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ORIGINAL PAPER

Effects of abandoned *Eucalyptus* plantations on lizard communities in the Brazilian Cerrado

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Abstract The rapid expansion of human altered landscapes affects biodiversity on every continent. A fundamental goal of conservation biologists is to understand why certain species are at risk of extinction while others are able to persist in human altered landscapes. Afforestation, the conversion of unforested lands to planted forest, is rapidly altering many natural landscapes worldwide. In the Cerrado (Brazilian savanna), a global biodiversity hotspot, a shortage of government incentives has the landscape riddled with abandoned plantation forests that are not subject to active restoration projects. Studies investigating the impacts of abandoned plantations on biodiversity are strikingly limited. We examine the effects of abandoned *Eucalyptus* plantations on the structure of Cerrado lizard communities. We assessed changes in lizard capture, richness and equitability along cerrado *sensu stricto—Eucalyptus* transects. Our results indicate abandoned *Eucalyptus* plantations have subsets of Cerrado species persisting with a great loss of endemic species. The cerrado *sensu stricto—Eucalyptus* linear transect analysis demonstrated distance from native habitat is positively correlated with loss of biodiversity. We performed correspondence analyses to summarize the variation in species captures across different sites, habitats and pitfall array positions. These analyses depicted strong species associations between habitats and their pitfall array positions. This study is the first to show the negative impacts of abandoned *Eucalyptus* plantations on Cerrado lizard communities, serving as a cautionary tale of Cerrado biodiversity non-resilience in abandoned *Eucalyptus* plantations. Mitigation requires that abandoned *Eucalyptus* plantations are made more suitable to Cerrado lizards by implementing targeted habitat heterogeneity restoration.

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Introduction

Conservation biologists are striving to mitigate the loss of biodiversity in rapidly expanding human altered landscapes. Approximately two thirds of the world's land surface is directly affected by anthropogenic habitat disturbance (Millennium Ecosystem Assessment 2005). Planted forests that involves destruction or modification of natural vegetation are a growing form of anthropogenic habitat disturbance adopted by many countries for socioeconomic reasons (Brockerhoff et al. 2008). Planted forests on land not previously classified as forest is termed afforestation. Afforestation alters every continent except Antarctica, with a global average increase of 5.6 million hectares per year (Food and Agriculture Organization 2010).

Brazil is among the ten countries reported with the greatest annual increase in planted forest area (Food and Agriculture Organization 2010). Brazil alone has more than four times the area of planted eucalypts of Australia, contributing to the human altered landscape within Brazil (Brockerhoff et al. 2013). Introduced from Australia, *Eucalyptus* spp. was first planted in Brazil in 1904. The Brazilian Forestry Code, to fuel growth in the Brazilian forest sector, enabled development of fiscal incentives establishing human-made forests. In 1966, the federal government passed a law allowing individuals and companies to use 50 % of their income tax payment for reforestation (Suchek 1991). Planted forest soared from 470 thousand (before the incentives) to 6.2 million ha. Brazil became the world's leader in *Eucalyptus* plantation providing wood for pulp and paper production (Soresini 1993). In 1988, the fiscal incentives for reforestation were finally discontinued by law, following criticism from individuals and organizations concerned with possible detrimental effects the plantations might have on the environment and on the social welfare of rural communities (Couto and Betters 1995).

In 2010, *Eucalyptus* spp. and *Pinus* spp. covered approximately 6.5 million ha of which 73 % consisted of *Eucalyptus* (Associação Brasileira de Produtores de Florestas Plantadas 2011). Although some of these plantations are still profitable, many were abandoned in the 1990s due to discontinuation of governmental economic incentives (Knadler and Sinimbu 2011). Today, a debate exists whether or not it is economically feasible to restore the large tracts of Cerrado that were altered into plantation forests. In periods of economic distress, it is reasonable to presume that many abandoned plantations will not be completely restored (Knadler and Sinimbu 2011). The impacts of abandoned plantations on biodiversity are virtually unknown. To our knowledge, this is the first study on the effects of abandoned *Eucalyptus* plantations on Cerrado lizard communities.

Cerrado lizards are an excellent group to study the effects of abandoned *Eucalyptus* plantations. Lizards play important roles, both as predators and prey, in structuring ecological communities (Dial and Roughgarden 1995; Schoener and Spiller 1996; Kanowski et al. 2006). The response of lizards to plantations is expected to differ from other terrestrial vertebrates, due to their relatively small size, limited mobility and lower energy and water requirements (Heatwole and Taylor 1987; Nagy et al. 1999). Particular habitat structures provide lizards with escape from predation (Milne and Bull 2000; Amo et al. 2007) as well as sunny places to bask, adhering to their specific ectothermic requirements

(Dıaz et al. 2000; Martın and Lopez 2002; Sabo 2003). Their survival is strongly dependent on specific microhabitat associations, increasing their susceptibility to anthropogenic habitat disturbances.

The Cerrado comprises a mosaic of vegetation physiognomies including woodlands, savannas, grasslands, gallery and dry forests (Ribeiro et al. 1981). It is the second largest biome in South America and is recognized as a biodiversity hotspot (Myers et al. 2000). This biome harbors a rich and endemic biota and suffers large-scale anthropogenic disturbance (Oliveira and Marquis 2002). Squamate populations and communities are relatively well studied in the Cerrado (Colli et al. 2002; Nogueira et al. 2009). Of the reported 267 Cerrado squamates, 42 % of the lizards are endemic (Nogueira et al. 2011). Researchers hypothesize there should be no natural Cerrado areas left by 2030 if the current rate of disturbance is not reversed (Machado et al. 2004b). Less than 3 % of the Cerrado is protected in natural reserves (Machado et al. 2004a; Rylands et al. 2007). Therefore, the role of biodiversity conservation in plantation management is an important priority (e.g., Hartley 2002; McDonald and Lane 2002; Lindenmayer and Hobbs 2004; Scott et al. 2006; Australian Forestry Standard 2007).

To date, the effects of *Eucalyptus* plantations on Cerrado biodiversity mainly focuses on birds, mammals and invertebrates. Some Cerrado species in *Eucalyptus* plantations are positively affected. The Turquoise-fronted parrot (*Amazona aestiva*) and Yellow-faced parrot (*Salvatoria xanthops*) persist in *Eucalyptus* plantations. These species benefit from roosting sites that provide night shelters and perching sites, decreasing competition among parrots (Carrara et al. 2007). Most ant species found in a native Cerrado vegetation also occur in *Eucalyptus* plantations, suggesting that ant regional richness does not depend on habitat complexity (Marinho et al. 2002). Furthermore, two of ten documented carnivore mammals (Canidae: *Cerdocyon thous*; Mustelidae: *Eira barbara)*, are more frequent in the *Eucalyptus* plantation compared to the Cerrado, demonstrating the ability of certain animals to adapt to human altered landscapes (Lyra-Jorge et al. 2008).

However, negative effects of *Eucalyptus* plantations are documented for butterfly, beetle, termite, bird and mammal Cerrado communities, with most species extirpated in *Eucalyptus* plantations while species able to persist occur at extremely low abundances (Zanuncio et al. 1998; Piratelli and Blake 2006; Calderon and Constantino 2007; Lyra-Jorge et al. 2008; Gries et al. 2012). Ecological consequences of plantations vary considerably depending on the type, magnitude, and intensity of disturbance on different taxa, since species interact differently with disturbed environments (Daily 2001; Hartley 2002; Koh et al. 2004; Lindenmayer and Hobbs 2004). This variation emphasizes the necessity to expand the research on the effects of plantations to a wider range of biomes and taxa (Barlow et al. 2007; Gardner et al. 2008; Hawes et al. 2009).

The objective of this study is to assess whether native Cerrado lizard species are able to establish themselves in abandoned *Eucalyptus* plantations, aiming to answer the following questions: Are there differences in lizard community diversity between cerrado and abandoned *Eucalyptus* habitats? Is there an effect of distance on community diversity along the cerrado s.s.—*Eucalyptus* linear transects? Are there modifications between species associations across different sites and habitats? Do modifications between species associations occur along the cerrado s.s.—*Eucalyptus* linear transects? Finally, we discuss the implications of results towards management strategies to enhance Cerrado lizard conservation in abandoned *Eucalyptus* plantations.

Materials and methods

Study sites

We conducted the study in Brasília, Distrito Federal, Brazil, a planned city in the core region of the Cerrado. Brasília was constructed in 1960 and has experienced anthropogenic habitat disturbance due to a rapidly growing population. We sampled lizards in two habitats: cerrado sensu stricto (s.s.) and abandoned plantations of *Eucalyptus grandis* within three reserves: Fazenda Água Limpa (FAL: 15°55′ S, 47° 55′ W), Floresta Nacional de Brasília (FLONA: 15°45′ S, 48°4′ W) and Parque Nacional de Brasília (PNB: 15°35′ S, 47°53′ W). The reserves range from 10 to 25 km apart from each other (Fig. 1). The cerrado s.s. is the predominant physiognomy in the Cerrado biome, consisting of a semi-open vegetation with grasses, scattered shrubs and palms of up to 1 m with twisted, stunted trees. The abandoned *Eucalyptus* plantations consist of a closed vegetation with leaf litter and tall, straight trees with a minimum height of 8 m. These abandoned *Eucalyptus* plantations are found within the reserves, remnants of land converted prior to the establishment of the reserves. The *Eucalyptus* plantations are the cause of clearance of the pristine cerrado s.s. (Cruls 1894; United Nations Educational Scientific and Cultural Organization 2002; Senra 2010). These plantations were abandonded in 1999 in the FAL, 1987 in the FLONA and 1961 in the PNB (Instituto Brasileiro de Desenvolvimento Florestal/Fundação Brasileira para Conservação da Natureza 1979; Silva et al. 2004; Gonçalves 2007).

Experimental design

We set up three U-shaped transects along the cerrado s.s.—*Eucalyptus* habitats, one in each reserve. The transition between the two habitats is abrupt, with a ~5 m wide dirt road separating them. Each U-shaped transect contained a total of 30 pitfall trap arrays ca 50 m apart from each other, with 15 pitfall arrays in each habitat. Twenty pitfall arrays (10 in each habitat) formed a continuous linear transect of 1 km from cerrado s.s. to abandoned *Eucalyptus* plantations. At each extremity of the linear transect, 5 pitfall arrays were extended perpendicularly forming the U-shape (Fig. 2). Each pitfall array consisted of four 35 l plastic buckets, buried in the ground and arranged in a "Y" configuration, with three buckets at the extremities connected to a central bucket by 6 m long plastic drift fences. The U-shaped transects were designed to test differences along a continuous linear transects while at the same time testing for differences between habitats. We added more pitfalls at the extremities of the transects in each habitat to increase the probability of capture.

Data acquisition

Every day we alternately checked one of the three transects for captured lizards consecutively from March to November 2009. This resulted in a sampling effort of 120 buckets for 30 pitfall trap arrays during 248 days, or 29,760 trap-days. We individually marked lizards by toe clipping and released them at the capture site, recording number of captures of each species for each transect.

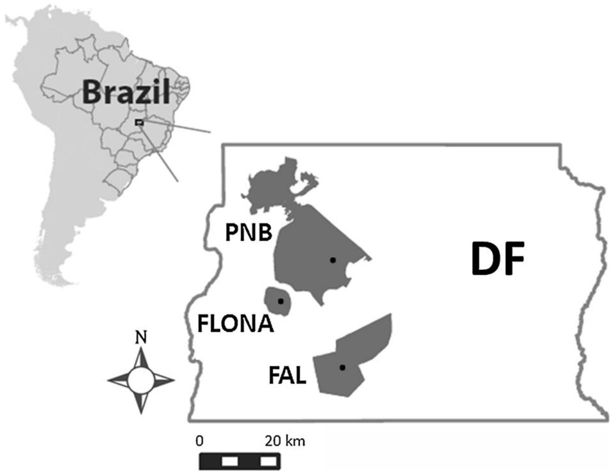

Fig. 1 Location of the study sites in Brasília, Distrito Federal, Brazil Brasília. *Circles* indicate location of transects within the three reserves. *FAL* Fazenda Água Limpa, *FLONA* Floresta Nacional de Brasília, *PNB* Parque Nacional de Brasília

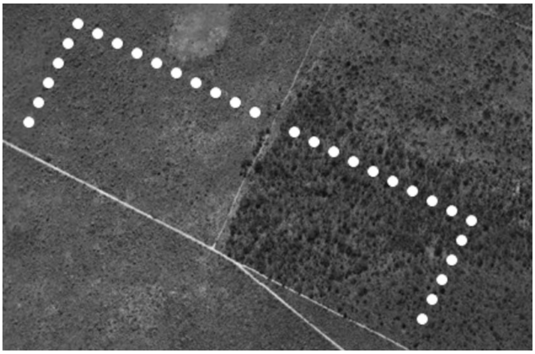

Fig. 2 Image of Parque Nacional de Brasília with *white circles* representing pitfall arrays. The cerrado s.s. is to the *left* and the abandoned *Eucalyptus* is to the *right*. Each *array* is separated from each other by a distance of 50 m

Statistical analyses

Diversity variation between habitats and along the linear transects

We performed statistical analyses on lizard captures, richness and equitability (measured as Hurlbert's Probability of Interspecific Encounter (PIE). Hurlbert's PIE is the probability that two randomly sampled individuals from the community represent two different species, ranging from 0 to 1, where 0 represents low and 1 represents high equitability (Hurlbert 1971). We compared richness and equitability with rarefaction, based on 10,000 randomizations, using EcoSim v7.0 (Gotelli and Entsminger 2004). When comparing two communities with different captures (e.g., *A* with more captures and *B* with less captures), rarefaction determines the expected number of species to be found in "rarefied" samples of community *B*, randomly drawn from community *A*. We derived the expectation and variance of species richness based on 1,000 randomized samples using the following options of EcoSim: independent sampling, species richness index and capture level used in sampling equal to the community with the least captures. In addition, we assessed changes in captures, richness, and equitability along the cerrado s.s.—*Eucalyptus* linear transects with Spearman's rank correlation. We correlated the total captures, richness and equitability with pitfall array position along the linear transect. We only used the 1 km linear portion of the transect. We carried out correlation analyses using R version 2.14.0 (R Development Core Team 2011).

Species associations between sites, habitats and pitfall array positions

We performed a correspondence analysis (CA) to summarize the variation in species captures across different sites (FAL, FLONA and PNB), habitats (cerrado s.s. vs. *Eucalyptus*) and pitfall arrays (within sites). To explain the CA ordination in terms of the linear transect, we used vector and surface fitting of pitfall array positions (as above). Vector fitting consists of finding directions in the CA ordination space towards which environmental vectors (pitfall array position) change most rapidly and to which they have maximal correlations with the CA ordination configuration (Oksanen et al. 2011).We assessed the significance of vector fitting with 999 Monte Carlo permutations. Surface fitting used thin plate splines under a generalized additive model (GAM) with Gaussian errors. We performed the correspondence analysis, vector and surface fitting using package *vegan* (Oksanen et al. 2011) under R version 2.14.0 (R Development Core Team 2011).

Results

We captured 1,102 lizards, representing seven families and 17 species (Table 1, Fig. 3). This corresponds to roughly 22 % of the lizard species known in the Cerrado biome (Nogueira et al. 2011) and 65 % of the lizard species known in Distrito Federal (G.R.C., unpublished data). Eight of these species are endemic to the Cerrado (47 %). The mean recapture rate for each individual was 0.15 ± 0.36. The dominant species were, in order of total captures, *Cercosaura ocellata*, *Micrablepharus atticolus*, *Mabuya frenata*, *Tropidurus itambere* and *Anolis meridionalis* (Table 1).

Diversity variation between habitats and along the linear transects

Pooled lizard capture was higher in cerrado s.s. than in abandoned *Eucalyptus* plantations (Table 1; $\chi^2_1 = 192.85$; $P < 0.001$). Five species (29 % of the total), *Anolis brasiliensis*, *Bachia bresslaui*, *Ophiodes* sp., *Polychrus acutirostris* and *Tupinambis duseni*, were never captured in abandoned *Eucalyptus* plantations (Table 1; Fig. 3). Rarefaction analyses indicated that both species richness (cerrado s.s.: 17, *Eucalyptus:* 12, $P < 0.001$) and equitability (cerrado s.s.: 0.92; *Eucalyptus:* 0.77; $P < 0.001$) were greater in cerrado s.s. Correlation analyses indicated a significant decrease in species capture and richness along the cerrado s.s.—*Eucalyptus* linear transect in all three sites. However, lizard equitability decreased along the linear transect only in PNB (Table 2; Fig. 4).

Species associations between sites, habitats and pitfall array positions

The first two axes of the CA on the pooled captures per site*habitat explained 77.6 % of the total variance in species captures (Fig. 5). Most of the variance in lizard capture along

Table 1 Number of lizards captured in pitfall traps placed in cerrado s.s. (CE) and abandoned *Eucalyptus* plantations (EU) in three reserves, at Brasília, Distrito Federal, Brazil

Taxon	FAL		FLONA		PNB		Total	Total	Grand total
	CE	EU	CE	EU	CE	EU	CE	EU	
Polychrotidae									
Anolis meridionalis[a]	25	1	53	5	21	2	99	8	107
Anolis brasiliensis[a]	6	0	17	0	3	0	26	0	26
Polychrus acutirostris	0	0	5	0	0	0	5	0	5
Leiosauridae									
Enyalius sp.[a]	0	0	5	1	0	0	5	1	6
Tropiduridae									
Tropidurus itambere	61	10	11	34	47	13	119	57	176
Tropidurus torquatus	2	2	1	2	0	2	3	6	9
Anguidae									
Ophiodes sp.[a]	0	0	3	0	0	0	3	0	3
Scincidae									
Mabuya dorsivittata	2	0	75	2	1	1	78	3	81
Mabuya frenata	8	3	1	40	31	93	40	136	176
Mabuya nigropunctata	4	7	0	0	0	0	4	7	11
Teiidae									
Ameiva ameiva	1	1	1	0	6	1	8	2	10
Cnemidophorus ocellifer	0	0	0	0	15	3	15	3	18
Tupinambis duseni[a]	2	0	0	0	2	0	4	0	4
Gymnophthalmidae									
Bachia bresslaui[a]	0	0	0	0	1	0	1	0	1
Cercosaura ocellata	193	17	10	5	35	8	238	30	268
Cercosaura schreibersii	0	0	15	1	0	0	15	1	16
Micrablepharus atticolus[a]	42	51	1	0	76	15	119	66	185
Capture	346	92	198	90	235	138	782	320	1,102
Richness	11	8	13	8	11	9	17	12	17

FAL Fazenda Água Limpa, *FLONA* Floresta Nacional de Brasília, *PNB* Parque Nacional de Brasília

[a] Endemic species (D'Angiolella et al. 2011; Nogueira et al. 2011)

the cerrado s.s.—*Eucalyptus* transect was explained by the first axis (46.5 % of the total variance), whereas differences in lizard captures among sites, primarily between FAL vs. FLONA and PNB, were mainly explained by the second axis (31.1 % of the total variance). *Mabuya frenata* had the lowest score on the first axis, being more frequently captured in abandoned *Eucalyptus* plantations, whereas *Mabuya nigropunctata* had the highest score on the second axis, being more captured in FAL (Fig. 5). The three CAs of lizard capture in each site, along with vector and surface fitting, depicted strong variation in the lizard community along the transects (Fig. 6). In FAL, five species (*Ameiva ameiva*, *M. frenata*, *M. nigropunctata*, *Micrablepharus atticolus* and *Tropidurus torquatus*) were captured in abandoned *Eucalyptus* plantations (Fig. 6); the same happened with three

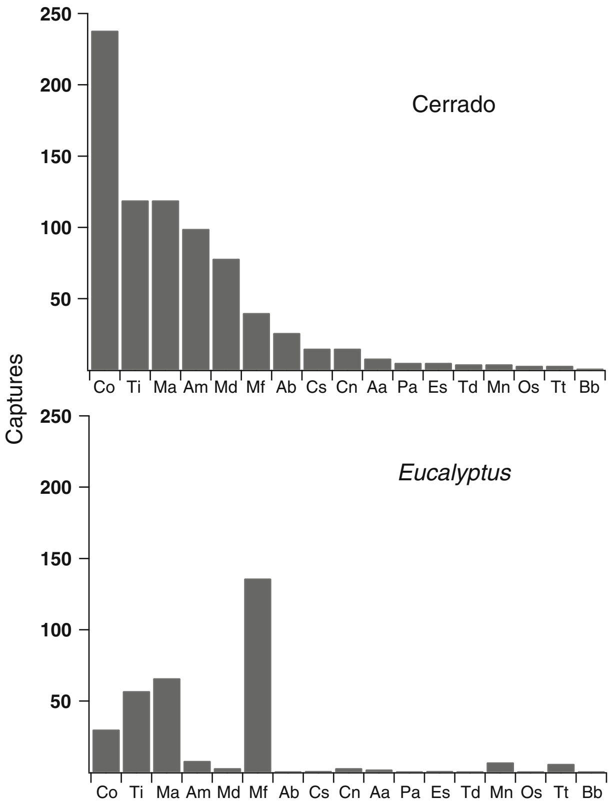

Fig. 3 Lizard capture in cerrado s.s. and abandoned *Eucalyptus* plantations in Brasília, Distrito Federal, Brazil. Aa, *Ameiva ameiva*; Ab, *Anolis brasiliensis*; Am, *Anolis meridionalis*; Bb, *Bachia bresslaui*; Co, *Cercosaura ocellata*; Cs, *Cercosaura schreibersii*; Cn, *Cnemidophorus ocellifer*; Es, *Enyalius* sp.; Md, *Mabuya dorsivittata*; Mf, *Mabuya frenata*; Ma, *Micrablepharus atticolus*; Mn, *Mabuya nigropunctata*; Os, *Ophiodes* sp.; Pa, *Polychrus acutirostris*; Ti, *Tropidurus itambere*; Tt, *Tropidurus torquatus*; Td, *Tupinambis duseni*

Table 2 Spearman's rank correlation between lizard diversity indices and pitfall array position along a cerrado s.s.—*Eucalyptus* transect in three reserves in Brasília, Distrito Federal, Brazil

Study site	r_S	*P*
FAL		
Capture	−0.92	<0.001
Richness	−0.86	<0.001
Equitability	−0.14	0.554
FLONA		
Capture	−0.70	<0.001
Richness	−0.75	<0.001
Equitability	−0.01	0.962
PNB		
Capture	−0.49	0.029
Richness	−0.72	<0.001
Equitability	−0.74	<0.001

FAL Fazenda Água Limpa, *FLONA* Floresta Nacional de Brasília, *PNB* Parque Nacional de Brasília

species (*M. frenata*, *T. itambere* and *T. torquatus*) in FLONA (Fig. 6), and with three species (*M. dorsivittata*, *M. frenata* and *T. torquatus*) in PNB (Fig. 6). In all three cases, the correlation of pitfall array position with the CA configuration was highly significant (FAL: $r^2 = 0.46$, $P = 0.001$; FLONA: $r^2 = 0.79$, $P = 0.001$; PNB: $r^2 = 0.60$, $P = 0.001$).

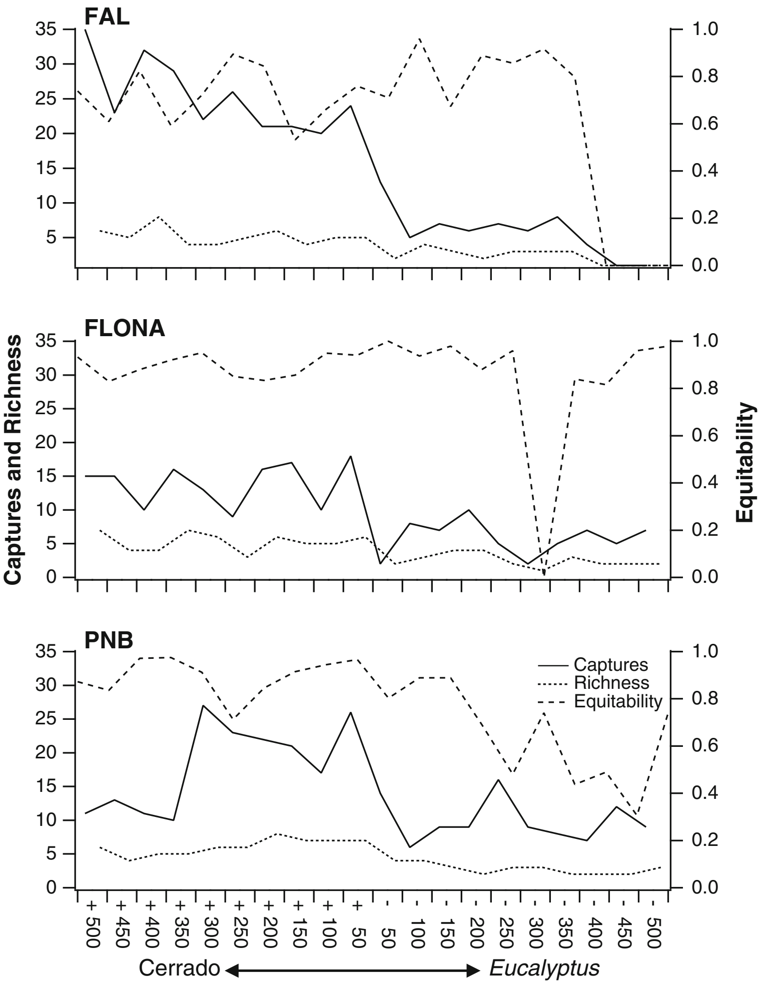

Fig. 4 Lizard capture, richness and probability of interspecific encounter along a linear transect from 500 m into the cerrado s.s. to 500 m into the abandoned *Eucalyptus* plantation habitat for each site. *Numbers* correspond to distance in meters from the abrupt dirt road dividing the habitats between +50 and −50 m

Discussion

Our study demonstrates that Cerrado lizard communities are impacted by a substantial decrease in species richness, endemism, equitability and captures in abandoned *Eucalyptus* plantations. This impact is verified along the cerrado s.s.—*Eucalyptus* linear transects with significant decreases occurring at the abrupt division between the habitats. The majority of Cerrado lizard species, particularly endemic species, are not able to establish themselves in abandoned *Eucalyptus* plantations.

The negative impact of plantations is not uniform across the community; some species thrive. In the Cerrado, researchers documented ant, bird and mammal species prospering in *Eucalyptus* plantations (Marinho et al. 2002; Carrara et al. 2007; Lyra-Jorge et al. 2008).

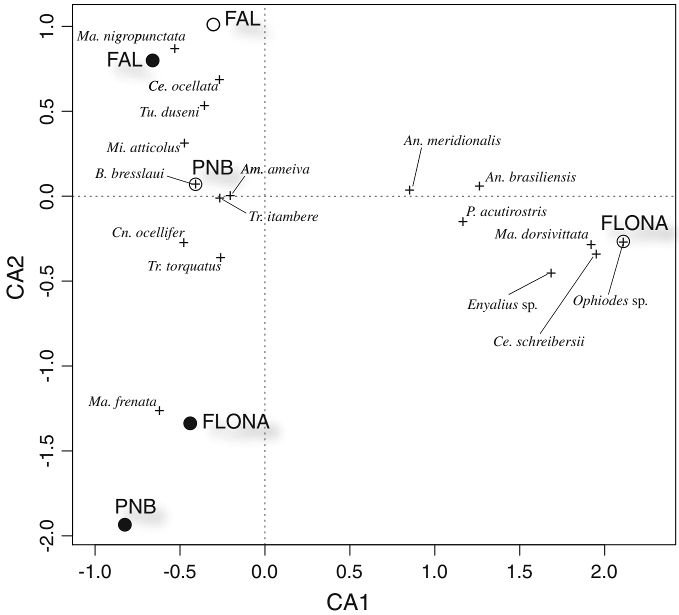

Fig. 5 Correspondence analysis for site by habitat. *FAL* Fazenda Água Limpa, *FLONA* Floresta Nacional de Brasília, *PNB* Parque Nacional de Brasília. The *opened circles* represent cerrado s.s. habitats while the *closed circles* represent abandoned *Eucalyptus* habitats

We found three lizard species (*Mabuya frenata*, *Micrablepharus atticolus* and *Tropidurus itambere*) captured in large enough numbers to be expected to persist in abandoned *Eucalyptus* plantations. An explanation for *Mabuya frenata's* ability to thrive in abandoned *Eucalyptus* plantations is provided by Vitt (1991), who documents *M. frenata* in the Cerrado is usually associated with dead tree trunks and branches on the ground and has a relatively low body temperature compared to other heliophilous lizards. In addition, this species is viviparous and has the advantage of giving live birth in cooler microclimates (Vrcibradic and Rocha 1998). The persistence of *Micrablepharus atticolus* and *Tropidurus itambere* in abandoned *Eucalyptus* plantations is likely favored by *Atta* nests, which are common within this habitat. *T. itambere* predominately eats ants while *M. atticolus* uses *Atta* nests as a refuge (Vitt 1991; Van Sluys 1993; Rodrigues 1996).

However, most Cerrado lizard species are negatively affected in abandoned *Eucalyptus* plantations. The correspondence analyses reinforced strong species associations between habitats and their pitfall array positions along the transect. Previous studies indicate that lizards are often associated with specific habitats based on fine—scale features of vegetation structure (Vitt et al. 1998, 2007; Mott et al. 2010; Garda et al. 2013). Plantations alter vegetation structure (McCullough 1999), solar radiation levels and environmental temperatures (Lemenih et al. 2004; Yirdaw and Luukkanen 2004). Cerrado lizard communities are dominated by habitat specialists, with predictable abundance differences among habitat types, resulting in low species overlap between open and forested habitats (Vitt 1991; Nogueira et al. 2009). All three of the captured Polychrotidae species were negatively impacted in abandoned *Eucalyptus* plantations. *Anolis meridionalis* is located on low bushes and grass clumps typical of open, grassland habitats (Vitt 1991). The species

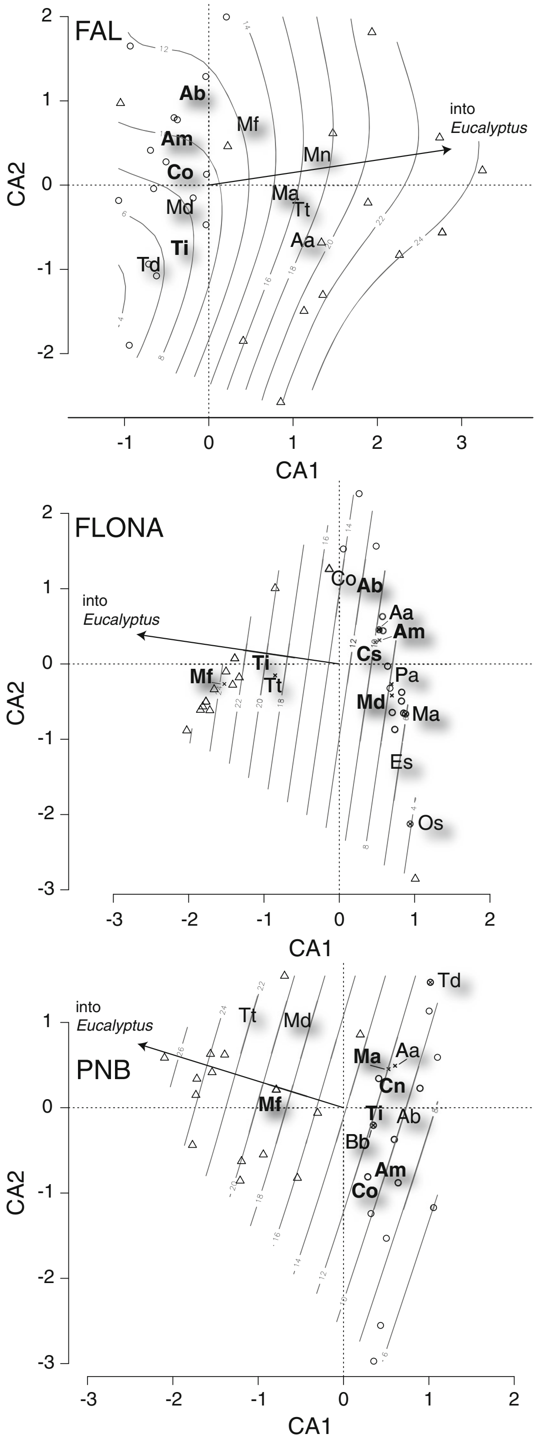

Fig. 6 Correspondence analysis for the species per site along a grid with surface fitting using thin plate splines under a generalized additive model (GAM) with Gaussian errors. Circles represent cerrado s.s. pitfall traps while *triangles* represent abandoned *Eucalyptus* pitfall traps. Aa, *Ameiva ameiva*; Ab, *Anolis brasiliensis*; Am, *Anolis meridionalis*; Bb, *Bachia bresslaui*; Co, *Cercosaura ocellata*; Cs, *Cercosaura schreibersii*; Cn, *Cnemidophorus ocellifer*; Es, *Enyalius* sp.; Md, *Mabuya dorsivittata*; Mf, *Mabuya frenata*; Mn, *Mabuya nigropunctata*; Ma, *Micrablepharus atticolus*; Os, *Ophiodes* sp.; Pa, *Polychrus acutirostris*; Ti, *Tropidurus itambere*; Tt, *Tropidurus torquatus*; Td, *Tupinambis duseni*

is characterized by a short tibia and relatively elongate body in comparison to its close relatives (D'Angiolella et al. 2011). These characteristics seem to be specific adaptations to the cerrado s.s. habitat, helping them jump vertically from the ground to grass and branches and then branch to branch (Losos et al. 2000). In the Cerrado, some species are documented to ingest a large proportion of plant material. This is true for two of the five species never captured in abandoned *Eucalyptus* plantations. *Polychrus acutirostris* eats spiders, orthoptera and plant material (Garda et al. 2012). The large teiid, *Tupinambis duseni* has a diet mostly comprised of plant material with phasmoidea and coleoptera of secondary importance (Colli et al. 1998). Interestingly, another two of the five species (*Ophiodes* sp. and *Bachia bresslaui*) never captured in abandoned *Eucalyptus* plantations are fossorial, indicating changes in soil compaction as a possible explanation for their absence. There also exists the possibility that false absences occur due to the restricted time-period of the study. It is important to keep in mind this study is pattern based on species relative abundance. More research on population demographic parameters is necessary to determine if abandoned *Eucalyptus* plantations are acting as population sinks.

The observed pattern of habitat segregation with fidelity to specific habitats and microhabitats is most likely the result of accumulated historical, intrinsic differences among lineages (Cadle and Greene 1993; Vitt et al. 1999, 2003), along with more recent ecological processes, such as competitive exclusion, prey abundances, and predation pressures (Pianka and Vitt 2003). Plantations are structurally simple in comparison to cerrado s.s., consisting of monocultures with individuals at the same height and distance from each other, decreasing the horizontal and vertical habitat structure. In addition to the reduced structural diversity found in abandoned *Eucalyptus* plantations, changes in the microclimate create a cooler environment with a smaller range of variation in temperature throughout the day and less radiant energy at ground level (Marco et al. 2005; Mott et al. 2010). Hence, the reduced structural diversity, shelter and limited oviposition success may explain why abandoned *Eucalyptus* plantations can sustain only a small proportion of the original fauna.

Management of abandoned *Eucalyptus* plantations is vital to maximize biodiversity conservation. Managed plantation forests support a diverse array of native species (Stallings 1991; Carnus et al. 2006; Fonseca et al. 2009). Several plantation management strategies can be applied at the stand and landscape scale to mitigate the effects of abandoned *Eucalyptus* plantations on the Cerrado lizard diversity.

At the stand scale, enhancing the structural complexity of the understory in *Eucalyptus* plantations provides better habitats for biodiversity. The *Eucalyptus* plantation understory diversity is likely to be the most influential factor determining bird and mammalian biodiversity found in these plantations (Stallings 1991; Lyra-Jorge et al. 2008). Planting a larger number of native tree species will also result in an increase of native biodiversity. Plantations with a mixture of exotic and native tree species are more resistant and resilient to natural and human disturbances (Jactel and Brockerhoff 2007) providing a more stable environment for native species. Furthermore, one can considerably improve habitat for native biodiversity by carefully selecting native tree species that provide specific microhabitat and food resources lacking in the *Eucalyptus* plantations (Hartley 2002; Carnus et al. 2006; Brockerhoff et al. 2008).

At the landscape scale, restoration of remnant native habitats within plantations should be an explicit target. Mosaics of native tree species is recommended for augmenting the biodiversity across the landscape, in addition to establishing corridors linking habitat patches forming forest, non-forest and riparian corridors (Brockerhoff et al. 2013). Biodiversity can also be enhanced by considering the spatial arrangement of plantation stands with respect to other landscape components, especially native forest remnants (Brockerhoff et al. 2008). Managed pine plantations provide habitat as well as thermal refuge for lizards dispersing from native forests with closed canopies and cool thermal environments, serving as an important element of the landscape mosaic where closed canopy forests are disappearing (Mott et al. 2010). In our study, abandoned *Eucalyptus* plantations can provide a similar purpose for the diminishing gallery forests. Gallery forests are an important feature of the mosaic Cerrado landscape, harboring many endemic species with specific tolerances to cooler environments (Colli et al. 2002; Nogueira et al. 2009).

The effective management of biodiversity in abandoned *Eucalyptus* plantations requires strategies that mimic the structural complexity of the Cerrado. Based on our results, we suggest implementing management strategies that maintain abandoned *Eucalyptus* plantation adjacent to gallery forests while actively restoring the plantations adjacent to cerrado s.s. The concurrent implementation of these strategies will assist in maximizing the conservation of the Cerrado biodiversity.

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