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Consequences of Simulated Loss of Open Cerrado Areas to Bird Functional Diversity

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Abstract

Over the past 35 years, more than two thirds of the Cerrado's original expanse has been taken by agriculture. Even if some attempts have been made to conserve closed cerrado physiognomies, open cerrado physiognomies, richer in species and more fragile, have been systematically ignored. These open physiognomies are used by almost half of the Cerrado bird species, many of which being endemics. Using data from 11 surveys carried out in Cerrado landscapes, we asked what would happen to bird functional diversity if open cerrado species became extinct. Open cerrado birds would be able to keep on average 59% of the functional diversity. If they became extinct, on average 27% of the functional diversity would be lost. In this case, the remaining functional diversity would be lower than what would be expected by chance in five sites. Although many functions were shared by both open cerrado and forest species, there was some degree of complementarity between them, highlighted by the decrease in functional diversity when the former became extinct. Destruction of open cerrado physiognomies would lead to a habitat simplification, decrease in bird functional diversity, and, ultimately, to a considerable impact on community functioning. Thus, open cerrado physiognomies must receive much more conservation attention than they are currently receiving, because they maintain a high bird functional diversity that would otherwise be considerably diminished were open cerrado species to become extinct.

Key words: Avian Assemblages, Conservation, Extinction, Habitat Heterogeneity, Savanna.

Introduction

Considered one of the 25 world's hotspots for biodiversity conservation (Myers *et al.* 2000), the Cerrado domain once occupied about 2 million km^2 of the Brazilian territory (Ratter *et al.* 1997). As its name implies, cerrado vegetation prevails in the Cerrado domain. The cerrado vegetation is not uniform in physiognomy, ranging from grassland to tall woodland, but most of its physiognomies within the range defined as tropical savanna (Coutinho 1990). In the Cerrado domain, interspersed with the prevailing cerrado vegetation, there are other vegetation types, such as seasonal forest, riparian forest, rocky grassland, and wet grassland.

Over the past 40 years, more than two thirds of the Cerrado's original expanse has been taken by agriculture (Cavalcanti & Joly 2002). At the current rate of destruction, the Cerrado will be gone by 2030 (Machado *et al.* 2004). Despite its high diversity and threatened conservation status, the Cerrado remains 'forgotten' (Marris 2005). Even if some attempts have been made to conserve closed cerrado physiognomies, open cerrado physiognomies, richer in species and more fragile (Castro *et al.* 1999), have been systematically ignored. For instance, São Paulo State (2009) passed recently a law intended to conserve the cerrado vegetation, but which, for some inexplicable reason, does not include open cerrado physiognomies.

Concerning bird diversity, the Cerrado contains 777 resident species (Silva & Santos 2005), 4.6% of which are endemic, ranking second among Brazilian phytogeographical domains in the number of threatened species and threatened endemics (Marini & Garcia 2005). Some birds in Cerrado live preferentially in open cerrado physiognomies, but they need a mosaic of habitats, and opportunity to move among them is a crucial premise for maintaining their populations (Piratelli & Blake 2006). Other bird species live exclusively in open cerrado physiognomies, growing, feeding, breeding, and nesting on them (Bagno & Marinho-Filho 2001). Open physiognomies are used by almost half of the Cerrado bird species, many of which being endemics (Silva 1995).

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Conservation of these preferential and exclusive open cerrado birds will strongly depend on an urgent programme of protection of large areas dominated by open cerrado physiognomies (Tubelis & Cavalcanti 2000).

Fragmentation is not a random process, but occurs especially where agricultural activities are more profitable (Baldi *et al.* 2006). Each economic activity that competes with native vegetation for space is subject to optimal topographic and landscape characteristics to its development (Baldi *et al.* 2006). For instance, about 95% of the areas with agricultural activities in the core region of the Cerrado domain are located in regions with at most 4° of slope (Miziara & Ferreira 2006). On these flatlands, we usually find non-wetland, open cerrado habitats, which are easily cleared and excellent places for conversion to large-scale agribusiness operations (Tubelis & Cavalcanti 2000). In São Paulo State, for example, destruction of these physiognomies led to a drastic loss of Cerrado bird species and, consequently, of biodiversity (Willis & Oniki 1992).

Biodiversity can influence community functioning through a variety of ways; for example, by altering the extent of resource use complementarity within an assemblage (Petchey *et al.* 2004). Studies on the relationship between biodiversity and community functioning originally used the number of species as a surrogate for biodiversity (Naeem *et al.* 1994). There is a growing consensus, however, that species number has a low explanatory power, because it does not take into account similarities or differences in the functional traits of species (Hooper *et al.* 2002). Functional diversity may be defined as the value and range of the functional differences among species in a community (Tilman 2001). It has been suggested that communities with greater diversity of functional traits, that is, with a higher functional diversity, will operate more efficiently (Tilman *et al.* 1997). Therefore, the functional diversity of a community will often be the most ecologically relevant biodiversity measure (Díaz & Cabido 2001), predicting the functional consequences of changes caused by humans (Loreau *et al.* 2001).

Within the Cerrado domain, no studies have yet evaluated habitat fragmentation on birds in the open habitats (Marini & Garcia 2005), which must receive much more conservation attention (Tubelis & Cavalcanti 2000). If many birds use preferentially or exclusively open cerrado physiognomies (Bagno & Marinho-Filho 2001), if the Cerrado is being rapidly destroyed (Marris 2005), and if the most vulnerable areas are the open, non-wetland ones (Tubelis & Cavalcanti 2000), then, unfortunately, a scenario in which most open cerrado birds become extinct is not unlikely. Using data from 11 surveys carried out in Cerrado landscapes, we asked what would happen to bird functional diversity in a scenario in which all open cerrado areas were lost to agribusiness and, thus, all open cerrado species became extinct: 1) what is the proportion of functional diversity that could be kept solely by open cerrado birds?; 2) what is the proportion of functional diversity that would be lost if they become extinct?; 3) if open cerrado bird species became extinct, would the decrease in functional diversity be different from what would be expected by chance?; and 4) are aquatic, open cerrado, and forest bird species redundant or complementary?

Material and Methods

We looked for bird surveys carried out in Cerrado landscapes, selecting those that had sampled for at least six months, including spring and summer, several vegetation types and cerrado physiognomies, including open ones. We found 11 surveys (Table 1), which we filtered to remove exotic and non-resident species in Brazil (CBRO 2009). We considered as residents also those migratory species that are summer residents in Cerrado (CBRO 2009). We classified them into habitats according to Bagno and Marinho-Filho (2001), Bagno & Abreu (2001), and Olmos *et al.* (2004), with additional information based on Ridgely and Tudor (1989, 1994), Erize *et al.* (2006), and Del Hoyo *et al.* (1992-2002, 2003-2006). For the sake of simplicity, we called those species that occur from grassland ("campo limpo") to woodland savanna ("cerrado sensu stricto") as "open cerrado species". So, we used the following classes: 1) aquatic species, including semi-aquatic ones; 2) open cerrado species, including obligate and preferential open cerrado species – respectively, C_1 and C_2 sensu Bagno and Marinho-Filho (2001); and 3) forest species, including obligate and preferential forest species – respectively, F_1 and F_2 sensu Bagno and Marinho-Filho (2001).

To calculate functional diversity, we used the following traits (Petchey *et al.* 2007, with some modifications): body mass, diet (a. vertebrates; b. invertebrates; c. foliage, tubers, and stems; d. fruits and arillate seeds; e. grains; f. flowers and flower buds; g. nectar), foraging method (a. pursuit; b. gleaning; c. pouncing; d. pecking; e. grazing; f. scavenging; g. probing), foraging substrate (a. water; b. mud; c. ground; d. vegetation; e. air), and activity period (a. diurnal; b. nocturnal). For body mass, we used Ramirez *et al.* (2008) and additional information from Del Hoyo *et al.* (1992-2002, 2003-2006). For the other traits, we used Del Hoyo *et al.* (1992-2002, 2003-2006) and additional information from Sick (1997).

After compiling functional data, we constructed a matrix with species in rows and functional traits in columns, with which we calculated functional diversity (FD; Petchey and Gaston 2002a). FD measures the extent of complementarity among species trait values by estimating the dispersion of species in trait space. Greater differences among species trait values represent greater trait complementarity and larger FD (Petchey and Gaston 2002a). It measures diversity at all hierarchical scales simultaneously, including the small functional differences among species ignored by functional groups and the large functional differences that might delineate these groups (Petchey & Gaston 2002a). Calculating FD involves four steps: 1) assembling the trait

Table 1. Total richness (S) and functional diversity (FD), open cerrado species richness and functional diversity, and contribution of open cerrado species to functional diversity in 11 sites: 1) Chapada dos Guimarães National Park (approximately, 15° 19' S and 55° 52' W; Lopes *et al.* 2009), 2) Rio das Mortes (approximately, 14° 40' S and 52° 21' W; Sick 1955), 3) Serra do Lajeado (09° 00'-11° 45' S and 47° 30'-49° 45' W; Bagno and Abreu 2001), 4) Emas National Park (17° 49'-18° 28' S and 52° 39'-53° 10' W; Hass 2005), 5) Águas Emendadas Ecological Station (15° 32'-15° 38' S and 47° 33'-47° 37' W; Bagno 1998), 6) IBGE Reserve (approximately, 15° 56' S and 47° 53' W; Negret 1983), 7) Brasília National Park (15° 35'-15° 45' S and 47° 53'-48° 05' W; Antas 1995), 8) Água Limpa Farm (approximately, 15° 45' S and 47° 57' W; Braz and Cavalcanti 2001, with additional observations by Motta-Junior), 9) Serra da Canastra National Park (approximately, 20° 15' S and 46° 37' W; Silveira 1998), 10) Serra do Cipó National Park (19° 00'-20° 00' S and 43° 00'-44° 00' W; Rodrigues *et al.* 2005), and 11) Itirapina Ecological Station (approximately, 22° 13' S and 47° 53' W; Motta-Junior *et al.* 2008, with additional observations by Motta-Junior).

Site	Total		Open cerrado species		Contribution
	S	FD	S	FD	
01 Guimarães	228	0.652	82	0.395	0.60
02 Rio das Mortes	240	0.682	73	0.338	0.50
03 Lajeado	339	0.869	115	0.475	0.54
04 Emas	336	0.861	143	0.494	0.57
05 Águas Emendadas	278	0.791	131	0.482	0.61
06 IBGE	263	0.716	121	0.457	0.64
07 Brasília	250	0.752	107	0.403	0.54
08 Água Limpa	208	0.586	82	0.372	0.63
09 Canastra	312	0.795	135	0.494	0.62
10 Cipó	224	0.674	102	0.400	0.59
11 Itirapina	230	0.716	124	0.457	0.64

matrix, 2) converting the trait matrix into a distance matrix, 3) producing a dendrogram by clustering the distance matrix, and 4) calculating the total branch length of the dendrogram necessary to connect all species in the community (Petchey & Gaston 2002, 2006). We used Gower distance and the unweighted pair group method with arithmetic averages (UPGMA) to produce, respectively, the distance matrix and the dendrogram (Petchey and Gaston 2002a). We standardised FD to vary between 0.0 (lowest FD) and 1.0 (highest FD).

We calculated total FD for each site, using the sum of the dendrogram branches necessary to connect all species that occurred in a given site. To estimate the proportion of functional diversity that could be kept solely by open cerrado birds, we calculated, for each site, open cerrado species FD. Then, we calculated their contribution, dividing open cerrado species FD by total FD. To estimate proportion of functional diversity that would be lost if open cerrado birds became extinct, we also calculated, for each site, the remaining FD, that is, functional diversity kept by aquatic and forest species. Then, we calculated their contribution, subtracting remaining FD from 1, and dividing the amount by total FD.

To test whether the decrease in functional diversity was different from what would be expected by chance if open cerrado birds became extinct, we compared observed open cerrado species FD to their respective null distributions generated by Monte Carlo procedures (1,000 repetitions), in which, for each site, the same numbers of species were removed at random. In this way, it was possible to answer whether the extinction of open cerrado species resulted in a different loss of FD than a random extinction of the same number of species. Finally, to illustrate whether aquatic, open cerrado, and forest bird species were redundant or complementary, we did a principal component analysis (Jongman *et al.* 1995), using the standardised functional trait matrix. We conducted all analyses in R (R Development Core Team 2009).

Results

In the 11 sites, we listed 551 bird species, for which we assigned functional traits. Of these 551 species, 59 were aquatic or semi-aquatic birds, 182 were open cerrado birds, and 310 were forest birds. On average, we found 264 species per site, of which 110 were open cerrado birds (Table 1). On the one hand, these open cerrado birds would be able to keep on average 0.59 – or 59% – of the functional diversity (Table 1). On the other hand, if open cerrado birds became extinct, on average 0.27 – or 27% – of the functional diversity would be lost (Table 2). In this case, the remaining FD would be lower than what would be expected by chance in five sites and within the random distribution in the remaining six (Table 3). First axis of the principal component analysis explained 16.30% of the variation and the second axis, 14.27% (Figure 1). In the ordination diagram, there was a trend to find aquatic species in the lower left, and open cerrado and forest species overlapped in the upper right (Figure 1).

Table 2. Total richness (S) and functional diversity (FD), remaining richness and functional diversity if open cerrado species became extinct, and loss of functional diversity if open cerrado species became extinct in 11 sites: 1) Chapada dos Guimarães National Park, 2) Rio das Mortes, 3) Serra do Lajeado, 4) Emas National Park, 5) Águas Emendadas Ecological Station, 6) IBGE Reserve, 7) Brasília National Park, 8) Água Limpa Farm, 9) Serra da Canastra National Park, 10) Serra do Cipó National Park, and 11) Itirapina Ecological Station.

Site	Total		Remaining		Loss
	S	FD	S	FD	
01 Guimarães	228	0.652	146	0.465	0.29
02 Rio das Mortes	240	0.682	167	0.564	0.17
03 Lajeado	339	0.869	224	0.684	0.21
04 Emas	336	0.861	193	0.642	0.25
05 Águas Emendadas	278	0.791	146	0.558	0.30
06 IBGE	263	0.716	142	0.511	0.29
07 Brasília	250	0.752	143	0.553	0.26
08 Água Limpa	208	0.586	126	0.402	0.31
09 Canastra	312	0.795	177	0.567	0.29
10 Cipó	224	0.674	122	0.471	0.30
11 Itirapina	230	0.716	106	0.484	0.32

Table 3. Remaining functional diversity (FD) if open cerrado species became extinct; 2.5 and 97.5% quantiles of 1,000 randomisations in which bird species were removed from communities. Sites: 1) Chapada dos Guimarães National Park, 2) Rio das Mortes, 3) Serra do Lajeado, 4) Emas National Park, 5) Águas Emendadas Ecological Station, 6) IBGE Reserve, 7) Brasília National Park, 8) Água Limpa Farm, 9) Serra da Canastra National Park, 10) Serra do Cipó National Park, and 11) Itirapina Ecological Station. Values in bold are significant ($\alpha = 0.05$).

Site	FD	2.5%	97.5%
01 Guimarães	0.395	0.337	0.430
02 Rio das Mortes	**0.338**	0.339	0.426
03 Lajeado	0.475	0.454	0.557
04 Emas	**0.494**	0.510	0.609
05 Águas Emendadas	**0.482**	0.492	0.584
06 IBGE	0.457	0.442	0.532
07 Brasília	**0.403**	0.429	0.524
08 Água Limpa	0.372	0.302	0.398
09 Canastra	0.494	0.465	0.567
10 Cipó	0.400	0.391	0.489
11 Itirapina	**0.457**	0.470	0.560

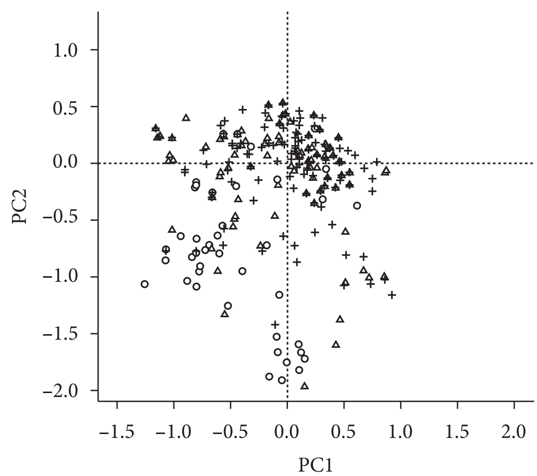

Figure 1. Principal component analysis plot of bird species scores. Circles: aquatic species, plus signs: open cerrado species, triangles: forest species. First axis explained 16.30% of the variation and second axis, 14.27%.

Discussion

The heterogeneous landscapes within the Cerrado domain contain 777 resident bird species (Silva & Santos 2005), of which we listed 511 for the 11 sites, a representative sample. Although most bird species listed were forest ones, open cerrado species represented an amount that cannot be neglected. Besides containing about one third of the bird species we listed, open habitats support a considerable number of rare and endemic species (Stotz *et al.* 1996). Nevertheless, open cerrado birds have been put aside by several studies, which tend to focus on forest birds (Tubelis & Cavalcanti 2000). Bias towards forest species may be seen in some classifications such as Silva (1995), in which Cerrado bird species are classified according to forest dependence.

We found that 59% of the bird functional diversity could be maintained solely by open cerrado species. If communities with lower functional diversity operate less efficiently (Tilman *et al.* 1997), then 59% of the bird functional diversity will not be enough to maintain all biological processes in the Cerrado. Nevertheless, this proportion indicates that many functions performed by birds in Cerrado landscapes could be carried out by these open cerrado species. Functional diversity equates to resource use complementarity so that differences in how species gain resources is the variation represented by functional diversity (Tilman *et al.* 1997). A greater resource use complementarity leads to more complete, or efficient use of resources, or both (Petchey & Gaston 2006). The relationship of functional diversity to extinction will depend on whether species from different habitats are functionally unique or redundant (Blackburn *et al.* 2005); in our case, whether open cerrado species are functionally unique, or whether some degree of functional redundancy exists between them and forest or aquatic species. Functionally complementary species are therefore important because they lead to a more complete and efficient use of resources within a community. Thus, if we want to maintain the functional diversity of communities, we should target complementary species. According to our results, although many functions were shared by both open cerrado and forest species, highlighted by the overlapping in ordination diagram, there was a degree of complementarity between them, highlighted by the 27% decrease in FD when the former became extinct.

The 'habitat heterogeneity theory' predicts that structurally complex landscapes may provide more niches and diverse ways of exploiting resources, thus increasing species diversity (MacArthur R.W. & MacArthur J.W. 1961). For example, shrub encroachment and landscape homogenisation are likely to lead to the loss of bird species associated with open savanna in favour of those associated with forests – since bird assemblages found in the former are distinct from those found in the latter – and ultimately lead to a decrease of bird diversity at landscape level (Sirami *et al.* 2009). Similarly, destruction of open cerrado physiognomies would lead to a habitat simplification and a decrease in bird functional diversity. Accordingly, the decrease in bird functional diversity we found when open cerrado birds were extinct is likely to have a considerable impact on community functioning.

One way to understand the effect of extinctions on biodiversity and community functioning is through simulated extinction scenarios, in which communities are disassembled using some a priori criterion (Purvis *et al.* 2000a), as we did here. Extinction simulations may be used to estimate functional loss in a given scenario and, consequently, to direct future management actions (Mouillot *et al.* 2008; Vamosi *et al.* 2008). Extinctions do not occur at random (Purvis *et al.* 2000a), but as particular responses of each species related to morphological or behavioural traits (McKinney 1997). Several studies have found higher functional loss than expected by chance (Purvis *et al.* 2000a, b; Petchey and Gaston 2002b; Vamosi *et al.* 2008). Although in six out of the 11 sites we found functional loss equal to what would be expected by chance, in the remaining five we found higher functional loss. Since the loss of many unique functional traits will lead to communities that operate less efficiently (Maherali & Klironornos 2007), the remaining five sites are more vulnerable to destruction of open cerrado physiognomies.

Extinctions are also not random in relation to habitat vulnerability. If crops are grown primarily on flat areas, sloping areas are preferably left as part of the "legal reserve" that landowners must preserve by Brazilian legislation (Carvalho *et al.* 2009). Thus, fragments of Cerrado are a non-random sample of topography of a given region, being located mainly in areas with greater slopes, where open cerrado physiognomies are less frequent (Carvalho *et al.* 2009). If so, open cerrado birds would be more likely to become extinct and, at least in some cases, we should expect a FD loss greater than a random removal of the same number of species.

Agriculture-dominated landscapes may be important for biodiversity conservation, since these areas can maintain a vegetation structure with more permeability in the matrix among fragments (Carvalho *et al.* 2009). In agricultural landscapes, pastures and crop fields may provide cover attractive to many grassland and savanna birds (WHC 1999). However, in many situations, cultural practices and harvesting operations may destroy nests and adults that attempt to live in these areas (WHC 1999), especially when one finds intensive pastures and highly mechanised agriculture, as in the Cerrado (Marini & Garcia 2005). Therefore, population persistence in the fragments depends not only on the type of matrix – cropland, silviculture, pasture, or urban areas – in which these fragments are embedded (Carvalho *et al.* 2009), but also on practices and management strategies carried out in the matrix (WHC 1999).

Moreover, besides habitat loss, there are other threats to open cerrado birds, such as hunting and invasive alien species. For instance, alien grasses have been invading Cerrado landscapes and nowadays are present in almost all fragments (Pivello *et al.* 1999). As long as open cerrado physiognomies are more vulnerable to alien grasses (Pivello *et al.* 1999) and as long as alien grasses are one of the main threats to bird conservation (Marini & Garcia 2005), plant invasion may affect open cerrado birds. Alien grasses may drastically reduce populations of some open cerrado bird species and increase populations of others, such as *Volatinia jacarina* and *Sicalis citrina* (Tubelis & Cavalcanti 2000).

Spatial heterogeneity is important to maintain bird functional diversity at broader scales. Continued declines in open cerrado bird species implies an increased awareness for the need to preserve, manage, and restore open habitats to recover and maintain viable open cerrado bird populations (WHC 1999). Thus, open cerrado physiognomies must receive much more conservation attention than they are currently receiving, and large intact areas of the Cerrado landscapes in which they are dominant must be urgently identified and converted to protected reserves (Tubelis & Cavalcanti 2000). This would also insure the presence of stopovers for migrant species and corridors of open habitats connecting Cerrado reserves (Tubelis & Cavalcanti 2000), maintaining a high bird functional diversity that would otherwise be considerably diminished were open cerrado species to become extinct.

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