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The importance of remnants of natural vegetation for maintaining ant diversity in Brazilian agricultural landscapes

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Abstract Brazil is one of the leading producers of soybeans and other annual crops, and in several regions landowners are required by law to maintain 20 % of their lands with natural vegetation (i.e. as "legal reserves"). However, there is a growing concern that some of these reserves will be subject to increased levels of disturbance or even be lost as a result of the ongoing legislation reforms. In this sense, studies that evaluate the conservation potential of retaining natural habitats within agricultural areas are of great importance. We assessed the efficiency with which remnants of natural vegetation conserve the native ant fauna in a context of intensive agriculture. We compared the structure of ground-dwelling ant assemblages between crop fields and reserves located in different farms. Ant species richness was much higher in the reserves than in the crops, and this pattern was consistent in spite of variations in the type of crop planted in each field, and in the size (39–149 ha) and vegetation (open or closed savanna) of the reserves. From 41.4 to 76.4 % of all species recorded within each farm were exclusively found in the reserves. Differences in species composition were strong not only because the reserves had much more species, but also because the species that were present in both habitats showed contrasting patterns of abundance in each habitat. Overall, our results highlight that even small remnants of natural vegetation can have a significant potential to maintain a higher diversity of ants within an agriculturally dominated landscape.

Keywords Agricultural intensification · Biodiversity conservation · Formicidae · Mosaic of land use types · Neotropical savannas

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Introduction

The world is currently facing a global land-use change in which 'modern' agriculture (sensu Pretty et al. 2011) is one of the main threats for natural ecosystems and their native biodiversity (Matson et al. 1997; Foley et al. 2005). In Latin America, regional economic development, international market demand, government policies, and development of new technologies have considerably accelerated the transformation of natural ecosystems into agrosystems through land use intensification (Barbier 2004). Brazil, in particular, has witnessed rapid land-cover changes in recent decades (Lepers et al. 2005). Notably, over the past 50 years, the Brazilian Cerrado has been suffering a rapid process of conversion into soy and maize fields, extensive cattle raising, and an imminent expansion of sugar cane plantations (Klink and Machado 2005; Houet et al. 2010). The Cerrado is a natural savanna-dominated biome characterized by a high richness and endemism of species that is nowa-days highly threatened, with deep problems regarding biodiversity conservation and land use (Myers et al. 2000; Cavalcanti and Joly 2002; Klink and Machado 2005). Intensive agriculture systems that are developed in the Cerrado region are essentially based on ''Green Revolution'' technologies, including high-yielding cultivars, chemical fertilizers and pesticides, heavy mechanization and irrigation (Ratter et al. 1997; Fearnside 2001).

Large-scale intensive agriculture has been causing extensive environmental damage, and is one of the main agents directly or indirectly responsible for the degradation, frag-mentation or destruction of the remaining natural habitats and their native communities of species (Hooper et al. 2005; Klink and Machado 2005). It leads to heavy biodiversity losses (Pimm and Raven 2000), thus inducing a simplification and homogenization of communities, consequently affecting the equilibrium of native ecosystems (McKinney and Lockwood 1999).

With global grain production expected to double by 2050 (Tilman et al. 2002), we are facing the challenge of managing trade-offs between immediate human needs and main-taining the capacity to provide ecosystem services (sensu Costanza et al. 1997) in the long term (Butler et al. 2007). In this sense, Nepstad et al. (2006) and Ferreira et al. (2012) argued that improved compliance with environmental laws, such as the Brazilian Forest Act (Brazilian legislation for the protection of natural vegetation in private landholdings, Law n°4771/65[1]), could result in increasingly global pressures on soy farmers and cattle ranchers, and thus contribute to improve the conservation of Brazilian threatened natural biomes. Currently, the total protected area of remaining natural Cerrado vegetation covers only a very small proportion of its original surface (Klink and Machado 2005). Further-more, the few remaining natural areas are threatened due to ongoing changes in the Brazilian Forest Act (Martinelli et al. 2010; Metzger et al. 2010; Ferreira et al. 2012). The Forest Act states that landowners in the Cerrado ecoregion outside of the Legal Amazon region must maintain 20 % of their land as a 'Legal Reserve' set-aside, and native veg-etation must remain along stream banks and steep slopes, among other sites, as 'Permanent Protection Areas' (Brannstrom 2001; Chomitz 2004).

Retaining natural habitats within agricultural areas may help to conserve species diversity and abundance (Ricketts et al. 2001; Marshall et al. 2006), and, in turn, enhance ecosystem services (De Marco and Coelho 2004; Ricketts et al. 2008; Wratten et al. 2012). Although conservation programs are focused in promoting the conservation of large areas with natural vegetation for maintaining biodiversity (Lucey and Hill 2012), even small

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[1] *Código Florestal*, Law n°4771, September 15, 1965, modified by *Medida Provisória*. 2166–67, August 24, 2001

private reserves, as those ensured by the Forest Act, may be an important species source for biodiversity conservation at local and regional scales. Although the effectiveness of natural habitats to maintain species diversity in agricultural areas has been demonstrated in some cases (e.g., Abensperg-Traun et al. 1996; Perfecto et al. 1997; Dunn 2000; Dauber et al. 2006; Teodoro et al. 2011) more data are required for assessing the generality of these findings (Lucey and Hill 2012). Furthermore, in intensively managed agricultural landscapes it is necessary to consider practical alternatives that reduce the impact generated by intensive agriculture, such as the implementation of a mosaic of land use types in homogeneous crop areas (Morandin et al. 2007) and/or organic farming (Bengtsson et al. 2005).

Agriculture intensification can affect terrestrial invertebrate communities, and thus the role that species play in ecosystem functioning (Postma-Blaauw et al. 2010). Among the ground-dwelling entomofauna, some organisms, like ants, are recognized as ecosystem engineers, playing essential ecological roles (Risch and Carrol 1982a, b; Folgarait 1998). In addition, because they are responsive to changing environmental conditions and relatively easy to sample and identify, they have been frequently used for conservation assessment purposes, to monitor environmental impact, ecosystem management, and the recovery of ecosystems (Majer 1983; Folgarait 1998; Andersen and Majer 2004).

The aims of this study were (a) to compare the species richness and composition of ground-dwelling ants between crop fields and adjacent savanna reserves, (b) determine the species most typical of each habitat (if any), (c) evaluate some of the characteristics of the species inhabiting the crop fields, and (d) estimate the number of species "secured" in the local agricultural landscape by the presence of reserves. Our general intent was to assess the efficiency with which private reserves actually preserve the native Cerrado ant fauna in a context of intensive agriculture.

Methods

Study site

The study was carried out in six different farms (see Appendix S1 in Supporting Information) located in the surroundings of Uberlândia (18° 56′, 48° 18′W) and Monte Alegre de Minas (18° 52′ S, 48° 52′W), in the western region of Minas Gerais state, Brazil, during the 2008 and 2009 wet seasons. This region is characterized by a dry winter (May–September) and a rainy summer (October–April), with the mean annual temperature and precipitation being around 22 °C and 1,650 mm, respectively. The soil geology is characterized by red latosols, and the original, natural vegetation is composed of typical Cerrado savannas and forests (Oliveira-Filho and Ratter 2002).

Sampling design

Within each farm we performed a thorough inventory of the ground-dwelling ant faunas present in the legal reserve and in the adjacent crop field (see Appendix S2 in Supporting Information). The farms we studied were randomly selected and, therefore, are likely to be representative of the farming/management conditions typical of our study area. All farms were devoted to the production of grains. However, the exact type of crop planted at the time of our study was somewhat variable as at that time: four farms were growing soy, one was growing maize, and one was growing sorghum (see Appendix S1 in Supporting Information). Nevertheless, it is important to notice that in all farms these three annual

crops are often planted in a rotational scheme (i.e., different crops are planted in different years). All farms had their legal reserves (as required by the Forest Act), but the exact size and the type of vegetation present in each reserve was variable (see Appendix S1 in Supporting Information), and such variation is likely to reflect the size and history of each farm as well as their original vegetation cover. Reserve size varied from 39 to 149 ha, and their vegetation was either open savanna (i.e., a savanna with scattered trees and a grassy understory, locally known as *cerrado ralo*) or closed woodland savanna (i.e., a savanna dominated by trees (>50 % of crown cover) and almost no grasses, locally known as *cerrado denso*) (see Appendix S2 in Supporting Information).

The ants were collected using both conventional and subterranean pitfall traps in order to collect species that forage on the soil surface (i.e., epigaeic species) as well as those that forage belowground (i.e., hypogaeic species) (Pacheco and Vasconcelos 2012b). Conventional traps consisted of 300 ml plastic cups buried so that the opening of the trap was leveled off with the soil surface and were filled to one-third of their volume with a mixture of alcohol (70 %) and glycerin. Subterranean traps consisted of closed 250 ml plastic containers, with four 1 cm and four 0.5 cm holes on their side, buried to a depth of 20 cm (for more technical details, see Pacheco and Vasconcelos (2012b). About 20 ml of a mixture composed of soy and palm oil was spread on the ground surface around each trap to attract more subterranean ant species (Pacheco and Vasconcelos 2012b). All traps (conventional and subterranean) were baited with sardine mixed with vegetable oil and operated in the field for seven consecutive days.

A total of 70 traps (35 of each type) were installed in each reserve (except at site 4, where only 60 traps were installed) and a total of 100 traps were installed in each crop field. Traps were placed in transects, and five of each of the two trap types were alternated along each transect with 20 m spacing. Transects were parallel and spaced 20–80 m apart. Traps that were removed by digging animals (3.3 % of all traps installed) were excluded from our analyses.

Collected specimens were sorted to morphospecies, and named (whenever possible) following Bolton's catalogue for species classification (Bolton et al. 2007). Voucher specimens of all species were deposited at the Zoological Collection of the Federal University of Uberlândia (MG) in Brazil.

Data analyses

To compare the overall number of species collected in the reserves and in the crops, sample-based and individual-based species rarefaction curves were built with EstimateS version 8.2 (Gotelli and Colwell 2001) using the Coleman estimator (Colwell 2006). As both produced qualitatively similar results, only individual-based rarefaction curves are presented here. Paired *t* tests were performed to analyze the within-farm differences between reserves and crops with regard to: (a) observed species richness, (b) rarified species richness (i.e., richness after controlling for differences in the sampling effort), (c) estimated species richness (calculated using both the Jackknife 1 and the ICE species richness-estimators; Colwell, 2006), and (d) the Shannon index of diversity. The assumption of data normality was checked using the Lilliefors test.

The possible influence of reserve size, type of vegetation in the reserve, and type of cultivated crop on the observed differences between reserves and crops was examined graphically. The intent here was simply to evaluate the generality of our findings, rather than performing a formal statistical test of the influence of reserve or crop type on the

difference in ant assemblages between reserves and crops. For this, a much larger number of replicates would be needed.

The hypothesis that community composition changes with habitat type was evaluated using Permutational Multivariate Analysis of Variance (formerly non-parametric Manova) (Anderson 2001). The level of compositional similarity between pairs of sampling sites was estimated with the Bray-Curtis index, which was calculated using data on the relative frequencies of each ant species in each site. To better visualize the differences in ant species composition between crops and reserves a non-metric multidimensional scaling (NMDS) ordination plot was built.

Nestedness analysis (Guimarães and Guimarães 2006) was performed to check if the ant assemblages in crops represented a subset of the reserve ant community. The analysis was based on a presence and absence matrix with all species (in decreasing order of frequency) in columns and the 12 sampling sites in rows (both reserves and crops). The degree of nestedness was calculated using the NODF value, which allows calculating the nestedness among columns (species) and rows (sites) separately. The degree of nestedness and its statistical significance were determined using the program Aninhado 3.0 (Guimarães and Guimarães 2006). The observed values were compared to the restrictive *Ce* null model, in which the probability of the observed level of structure (i.e., nestedness) can be explained by a derived probability of cell occupancy (Almeida-Neto et al. 2008).

The Indicator Value (IndVal) method of Dufrene and Legendre (1997) was used to determine which species were most strongly associated with reserves or crops. The indicator value, which ranges from zero (no indication) to 100 % (perfect indication), was calculated for all species using data on species' relative densities (total number of species records divided by the total number of traps) in each reserve or crop. The significance of the maximum indicator values for each species was evaluated using Monte Carlo randomization tests (499 iterations).

IndVal was also used to assess the main habitat association (open savanna or closed woodland savanna) of the species collected in the reserves. The indicator value was calculated for all species present in at least one reserve using data on species' relative densities (total number of species records divided by the total number of traps) in each reserve. We classified a given species as associated primarily to a given habitat (open or closed savanna) if it received an indicator value ≥50 % for that habitat and if the difference between this value and the indicator value received by this same species in the other habitat was greater than 25 %. In this way *Camponotus crassus*, for instance, was classified as an open savanna species because it received an indicator value of 88 for the open savanna and of only 6 for the closed woodland savanna. In contrast, *Camponotus rufipes* was classified as a closed savanna species because it received an indicator value of 63 for the closed savanna and of 18 for the open savanna. Species not fitting these criteria were classed as habitat generalists, such as *Odontomachus bauri* which had indicators values of 31 and 29 for the open and closed savannas respectively.

We used randomized-blocked Anova to test for differences in the number of habitat generalist species, of open savanna species, and of closed savanna species within crops. Farm was treated as a blocking factor. Data on species richness within each habitat category was log transformed prior to the analysis. The assumptions of this analysis were checked through visual examination of the residual plot.

Results

In total we found 200 ant species from 48 genera in the reserves and 101 species from 29 genera in the crops (Fig. 1a) (the complete species list is available from the authors upon request). Of the species collected in the reserves, 158 were caught exclusively in pitfall traps, eight were caught exclusively in subterranean traps, and 34 species were collected in both. In the crops the proportion of species found exclusively above ground was comparatively smaller (64 species were found exclusively above ground, five exclusively below ground and 32 species in both strata). Consequently, differences in overall ant species richness between reserves and crops were much greater above ground than below ground (Fig. 1b, c).

Reserves also supported a greater diversity of ant species at a per farm basis. This difference was significant in comparisons involving the observed species richness (paired *t* test, t = 6.2, df = 5, *P* = 0.002), the estimated species richness (ICE, t = 6.7, df = 5, *P* = 0.001; Jacknife 1, t = 7.7, df = 5, *P* = 0.001), the Shannon diversity index (t = 5.9, df = 5, *P* = 0.002), and the rarified species richness (t = 7.4, df = 5, *P* = 0.001) (see Appendix S3 in Supporting Information). That reserves sustained much more species than crops was true in all six farms studied. In addition, in all these farms, a large proportion of the species recorded were exclusively found in the reserves. Consequently, the number of species "secured" by these reserves within the local landscape was high varying from 29 to 68 species, which represents from 41.4 to 76.4 % of all species found within a given farm (see Appendix S3 in Supporting Information). Visual examination of the data suggests that the proportion of species exclusively found in the reserves was independent of reserve size but that reserves of closed, woodland savanna tended to present more exclusive species than those of open savanna (Fig. 2).

This latter pattern was further confirmed by our ordination analysis. There were strong and significant differences in ant species composition between crops and reserves (Permutational Manova, $F_{1,10}$ = 3.33, *P* = 0.005), but these differences were greater for reserves of closed than for those of open savannas (Fig. 3). This is likely to reflect the fact that crops presented proportionally more species typical of open savannas than species of closed woodland savannas or habitat generalist species (Randomized-Blocked ANOVA, $F_{2,10}$ = 12.30, *P* = 0.002; Fig. 4).

Differences in species composition between reserves and crops were relatively strong not only because the reserves had more species, but also because the species that were present in both habitats showed contrasting patterns of occurrence in each habitat (Fig. 5). In total, 111 of the 200 species collected in the reserves (55.5 %) were found exclusively in this habitat. In contrast, only 12 of the species collected in the crops (11.9 %) were exclusively found there, and most of these were rare species. Not surprisingly, results of the nestedness analysis (NODF = 59.55, NODF (Ce) = 29.25, *P* < 0.001) indicate that the species present in the areas with less ant species (represented by the crops in almost all cases) consisted of a subset of the species found in the areas with a greater number of species (represented in most cases by the reserves, see Appendix S3 in Supporting Information).

Species exclusively found or strongly associated with the reserves (i.e., indicator species), included several species of *Camponotus*, *Cephalotes*, *Crematogaster*, *Ectatomma* and *Gnamptogenys* (Table 1). Only two species, *Dorymyrmex brunneus* and *Pheidole* sp. 4 (*megacephala* group), were considered as indicators of crops. Although these two species were not exclusively found in the crops, they presented a much greater frequency of occurrence in the crops than in the reserves. In fact *Dorymyrmex brunneus* was present in nearly one-third (29.5 %) of the traps placed in the crops. Other highly frequent species in
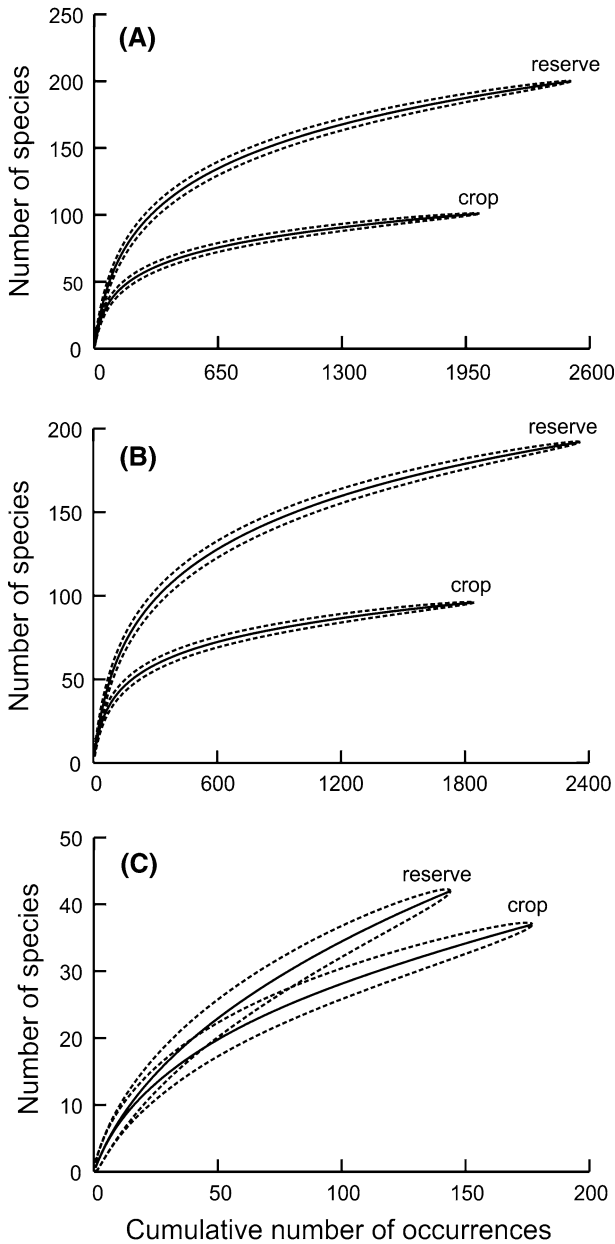
Fig. 1 Individual-based rarefaction curves showing the number of ant species collected in six savanna reserves and in six nearby crop fields in relation to the number of species occurrences. **a** All species, **b** species collected in traps placed on the soil surface, **c** species collected in subterranean traps. *Dotted lines* represent ± SD around mean values. Note the different *scales* in the *x axes*

the crops were *Pheidole oxyops* and *Pheidole* sp.1 (*flavens* group) (Fig. 5). *Solenopsis saevissima* although also very frequent in some sites was not found in two of the six crop fields studied.
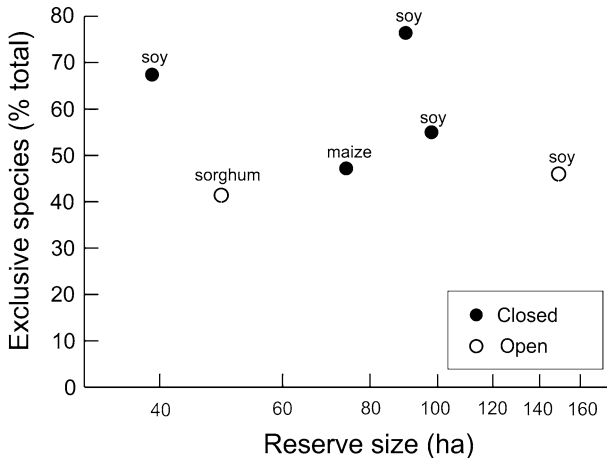
Fig. 2 Percentage of the total number of species found within each study farm that was exclusively recorded in the reserve, for reserves of different size and vegetation cover (*open* savanna or *closed*, woodland savanna). The type of crop planted in each farm is indicated above the symbols
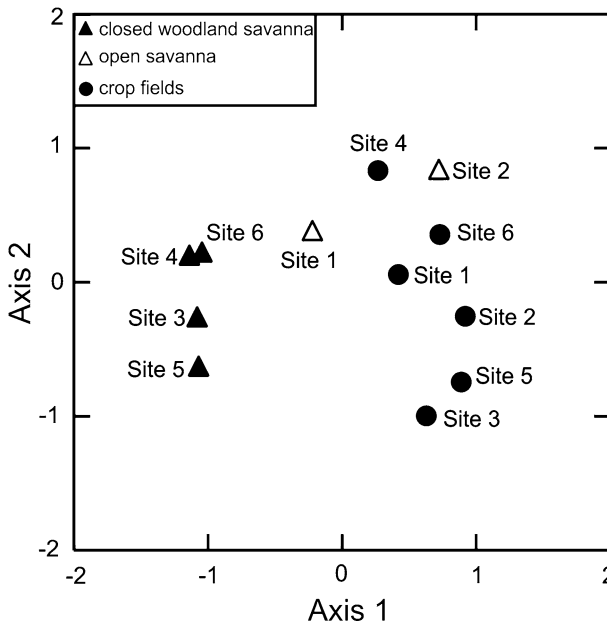

Fig. 3 NMDS ordination (stress = 0.14) *plot* illustrating the differences in ant species composition between savanna reserves and adjacent crop fields. Site numbers correspond to different farms

Discussion

It is commonly acknowledged that the conversion of natural habitats into intensive monocultures will generally lead to a simplification of terrestrial native communities (Ekroos et al. 2010; Almeida et al. 2011; Medan et al. 2011), impacting species richness,

Fig. 4 Number of ant species found in crops that were characteristic of different savanna habitats. *Lines in the box plots* indicate median values; *upper and lower border of box* show 25th and 75th percentiles; whiskers indicated he 10th and 90th percentiles. *Letters above the box plots* indicate significant differences in pairwise comparisons
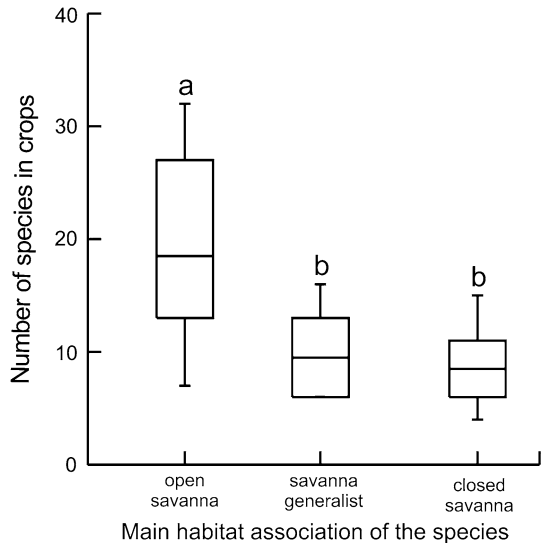
taxonomic composition and even functional structure (Schmidt and Diehl 2008; Sharley et al. 2008; Barragán et al. 2011). Examples of such effects have been reported for ecosystems ranging from grasslands to forests, and for a wide variety of taxonomic groups, including invertebrates, vertebrates and plants. For instance, a recent review of the effects of agricultural intensification in coffee landscapes in Latin America indicate that a large number of forest ants, birds, and tree species disappear when native forest is replaced by coffee plantations of high management intensity (Philpott et al. 2008). In Brazil, replacement of native grasslands by pastures planted with exotic grasses resulted in species losses, increased dominance, and significant changes in the composition of dung-beetle assemblages (Almeida et al. 2011). Similarly, in Finland, alpha and beta diversity of butterflies and moths was found to decrease as agricultural intensity increased (Ekroos et al. 2010).

Conversion of forest into plantations is generally detrimental for ant diversity (Perfecto et al. 1997; Armbrecht et al. 2005). Similarly, here, we have showed that the natural savanna vegetation of the Cerrado support more ant species than the crops, both globally and at each sampled farm. The fact that our results were consistent among the different studied farms, in spite of the differences in reserve size, vegetation type, and cultivated crop among these farms suggest that the observed species losses is a general phenomenon in our study region. Furthermore, it is important to note that the magnitude of species loss due to conversion of Cerrado natural habitats into crops was probably underestimated in our study given the close proximity between crops and reserves sampled within each farm.

Our results indicate that crops negatively impact the diversity of ants foraging above and below ground. However, the magnitude of this effect was much smaller for the species that forage below ground and this may be because, as also seen in some forest ecosystems (Berman and Andersen 2012), in the Cerrado relatively few ant species have cryptobiotic morphology and strictly subterranean habits (i.e., are truly hypogaeic species) (Pacheco and Vasconcelos 2012b). Nevertheless, overall, notable changes in the composition of ground-dwelling ant assemblages were observed. Indeed, the ant communities in the crops (regardless of the crop type) were largely composed of a subset of species occurring in the
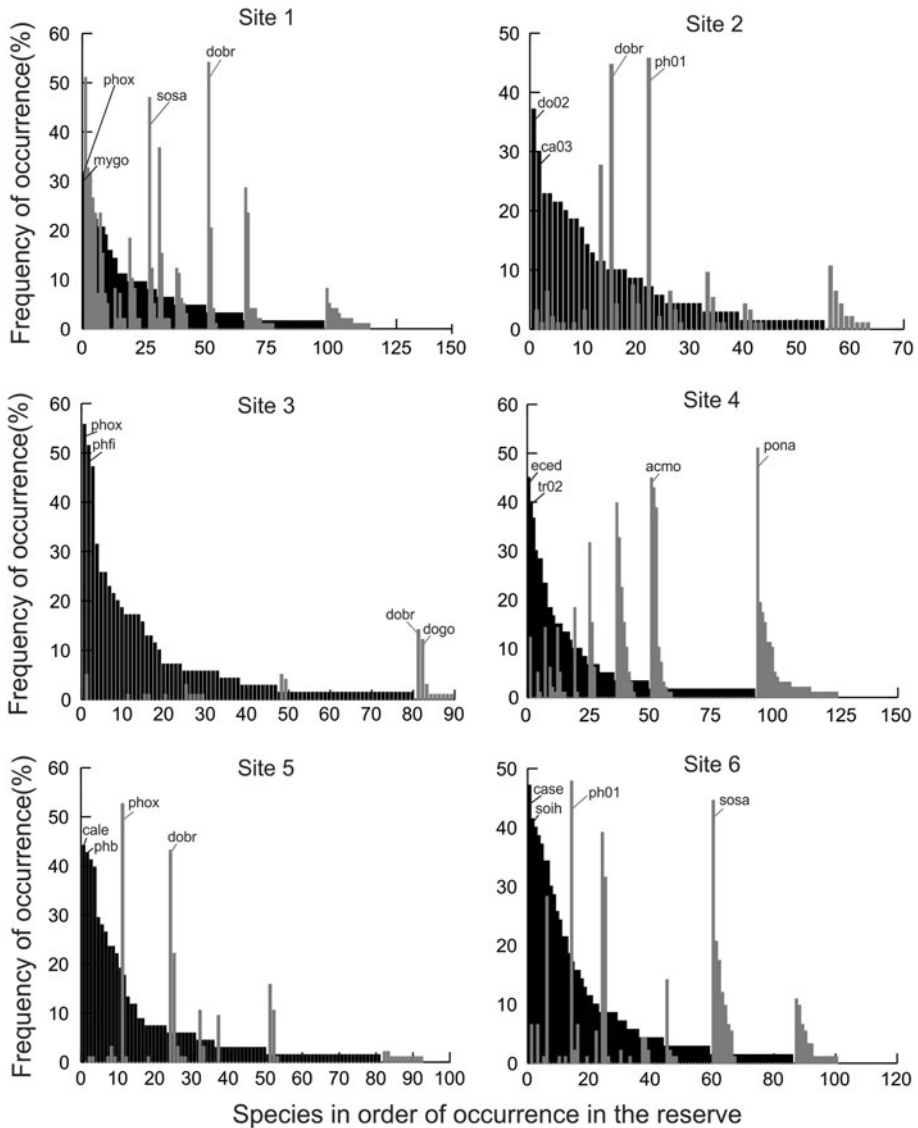
Fig. 5 Diversity-occurrence plots of the ant species collected at six different sites. Frequency of occurrence represents the percentage of traps in which the species was recorded. Each bar represents a different species, and bars with different colors represent the two habitats sampled: savanna reserves (*black bars*) or crop fields (*grey bars*). The names of the two most frequent species in each habitat are indicated: phox *Pheidole oxyops*, dobr *Dorymyrmex brunneus*, sosa *Solenopsis saevissima*, do02 *Dorymyrmex pyramicus* sp.2, ph01 *Pheidole* sp. 1 (flavens group), dogo *Dorymyrmex goeldii*, mygo *Mycocepurus goeldii*, ca03 *Camponotus* sp.3, eced *Ectatomma edentatum*, pona *Pogonomyrmex naegeli*, acmo *Acromyrmex* cf. *subterraneus molestans*, cale *Camponotus lespesii*, phb *Pheidole* sp.B (*diligens* group), case *Camponotus sericeiventris*, soih *Solenopsis iheringi*

reserves. Similarity in ant species richness and composition was generally greater among the different reserves (even though some of these reserves were more than 50 km apart from each other) than between a given reserve and the crop located just a few meters away.

Table 1 List of the indicator ant species (i.e., species with a strong association with the reserves or crops) and their respective indicator values

Species	Indicator value (%)	Habitat		P
		Reserve	Crop field	
Ectatomma edentatum	86.3	**0.20/100**	0.03/33	0.02
Camponotus lespesii	83.3	**0.19/83**	0/0	0.02
Crematogaster nitidiceps	83.3	**0.05/83**	0/0	0.02
Gnamptogenys regularis	83.3	**0.03/83**	0/0	0.02
Pachycondyla harpax	83.3	**0.05/83**	0/0	0.02
Nylanderia sp. 1	83.3	**0.08/83**	0/0	0.02
Camponotus sp. 40	82.1	**0.11/83**	0.002/17	0.02
Camponotus rufipes	81.6	**0.08/83**	0.002/17	0.02
Camponotus atriceps	81.4	**0.07/83**	0.002/17	0.02
Pheidole fracticeps	80.7	**0.22/83**	0.007/67	0.05
Camponotus (*Myrmothrix*) cf. *cingulatus*	80.3	**0.10/83**	0.004/17	0.05
Carebara brevipilosa	79.0	**0.06/83**	0.003/33	0.02
Brachymyrmex sp. 2	78.7	**0.16/100**	0.04/83	0.02
Pachycondyla verenae	74.9	**0.11/83**	0.01/17	0.03
Azteca sp. 1	66.7	0.01/67	0/0	0.06
Cephalotes pusillus	66.7	0.05/67	0/0	0.06
Ectatomma lugens	66.7	0.17/67	0/0	0.06
Ectatomma permagnum	66.7	0.05/67	0/0	0.06
Odontomachus chelifer	66.7	0.06/67	0/0	0.06
Pheidole sp.nr. *variegata*	66.7	0.04/67	0/0	0.06
Trachymyrmex sp. 2	66.7	0.14/67	0/0	0.06
Camponotus sp. 11	66.7	0.02/67	0/0	0.06
Camponotus sp. 13	66.7	0.02/67	0/0	0.06
Pachycondyla sp. 6 (*crassinoda* complex)	66.7	0.05/67	0/0	0.06
Pachycondyla inversa	66.7	0.03/67	0/0	0.06
Pheidole sp. 28 (*punctatissima* group)	66.7	0.09/67	0/0	0.06
Pheidole sp. 34 (*fallax* group)	66.7	0.04/67	0/0	0.06
Wasmannia auropunctata	64.1	0.04/67	0.002/17	0.06
Camponotus melanoticus	63.7	0.04/67	0.002/17	0.06
Pheidole sp. 4	96.2	0.002/17	**0.06/100**	0.003
Dorymyrmex brunneus	89.8	0.03/67	**0.30/100**	0.003

Numbers in the habitat columns represent, respectively, the mean relative density and the proportion of sites in which the species was found. Values in bold indicate the habitat to which the species is significantly associated. *P* values show the significance of the indicator values

This strongly suggests that differences in the habitat structure between reserves and crops have a much more important effect on structuring the ant communities than distance among sampling sites.

Agricultural intensification and particularly the extensive management in crops (including tillage operations, use of pesticides, fertilizer inputs, permanent land arability, and simplification of habitat structure through vegetation loss) is one of the main factors explaining the substantial loss of native species—notably the more specialized species (Ekroos et al.

2010)—once natural areas of vegetation are replaced by extensive crop fields (Benton et al. 2003; Lange et al. 2008; Sharley et al. 2008). For ants, nest site limitation—caused by a lack of leaf-litter, decaying logs, or live trees (Philpott and Foster 2005; Armbrecht et al. 2006; Klimes et al. 2012)—is one of the most important factors limiting the development of a diverse fauna in intensely managed crop fields (Armbrecht et al. 2005). Furthermore, negative interspecific interactions with dominant ants may further limit the number of coexisting species in crops. In fact, all crop fields we sampled were dominated by generalist species, such as *Dorymyrmex*, *Pheidole* and *Solenopsis* sp., which often have superior competitive abilities against other ant species (Holldobler and Wilson 1990; Andersen 2000).

Our results also indicate that the magnitude of native species losses due to conversion of Cerrado natural habitats is variable depending on the type of habitat the species was originally associated with. This appears to be a general pattern among ants, as similar results have been found in other regions of the world including, for instance, the Argentine Chaco (Bestelmeyer and Wiens 1996) and many parts of Australia (Hoffmann et al. 2000; Hoffmann 2003; Hoffmann and Andersen 2003). Here, and in accordance with previous reports (Ribas et al. 2003; Pacheco and Vasconcelos 2012a), we have showed that many Cerrado ant species are associated either with open or with closed savanna habitats. Furthermore, the species associated with closed savannas were significantly less frequent in the crops than those associated with open savannas. These differences probably reflect the inherent differences in the ecology of species inhabiting open or closed savannas, i.e. whether they are adapted or not to the microclimatic conditions and the resources available in the crops, and so their ability to adapt, maintain and survive in a disturbed habitat (Hoffmann and Andersen 2003; Alonso 2010; Dahms et al. 2010). In Australia, for instance, cryptic species and specialist predators have highly specialized requirements and this make them especially sensitive to disturbance (Hoffmann and Andersen 2003). Similarly, here, many of the species associated with closed woodland savannas, such as several arboreal and several poneromorph species, have more specialized nesting site requirements and therefore appear vulnerable if not threatened by the current land use changes in the Cerrado. On the other hand, the relative success of many *Solenopsis* and *Dorymyrmex* species in the crop fields we studied may be explained by the fact that these species are well adapted to open habitats (Wetterer 2011; Cuezzo and Guerrero 2012).

Conclusions

To our knowledge, this study is the first showing how it is important to maintain private reserves of native Cerrado vegetation within agricultural landscapes for ant species conservation. Our results highlighted that even small fragments of natural vegetation (e.g. the closed savanna fragment with only 39 ha of area; see Appendix S1 in Supporting Information) have a significant potential to maintain a higher diversity of ants within an agriculturally dominated landscape. In this sense, the proposed changes in the current legislation, which will lead to a decrease in the amount of protected areas within private lands and/or in diminished levels of protection (Martinelli et al. 2010; Metzger et al. 2010), are likely to drastically reduce the local diversity of ants given that, as shown here, the species exclusively found in the reserves represent 41–76 % of all species found within a given property. According to Altieri (1999) there are two main strategies to increase biodiversity within an agrosystem: (1) to reduce the extent of the isolation of the agricultural area from natural vegetation, and (2) to maintain and increase the diversity of vegetation within and around the agricultural land. In our view and considering our focal

organisms (ants), the presence of private reserves within agricultural lands is of great help for both of these strategies.

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