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Edge Effects and Nature Reserves: A Study of Protected Birds in Grasslands Adjacent to Agricultural Landscapes in a Central Brazilian Cerrado

Tubelis DP*

Department of Biosciences, Federal Rural University of the Semi-Arid, Brazil

***Corresponding author:** Dárius P Tubelis, Department of Biosciences, Federal Rural University of the Semi-Arid, Av. Francisco Mota, 572, Mossoró, Rio Grande do Norte state, Brazil, Email: darius.tubelis@gmail.com

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Abstract

Although studies of edge effects have great importance for reserve design, they have rarely investigated impacts into nature reserves. This study aimed to examine edge effects associated with adjacent agricultural landscape on birds at Parque Nacional das Emas, Brazil. Study sites [n = 36] were plots in the natural grassland habitat located at four distance bands in relation to the boundary line between protected vegetation and agricultural fields [0-500 m, 500-1,000 m, 1,000-1,500 m and interior]. Birds were surveyed through transect counts between October 2006 and February 2007. GLMMs were used to analyse variation in the abundance of selected species and trophic guilds among distance intervals, while species richness was compared through curves of rarefaction. Variation in community composition was evaluated through Correspondence Analysis. A total of 59 species were recorded. Species more sensitive to proximity to agriculture were insectivores such as *Culicivora caudacuta* and *Alectrurus tricolor*. Granivores and omnivores were more abundant close to rather than distant from agriculture. The species richness of the whole community and that of guilds did not vary among distance intervals, as result of species replacement. Communities found in the 0-500 m and 500-1,000 m intervals were very distinct from those of the interior. Edge effects penetrated up to 1,500 m into the park, being more intense within 1 km from adjacent modified landscapes. This study suggests that more effort should be done to establish effective buffer zones [> 1.5 km in width] and avoid the settlement of agribusiness adjacent to nature reserves in Cerrado.

Keywords: Agribusiness; Biodiversity; Boundary; Edge Effects; Landscape Matrix; Savanna

Introduction

Patch-matrix interactions can influence wildlife survival and ecological processes in heterogeneous landscapes [1,2]. Among them are edge effects - impacts associated with the surrounding land on the biota and environment [3-5].

Edge effects can involve a diverse range of ecological factors, mechanisms and species responses [6-9]. For example, animal species may occur in lower or higher abundances at edges than in interior portions of remnants [10-12]. Furthermore, birds inhabiting edges of remnants can experience higher rates of nest predation than birds living in the interior of remnants [13,14]. Compilations of studies have shown that the magnitude and extent of edge effects varies in function of aspects such as the boundary type, the region and the species investigated [15-18].

Most studies examined in extensive literature reviews involved sampling of biodiversity and environmental variables in relatively small fragments [when compared to nature reserves] embedded within human-modified matrix types [3,16,19,20]. However, the penetration of edge effects within nature reserves was investigated by a much lower number of studies [21-24]. Investigations like these are highly desirable and important because they can provide information on the effective area of reserves and to the planning of buffer zones [25,26].

The scarcity of information on edge effects obtained in nature reserves is even more serious for the Cerrado. This savanna ecosystem dominates central Brazil, and is considered one of the world's hotspots for biodiversity conservation [27-29]. In Cerrado, intense occupation of landscapes, mainly by agriculture, has dramatically modified the cover of native vegetation [30-33]. As a result, several nature reserves are now bordered by intensively modified land [34-36].

Despite the growing number of boundaries between protected and modified landscapes in Cerrado, only a few studies have examined penetration of edge effects into conservation units [37-39]. On the other hand, other previous studies on edge effects sampled relatively small fragments immersed in modified landscapes. For birds, artificial nests were used to examine predation rates at edges and interior portions of small forest remnants [40], and no information is available for the effects on bird communities whether in small remnants or reserves. Thus, the influence of edge effects on nature reserves is unknown for most of the Cerrado´s biodiversity, as occurs around the world.

This study was conducted at boundaries between agricultural landscapes and protected vegetation at Parque Nacional das Emas, western Cerrado, southwestern Brazil. I hypothesized that the establishment of large-scale agriculture adjacent to the park would lead to edge effects on bird communities inhabiting the park. I also aimed to know how deep edge effects penetrate into this nature reserve to give support to the planning of a buffer zone around it. To verify this, I investigated variations in the relative abundances of different species, and in attributes of the community, such as the abundance and richness of feeding guilds, and total species richness. Results were discussed in terms of biodiversity conservation at boundaries between nature reserves and modified landscapes in the Cerrado and other regions.

Methods

Study Area

The Cerrado is a vegetation province that occupies about 2,000,000 km^2 in Brazil, Paraguay and Bolivia, being the second largest ecosystem in extension in South America [41,42]. It dominates central Brazil and extends through peninsulas and isolated patches to other vegetation provinces, such as the Atlantic Forest [43]. Most landscapes are dominated by cerrado *sensu lato* - a gradient of xeromorphic savanna vegetation including grasslands and woodlands. This gradient covers most uplands, where vegetation such as dry forests and rocky grasslands also occur. Valleys are mainly occupied by gallery forests, marshes and floodplain grasslands [44].

This study was conducted at Parque Nacional das Emas, a 132,000 ha nature reserve located in the state of Goias [17º49´- 18º28´ S and 52º39´- 53º10´ W], western Cerrado, southwestern Brazil (Figure 1). This park harbours most physiognomies typical of Cerrado´s landscapes [34]. Shrubby grasslands are the main matrix type. Other physiognomies within the park are savanna woodlands, riverine forests and flood plain grasslands with palms [34,45].

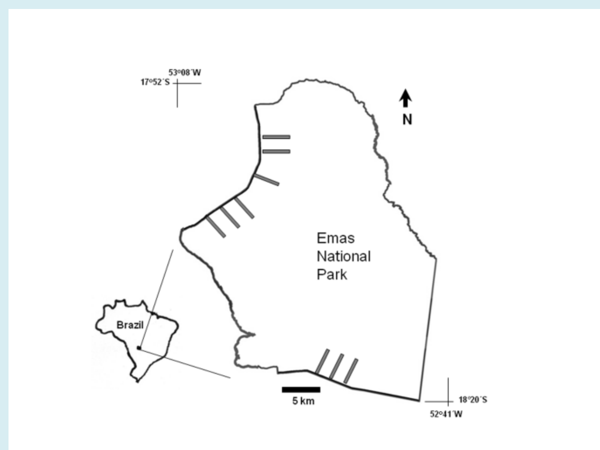

Figure 1: Map of the study area in western Cerrado, southwestern Brazil, with the nine grassland areas [gray rectangles] where birds were surveyed at Parque Nacional das Emas, adjacent to agricultural landscape.

Shrubby grasslands [*campo sujo*] are physiognomies that occur on strongly drained sites with deep water table and low soil fertility [44]. They have a dense grass layer, numerous shrubs and scattered trees [43,46]. A high richness of plant species can be found in shrubby grasslands [47,48].

Elevations range between 720 and 900 m, and most of the park consists of flat tableland covered by grasslands [45]. The regional climate is strongly seasonal and marked by two well defined periods: wet and dry seasons. Annual rainfall ranges between 1,200 and 2,000 mm. Most of the annual precipitation falls between October and April. The dry season occurs between May and September. Temperatures may descend to 0 °C in the Winter [July] and reach 40 °C in the Summer [January, February] [49].

The park is surrounded by agricultural fields, pastures and remnants of native vegetation. Agriculture in this area is mostly intensive and includes a rotation system that involves the cultivation of soybean and corn plantations between October and March, and cotton and other cultures in other periods of the year. The most external portions of the park are firebreaks, that are bands of grassland and woodland vegetation managed for fire control and usually 50 m wide [34,45]. An unpaved road separates firebreaks and non-managed vegetation within the park. A 10 m wide road with low car traffic lies between the park and adjacent agricultural fields and is mainly used for the transportation of grains produced in this Cerrado region [34]. In this study, I considered as boundary line the band of modified land located between agricultural fields and the non-managed grasslands that were surveyed. Thus, the boundary line included unpaved roads, firebreaks and the paved road.

Study Sites

A total of 36 study sites were selected. They were plots [500 m x 140 m] of non-managed shrubby grassland vegetation [hereafter called "grassland"] located at Parque Nacional das Emas. They were distributed along nine stripes, each including a plot in the four distance intervals [bands] defined from the inner size of the boundary line: 0-500 m, 500-1,000 m, 1,000-1,500 m and interior [ranging between 2,000 m and 3,000 m]. These stripes were distant at least 500 m from each other. With the exception of those of the interior band, sites were situated with their longest axis perpendicular to the boundary line.

Bird Surveys

Bird counts were carried out during three sampling periods between late October 2006 and early March 2007, with a 15-20 days interval between consecutive periods. This period corresponds to the breeding season of most grassland and woodland species and coincides with the wet season in the study area [50]. Seasonal biases were controlled through sampling each study site once within the three sampling periods. Thus, 108 samples were performed during this study.

Birds were surveyed through transect counts [51]. A sample consisted in walking along a 500 m transect through the middle of a site over 20 min and recording all birds heard and/or seen within its limits. Birds flying over the study sites without using the vegetation or other resources were not recorded. Three to four study sites were surveyed each morning, between sunrise and 08:00 h. To avoid time biases, the schedule of sampling of each study site was different in each of the sampling periods.

The taxonomy of bird species followed the Brazilian Committee of Ornithological Records - CBRO [52]. Bird species were grouped into seven trophic guilds following relevant literature [50]: carnivores, granivores, frugivores, insectivores, omnivores, necrophagous and nectarivores. Classification of species as endemic followed major publications on birds of the Cerrado region [53-56].

Statistical Analyses

To explore the differences in community composition among distance bands, a Correspondence Analysis was performed with the matrix of the 36 study sites and the mean number of individuals of each species detected during the three samples at each site. To avoid spurious effects of rarely recorded species, species that were found in less than five samples or had less than ten individuals detected during the study were excluded. The SPSS version 17 was used for this analysis. The software EstimateS 8.2 was used to calculate the relation between the number of observed species, obtained by the Mao Tau estimator, and the cumulative number of individuals recorded through sampling in each distance band [57]. To compare species richness among distance bands, it was used the Mao Tau observed species richness and confidence intervals expected for the number of individuals detected in the distance band where this number was lowest [58]. This procedure was applied for the whole set of species found in the study and for the trophic guilds with more species [granivores, insectivores and omnivores].

The influence of distance band on trophic guilds abundance and abundance of best represented species, selected according to the above defined criteria, was analyzed using generalized linear mixed models [GLMM]. Abundance was calculated as the total number of individuals counted at each site. The models included the distance to the boundary line as a fixed effect, coded as a covariate ranging from 1 [0-500 m band] to 4 [interior], and strip as a random effect. These analyses would permit to detect if there is a positive or negative trend of abundance change from the park boundary. In order to evaluate to which distance the edge effect on bird abundance is detected, additional GLMMs were performed but treating the distance band as a fixed effect, unordered factor. Treatment contrasts were done with the interior distance band as the reference level. Thus, the model computes coefficients that are a measure of the difference between each distance band and the interior band. It is possible that if I had sampled at further distances in the interior of the park, the abundance of some species or guilds would continue to change. Therefore, I assume that a significant difference between a given distance band and the interior band indicates that the edge effect penetrates at least until the former band. GLMMs were fitted using the "lme4" package [59] in the R statistical system [version 2.10.11] [60]. The Poisson error distribution and log link recommended for count data were used [61].

Results

Patterns of Species Responses

A total of 59 bird species belonging to 23 families were recorded in the 36 study sites. The GLMMs evaluated variation in the abundance of 36 selected species along the four distance bands [see graphs, figure caption and table for significance and p values]. Six species showed a significant negative slope, thus being less abundant in grasslands located at deeper portions of the park (Figure 2a & Table 2). They included four granivores [*Volatinia jacarina, Sporophila plumbea*, *Saltatricula atricollis* and *Ammodramus humeralis*], *Neothraupis fasciata* and *Eupsittula aurea*. The edge effect [variation in abundance] was detected at least until the 1,000-1,500 m band in *N. fasciata* abundance, until the 500-1,000 m band in the case of *S. plumbea*, *V. jacarina* and *E. aurea*, while only the first band was different to interior for *A. humeralis* and *S. plumbea*. However, this last species was not detected in the interior band and the contrasts in its model included the 1,000-1,500 m band as the reference level. Three other species showed a marginally significant negative slope across the gradient of distance from the boundary line (Figure 2b & Table 2). Among these species, *Cypsnagra hirundinacea* had fairly constant abundances in the three more external distance intervals and decreased significantly in the interior. There is also some evidence of edge effects in *Synallaxis albescens* since its abundance in the more external band was close to significantly different from the interior, but in the case of *Caracara plancus* no differences were detected (Figure 2b & Table 2).

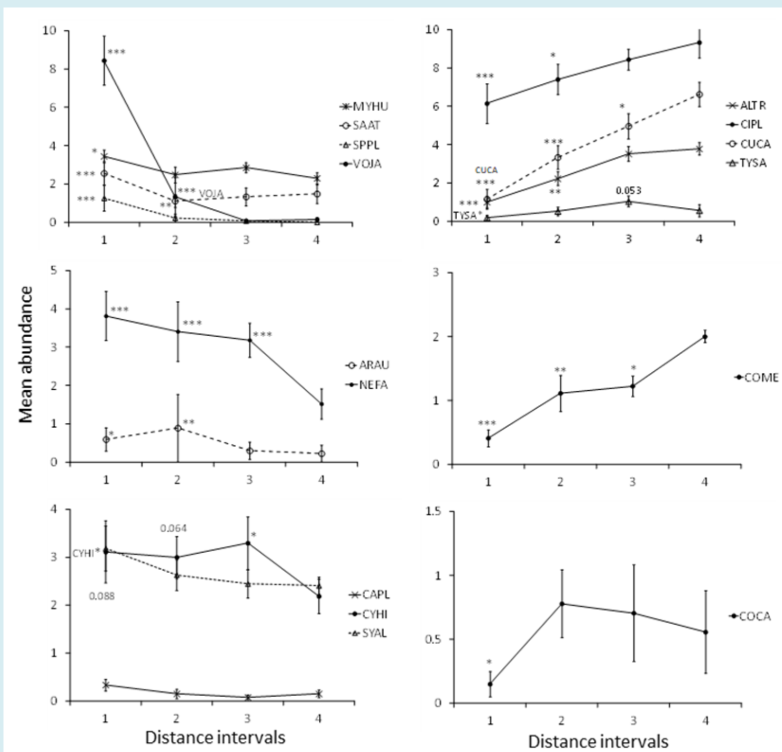

Figure 2: Mean abundance [± 1 SE] of bird species for which variation along four distance intervals in grasslands protected at Parque Nacional das Emas [SW Brazil] was detected using GLMM. Left column: species with a negative slope. Right column: species with positive slope. Graphs at the top include species belonging to the prevailing guild in each slope group: granivores [negative] and insectivores [positive]. Middle graphs: species with significant slopes belonging to other guilds. Bottom graphs: species with marginally significant slopes. Distance intervals are coded from the boundary line to the park core area as: 1 [0-500 m], 2 [500-1,000 m], 3 [1,000-1,500 m] and [4] interior. The significance of the contrasts comparing each of the first three distance bands with the interior band is shown close to significant mean symbols. In some cases, species codes are written close to significance symbols to avoid ambiguities. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$. For marginally significant comparisons the p value is shown. Note the different y-axis scales for each graph. See Table 2 for species codes.

Family / Species	Code	Guild	Distance band				P-value
			P1	P2	P3	P4	
Rheidae							
Rhea americana	REAM	OMN	0.07	0.2	0.2	0	0.1252
Tinamidae							
Crypturellus parvirostris	CRPA	OMN	0.19	0.3	0.3	0	0.2
Rhynchotus rufescens	RYRU	OMN	1.22	1	0.8	1	0.229
Nothura minor	NOMI	OMN	0.33	0.2	0.3	1	0.245
Nothura maculosa	NOMA	OMN	1.89	1.2	1.4	2	0.361
Taoniscus nanus	TANA	OMN	0.15	0.2	0.2	0	0.1572
Columbidae							
Patagioenas picazuro	COPI	GRA	0.07	0.1	0.1	0	--
Caprimulgidae							
Nanochordeiles pusillus	CHOR	INS	0.04	0	0	0	--
Trochilidae							
Colibri serrirostris	COSE	NEC	0.07	0.1	0.1	0	--
Rallidae							
Micropygia schomburgkii	MISC	OMN	0.15	0	0	0	--
Ardeidae							
Syrigma sibilatrix	SYSI	INS	0.07	0	0	0	--
Cathartidae							
Sarcoramphus papa	SAPA	NCR	0	0	0	0	--
Coragyps atratus	COAT	NCR	0	0	0.1	0	--
Cathartes burrovianus	CABU	NCR	0	0.1	0	0	--
Accipitridae							
Elanus leucurus	ELLE	INS	0.15	0.3	0.1	0	0.923
Circus buffoni	CIBU	CAR	0.04	0	0.1	0	--
Heterospizias meridionalis	HEME	CAR	0.04	0.1	0.2	0	0.2323
Geranoaetus albicaudatus	BUAL	CAR	0.11	0.4	0.2	0	1
Strigidae							
Athene cunicularia	SPCU	INS	0.04	0.1	0.3	0	0.1029
Picidae							
Colaptes campestris	COCA	INS	0.15	0.8	0.7	1	0.075
Cariamidae							
Cariama cristata	CACR	OMN	0.59	0.4	0.2	1	0.549
Falconidae							
Caracara plancus	CAPL	OMN	0.33	0.2	0.1	0	0.096
Milvago chimachima	MICH	CAR	0.04	0	0	0	--
Falco sparverius	FASP	INS	0.15	0	0	0	--
Falco femoralis	FAFE	INS	0	0.2	0.2	0	0.3274
Psittacidae							
Alipiopsitta xanthops	AMXA	FRU	0.33	0.2	0	1	0.1096
Eupsittula aurea	ARAU	FRU	0.59	0.9	0.3	0	0.0062
Ara ararauna	ARAR	FRU	0.48	0.2	0.3	1	0.836
Thamnophilidae							

Formicivora rufa	FORU	INS	0	0.1	0	0	--
Melanopareiidae							
Melanopareia torquata	METO	INS	1.22	1.2	1	1	0.6
Furnariidae							
Synallaxis albescens	SYAL	INS	3.19	2.6	2.4	2	0.0735
Tyrannidae							
Euscarthmus rufomarginatus	EURU	INS	0.04	0.2	0.1	0	0.4412
Elaenia cristata	ELCR	OMN	0.48	0.3	0.2	0	0.242
Elaenia chiriquensis	ELCH	OMN	0.19	0.3	0.2	0	0.447
Elaenia spp.	ELSP	INS	0	0	0	0	--
Culicivora caudacuta	CUCA	INS	1.15	3.3	5	7	0
Tyrannus melancholicus	TYAL	INS	0	0	0	0	--
Tyrannus savana	TYSA	INS	0.19	0.5	1	1	0.0143
Alectrurus tricolor	ALTR	INS	1	2.2	3.5	4	0
Xolmis velatus	XOVE	INS	0	0	0.1	0	--
Nengetus cinereus	XOCI	INS	0.33	0.2	0.2	0	0.109
Corvidae							
Cyanocorax cristatellus	CYCR	OMN	0	0	0.1	0	--
Hirundinidae							
Tachycineta leucorrhoa	TALE	INS	0	0.7	0	0	--
Troglodytidae							
Cistothorus platensis	CIPL	INS	6.15	7.4	8.4	9	0
Passerellidae							
Ammodramus humeralis	MYHU	GRA	3.44	2.5	2.9	2	0.0322
Zonotrichia capensis	ZOCA	GRA	0.22	0	0	0	--
Thraupidae							
Charitospiza eucosma	CHEU	GRA	0.04	0	0	0	--
Coryphaspiza melanotis	COME	GRA	0.41	1.1	1.2	2	0
Emberizoides herbicola	EMER	GRA	4.74	5	4.5	4	0.358
Saltatricula atricollis	SAAT	GRA	2.56	1.1	1.3	2	0.0065
Volatinia jacarina	VOJA	GRA	8.44	1.3	0.1	0	0
Sporophila plumbea	SPPL	GRA	1.26	0.2	0.1	0	0
Sporophila bouvreuil	SPBO	GRA	0.22	0.2	0.2	0	0.927
Sporophila palustris	SPPA	GRA	0	0	0.2	0	--
Sporophila hypochroma	SPHC	GRA	0	0	0.2	0	--
Cypsnagra hirundinacea	CYHI	OMN	3.11	3	3.3	2	0.0912
Sicalis citrina	SICI	GRA	0.15	0	0	0	--
Sicalis luteola	SIFL	GRA	0	0	0	0	--
Neothraupis fasciata	NEFA	OMN	3.81	3.4	3.2	2	0

Table 2: Mean abundance [individuals/sample] of bird species estimated from three visits between October 2006 and February 2007 in four distance bands in protected grasslands at Emas National Park, southwestern Brazil. Distance bands are in relation to the boundary line between the park and adjacent agriculture: 0-500 m [P1], 500-1,000 m [P2], 1,000-1,500 m [P3] and interior [P4]. Code: four letters code used to identify species in the figures. Trophic guilds: insectivores [INS], omnivores [OMN], granivores [GRA], frugivores [FRU], carnivores [CAR], nectarivores [NEC] and necrophagous [NCR]. The column "P-value" gives values of significance for the slope of the GLMM relating abundance to distance band. The sequence and taxonomy of species followed the Brazilian Committee of Ornithological Records - CBRO [52].

On the other hand, the slope was positive and significant for five species, thus being more abundant in deeper portions of the park (Figure 2c & Table 2). These included *Coryphaspiza melanotis*, and four insectivores [*Cistothorus plantesis* and the tyrants *Alectrurus tricolor*, *Culicivora caudacuta* and *Tyrannus savana*]. Similarly, variation in the abundance of *Colaptes campestris* had a marginally significant positive slope, since this species presented a low abundance close to the boundary line but increased noticeably in the next distance intervals (Figure 2d & Table 2). Like in the negative slope species group, there was variability in minimum distance at which edge effects were detected, that reached in some species at least until 1,000-1,500 m band [*C. caudacuta* and *C. melanotis*], in others until 500-1,000 m [*C. plantensis* and *A. tricolor*] or just the first band [*T. savana* and *Colaptes campestris*].

The abundance of other 21 species did not vary significantly among the four distance bands. They could be broadly divided into two groups of species. First, were those that occurred with very similar numbers in the four distance categories, such as *Rhynchotus rufescens*, *Nothura maculosa*, *Emberizoides herbicola* and *Sporophila bouvreuil* (Table 2). The other group included species that occurred in higher or lower abundances in one or two of the intermediate distance bands [500-1,000 m or 1,000-1,500 m]. Thus, the slope across the sequence of the four distance bands was not positive or negative. Among them, some species had significant lower abundance in middle distances, such as *Alipiopsitta xanthops* in band 2, and *Cariama cristata*, *Elaenia chiriquensis* and *Falco femoralis* in band 3 (Table 2).

Most families with more than one species analyzed included at least one whose abundance was affected by the distance to edge, the exception being Accipitridae and Tinamidae. Species endemic to the Cerrado region tended not to vary in abundance with distance to the boundary line. Among them, two species [*Cyanocorax cristatellus* and *Charitospiza eucosma*] had too low numbers. The abundances of *Euscarthmus rufomarginatus* and *A. xanthops* did not show a positive or negative response to adjacent modified land. On the other hand, two species with a large number of records [*C. hirundinacea*, *S. atricollis* and *N. fasciata*] were more numerous in some of the more external distance intervals than in the other two bands.

Trophic Guilds

The GLMMs for trophic guilds showed that variation in abundance across the range of distances studied was significant for three guilds [see also graphs, figure caption and table for significance and p values]. Insectivores had a significant positive slope [slope = 0.183, $z = 9.46$, $P < 0.001$], thus increasing in abundance with increasing distances from the boundary line (Figure 3). On the other hand, abundance of omnivores and granivores decreased farther from the boundary [slope = -0.108, $z = 4.05$, $P < 0.001$; slope = -0.311, $z = 12.29$, $P < 0.001$, respectively]. Despite this similar pattern, the decrease in abundance between the 0-500 m and 500-1,000 m distances bands seemed to be stronger for granivores than for omnivores. In these three guilds, the edge effect was detected at least until 500-1,000 m, but in omnivores and insectivores it seems to be acting also in the 1,000-1,500 m band since their abundance showed marginally significant differences with the interior. Slopes of the abundances of nectarivorous, frugivorous and necrophagous birds along the four distance bands were not significant (Figure 3).

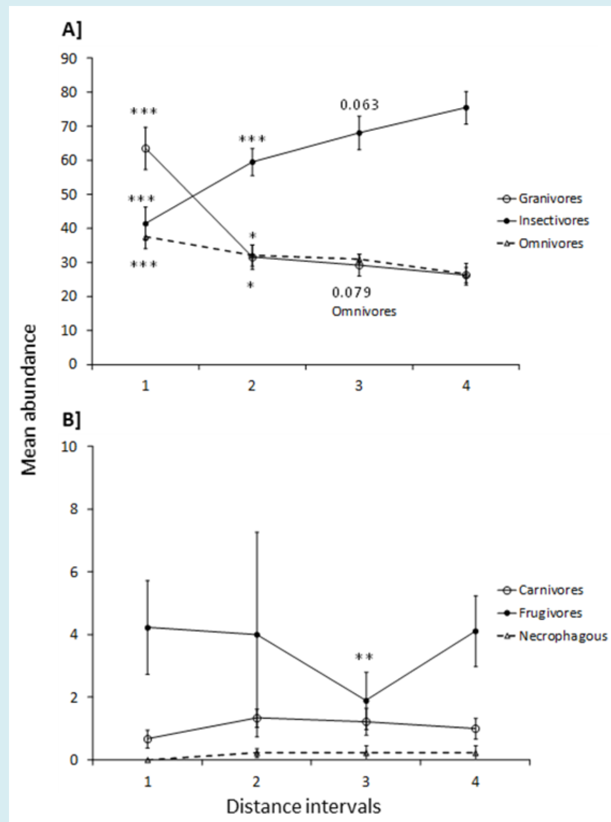

Figure 3: Mean total abundance [±1 SE] of six trophic guilds along four distance intervals to the boundary line between non-managed vegetation in the Parque Nacional das Emas [SW Brazil] and adjacent agriculture. A] guilds for which the GLMM showed a significant relationship. B] guilds for which GLMM were not significant. Distance intervals are coded from the edge to the interior as: 1 [0-500 m], 2 [500-1,000 m], 3 [1,000-1,500 m] and 4 [interior]. The significance of the contrasts comparing each of the first three distance bands with the interior band is shown close to significant mean symbols. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$. For marginally significant comparisons the p value is shown. Note the different y-axis scales for each graph.

The observed richness [Mao Tau estimator] considering the whole set of species was very similar in all distance bands and their confidence intervals overlapped broadly. This pattern of similar abundances across the preserved portion of the boundary between the park and agricultural fields also occurred for granivorous, omnivorous and insectivorous birds (Table 1).

Distance bands	Species richness	95% Confidence intervals
All species		
0-500 m	44.8	40.1 - 49.5
500-1,000 m*	46	39.1 - 53.0
1,000-1,500 m	46.8	42.4 - 51.2
Interior	45.3	38.5 - 52.2
Granivores		
0-500 m	8.8	6.8 - 10.9
500-1,000 m	8.4	4.6 - 12.1
1,000-1,500 m	9.4	5.3 - 13.6
Interior*	8	6.2 - 9.8
Insectivores		
0-500 m*	13	10.8 - 15.2
500-1,000 m	14	10.5 - 17.5
1,000-1,500 m	12.7	11.0 - 14.5
Interior	13.1	10.4 - 15.8
Omnivores		
0-500 m	12.7	12.1 - 13.2
500-1,000 m	13.6	11.8 - 15.5
1,000-1,500 m	14.5	12.3 - 16.7
Interior*	13	11.1 - 14.9

Table 1: Species richness and 95% confidence intervals obtained from individual-based Mao Tau rarefaction curves, run for the whole set of species and the most abundant trophic guilds found in the four distance bands at Parque Nacional das Emas, southwestern Brazil. Species richness and confidence intervals are the values estimated for a number of individuals sampled equal to the number found in the distance band where less individuals were counted [marked with *].

Community Composition

Community composition was summarized by the Correspondence Analysis, which identified two major axes that altogether explained 42.5% of the total variation in the data set (Figure 4). Axis 1, which captured 29.9% of the variation, clearly described an interior-to-edge gradient in community composition. Grasslands in the 0-500 m distance band were the most distinct group. Sites in this distance band had low overlap with those of the 500-1,000 m, and were even more distinct from those of the interior and 1,000-1,500 m distance bands. Sites in the 500-1,000 m band were in the middle of the gradient. Their overlap was higher with the interior and 1,000-1,500 m distance bands than with the 0-500 m band. Sites located in the interior and 1,000-1,500 m distance bands overlapped widely and their species composition was less variable than the two more external bands, as shown by the concentrated distributions of these sites (Figure 4).

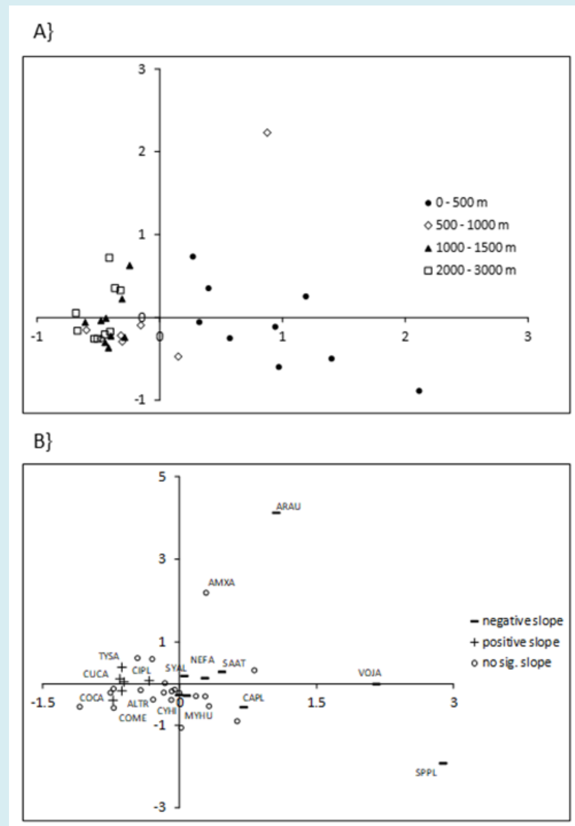

Figure 4: Results of the Correspondence Analysis performed with the abundance of 36 bird species detected in grasslands at four distance bands in relation to the boundary line between non-managed vegetation of Parque Nacional das Emas and adjacent agricultural fields. A] ordination of the 36 study sites. The nine replicates of each distance band are identified by specific symbols. B] ordination of the bird species recorded in the 36 study sites, and that followed the two criteria [ten or more individuals, recorded in five or more samples]. The symbols of species groups are defined by the type and significance of slope in the GLMM fitted to each species. See Table 2 for species codes.

Species more associated with the 0-500 m distance band were *V. jacarina*, *S. plumbea* and *C. plancus* (Figure 4). On other hand, the 500-1,000 m distance band was more related to species such as *N. fasciata*, *S. atricollis*, *S. albescens*, *A. humeralis* and *E. aurea*. Species more associated with the interior and 1,000-1,500 m distance bands were *C. caudacuta*, *A. tricolor* and *C. melanotis* (Figure 4).

Part of the larger variation of sites located in the two most external distance bands was due to their distribution along Axis 2 [Figure 4]. Species responsible for this variation were *A. xanthops*, *E. aurea* and *S. plumbea*, all of them species that form flocks that often move long distances and select particular sites in function of food availability. Of these three species, only *A. xanthops* did not have its abundance related to the distance to the boundary line (Table 2).

Discussion

Changes in Community Composition and Abundance of Species and Guilds

Substantial variation across the range of distances to the boundary line studied was noted for the abundance of 15 species [42% of the total evaluated], the abundance of half of the trophic guilds examined and the overall community composition. These results are in agreement with my hypothesis that adjacent agriculture would lead to edge effects on bird communities inhabiting grasslands at Parque Nacional das Emas. Thus, impacts of intensive agriculture in Cerrado exceed the mere conversion of native vegetation [30,31] and include also edge effects on its biodiversity inside reserves.

About one fifth of the species were detected to be less numerous at shorter than at greater distances from adjacent modified land. Thus, they would be the species most affected negatively if agribusiness settlement be juxtaposed to nature reserves in Cerrado, especially in cases of narrow and/or small conservation units, due to ratios between edge and core areas [4,25,62]. Nine other species showed an opposite pattern of abundance and thus are species more positively related to influences of adjacent modified land. These species are likely to compete with or even replace typical grasslands bird species along the more external portions of the park.

A relatively large group contained species whose abundance did not change across the boundary. This result is contrary to the relatively high proportion of bird species sensitive to edges commonly found in tropical forests [11,22,63]. This might reflect the fact that juxtaposed modified land has no influence on their abundances, likely the case of species with numerous individuals detected in several samples, such as *E. herbicola*, *M. torquata* and *N. maculosa*. On the other hand, no significant variation in the abundance of some species may reflect limitation of the sampling method or sample size. For example, large birds such as raptors and *R. americana*, and flocks of psitacids, were usually seen during the counts, but often >70 m from the observer, beyond the surveyed plots. In the case of low-density species, few individuals were detected and patterns of abundance variation may reflect a greater influence of chance. This latter fact also might explain the lack of variation among distance intervals in the abundance of frugivores, nectarivores and carnivores, as they occurred in low numbers.

On the other hand, the increase of omnivores near the park border might reflect their high flexibility in the acquisition of food items. Three tinamous [*N. maculosa*, *R. rufescens* and *C. parvirostris*] adapt well to disturbed vegetation in Cerrado [50,64] and were commonly found in the more external distance bands, likely due to their flexibility to habitat modification. Three large species [*R. americana*, *C. cristata* and *C. plancus*] often feed opportunistically on roads, firebreaks and agricultural fields [pers. obs.], thus using frequently nearby protected grasslands.

Granivorous birds also had a dramatic increase in grasslands located close to adjacent agricultural land. This increase was mainly due to high numbers of *V. jacarina*, which was closely associated to exotic grasses. Other finches well adapted to pastures [64], such as *S. plumbea* and *A. humeralis*, also were found using exotic grasses that occurred mainly < 150 m from the adjacent firebreaks. However, this overall pattern of edge affinity showed by granivores was opposite to that shown by *C. melanotis* which increased in abundance in more interior grasslands. Requirement of seeds of native grasses and competition with other finch species may be involved in this strong and negative response to adjacent modified land.

Insectivores appeared to be severely affected by adjacent agricultural landscape, as their abundance decreased by approaching to the park border. This high sensitivity to adjacent modified land also has been found for guilds of insectivorous birds in tropical forests [11,22]. I suspect that this pattern found at Parque Nacional das Emas might reflect, in part, low food availability near adjacent agriculture, as there is an influx of agrochemicals used in plantations that might kill invertebrates in the park.

The species richness of the whole communities and that of the most abundant trophic guilds did not vary with distance to the boundary line. This pattern of equal species richness across the range of grassland studied might result mainly of two factors. First, some species were ubiquitous in relation to distance to adjacent modified land and others were recorded only rarely. Second, some species and some trophic guilds showed opposite patterns of response to the proximity to adjacent modified landscape. Thus, a substitution of species tended to occur along the strips of grasslands examined at Parque Nacional das Emas, producing a change of community composition but keeping species richness fairly constant.

Strength of the Edge Effects in Cerrado and Other Regions

Knowledge on the magnitude and extent of edge effects is important to understand how biodiversity can be affected by adjacent matrix in human-modified landscapes [62]. In my study, I have been able to estimate the extent of edge effects penetration on grasslands at Parque Nacional das Emas. Analysis at the level of the community composition revealed that the influence of edge effects on grasslands leads to substantial changes in bird communities up to 1,000 m into the park. The analyses of trophic guilds showed that the penetration of edge effects can reach up to 1,500 m into the park, being very strong at less than 1,000 m from the boundary line. Considering all the analyses of this study, I conclude that strong edge effects penetrate up to 500 m into protected grasslands, becoming less intense but still intense up to 1,000 m from the boundary line, and moderately affecting some taxa, such as the threatened *C. caudacuta* and *C. melanotis*, up to 1,500 m into the Parque Nacional das Emas.

My study is the first to examine variation in bird communities across boundaries between modified land and remnant vegetation in Cerrado. Previously, two studies investigated predation rates of artificial and natural bird nests in forests remnants [<300 ha] surrounded by cleared areas in southeastern Cerrado, and found that predation rates in forest interiors and edges were comparable [40]. Similarly, no relationship between predation of artificial nests and distance to the modified matrix was found across a 2 km range of savanna in a reserve in central Brazil [65]. They also surveyed jays *C. cristatellus* [a nest predator] but no variation in abundance with distance to the border was detected.

Further studies of edge effects conducted in Cerrado´s nature reserves involved grasses and mammals. The African grass *Brachyaria decumbens* was highly abundant along a 10 m wide strip bordering the Cerrado Pé-de-Gigante reserve, while *Melinis minutiflora* was found through the entire extension of a small reserve in southeastern Brazil [37,38]. Domestic dogs were considered to be an edge effect penetrating 400 m into Parque Nacional de Brasília [39].

In relation to birds in regions other than Cerrado, a few studies examined edge effects along great distances across boundaries between modified land and continuous vegetation in protected or intact landscapes. For example, main changes in the community of terrestrial insectivorous birds occurred up to 0.3 km into continuous forests adjacent to petroleum operations in Ecuador [22]. Also, for most guilds of studied understory birds, strongest edge effects occurred up to 70 m from an unpaved road crossing a continuous forest tract in the Brazilian Amazon [11]. Substantial changes in bird diversity and in the abundance of terrestrial insectivores occurred up to 200 and 600 m into a forest reserve surrounded by developed areas in Malaysia [24].

Therefore, the extent of edge effects detected in my study is similar to or greater than those observed in Cerrado´s nature reserves or for birds in extensive portions of continuous forests in other tropical regions. My study, conducted across a landscape dominated by non-forest native vegetation, reinforces the fact that edge effects can occur over large distances, as documented by scarce studies of plants in tropical forests [26,62]. Due to the dramatic edge effects observed at Parque Nacional das Emas, I suggest that more attention should be devoted to grasslands in Cerrado, agreeing with studies that assessed their biodiversity [37,47,64,66,67].

Studies conducted worldwide have brought evidence that matrix types more appropriate for biodiversity conservation often are those with vegetation structure similar to that of remnants [68,69]. Although I have not compared matrix types, my study suggests that dramatic edge effects on remnants can occur even when there is some similarity between the structure of the native vegetation and the exotic matrix, due in this case to the height of soybean plants being similar to most grassland plants [despite the complex structure and floral diversity of grasslands]. Thus, the degree and intensity of human manipulation of the matrix is of paramount importance.

Factors Involved in the Edge Effects

Several factors might contribute to the edge effects found in my study. First, roads established between the agricultural fields and non-managed vegetation in the park might contribute to variation in the abundance of some species near the park limits, in a way similar to that noted in other regions [70]. Second, exotic grasses [*B. decumbens* and *M. minutiflora*] are abundant along margins of roads and non-managed protected grasslands in the Parque Nacional das Emas, as occurs in other Cerrado reserves [34,37,38]. Both species replace native grasses and provide habitat and food resources for species such as *V. jacarina* [64], especially close to the park border.

The use of substantial amounts of agrochemicals in the cultivation of soybean and other plantations Embrapa [71] also might contribute to negative responses of some species to nearby agricultural land. As noted by smell on more than five occasions, chemicals can be brought by wind up to 1-2 km inside the park during their application on exotic fields. This income of chemicals might kill invertebrates, and contaminate plants and vertebrates in grasslands. The invasion by dust from bare ground, containing or not chemicals, between periods of cultivation also can influence communities. The potential contribution of firebreaks on edge effects also should not be neglected. Besides accidental burning of nearby grasslands during their maintenance operations, firebreaks are marked by the abundance of exotic grasses and plant resources that attract some bird species [72].

Therefore, several factors might be involved in these edge effects at Parque Nacional das Emas. This accumulation of effects is strongly tied to the establishment of large-scale agriculture focusing on soybean production in this Cerrado region. The paved road of the boundary was created with the main purpose of transporting the production of soybean grains. Adjacent unpaved roads were created for the traffic of vehicles within farms and the park, and firebreaks were settled to protect the park from fire originated in adjacent properties. All these land modifications result of the establishment of such agricultural system [agribusiness] that leads to these strong edge effects at Parque Nacional das Emas.

Conclusions and Conservation Issues

In the Cerrado, studies of biodiversity conservation in protected areas have often focused on the planning of reserve systems [54,73,74]. My study suggests that more conservation attention and research should focus on threats to reserves due to intense edge effects. This would better support conservation plans involving buffer zones around nature reserves in Cerrado.

Near half of the perimeter of Parque Nacional das Emas is bordered by agriculture focused on soybean plantations [34]. To avoid further negative consequences, remnants of native vegetation adjacent to this park should not be cleared as they would buffer edge effects. This procedure could also be applied to other Cerrado's reserves threatened by nearby intensive agriculture, such as Parque Nacional Grande Sertão Veredas, Estação Ecológica de Uruçuí-Una.

For portions of reserves juxtaposed to agricultural fields, I suggest that agreements with landowners be done to eliminate the application of agrochemicals close to them. Additionally, attention to the wind direction and the avoidance of aircraft maneuvers over the park should be followed to avoid that agrochemicals reach the park during the application of chemicals. Enlargement of reserves and restoration of areas now used for cultivation would be more difficult tasks, but also desirable.

Soybean and other agricultural plantations cover substantial portions of landscapes in Cerrado and are likely to increase in extension [75-78]. Thus, it would be important to act urgently to avoid the establishment of intensive agriculture adjacent to nature reserves still surrounded by native vegetation as currently occur in northern Cerrado, such as in the states of Piaui, Maranhão and Tocantins. In these cases, large scale agriculture focusing on soybean should be established at least 1.5 km from nature reserves to alleviate edge effects on biodiversity. Within this range of distance from reserves, environment friendly activities, such as ecotourism and sustainable exploitation of natural resources, would be very welcome to ensure effective buffer zones around nature reserves in Cerrado.

Although the establishment of buffer zones involves complex ecological and social considerations, it should be always among the priority actions for biodiversity conservation in Cerrado. With adequate buffer zones, the pessimist landscape changes predicted to occur in Cerrado will not be juxtaposed to most or all nature reserves in the future.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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