastures that do not require fire management. Changing the governmental policies of subsidies for native pasture replacement, and making the fire-management processes less bureaucratic, would help prevent biodiversity loss in cerrado grasslands.

CONCLUSIONS

Although exotic pastures were not devoid of a native dung beetle fauna, we show that they contain a marked lower abundance and altered species composition when compared with the native pastures in the same region. Our results therefore highlight the importance of maintaining native pastures in the cerrado agro-pastoral landscape. They reveal how the ongoing conversion of native pastures into exotic pastures is causing changes in dung beetle communities, which could have possible cascading effects on the important ecological services provided by these insects. Although subtle changes in landscape structure and function may be more difficult to detect and may not attract as much attention as more drastic structural changes (such as deforestation), our findings emphasize their potential importance for the conservation of biodiversity associated with tropical savannas.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

TABLE S1. *Table of mean abundance per pasture; significance level of abundance between pasture systems according to Kruskal–Wallis test; and mean dry body weight per species of dung beetles collected and their functional guild in native and exotic pastures in Carrancas, Minas Gerais, Brazil.*

TABLE S2. *Indicator species of two pasture types calculated with IndVal (related with species frequency and relative abundance); significance level; mean abundance and standard error (SE) trap per system.*

FIGURE S1. Map of study area showing Carrancas city in the South of Minas Gerais (MG) State in SE Brazil.

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