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ECOSYSTEMS

The selection of indicator species of birds and mammals for the monitoring of restoration areas in a highly fragmented forest landscape

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Abstract: Indicator species are frequently used to monitor restoration areas. However, species of conservation concern are usually absent in highly fragmented landscapes, making the selection of indicator species a challenging task. Here, we select indicator species of birds and mammals to be used for the evaluation of restoration sites in a highly fragmented landscape, the Capivara-Taquaruçu Dams region located in north Paraná, Brazil. By using the Index of Biotic Integrity (IBI), we show that the Capivara-Taquaruçu Dams landscape has low IBI values and bird richness when compared with two other landscapes in the north of Paraná. Therefore, we used the Individual Indicate Value to identify birds and mammals associated with forest fragments in the Capivara-Taquaruçu Dams landscape. Six bird and four mammal species were selected as indicators of forest fragments, none of which were of conservation concern. However, monitoring of these species could help evaluate the recovery of restoration sites in the Capivara-Taquaruçu Dams region. Lastly, several species of birds and mammals were frequently recorded in the restoration sites, including vulnerable species such as the lowland tapir (*Tapirus terrestris*). This is indicative that restoration sites can be important habitats in highly fragmented landscapes despite the loss of biodiversity.

Key words: Atlantic Forest, forest fragments, IndVal, monitoring, restoration, semideciduous forest.

INTRODUCTION

The key idea behind indicator species is how a given species responds to environmental conditions. In conservation management, indicator species are used as a proxy to determine the environmental conditions (e.g. ecological diversity, pollution, ecological disturbance) of a specific locality, usually using occurrence and/or abundance data (Noss 1990). Although there is an apparent rationality to the use of indicator species in conservation biology, several authors recommended that indicator species should be used with caution. For example, Caro (2003) has highlighted the importance of establishing exactly what an indicator species indicates. Other authors caution on how precise sampling designs are and how imprecision in the detection of indicator species can affect results (Yoccoz et al. 2001, Mattfeldt et al. 2009). In order to improve accuracy, some authors have proposed the use of other ecological indicators, such as landscape metrics (Banks-Leite et al. 2011) and functional indicators (Farwig et al. 2017), in addition to the use of taxonomic indicators.

Furthermore, the sensitivity of a single species to evaluate anthropogenic disturbances can vary along its geographical distribution (Doherty et al. 2003, Anjos et al. 2010, Uezu & Metzger 2011). This means that the same species will not present the same response to anthropogenic disturbances throughout its range. Bird species of the Atlantic rain forest are a good example of this ecological process. In this case, levels of sensitivity to deforestation vary among bird species according to the position of the fragmented landscape in the geographical range of the bird species (Orme et al. 2019). Higher sensitivity to deforestation was found at the edge of a bird species' range, probably due to different factors, such as lower population size and/or lower genetic variability (see Orme et al. 2019 for details). Therefore, a species could be a good ecological indicator in one region while being an imprecise indicator in another one. This suggests that the choice of indicator species will also depend on the region where the monitoring program takes place.

The Atlantic Forest of Brazil has suffered intense landscape alterations, being a highly fragmented ecosystem (see Ribeiro et al. 2009). Because of the large number of disconnected forest fragments, restoration activities could be used to increase the area of the remaining forest fragments (i.e., increased forest cover) and/or to create forest corridors (i.e., increased connectivity), contributing to the persistence of biodiversity (e.g. Brancalion et al. 2013, Crouzeilles et al. 2015, Laurance 2010, Morrison et al. 2010, Batisteli et al. 2018). In fact, the Brazilian "Native Vegetation Protection Law" (NVPL) stipulates that forest vegetation must be maintained in all areas close to water (e.g., rivers and lakes). These areas are called "Permanent Areas of Protection" by the NVPL, and when vegetation is absent, landowners are obliged to restore the vegetation in these areas. This, together with the so-called "Legal Reserves" – a proportion of private property that is set aside for native vegetation – is considered an important legal mechanism for biodiversity conservation (see Metzger et al. 2019 for a discussion on Legal Reserves). Therefore, it is important to monitor restoration areas in order to evaluate the trajectory of restoration and to measure the level of recovery of the Permanent Areas of Protection. In this context the selection of indicator species is an essential part of the development of an appropriate monitoring protocol specific for the restoration of Permanent Areas of Protection. Moreover, there is evidence suggesting that fauna plays a crucial role in ecosystem functioning (e.g. Morrison et al. 2010). For example, birds and mammals are important pollinators and seed dispersers of native plants, facilitating the restoration process, which is why they are frequently used as indicators (Batisteli et al. 2018, Silva et al. 2002, 2020). However, fauna is usually overlooked during the monitoring of restoration areas (Cross et al. 2019). A similar situation is found for the Atlantic Forest, although recent efforts have focused on taxonomic recovery and the increase in the ecological process (e.g. Audino et al. 2014, Alexandrino et al. 2016, Santos Junior et al. 2016, Kenup et al. 2017, Batisteli et al. 2018, Genes et al. 2018). In the present study we select indicator species of birds and mammals for a long-term monitoring program that is currently underway in the highly fragmented north of the state of Paraná, southern Brazil. In this area, restoration of Permanent Areas of Protection began 18 years ago (2002), and it is important to evaluate the progress of these restoration sites, as described by the "International principles and standards for the practice of ecological restoration" (see Gann et al. 2019). However, the region suffered greatly with forest loss and forest fragmentation. A previous study in the north of Paraná showed that the majority of forest fragments have low values of biotic integrity due to the loss of sensitive bird species to forest fragmentation (Anjos et al. 2009). Here we studied a fragmented landscape of the Atlantic forest where sensitive species to forest fragmentation have already been extirpated.

In this study we investigated forest fragments and nearby restoration sites to select indicator species of birds and mammals to be used in the evaluation of the recovering trajectory of Permanent Areas of Conservation. Because our study region is highly fragmented, we first evaluated the Biotic Integrity of forest fragments close to the restoration sites (using data on birds) and compared them with previously obtained data on birds of other fragmented landscapes of northern Paraná (see Anjos et al. 2009). If the studied forest fragments and restoration sites have low Biotic Integrity, then few species of conservation concern will be present, for example, species that are sensitive to forest fragmentation. Thus, our second goal was to select indicator species of birds and mammals in a landscape where species of conservation concern have already been lost due to deforestation and forest fragmentation. Therefore, our focus is on a single fragmented landscape where species of conservation concern have been potentially lost, but where it is also important to monitor the trajectory of restoration sites.

MATERIALS AND METHODS

Biotic integrity and study area

In the present study we recorded birds and mammals in four forest fragments (FF), coded as AlvFF, CghFF, IbiFF, and SanFF, and five forest restoration sites (RS), coded as Anh1RS, Anh2RS, Cap1RS, Cap2RS, and CghRS, in the region of the Capivara-Taquaruçu Dams, northern Paraná (Fig. 1; Table I). We used the Index of Biotic Integrity (IBI) to evaluate the Biotic Integrity of the studied FFs, which was developed for birds (see Anjos et al. 2009). The IBI is based on bird species sensitivity to forest fragmentation considering three categories: species with high, medium, and low sensitivity. Species were categorized according to their occurrences in forest fragments of different sizes and levels of isolation (see Anjos 2006). Ten bird species of each category were selected to calculate the IBI (for details see Anjos et al. 2009), and selected bird species were those with higher detection potential in FFs. For each site we recorded the number of selected species that were present and allocated different weights according to their sensitivity to forest fragmentation (see Anjos et al 2009): species with high sensitivity had a weight of 3, medium sensitivity a weight of 2, and low sensitivity a weight of 1. We then summed the values and divided by 60 according to the equation below:

$$IBI = \frac{3(number\ of\ HS) + 2(number\ of\ MS) + number\ of\ LS}{60},$$

where HS = species with high sensitivity to forest fragmentation, MS = species with medium sensitivity to forest fragmentation, and LS = species with low sensitivity to forest fragmentation.

Northern Paraná is characterized by a high rate of forest fragmentation. Deforestation began around 1930 with the expansion of coffee plantations (Soares & Medri 2002), which explains the low values of IBI found in the remaining forest fragments (see Anjos et al. 2009). However, there is a large and well-preserved forest area in the north of Paraná, the Mata dos Godoy State Park (656 ha), which has a high value of IBI (0.85; Anjos et al. 2009) and where 331 bird species were recorded over 23 years of monitoring (Willrich et al. 2016). Therefore, in the present study we first compared, using only the data on birds, the number of species and the values of IBI of the four studied forest fragments AlvFF, CghFF, IbiFF, and SanFF with data from eight other forest fragments previously obtained for

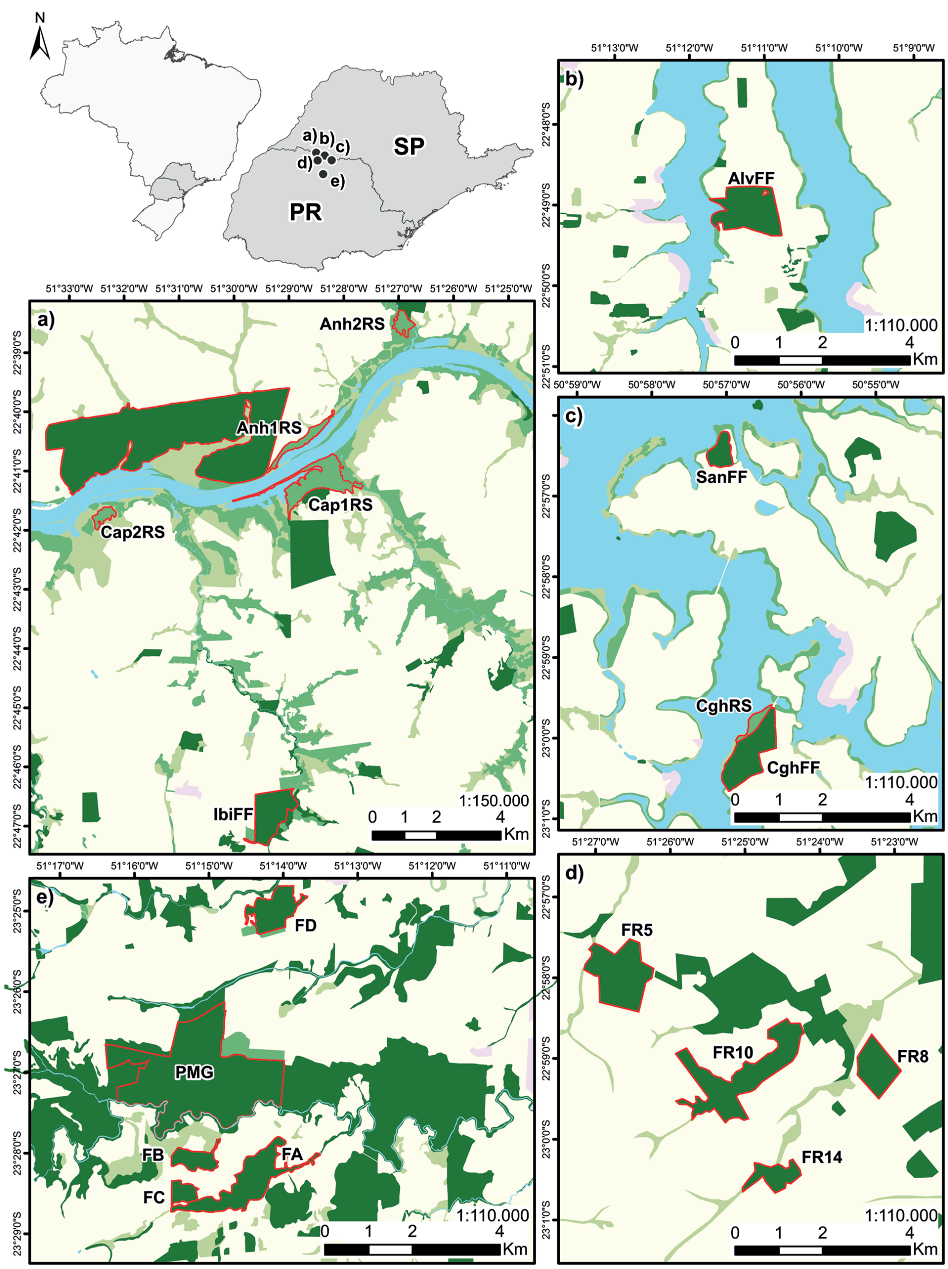

Figure 1. Location of studied sites in northern Paraná, southern Brazilian Atlantic Forest. Panels **a), b)** and **c)** are three different locations in the Capivara-Taquaruçu Dams region (distances between locations ranging from 15 to 43 km). Panel **d)** refers to the region of the Bela Vista do Paraíso. Panel **e)** refers to the region of the Mata dos Godoy State Park (PMG). IbiFF (Ibicatu forest fragment); AlvFF (Alvorada forest fragment); SanFF (Santo Antônio forest fragment); CghFF (Congonhas forest fragment); Anh1RS (Anhumas 1 restoration site); Anh2RS (Anhumas 2 restoration site); Cap1RS (Capim 1 restoration site); Cap2RS (Capim 2 restoration site); CghRS (Congonhas restoration site). Data and precise location of forest fragments: FA, FB, FC, FD, FR5, FR8, FR10 and FR14 can be found in Anjos et al. (2009).

the north of Paraná (Anjos et al. 2009). We used the forest fragments coded in Anjos et al. (2009) as FA, FB, FC, and FD, which are in the region of the Mata dos Godoy State Park, and FR5, FR8, FR10, and FR14, which are in the region of Bela Vista do Paraíso city (see Table I and Fig. 1).

The selected restoration sites in the region of Capivara-Taquaruçu Dams were implemented between 2002 and 2005 in a controlled manner by the planting of native, pioneering, and secondary tree species. The areas had no vegetation cover and were expropriated areas for the construction of two hydroelectric dams located on the Tibagi and Paranapanema rivers. During the samplings of birds and mammals (2015-2017), the restoration sites were composed of small trees with an average height of 10.5 m (9-12 m). Restoration sites ranged between 16 and 171 ha in size (Table I). The selected sites are located in the region of the semideciduous seasonal

Table I. Sampling sites divided according to forest types, coordinates, information on area size (ha) and sampling effort for mammals and birds (*The sample effort presented in Anjos et al. 2009 is showed in field hours). FF (Forest Fragment); RS (Restoration Sites). FA, FB, FC, and FD are forest fragments in the region of the Mata dos Godoy State Park; FR5, FR8, FR10, and FR14 are forest fragments in the region of Bela Vista do Paraíso city.

Sites	Latitude	Longitude	Size (ha)	Sampling effort		
				Mammal (camera trap-days)	Mammal (sand plot-days)	Bird (transects-days)
Capivara-Taquaruçu Dams						
Forest Fragments						
AlvFF	22°49.109’S	51°11.279’O	132	144	144	32
CghFF	23°00.266’S	50°56.789’O	106	162	132	32
IbiFF	22°46.875’S	51°29.422’O	150	150	144	32
SanFF	22°56.503’S	50°57.115’O	32	144	138	32
Restoration Sites						
Anh1RS	22°40.609’S	51°28.865’O	46	168	144	32
Anh2RS	22°38.507’S	51°26.962’O	30	168	144	32
Cap1RS	22°41.140’S	51°28.296’O	171	156	144	32
Cap2RS	22°41.761’S	51°32.401’O	26	156	144	32
CghRS	22°59.805’S	50°56.666’O	16	162	132	32
Forest Fragments - Bela Vista do Paraíso						
FA	23°28.136’S	51°14.331’O	56	-	-	12h*
FB	23°28.105’S	51°15.285’O	25	-	-	12h*
FC	23°28.521’S	51°15.369’O	28	-	-	12h*
FD	23°25.136’S	51°14.181’O	87	-	-	12h*
Forest Fragments - Mata dos Godoy State Park						
FR5	22°58.055’S	51°26.638’O	165	-	-	12h*
FR8	22°59.193’S	51°23.233’O	90	-	-	12h*
FR10	22°59.428’S	51°25.407’O	70	-	-	12h*
FR14	23°00.490’S	51°24.653’O	46	-	-	12h*

forest. Due to deforestation, the landscape in the region of the Capivara-Taquaruçu Dams is now characterized by a matrix type, consisting of sugarcane monoculture or corn-soybean crop rotation. The monitoring program underway in the restoration sites and close-by forest fragments is part of the “Atlantic Forest of the North of Paraná Long-Term Ecological Research Network (PELD- MANP)” and includes other organisms, such as plants and insects.

Field methods

Birds and mammals in the four forest fragments and five restoration sites of the Capivara-Taquaruçu Dams were recorded along a pair of 500 m transects in each forest fragment and restoration area, which were placed 200 m apart from each other. The same transects were used for both taxa, but the methods used for recording species were different: visually and/or listening in the case of birds, and for mammals we used camera traps and track counts in sand plots (see below). For forest fragments, the sampling points were distributed with a minimum distance of 50 m from the edge, while the minimum distance for restoration sites was 25 m.

Samplings of birds were carried out during 16 mornings in each transect. Sampling of each site occurred during four consecutive days and was repeated every 10 weeks from September 2015 to May 2016. Samples were performed using the line transect method with a maximum recording distance of 100 m (see Bibby et al. 1992). Both visual and auditive species identification were considered. We considered the presence of each species per sampled day to estimate the frequency of occurrence of the species at each transect and the sampling effort was computed in transect-days. Information on the bird sampling effort is provided in Table I.

Mammals were sampled from September 2015 to June 2017 in six surveys. Each survey consisted of four to six consecutive days of samplings, which was repeated every 10 weeks. In total, 334 days of samplings were performed for mammals, ranging from 24 to 28 days per area. For each sampling day we used two sampling techniques - camera trapping and track counts using sand plots 1 m^2 in area. Three camera traps and three sand plots were placed interchangeably in each transect 100 m apart from each other (largest possible distance given the size of the smallest remnant). For each transect, the distance between each sampling technique was 200 m. Sand plots were not sampled on rainy days. Thus, the sampling effort of each transect was 68 to 84 camera trap-days and 66 to 84 sand plot-days. The total sampling effort was 1408 (mean: 156.7 ± 9.2) camera trap-days and 1268 (mean: 140.7 ± 5.6) sand plot-days. Cameras were installed on tree trunks placed 20 cm above the ground and remained operating throughout the sampling period, programmed to film for 20 s post-activation. We used the Bushnell Trophy Cam model 119537C, with a fixed infrared range of up to 10 m, configured in high resolution shooting mode (720 p). To avoid pseudo replication and to minimize detection differences between methodologies, we only considered the first record of the species every 24 hours for each sampling point (Cassano et al. 2012). Subsequently, we calculated the frequency of occurrence of each species in each site using the total sampling effort (camera trap-days and sand plot-days). Detailed information on mammal sampling effort is provided in Table I. Species identification was based on the use of the following identification guides: Becker & Dalponte (2013), Borges & Tomás (2004), Moro-Rios et al. (2008), and Reis et al. (2014).

Species richness and the Index of Biotic Integrity (IBI)

We compared bird species numbers and the IBI for the forest fragments among the regions: Capivara-Taquaruçu Dams, Bela Vista do Paraíso, and Mata dos Godoy State Park. The average number of species per fragment and the IBI values were calculated for each region. If the values of species number and average IBI in the forest fragments of Capivara-Taquaruçu Dams were lower than in Bela Vista do Paraíso and Mata dos Godoy State Park we discarded using the sensitive species as indicators, and then followed the procedure presented in the next section.

Selecting indicator species

First, we investigated how good our sampling effort was by examining accumulation curves from both birds and mammals at each sample site. For this, we considered the total sampling effort of each area for each group, that is, camera trap-days and sand plot-days for mammals and transect-days for birds. The curves were created in R version 3.6.3® (R Development Core Team 2020) using the iNEXT package (Hsieh et al. 2016). Next, we selected indicator species using the Individual Indicate Value (IndVal) proposed by Dufrêne & Legendre (1997). The IndVal is based on the percentage of occurrence of a given species in different habitats and gives the probability of its association to a particular habitat (see Dufrêne & Legendre 1997). Because in our study we worked with forest fragments and restoration sites, this analysis allowed us to identify the level of association of birds and mammals for these two habitats, enabling the selection of indicator species that are fairly common at a local scale. The IndVal analysis was conducted in R version 3.6.3® (R Development Core Team 2020) using the labdsv package (Roberts 2016).

RESULTS

The number of bird species (Table II) and IBI values (Table III) were higher in the forest fragments in the region of the Mata dos Godoy State Park, intermediate in the region of Bela Vista do Paraíso, and lower in the region of the Capivara-Taquaruçu Dams (Fig. 2).

Overall, we recorded 102 bird species and 27 mammal species considering both forest fragments and restoration sites sampled in the Capivara-Taquaruçu Dams (Table II). Sampling effort was similar for both taxa (birds and mammals), where we managed to sample 88-97% of expected bird species and 95-100% of expected mammal species (Fig. 3). Eleven species of birds and six species of mammals were selected as indicator species using the IndVal method (Fig. 4). Among these species, six species of birds and four of mammals were selected as indicators of forest fragments for the study region (Fig. 4). Therefore, these species should be included in the monitoring of the recovery trajectory of the restoration areas in the region of the Capivara-Taquaraçu Dams. The six species of birds selected were: *Basileuterus culicivorus*, *Hemithraupis guira*, *Herpsilochmus rufimarginatus*, *Piaya cayana*, *Setophaga pitiayiumi*, and *Thamnophilus pelzeni*. The four species of mammal selected were: *Cuniculus paca*, *Leopardus wiedii*, *Nasua nasua*, and *Tamandua tetradactyla*. (see Fig. 4; Table IV).

DISCUSSION

The six bird species selected as indicator species for the region of the Capivara-Taquaruçu Dams are not of conservation concern, or even sensitive to forest fragmentation. They are better recognized as common species in northern Paraná. Because levels of sensitivity to deforestation vary according to where in the geographical range of the bird species the fragmented landscape is positioned (Orme et al. 2019), it is possible that these bird species are sensitive to deforestation in other regions of the Atlantic Forest. As Caro (2003) mentioned, it is important to show exactly what an indicator species indicates. In the case of this study, the indicator bird species would indicate that the restoration areas could become similar to the forest fragments nearby. However, nearby forest fragments have low IBI values and species numbers when compared with data from the regions of the Mata dos Godoy State Park and Bela Vista do Paraíso fragment (Fig. 2). Therefore, the restoration efforts in the Capivara-Taquaruçu Dams will be limited regarding the conservation of bird species for northern Paraná because of the lack of sensitive species, and bird communities will be less structured and with lower bird richness.

Table II. **Species of birds and mammals recorded in forest fragments and restoration sites located in northern Paraná, southern Brazilian Atlantic Forest. Conservation status according to the IUCN red list of threatened species (DD: Data Deficient; LC: Least Concern; NT: Near Threatened; VU: Vulnerable) is also provided.**

FF (Forest Fragment); RS (Restoration Sites).

	Conservation status	Forest Fragments				Restoration Sites				
		AlvFF	CghFF	IbiFF	SanFF	Anh1RS	Anh2RS	Cap1RS	Cap2RS	CghRS
Birds										
Amazona aestiva	NT			X			X	X		
Anhima cornuta	LC							X	X	
Aramides saracura	LC	X	X	X	X					X
Ardea cocoi	LC				X					
Arremon flavirostris	LC		X	X	X		X		X	X
Baryphthengus ruficapillus	LC		X							
Basileuterus culicivorus	LC	X	X	X	X			X	X	X
Buteo brachyurus	LC		X							
Cacicus haemorrhous	LC							X	X	
Camptostoma obsoletum	LC	X	X	X	X	X	X	X	X	X
Capsiempis flaveola	LC					X				
Caracara plancus	LC				X			X	X	X
Celeus flavescens	LC	X			X				X	X
Chlorostilbon lucidus	LC	X	X	X		X	X			X
Cnemotriccus fuscatus	LC	X	X	X	X	X	X	X	X	X
Coereba flaveola	LC							X		
Colaptes melanochloros	LC	X			X					X
Columbina squammata	LC						X			X
Columbina talpacoti	LC				X	X		X	X	X
Conirostrum speciosum	LC	X	X	X	X	X	X	X	X	X
Conopophaga lineata	LC			X	X					
Coragyps atratus	LC	X	X	X	X	X		X	X	
Coryphospingus cucullatus	LC	X				X	X	X		X
Corythopis delalandi	LC	X	X		X		X			X
Crax fasciolata	LC						X			
Crotophaga ani	LC									X
Crypturellus parvirostris	LC					X	X			
Crypturellus tataupa	LC	X	X	X		X	X	X	X	X
Cyanocorax chrysops	LC	X	X	X		X	X	X	X	X
Cyclarhis gujanensis	LC	X	X	X	X	X	X	X	X	X
Dacnis cayana	LC					X			X	
Dryocopus lineatus	LC	X	X	X	X	X		X		X
Dysithamnus mentalis	LC			X	X			X		
Euphonia chlorotica	LC	X	X	X	X	X	X	X	X	X

Table II. Continuation.

Guira guira	LC									X
Hemithraupis guira	LC	X	X	X	X	X			X	X
Herpsilochmus rufimarginatus	LC	X		X	X	X				
Hylocharis chrysura	LC		X	X			X			X
Hypoedaleus guttatus	LC			X						
Ictinia plumbea	LC		X	X						
Lathrotriccus euleri	LC	X	X	X	X	X	X	X	X	X
Leptopogon amaurocephalus	LC		X	X	X	X				
Leptotila rufaxilla	LC	X	X	X	X	X	X	X	X	X
Leptotila verreauxi	LC	X	X	X	X	X	X	X	X	X
Leucochloris albicollis	LC				X			X		
Mackenziaena severa	LC				X					
Megarynchus pitangua	LC	X	X	X	X	X	X	X	X	X
Mesembrinibis cayennensis	LC						X			
Micrastur ruficollis	LC				X					
Micrastur semitorquatus	LC							X	X	
Myiarchus ferox	LC	X		X	X	X		X	X	
Myiarchus tyrannulus	LC				X	X	X	X	X	
Myiodynastes maculatus	LC	X	X	X	X	X	X		X	X
Myiopagis caniceps	LC	X								X
Myiopagis viridicata	LC				X	X	X	X	X	
Myiophobus fasciatus	LC							X		
Myiornis auricularis	LC		X	X	X			X	X	X
Myiothlypis flaveola	LC	X	X	X	X	X	X	X	X	X
Myiozetetes similis	LC							X	X	
Nyctidromus albicollis	LC					X				
Pachyramphus castaneus	LC	X								
Pachyramphus polychopterus	LC			X	X		X		X	
Pachyramphus validus	LC		X							X
Patagioenas cayennensis	LC		X	X						
Patagioenas picazuro	LC	X	X	X	X	X	X	X	X	X
Penelope superciliaris	LC	X	X	X				X		X
Phaethornis pretrei	LC					X				
Phylloscartes ventralis	LC			X				X		
Piaya cayana	LC	X	X	X	X	X	X	X	X	X
Picumnus cirratus	LC		X			X				X
Picumnus temminckii	LC	X	X	X	X	X	X	X	X	X
Pionus maximiliani	LC	X	X	X	X	X		X	X	X
Pitangus sulphuratus	LC	X	X	X	X	X	X	X	X	X
Platyrinchus mystaceus	LC			X						

Table II. **Continuation.**

Psittacara leucophthalmus	LC		X	X		X	X	X	X	
Pteroglossus bailloni	NT	X								
Pyrrhura frontalis	LC	X	X	X		X	X	X	X	X
Ramphastos toco	LC							X		
Rupornis magnirostris	LC		X	X	X	X	X	X	X	X
Saltator similis	LC									X
Selenidera maculirostris	LC			X						
Setophaga pitiayumi	LC	X	X		X					
Sittasomus griseicapillus	LC		X							
Synallaxis frontalis	LC	X						X		
Syndactyla rufosuperciliata	LC							X		
Tachyphonus coronatus	LC	X								X
Tangara sayaca	LC	X	X		X	X	X	X	X	X
Thamnophilus caerulescens	LC	X			X			X		
Thamnophilus doliatus	LC		X		X	X		X		X
Thamnophilus pelzelni	LC	X	X	X	X	X	X	X	X	X
Tityra cayana	LC	X	X	X						
Tityra inquisitor	LC	X	X							
Trichothraupis melanops	LC	X			X	X		X	X	X
Troglodytes musculus	LC					X				X
Trogon surrucura	LC	X							X	
Turdus amaurochalinus	LC				X	X	X	X		
Turdus leucomelas	LC	X	X	X	X	X	X	X	X	X
Turdus rufiventris	LC			X				X	X	
Tyrannus melancholicus	LC							X		X
Vanellus chilensis	LC								X	X
Veniliornis spilogaster	LC								X	
Zonotrichia capensis	LC	X				X				
Mammals										
Alouatta guariba	VU				X					
Cerdocyon thous	LC	X	X	X	X		X	X	X	X
Coendou spinosus	LC	X			X					
Cuniculus paca	LC	X	X	X	X		X			X
Dasyprocta azarae	LC	X	X	X	X	X	X	X	X	X
Dasypus novemcinctus	LC	X	X	X	X	X	X	X	X	X
Didelphis albiventris	LC	X	X	X	X	X	X	X	X	X
Eira barbara	LC			X	X	X	X	X		X
Euphractus sexcinctus	LC	X	X	X	X	X	X	X		X
Galictis cuja	LC					X				X
Hydrochoerus hydrochaeris	LC							X		X

Table II. Continuation.

Leopardus guttulus	VU		X	X						X
Leopardus pardalis	LC			X		X	X	X		
Leopardus wiedii	NT		X	X						
Lontra longicaudis	NT									X
Mazama americana	DD		X			X				
Myocastor coypus	LC			X				X		
Nasua nasua	LC	X	X	X	X	X	X		X	X
Pecari tajacu	LC	X			X	X				
Procyon cancrivorus	LC				X			X		X
Puma concolor	LC	X	X		X	X	X	X		X
Puma yagouaroundi	LC			X		X				
Sapajus nigritus	NT	X	X		X	X	X			X
Sylvilagus brasiliensis	LC					X	X	X	X	X
Tamandua tetradactyla	LC	X	X	X	X	X	X	X		
Tapirus terrestris	VU			X		X	X	X	X	X
Tayassu pecari	VU					X				

We do not have data on IBI values for mammals in northern Paraná, so it is not possible to evaluate the Biotic Integrity of the studied forest fragments regarding this group of organisms. Despite the low number of species selected in this study, mammals are often considered to be good bioindicators due to their ecological and environmental requirements (Jorge et al. 2013). Mastofauna of altered environments are composed mainly of generalist species such as puma (*Puma concolor*) and the nine-banded armadillo (*Dasypus novemcinctus*) (Magioli et al. 2014), both of which were recorded in large numbers in our study areas. We also recorded three of the four species selected as indicators of forest fragments in the restoration sites, the agouti (*Cuniculus paca*), the south American coati (*Nasua nasua*), and the southern tamandua (*Tamandua tetradactyla*). These species do not seem to be influenced by other variables that would delimit their occurrence, such as forest cover and amount of forest edge (see Beca et al. 2017), being able to cross the matrix and occupy a diversity of habitats, such as restoration sites (Beca et al. 2017, Cassano et al. 2012, 2014).

The studied restoration sites currently shelter less biodiversity when compared to the regions of the Mata dos Godoy State Park and the Bela Vista do Paraíso fragment, but their importance could be higher in the future. In the region of the Capivara-Taquaruçu Dams there are two Protected areas (one of them – IbiFF – was included in this study), in addition to numerous small and some medium-sized forest fragments (Fig. 1). The restoration of the evaluated sites occurred for legal reasons and not due to their biological value, which is why they are of little importance for threatened species. However, these restoration sites can act as ecological corridors between the two conservation units and other forests fragments located in the region. For example, we found that the lowland tapir (*Tapirus terrestris*), a species considered at a vulnerable risk of extinction, was associated with reforestation sites. In fact, several bird and mammal species have frequently been recorded in the restoration sites, including three other

Table III. **Index of Biotic Integrity (IBI; see Anjos et al. 2009) for forest fragments and restoration sites located in northern Paraná, southern Brazilian Atlantic Forest. Only recorded bird species were used. FF (Forest Fragment); RS (Restoration Sites).**

	Forest Fragments				Restoration Sites				
	AlvFF	**CghFF**	**IbiFF**	**SanFF**	**Anh1RS**	**Anh2RS**	**Cap1RS**	**Cap2RS**	**CghRS**
Selenidera maculirostris			X						
Sittasomus griseicapillus		X							
Trogon surrucura	X							X	
Basileuterus culicivorus	X	X	X	X			X	X	X
Conopophaga lineata			X	X					
Crypturellus parvirostris					X	X			
Cyclarhis gujanensis	X	X	X	X	X	X	X	X	X
Thamnophilus caerulescens	X			X			X		
IBI (Anjos et al. 2009)	0.08	0.03	0.05	0.07	0.03	0.03	0.05	0.07	0.03

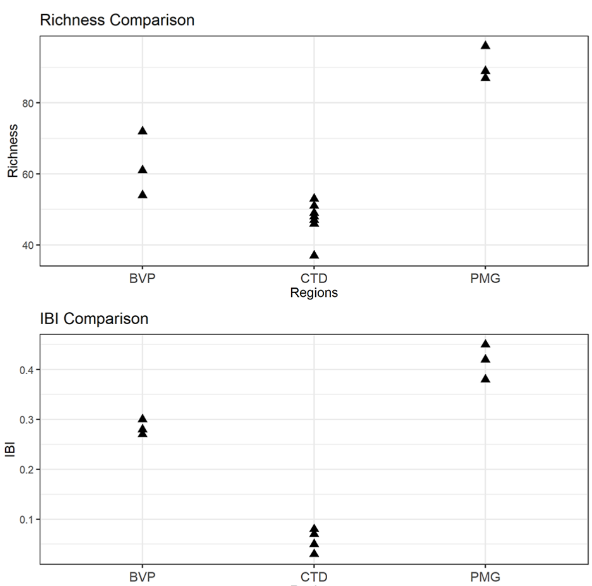

Figure 2. **Bird richness is presented in the top graph, while the Index of Biotic Integrity (IBI), considering only bird species, is presented in the bottom graph. Studied regions are located in northern Paraná, southern Brazilian Atlantic Forest. CTD - Capivara-Taquaruçu Dams; BVP - Bela Vista do Paraíso; PMG - Mata dos Godoy State Park.**

mammal species (southern tiger cat - *Leopardus guttulus*; neotropical otter - *Lontra longicaudis*; and white-lipped peccary - *Tayassu pecari*), which are considered as having some degree of vulnerability to extinction (see Table II). These results indicate that the habitat is being used and that several species are potentially contributing with important ecological functions, such as seed dispersion.

One of the eight principles for the international practices of ecological restoration (see Gann et al. 2019) is on the importance of correctly recognizing the native species in a baseline inventory, which will allow measurement of the recovery of the biotic integrity of an ecosystem. In addition, it is important to evaluate how to measure the trajectory of restoration. For example, what is the expected temporal tendency of indicator species? What is the desired magnitude? And what is the periodicity at which species monitoring should take place? Here we show the importance of a preliminary approach to test the level of Biotic Integrity of the forest fragments based on a preliminary inventory that can be used as a baseline to evaluate the progression of restoration sites in the Capivara-Taquaruçu Dams region. Indeed, by using the frequency of occurrence of the species, we showed that it is

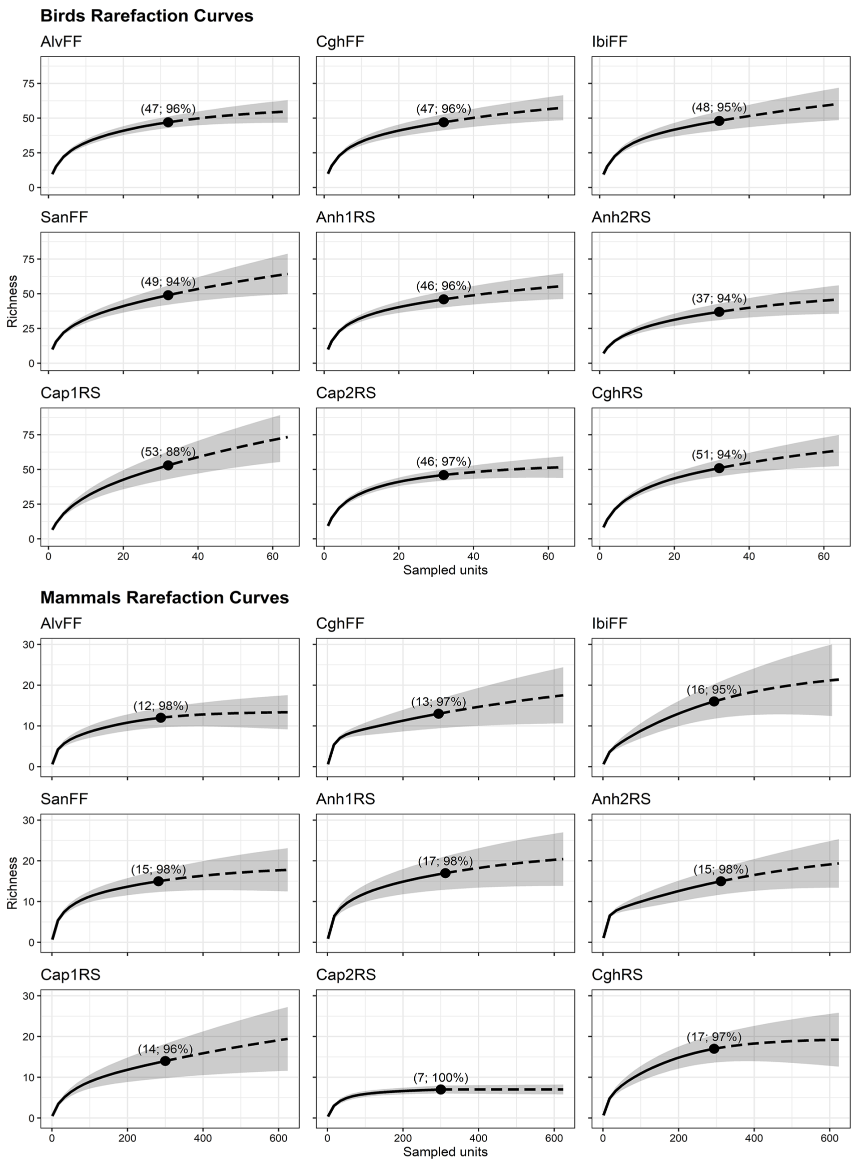

Figure 3. **Rarefaction curves of birds and mammals of Forest Fragment (FF) sites and Restoration Sites (RS) sampled in northern Paraná, southern Brazilian Atlantic Forest. Dashed line represents extrapolation of the sample size used. Transparency represents 95% confidence intervals obtained through 200 resamples (draw with replacement). Values in parentheses indicate number of recorded species and percentage of expected species that have been recorded, respectively. IbiFF (Ibicatu forest fragment); AlvFF (Alvorada forest fragment); SanFF (Santo Antônio forest fragment); CghFF (Congonhas forest fragment); Anh1RS (Anhumas 1 restoration site); Anh2RS (Anhumas 2 restoration site); Cap1RS (Capim 1 restoration site); Cap2RS (Capim 2 restoration site); CghRS (Congonhas restoration site).**

possible to monitor restoration sites in highly fragmented landscapes. In our approach, the level of recovery of a given restoration area could be measured considering the number of indicator species that reach a similar frequency of occurrence in both restoration sites and nearby forest fragments. This number of species could then be divided by the total number of indicator species, in the case of our study by ten species (four species of mammals and six species of birds). This measurement could be used to evaluate the recovery level of the restoration sites and measured again periodically over time. We suggest that monitoring should occur annually, in spring or summer, to increase the detection of species. A desired recovering goal could be considered when 80% of indicator species reach a similar frequency of occurrence in restoration sites to those found in forest fragments. We know that species have different colonization potential, with understory insectivorous bird species expected to be the last to colonize restoration sites (Stratford & Stouffer 2013, Santos Junior

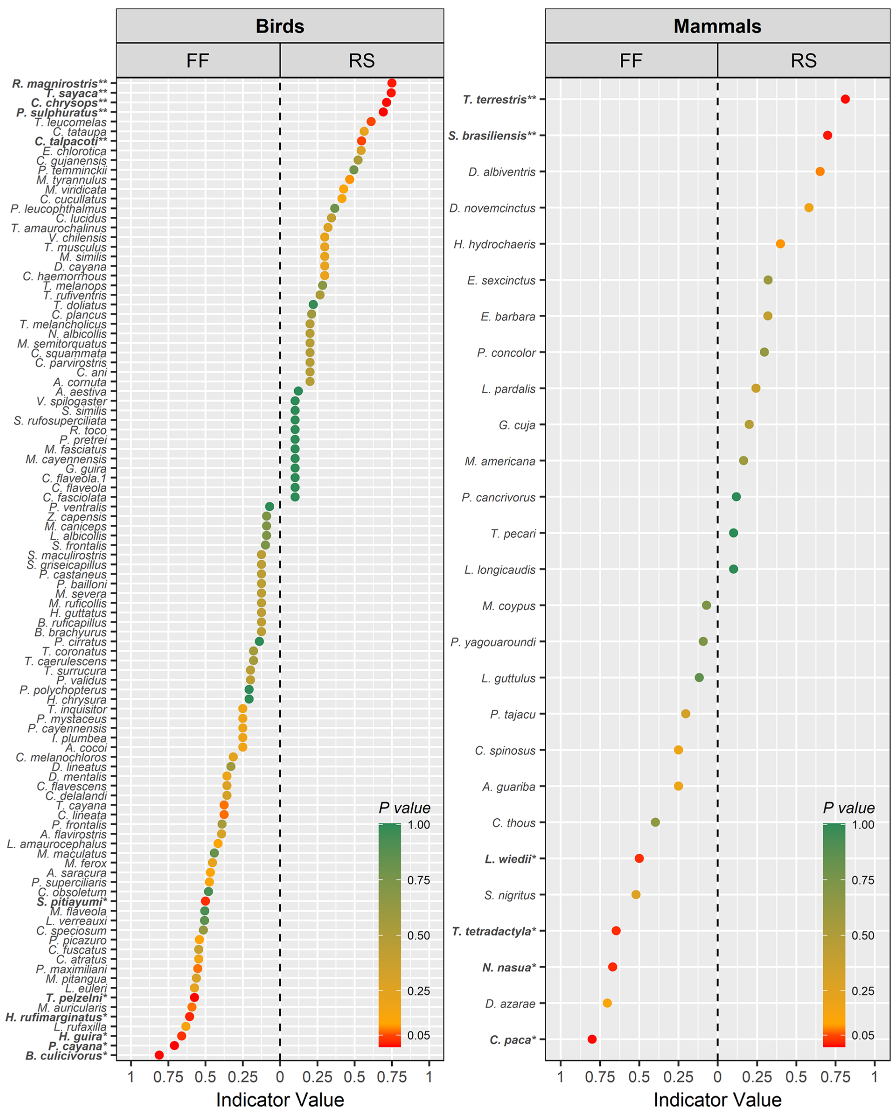

Figure 4. Individual Indicate Value (IndVal) for species of birds and mammals that were recorded in more than 20% of sampled sites (at least 11 sampling sites) in northern Paraná, southern Brazilian Atlantic Forest. FF (Forest Fragment); RS (Restoration Sites). * Indicator species of forest Fragments (FF). ** Indicator species of Restoration Sites (RS).

et al. 2016). However, all the bird and mammal indicator species presented here have high tolerance to forest edge, and therefore should have high potential to colonize restoration sites.

Monitoring of the targeted indicator species could be performed using different field methods to those presented in this study. In the case of birds, acoustic monitoring using autonomous recordings and the use of automatic call recognition using key vocalizations of indicator species is a possibility, especially because of the recent expansion in automated detection methods (see Deichmann et al. 2017, Jorge et al. 2018). Although the costs of autonomous recording equipment can be high, there are cheaper recorders that can be very useful for a variety of situations. For mammals, the monitoring could be focused on the use of camera traps. This equipment is relatively non-invasive, and can remain in the field for long periods of time, produce verifiable data, and offer a highly-repeatable method of data collection (Wearn & Glover-Kapfer 2017).

An important caveat of our study is that we did not evaluate the detectability of species in our field design (see Archaux et al. 2011).

Table IV. Individual Indicate Value (IndVal) of forest fragments (FF) and forest restorations sites (RS) and site of occurrence for selected indicator species of birds and mammal sampled in northern Paraná, southern Brazilian Atlantic Forest.

			Forest Fragments				Restoration Sites				
	FF	**RS**	**AlvFF**	**CghFF**	**IbiFF**	**SanFF**	**Anh1RS**	**Anh2RS**	**Cap1RS**	**Cap2RS**	**CghRS**
Birds											
Basileuterus culicivorus	0.81	0.11	X	X	X	X			X	X	X
Columbina talpacoti	0.01	0.55					X		X	X	X
Cyanocorax chrysops	0.21	0.71	X	X	X		X	X	X	X	X
Hemithraupis guira	0.66	0.12	X		X	X	X			X	X
Herpsilochmus rufimarginatus	0.61	0.00	X		X	X	X				
Piaya cayana	0.71	0.26	X	X	X	X	X	X	X	X	X
Pitangus sulphuratus	0.27	0.69	X	X	X	X	X	X	X	X	
Rupornis magnirostris	0.06	0.75				X	X	X	X	X	X
Setophaga pitiayumi	0.50	0.00	X	X		X					
Tangara sayaca	0.13	0.75	X	X		X	X	X	X	X	X
Thamnophilus pelzelni	0.57	0.43	X	X	X	X	X	X	X	X	X
Mammals											
Cuniculus paca	0.80	0.03	X	X	X	X		X			X
Leopardus wiedii	0.50	0.00		X	X						
Nasua nasua	0.67	0.26	X	X	X	X	X	X		X	X
Sylvilagus brasiliensis	0.00	0.70	X	X	X	X	X	X	X		
Tamandua tetradactyla	0.65	0.10	X	X	X	X	X	X	X		
Tapirus terrestris	0.02	0.81	X	X	X	X	X	X	X	X	X

Species richness is very sensitive to even small differences in mean probability of detection among treatments, with crucial implications in data interpretation (Archaux et al. 2011). In the case of birds, species have a dissimilar probability of being recorded at 100 m ranges during the transect method, leading to imperfect detectability of bird species in our study. However, the selected indicator bird species are known to present high detectability in the north of Paraná, with the exception of *Thamnophilus pelzeni* (see Bochio & Anjos 2012). In the case of mammals, detectability can also be an issue. For example, capture rates using camera traps can be affected by the passive infrared sensor that varies according to camera model. Other factors can also bias capture rates such as habitat type (e.g., vegetation density, open vs closed), temperature, relative humidity, and animal size, which are known to affect the range of the infrared sensor (Kelly & Holub 2008, Rowcliffe et al. 2011, Rovero et al. 2013). Although we did not estimate detectability of mammals, bias should be reduced because we used the same camera model with the same configuration. We also set up cameras at the same height and sampling was carried out during the same period of the year, so bias regarding differences in temperature and relative humidity should also be reduced. However, bias regarding vegetation density (reforestation sites have lower canopy height) and animal size are factors that could have influenced species capture rate.

It is important to highlight that in landscapes with larger forest fragments and high Biotic Integrity, one should expect to find species of conservation concern. Obviously, species of conservation concern should be used as indicators when they are available. There are several indices that incorporate species of conservation concern and that give an accurate measurement of environmental quality, such as the recently presented Indicator Species Score (ISS; see MacKenzie et al. 2018). Here, we presented an alternative for landscapes where species of conservation concern are missing, and we would like to point out that this alternative is only useful in highly fragmented and disturbed landscapes that have suffered great biodiversity loss.

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REFERENCES

ALEXANDRINO ER, BUECHLEY ER, PIRATELLI AJ, PASCHOALETTO KM, FERRAZ MB, MORAL RA, ŞEKERCIOĞLU ÇH, SILVA WR & COUTO HTZ. 2016. Bird sensitivity to disturbance as an indicator of forest patch conditions: An issue in environmental assessments. Ecol Indic 66: 369-381.

ANJOS L. 2006. Bird Species Sensitivity in a Fragmented Landscape of the Atlantic Forest in Southern Brazil. Biotropica 38: 229-234.

ANJOS L, BOCHIO GM, CAMPOS JV, MCCRATE GB & PALOMINO F. 2009. Sobre o uso de níveis de sensibilidade de aves à fragmentação florestal na avaliação da Integridade Biótica: um estudo de caso no norte do Estado do Paraná, sul do Brasil. Rev Bras Ornitol 17: 28-36.

ANJOS L, HOLT RD & ROBINSON S. 2010. Position in the distributional range and sensitivity to forest fragmentation in birds: a case history from the Atlantic forest, Brazil. Bird Conserv Int 20: 392-399.

ARCHAUX F, HENRY PY & GIMENES O. 2011. When can we ignore the problem of imperfect detection in comparative studies? Methods Ecol Evol 3: 188-194.

AUDINO LD, LOUZADA J & COMITA L. 2014. Dung beetles as indicators of tropical forest restoration success: Is it possible to recover species and functional diversity? Biol Conserv 169: 248-257.

BANKS-LEITE C, EWERS RM, KAPOS V, MARTENSEN AC & METZGER JP. 2011. Comparing species and measures of landscape structure as indicators of conservation importance. J Appl Ecol 48: 706-714.

BATISTELI AF, TANAKA MO & SOUZA ALT. 2018. Bird Functional Traits Respond to Forest Structure in Riparian Areas Undergoing Active Restoration. Diversity 10: 90.

BECA G, VANCINE MH, CARVALHO CS, PEDROSA F, ALVES RSC, BRUSCARIOL D, PERES CA, RIBEIRO MC & GALETTI M. 2017. High mammal species turnover in forest patches immersed in biofuel plantations. Biol Conserv 210: 352-329.

BECKER M & DALPONTE JC. 2013. Rastros de mamíferos silvestres brasileiros: um guia de campo. 3[nd] ed, Rio de Janeiro: Technical Books, 172 p.

BIBBY CJ, BURGESS ND & HILL DA. 1992. Bird census technique, London, Academic press limited, UK, 257 p.

BOCHIO GM & ANJOS L. 2012. The Importance of Considering Bird Detectability for Assessing Biological Integrity. Nat Conservação 10: 72-76.

BORGES PAL & TOMÁS WM. 2004. Guia de Rastros e Outros Vestígios de Mamíferos do Pantanal. Corumbá: Embrapa Pantanal, 139 p.

BRANCALION PHS, MELO FPL, TABARELLI M & RODRIGUES RR. 2013. Restoration reserves as biodiversity safeguards in human-modified landscapes. Nat Conservação 11: 186-190.

CARO TM. 2003. Umbrella species: critique and lessons from East Africa. Anim Conserv 6: 171-181.

CASSANO CR, BARLOW J & PARDINI R. 2012. Large Mammals in an Agroforestry Mosaic in the Brazilian Atlantic Forest. Biotropica 44: 818-825.

CASSANO CR, BARLOW J & PARDINI R. 2014. Forest loss or management intensification? Identifying causes of mammal decline in cacao agroforests. Biol Conserv 169: 14-22.

CROSS SL, BATEMAN PW & CROSS AT. 2019. Restoration goals: Why are fauna still overlooked in the process of recovering functioning ecosystems and what can be done about it? Ecol Manag Restor 21: 4-8.

CROUZEILLES R, BEYER HL, MILLS M, GRELLE CEV & POSSINGHAM P. 2015. Incorporating habitat availability into systematic planning for restoration: a species-specific approach for Atlantic Forest mammals. Divers Distrib 21: 1027-1037.

DEICHMANN JL, HERNÁNDEZ-SERN A, DELGADO JAC, CAMPOS-CERQUEIRA M & AIDE TM. 2017. Soundscape analysis and acoustic monitoring document impacts of natural gas exploration on biodiversity in a tropical forest. Ecol Indic 74: 39-48.

DOHERTY JR PF, BOULINIER T & NICHOLS JD. 2003. Local extinction and turnover rates at the edge and interior of species' ranges. Annales Zoologici Fennic 40: 145-153.

DUFRÊNE M & LEGENDRE P. 1997. Species Assemblages and Indicator Species: The Need for a Flexible Asymmetrical Approach. Ecol Monogr 67: 345-366.

FARWIG N, BENDIZ J & BECK E. 2017. Introduction to the Special Issue "Functional monitoring in megadiverse tropical ecosystems". Ecol Indic 83: 524-526.

GANN GD ET AL. 2019. International principles and standards for the practice of ecological restoration. Second edition. Restor Ecol 27(S1): S1-S46.

GENES L, FERNANDEZ FAS, VEZ-DE-MELLO FZ, ROSA P, FERNANDEZ E & PIRES AS. 2018. Effects of howler monkey reintroduction on ecological interactions and processes. Conserv Biol 33: 88-98.

HSIEH TC, MA KH & CHAO A. 2016. iNEXT: An R package for rarefaction and extrapolation of species diversity (Hillnumbers). Methods Ecol Evol 7: 1451-1456.

JORGE FC, MACHADO CG, NOGUEIRA SSC & NOGUEIRA-FILHO SLG. 2018. The effectiveness of acoustic indices for forest monitoring in Atlantic rainforest fragments. Ecol Indic 91: 71-76.

JORGE MLS, GALETTI M, RIBEIRO MC & FERRAZ KMPMB. 2013. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. Biol Conserv 163: 49-57.

KELLY MJ & HOLUB EL. 2008. Camera trapping of carnivores: trap success among camera types and across species, and habitat selection by species, on Salt Pond Mountain, Giles Country, Virginia. Northeast Nat 15: 249-262.

KENUP CF, SEPULVIDA R, KREISCGER C & FERNANDEZ FAS. 2017. Walking on their own legs: unassisted population growth of the agouti *Dasyprocta leporina*, reintroduced to restore seed dispersal in an Atlantic Forest reserve. Oryx 52: 571-578.

LAURANCE WF. 2010. Habitat destruction: Death by a thousand cuts. In: Sodhi NS & Ehrlich PR (Eds), Conservation Biology for All, New York: Oxford Scholarship Online, New York, USA, p. 73-86.

MACKENZIE T, NORMAND L, IWANYCKI N, MILLER G & PRIOR P. 2018. Assessing the utility of a novel terrestrial biodiversity quality indicator with 10 years of monitoring data. Ecol Indic 85: 422-431.

MAGIOLI M, FERRAZ KMPMB & RODRIGUES MG. 2014. Medium and large-sized mammals of an isolated Atlantic Forest remnant, southeast São Paulo State, Brazil. Check List 10: 850-856.

MATTFELDT SD, BAILEY LL & GRANT EHC. 2009. Monitoring multiple species: Estimating state variables and exploring the efficacy of a monitoring program. Biol Conserv 142: 720-737.

METZGER JP ET AL. 2019. Why Brazil needs its Legal Reserves. Perspect Ecol Conserv 17: 91-103.

MORO-RIOS RF, SILVA-PEREIRA JE, SILVA PW, MOURA-BRITTO M & PATROCÍNIO DNM. 2008. Manual de Rastros da Fauna Paranaense. Curitiba: Instituto Ambiental do Paraná, 70 p.

MORRISON EB, LINDELL CA, HOLL KD & ZAHAWI RA. 2010. Using behavioral ecology to assess the quality of tropical forest restoration sites: Patch size effects on avian foraging patterns. J Appl Ecol 47: 130-138.

NOSS RF. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conserv Biol 4: 355-364.

ORME CDL, MAYOR S, ANJOS L, DEVELEY PF, HATFIELD JH, MORANTE-FILHO JC, TYLIANAKIS JM, UEZU A & BANKS-LEITE C. 2019. Distance to range edge determines sensitivity to deforestation. Nat Ecol Evol 3: 886-891.

R DEVELOPMENT CORE TEAM. 2020. R: A Language and Environment for Statistical Computing. Version 3.6.3. R foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

REIS NR, FREGONEZI MN, PERACCHI AL, SHIBATTA OA, SARTORE ER, ROSSANEIS BK, SANTOS VR & FERRACIOLI P. 2014. Mamíferos Terrestres de Médio e Grande Porte da Mata Atlântica. Technical Rio de Janeiro: Books Editora, 146 p.

RIBEIRO MC, METZGER JP, MARTENSEN AC, PONZONI FJ & HIROTA MM. 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol Conserv 142: 1141-1153.

ROBERTS DW. 2016. labdsv: Ordination and Multivariate Analysis for Ecology. R package version 1.8-0. https://CRAN.R-project.org/package=labdsv.

ROVERO F, ZIMMERMANN F, BERZI D & MEEK P. 2013. "Which camera trap type and how many do I need?" A review of camera features and study designs for a range of wildlife research applications. Hystrix 24: 148-156.

ROWCLIFFE MJ, CARBONE C, JANSEN PA, KAYS R & KRANSTAUBER B. 2011. Quantifying the sensitivity of camera traps: an adapted distance sampling approach. Methods Ecol Evol 2: 464-476.

SANTOS JUNIOR PCAS, MARQUES FC, LIMA MR & ANJOS L. 2016. The importance of restoration areas to conserve bird species in a highly fragmented Atlantic forest landscape. Nat Conservação 14: 1-7.

SILVA BG, KOCK I & PIRATELLI AJ. 2020. Fruit and flower availability affect bird assemblages across two successional stages in the Atlantic forest. Stud Neotrop Fauna E 55: 1-13.

SILVA W, DE MARCO J, HASUI E & GOMES V. 2002. Patterns of fruit-frugivore interactions in two Atlantic Forest bird communities of southeastern Brazil: implications for conservation. In: Levey DJ, Silva WR & Galetti M (Eds), Seed dispersal and frugivory: ecology, evolution, and conservation, Wallingford: CABI Publ, Oxford, England p. 423-436.

SOARES FS & MEDRI ME. 2002. Alguns aspectos da colonização da bacia do rio Tibagi. In: Medri ME, Bianchini E, Shibatta OA & Pimenta JA (Eds), A bacia do rio Tibagi. Londrina: Edição dos autores, Paraná, Brasil, p. 69-79.

STRATFORD JÁ & STOUFFER PC. 2013. Microhabitat associations ofterrestrial insectivorous birds in Amazonian rainforest and second-growth forests. J Field Ornithol 84: 1-12.

UEZU A & METZGER JP. 2011. Vanishing bird species in the Atlantic Forest: relative importance of landscape configuration, forest structure and species characteristics. Biodivers Conserv 20: 3627-3643.

WEARN OR & GLOVER-KAPFER P. 2017. Camera-trapping for conservation: a guide to best-practices. WWF Conservation Technology Series 1(1). Woking: WWF-UK, 180 p.

WILLRICH G, CALSAVARA LC, LIMA MR, OLIVEIRA RC, BOCHIO GM, ROSA GLM, MUZI VC & ANJOS L. 2016. Twenty-three years of bird monitoring reveal low extinction and colonization of species in a reserve surrounded by an extremely fragmented landscape in southern Brazil. Rev Bras Ornitol 24: 235-259.

YOCCOZ NG, NICHOLS JD & BOULINIER T. 2001. Monitoring of biological diversity in space and time. Trends Ecol Evol 16: 446-453.

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All authors had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Fernanda Cristina Marques was responsible for the geoprocessing data and the acquisition of field data, and processing and analysis of data for mammals. Gabriela Menezes Bochio was responsible for the acquisition of field data, and processing and analysis of data for birds. Marcos Robalinho Lima was analysis supervisor. Luiz dos Anjos was academic advisor and project supervisor.