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The importance of isolated patches for maintaining local bird biodiversity and ecosystem function: a case study from the Pernambuco Center of Endemism, Northeast Brazil

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ABSTRACT. The Atlantic Forest has been highly fragmented, with the Pernambuco Center of Endemism (PCE) one of the priority areas for conservation. The Mata do Cedro forest, located in Alagoas state, northeastern Brazil, is a forest fragment within the PCE surrounded by a matrix of sugarcane that acts as a refuge for several threatened bird species, some of which are endemic to the region. Here, we characterize the bird community in Mata do Cedro using measures of species abundance, frequency of occurrence, habitat use and sensitivity to human disturbance. The functional role of species was investigated with a functional dendrogram. We registered 111 species, most resident and forest dependent. The most representative trophic categories were insectivores followed by frugivores. Of the species found, 11 are highly sensitive to human disturbances and 11 are endemic to the PCE. The bird community of the fragment is highly diversified, with endemic taxa and balanced trophic categories typical of preserved tropical forests. This community structure together with the occurrence of threatened species reinforces the importance of Mata do Cedro for the maintenance of local biodiversity and ecosystem functions.

KEYWORDS. Atlantic Forest, fragmentation, functional groups, community structure, Alagoas.

RESUMO. A importância dos fragmentos isolados para a manutenção da avifauna local e funções ecossistêmicas: caso de estudo no Centro de Endemismo Pernambuco, Nordeste do Brasil. A Mata Atlântica está altamente fragmentada, sendo o Centro de Endemismo Pernambuco (CEP) uma das áreas prioritárias para a conservação. A Mata do Cedro, localizada no estado de Alagoas, nordeste do Brasil, é um fragmento florestal do CEP rodeado por uma matriz de cana-de-açúcar que atua como refúgio para várias espécies de aves ameaçadas, algumas das quais são endêmicas da região. Este estudo caracterizou a comunidade de aves usando medidas de abundância de espécies, frequência de ocorrência, uso do habitat e sensibilidade aos distúrbios humanos. O papel funcional das espécies foi investigado com um dendrograma funcional. Nós registramos 111 espécies, sendo a maioria residente e dependente de florestas. As categorias tróficas mais representativas foram insetívoros, seguidas por frugívoros. Das espécies registradas, 11 são altamente sensíveis aos distúrbios humanos e 11 são endêmicas do CEP. A comunidade de aves do fragmento é altamente diversificada, com táxons endêmicos e categorias tróficas balanceadas típicas de florestas tropicais conservadas. Esta estrutura da comunidade, juntamente com a ocorrência de espécies ameaçadas, reforça a importância da Mata do Cedro para a manutenção da biodiversidade local e funções ecossistêmicas.

PALAVRAS-CHAVE. Mata Atlântica, fragmentação, grupos funcionais, estrutura de comunidade, Alagoas.

Birds are key players in ecosystems, maintaining crucial ecosystem functions, such as predation, pollination, ecosystem engineering and seed dispersion (Sekercioglu *et al.*, 2004; Sekercioglu, 2006; Whelan *et al.*, 2008). However, in highly fragmented habitats a large number of diet specialized species, such as large frugivores and understory insectivores, perish (Antunes, 2005). In addition, changes in solar radiation, humidity and wind pattern associated with fragmentation are important for many organisms, as well as increases of edge habitats (Ranta *et al.*, 1998). Furthermore, the degree of isolation between fragments can reduce genetic variability of populations and cause functional homogenization, restricting the quality of those fragments throughout time (Clavel *et al.*, 2010).

Indeed, functional structure of bird communities has emerged as one of the key aspects to be considered in studies of habitat fragmentation (Girao *et al.*, 2007; Cadotte *et al.*, 2011). Habitat fragmentation may lead to species loss from smaller fragments (Shaffer, 1981) and, since highly specialized species are generally the most vulnerable to local extinction (Shultz *et al.*, 2005), functional structure analysis may provide a measure of patche quality. Using this concept, is therefore possible to quantify the impact of fragmentation on species in a given area based on the ecological functions they mediate (Griffin *et al.*, 2009).

The Brazilian Atlantic Forest is one of the most threatened biomes in the world due to a long history of deforestation and degradation (Shimamoto *et al.*, 2014).

In the Northeast region, one particular area known as the Pernambuco Center of Endemism (PCE) (Silva *et al.*, 2004) is both biologically rich and highly degraded (Silva & Tabarelli, 2000). The PCE contains only 2% of its original vegetation cover and also suffers from high levels of illegal hunting and trapping of wildlife (Silva & Tabarelli, 2000; Silveira *et al.*, 2003).

In this study, we aim to characterize functional structure of a bird community of a fragmented area of the PCE.

MATERIAL AND METHODS

Study area. The Mata do Cedro Forest fragment (09°31'S, 35°54'W) is situated within the Pernambuco Center of Endemism (PCE), in the municipality of Rio Largo, Alagoas State, northeast Brazil. It is characterized as open ombrophilous forest and covers approximately 1000 ha (Pereira *et al.*, 2014, 2016) surrounded by sugar cane monocultures. Inside the forest there are several clearings undergoing regeneration and a network of wide trails. The middle stratum and canopy have several species of epiphytes and lianas.

Bird Sampling. Bird surveys were conducted from March 2010 to September 2011 using count points (Vielliard & Silva, 1990), with adaptations suggested by Vergara *et al*. (2010). Ten minutes were spent in each point with 2-5 minutes waiting period before starting the recording of contacts to minimize the disturbance of the arrival of the observer to the point. Eighteen points 200 m equidistant from each other were previously selected from preexisting track. Distance between the points was measured with GPS.

During sampling all audio and visual contacts were recorded. The visual contacts were obtained through direct observation with binoculars. The identifications were made based on a field guide (Sigrist, 2009). Vocalizations were recorded with a Sony digital recorder and Yoga directional microphone. Recordings were later analyzed and compared with those available from electronic databases (http://www.xeno-canto.org/). The playback method was used with the aid of an amplifier box and the unknown individual recording vocalization was reproduced in order to lure the animal and make a visual identification.

Samples taken between March 2010 to November 2010 did not follow a standard in sampling effort and served to widen the qualitative survey and help familiarize the researcher with the local avifauna. Samples taken between December 2010 and September 2011 were standardized, so that 10 points were sampled at each visit, drawn from the 18 previously selected points. To obtain the total species richness the records of the entire study (14 visits = 70 hours) were considered, at listening points and outside of these (in moving from one point to another or on active pursuits).

Analysis. A Spot Index of Abundance (IPA) following Vielliard & Silva (1990) was calculated to describe the abundance of each species, considering data from eight visits in the period December 2010 to September 2011 (13.33 hours). The degree of heterogeneity of the area based on proportional abundance of all species in the community was evaluated using the Shannon index. Pielou's evenness index was used to verify the relationship between the diversity observed and the maximum possible diversity for the same number of species. This index was calculated with data from eight visits conducted from December 2010 to September 2011.

The frequency of occurrence (FO) was based on the number of visits, expressed as a percentage, in which each species appeared (Vielliard & Silva 1990). Species with FO greater than or equal to 75% are considered residents and abundant (Aleixo & Vielliard, 1995; Almeida *et al*., 1999). Each species was assigned a category of abundance following Almeida *et al*. (1999): (a) Resident: FO species with over 50%; (b) Occasional: species living in other environments that occasionally exploit a feature of the forest; (c) Wandering: species of irregular occurrence in the woods or that were found only once; (d) Migrating: migratory species.

Regarding habitat use, species were classified based on information obtained from the field, complemented by Ridgely & Tudor (1989, 1994), Silva (1995), Parker *et al*. (1996) and Sick (1997), as forest independent, forest semi-dependent and forest dependent.

Taxa were grouped on their trophic categories according to Traylor & Fitzpatrick (1982), Terborgh *et al*. (1990), Ridgely & Tudor (1989, 1994) and Sick (1997). Preferred foraging stratum (soil, intermediate, superior or vertical) were based on Donatelli *et al*. (2004) and Sick (1997). Sensitivity to human disturbance was assessed by placing species in one of three ordinal categories (high; average and low) following Parker *et al*. (1996). The software Analytic Rarefaction 1.3 (Holland, 2003) was used to calculate the cumulative rarefaction species curve. Based on each species registered (rows) and its respective functional traits (columns), a matrix was constructed for obtaining a functional dendrogram using R software, Picante and Vegan packages (R Core Team, 2014). An adaptation of the Gower Distance (Pavoine *et al*., 2009) was used to calculate similarity. The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) algorithm (Sokal & Michener, 1958) was used for constructing dendrograms and clustering.

Scientific nomenclature follows the recommendations of the Brazilian Ornithological Records Committee (Piacentini *et al.*, 2015). Endemic species of the PCE were identified based on Pereira *et al*. (2016) and endemic Atlantic Forest species were based on Cracraft (1985). The classification of endangered species and their categories was based on the Brazilian Red List (MMA, 2014).

RESULTS

We recorded a total of 111 bird species belonging to 37 families and 15 orders (Tab. I) and the prevailing order was Passeriformes with 69 species. However, the quantitative survey only recorded 89 species, and the associated rarefaction curve does not reach an asymptote, indicating that several species remain undetected (Fig. 1). The IPA by species (Tab. II) ranged between 0.9375 (75 contacts)

Tab. I. List of taxa recorded in the Mata do Cedro, state of Alagoas, Brazil in the study period through qualitative and quantitative sampling with Habitat dependency category - Forest independent (FI), Semi-dependent (SD), Forest dependent (FD); Trophic Category - aquatic (AQ), Scavenger (SC), Frugivorous (FR), Granivores (GR), Insectivorous (IN), Nectarivorous (NC), Omnivores (ON), Predators (PD); Strata - Soil (SL), Intermediate (IN), Superior (SP); Sensitivity to human disturbances – High (H), Average (AV) and Low (L); Threat category and Endemism: Vulnerable (VU), Endangered (EN), Endemic to Pernambuco Center (PC) and Endemic to Atlantic Forest (AT).

Taxa	Hab.	Trop. Cat.	Strata	Sens.	Thr/End
TINAMIFORMES					
Tinamidae					
Crypturellus parvirostris (Wagler, 1827)	FI	FR	SL	L	-
Rhynchotus rufescens (Temminck, 1815)	FI	FR	SL	L	-
PELECANIFORMES					
Ardeidae					
Butorides striata (Linnaeus, 1758)	FI	AQ	SL	L	-
CATHARTIFORMES					
Cathartidae					
Cathartes aura (Linnaeus, 1758)	FI	SC	SP	L	-
Cathartes burrovianus Cassin, 1845	FI	SC	SP	A	-
Coragyps atratus (Bechstein, 1793)	FI	SC	SP	L	-
ACCIPITRIFORMES					
Accipitridae					
Leptodon forbesi (Swann, 1922)	FD	PD	SP	A	EN
Geranospiza caerulescens (Vieillot, 1817)	SD	PD	SP	A	-
Rupornis magnirostris (Gmelin, 1788)	FI	PD	SP	L	-
Geranoaetus albicaudatus (Vieillot, 1816)	FI	PD	SP	L	-
Buteo brachyurus Vieillot, 1816	SD	PD	SP	A	-
Buteo albonotatus Kaup, 1847	FD	PD	SP	A	-
CHARADRIIFORMES					
Charadriidae					
Vanellus chilensis (Molina, 1782)	FI	AQ	SL	L	-
COLUMBIFORMES					
Columbidae					
Columbina talpacoti (Temminck, 1811)	FI	GR	SL	L	-
Patagioenas speciosa (Gmelin, 1789)	FD	FR	SP	A	-
Leptotila rufaxilla (Richard & Bernard, 1792)	FD	FR	IN	A	-
Geotrygon montana (Linnaeus, 1758)	FD	FR	SL	A	-
CUCULIFORMES					
Cuculidade					
Piaya cayana (Linnaeus, 1766)	SD	IN	SP	L	-
Crotophaga ani Linnaeus, 1758	FI	IN	IN	L	-
Tapera naevia (Linnaeus, 1766)	FI	IN	IN	L	-
CAPRIMULGIFORMES					
Caprimulgidae					
Nyctidromus albicollis (Gmelin, 1789)	SD	IN	SL	L	-
APODIFORMES					
Trochilidae					
Glaucis hirsutus (Gmelin, 1788)	FD	NC	IN	L	-
Phaethornis ruber (Linnaeus, 1758)	FD	NC	IN	A	-
Phaethornis pretrei (Lesson & Delattre, 1839)	SD	NC	IN	L	-
Anthracothorax nigricollis (Vieillot, 1817)	SD	NC	SP	L	-
Chrysolampis mosquitus (Linnaeus, 1758)	SD	NC	IN	L	-
Chlorestes notata (Reich, 1793)	FD	NC	IN	L	-
Thalurania watertonii (Bourcier, 1847)	FD	NC	IN	A	EN, AT
CORACIIFORMES					
Alcedinidae					
Chloroceryle amazona (Latham, 1790)	SD	AQ	IN	L	-
Chloroceryle americana (Gmelin, 1788)	SD	AQ	IN	L	-
Momotidae					
Momotus momota marcgrviana Pinto & Camargo, 1961	FD	IN	SP	A	EN, PC
GALBULIFORMES					
Galbulidae					

Tab. I. Cont.

Taxa	Hab.	Trop. Cat.	Strata	Sens.	Thr/End
Galbula ruficauda Cuvier, 1816	FD	IN	IN	L	-
PICIFORMES					
Ramphastidae					
Pteroglossus aracari (Linnaeus, 1758)	FD	FR	SP	A	-
Picidae					
Picumnus pernambucensis Zimmer, 1947	FD	IN	IN	A	PC
Veniliornis affinis (Swainson, 1821)	FD	IN	IN	A	-
Veniliornis passerinus (Linnaeus, 1766)	SD	IN	IN	L	-
FALCONIFORMES					
Falconidae					
Caracara plancus (Miller, 1777)	FI	PD	SL	L	-
Milvago chimachima (Vieillot, 1816)	FI	PD	SP	L	-
Herpetotheres cachinnans (Linnaeus, 1758)	SD	PD	SP	L	-
Micrastur ruficollis (Vieillot, 1817)	FD	PD	IN	A	-
PSITTACIFORMES					
Psittacidae					
Diopsittaca nobilis (Linnaeus, 1758)	SD	FR	SP	A	-
PASSERIFORMES					
Thamnophilidae					
Myrmotherula axillaris (Vieillot, 1817)	FD	IN	IN	A	-
Formicivora grisea (Boddaert, 1783)	SD	IN	IN	L	-
Dysithamnus mentalis (Temminck, 1823)	FD	IN	IN	A	-
Herpsilochmus rufimarginatus (Temmick, 1822)	FD	IN	SP	A	-
Thamnophilus aethiops distans Pinto, 1954	FD	IN	SL	H	EN, PC
Myrmoderus ruficauda soror Pinto, 1940	FD	IN	SL	A	EN, PC
Pyriglena pernambucensis Zimmer, 1931	FD	IN	SL	A	VU, PC
Conopophagidae					
Conopophaga melanops nigrifrons Pinto, 1954	FD	IN	IN	H	VU, PC
Formicariidae					
Formicarius colma Boddaert, 1783	FD	IN	SL	H	-
Dendrocolaptidae					
Dendrocincla taunayi Pinto, 1939	FD	IN	IN	H	EN, PC
Sittasomus griseicapillus (Vieillot, 1818)	FD	IN	IN	A	-
Xiphorhynchus guttatus (Lichtenstein, 1820)	FD	IN	IN	A	-
Dendroplex picus (Gmelin, 1788)	SD	IN	IN	L	-
Xenopidae					
Xenops minutus alagoanus Pinto, 1954	FD	IN	IN	A	VU, PC
Furnariidae					
Synallaxis frontalis Pelzeln, 1859	SD	IN	IN	L	-
Pipridae					
Neopelma pallescens (Lafresnaye, 1853)	FD	FR	IN	A	-
Ceratopipra rubrocapilla (Temminck, 1821)	FD	FR	SP	H	-
Manacus manacus (Linnaeus, 1766)	FD	FR	IN	L	-
Chiroxiphia pareola (Linnaeus, 1766)	FD	FR	IN	H	-
Tityridae					
Schiffornis turdina intermedia Pinto, 1954	FD	FR	IN	H	VU, PC
Platyrinchidae					
Platyrinchus mystaceus niveigularis Pinto, 1954	FD	IN	IN	H	VU, PC
Rhynchocyclidae					
Mionectes oleagineus (Lichtenstein, 1823)	SD	FR	IN	A	-
Leptopogon amaurocephalus Tschudi, 1846	FD	FR	IN	A	-
Tolmomyias poliocephalus (Taczanowski, 1884)	FD	IN	SP	A	-
Tolmomyias flaviventris (Wied, 1831)	FD	IN	SP	L	-
Todirostrum cinereum (Linnaeus, 1766)	SD	IN	IN	L	-
Hemitriccus griseipectus naumburgae (Zimmer, 1945)	FD	IN	IN	H	VU, PC
Tyrannnidae					
Ornithion inerme Hartlaub, 1853	FD	IN	SP	A	-
Camptostoma obsoletum (Temminck, 1824)	FI	IN	SP	L	-

Tab. I. Cont.

Taxa	Hab.	Trop. Cat.	Strata	Sens.	Thr/End
Elaenia flavogaster (Thunberg, 1822)	SD	FR	SP	L	-
Myiopagis gaimardii (d'Orbigny, 1839)	FD	FR	SP	A	-
*Myiopagis caniceps (*Swainson, 1835*)*	FD	FR	SP	A	-
Capsiempis flaveola (Lichtenstein, 1823)	SD	IN	IN	L	-
Attila spadiceus (Gmelin, 1789)	FD	IN	SP	A	-
Legatus leucophaius (Vieillot, 1818)	FD	FR	IN	L	-
Myiarchus ferox (Gmelin, 1789)	SD	IN	IN	L	-
Rhytipterna simplex (Lichtenstein, 1823)	FD	IN	IN	H	-
Pitangus sulphuratus (Linnaeus, 1766)	FI	IN	SP	L	-
Megarynchus pitangua (Linnaeus, 1766)	FD	IN	SP	L	-
Myiozetetes similis (Spix, 1825)	SD	IN	SP	L	-
Tyrannus melancholicus Vieillot, 1819	FI	IN	SP	L	-
Arundinicola leucocephala (Linnaeus, 1764)	FI	IN	IN	A	-
Lathrotriccus euleri (Cabanis, 1868)	FD	IN	IN	A	-
Vireonidae					
Cyclarhis gujanensis (Gmelin, 1789)	FD	IN	IN	L	-
Vireo chivi (Vieillot, 1817)	FD	IN	IN	L	-
Hirundinidae					
Stelgidopteryx ruficollis (Vieillot, 1817)	FI	IN	SP	L	-
Progne tapera (Vieillot, 1817)	FI	IN	SP	L	-
Tachycineta albiventer (Boddaert, 1783)	FI	IN	IN	A	-
Hirundo rustica Linnaeus, 1758	FI	IN	SP	L	-
Troglodytidae					
Troglodytes musculus Naumann, 1823	FI	IN	IN	L	-
Pheugopedius genibarbis (Swainson, 1838)	FD	ON	IN	L	-
Donacobiidae					
Donacobius atricapilla (Linnaeus, 1766)	FI	IN	IN	A	-
Turdidae					
Turdus leucomelas Vieillot, 1818	SD	ON	IN	L	-
Turdus fumigatus Lichtenstein, 1823	FD	ON	IN	A	-
Passerellidae					
Ammodramus humeralis (Bosc, 1792)	FI	GR	SL	L	-
Arremon taciturnus (Hermann, 1783)	FD	ON	SL	L	-
Parulidae					
Basileuterus culicivorus (Deppe, 1830)	FD	IN	IN	A	-
Thraupidae					
Tangara palmarum (Wied, 1823)	SD	FR	SP	L	-
Nemosia pileata (Boddaert, 1783)	SD	FR	SP	L	-
Hemithraupis guira (Linnaeus, 1766)	FD	FR	SP	L	-
Volatinia jacarina (Linnaeus, 1766)	FI	GR	IN	L	-
Lanio cristatus (Linnaeus, 1766)	FD	FR	SP	A	-
Dacnis cayana (Linnaeus, 1766)	FD	FR	SP	L	-
Coereba flaveola (Linnaeus, 1758)	SD	NC	SP	L	-
Saltator maximus (Statius Muller, 1776)	FD	ON	IN	L	-
Fringillidae					
Euphonia chlorotica (Linnaeus, 1766)	SD	FR	SP	L	-
Euphonia violacea (Linnaeus, 1758)	FD	FR	SP	L	-
Estrildidae					
Estrilda astrild (Linnaeus, 1758)	FI	GR	IN	L	-

for Blue-backed Manakin *Chiroxiphia pareola* and 0.0125 (one contact) in 16 species whereas the value of the diversity index was 3.87 and the evenness index was 0.86.

The frequency of occurrence of the 89 species recorded in the quantitative survey revealed that 12 species had 100% FO and 14 had 12.5% FO (one contact). The category of abundance (status) of these species consisted of 66% resident species, 16% wandering, 13% occasional and 4% migrating species (Tab. II). Forest dependent species were the most represented, making up 51.35% of records (n = 57). Semi-dependent (n = 27) and independent (n = 27) species corresponded to the same percentage (24.32%) (Tab. I).

Tab. II. Spot Index of Abundance (IPA) found for each species based on count points, frequency of occurrence (FO) and status: resident (RE), occasional (OC), wandering (WA) and migration (MI) in the Mata do Cedro, state of Alagoas, Brazil.

Taxa	Total of contacts	IPA	FO%	*Status*
Crypturellus parvirostris (Wagler, 1827)	3	0.04	37.50	OC
Butorides striata (Linnaeus, 1758)	1	0.01	25.00	OC
Cathartes aura (Linnaeus, 1758)	2	0.03	50.00	OC
Cathartes burrovianus Cassin, 1845	3	0.04	37.50	OC
Coragyps atratus (Bechstein, 1793)	3	0.04	25.00	OC
Leptodon forbesi (Swann, 1922)	2	0.03	12.50	WA
Geranospiza caerulescens (Vieillot, 1817)	1	0.01	12.50	WA
Rupornis magnirostris (Gmelin, 1788)	2	0.03	25.00	OC
Caracara plancus (Miller, 1777)	5	0.06	25.00	OC
Herpetotheres cachinnans (Linnaeus, 1758)	1	0.01	12.50	WA
Micrastur ruficollis (Vieillot, 1817)	3	0.04	37.50	RE
Vanellus chilensis (Molina, 1782)	5	0.06	37.50	OC
Patagioenas speciosa (Gmelin, 1789)	13	0.16	100.00	RE
Leptotila verreauxi Bonaparte, 1855	1	0.01	12.50	WA
Leptotila rufaxilla (Richard & Bernard, 1792)	1	0.01	12.50	WA
Geotrygon montana (Linnaeus, 1758)	2	0.03	37.50	RE
Diopsittaca nobilis (Linnaeus, 1758)	8	0.10	87.50	RE
Piaya cayana (Linnaeus, 1766)	10	0.13	75.00	RE
Crotophaga ani Linnaeus, 1758	2	0.03	37.50	OC
Tapera naevia (Linnaeus, 1766)	1	0.01	12.50	WA
Glaucis hirsutus (Gmelin, 1788)	1	0.01	12.50	V
Phaethornis ruber (Linnaeus, 1758)	9	0.11	75.00	RE
Phaethornis pretrei (Lesson & Delattre, 1839)	1	0.01	12.50	WA
Chlorostilbon notatus (Reich, 1793)	2	0.03	25.00	RE
Thalurania watertonii (Bourcier, 1847)	1	0.01	12.50	WA
Chloroceryle amazona (Latham, 1790)	1	0.01	12.50	WA
Galbula ruficauda Cuvier, 1816	5	0.06	62.50	RE
Pteroglossus aracari (Linnaeus, 1758)	1	0.01	12.50	WA
Picumnus pernambucensis Zimmer, 1947	13	0.16	75.00	RE
Veniliornis affinis (Swainson, 1821)	2	0.03	25.00	RE
Veniliornis passerinus (Linnaeus, 1766)	2	0.03	25.00	RE
Myrmoderus ruficauda soror Pinto, 1940	1	0.01	25.00	RE
Myrmotherula axillaris (Vieillot, 1817)	16	0.20	100.00	RE
Formicivora grisea (Boddaert, 1783)	8	0.10	100.00	RE
Dysithamnus mentalis (Temminck, 1823)	13	0.16	87.50	RE
Herpsilochmus rufimarginatus (Temminck, 1822)	26	0.33	100.00	RE
Thamnophilus aethiops distans Pinto, 1954	13	0.16	87.50	RE
Pyriglena pernambucensis Zimmer, 1931	12	0.15	87.50	RE
Conopophaga melanops nigrifrons Pinto, 1943	12	0.15	100.00	RE
Formicarius colma Boddaert, 1783	6	0.08	75.00	RE
Dendrocincla taunayi Pinto, 1939	4	0.05	25.00	RE
Xiphorhynchus guttatus (Lichtenstein, 1820)	26	0.33	12.50	WA
Dendroplex picus (Gmelin, 1788)	1	0.01	100.00	RE
Xenops minutus alagoanus Pinto, 1954	10	0.13	25.00	RE
Neopelma pallescens (Lafresnaye, 1853)	6	0.08	87.50	RE
Ceratopipra rubrocapilla Temminck, 1821	47	0.59	62.50	RE
Manacus manacus (Linnaeus, 1766)	10	0.13	100.00	RE
Chiroxiphia pareola (Linnaeus, 1766)	75	0.94	62.50	RE
Schiffornis turdina intermedia Pinto, 1954	19	0.24	100.00	RE
Platyrinchus mystaceus niveigularis Pinto, 1954	15	0.19	100.00	RE
Mionectes oleagineus (Lichtenstein, 1823)	3	0.04	75.00	RE
Leptopogon amaurocephalus Tschudi, 1846	5	0.06	50.00	RE
Tolmomyias poliocephalus (Taczanowski, 1884)	13	0.16	62.50	RE
Tolmomyias flaviventris (Wied, 1831)	53	0.66	75.00	RE
Hemitriccus griseipectus naumburgae (Zimmer, 1945)	28	0.35	100.00	RE
Ornithion inerme Hartlaub, 1853	3	0.04	100.00	RE
Elaenia flavogaster (Thunberg, 1822)	4	0.05	37.50	RE

Tab. II. Cont.

Taxa	Total of contacts	IPA	FO%	*Status*
Myiopagis gaimardii (d'Orbigny, 1839)	7	0.09	62.50	RE
Myiopagis caniceps (Swainson, 1835)	4	0.05	62.50	RE
Attila spadiceus (Gmelin, 1789)	8	0.10	37.50	RE
Legatus leucophaius (Vieillot, 1818)	6	0.08	75.00	RE
Myiarchus ferox (Gmelin, 1789)	1	0.01	37.50	RE
Rhytipterna simplex (Lichtenstein, 1823)	16	0.20	25.00	RE
Pitangus sulphuratus (Linnaeus, 1766)	8	0.10	87.50	RE
Megarynchus pitangua (Linnaeus, 1766)	6	0.08	87.50	RE
Myiozetetes similis (Spix, 1825)	10	0.13	62.50	RE
Tyrannus melancholicus Vieillot, 1819	4	0.05	87.50	RE
Lathrotriccus euleri (Cabanis, 1868)	2	0.03	75.00	RE
Cyclarhis gujanensis (Gmelin, 1789)	2	0.03	25.00	RE
Vireo chivi (Vieillot, 1817)	30	0.38	50.00	OC
Stelgidopteryx ruficollis (Vieillot, 1817)	4	0.05	75.00	MI
Progne tapera (Vieillot, 1817)	7	0.09	50.00	MI
Tachycineta albiventer (Boddaert, 1783)	3	0.04	37.50	MI
Hirundo rustica Linnaeus, 1758	1	0.01	75.00	OC
Pheugopedius genibarbis (Swainson, 1838)	47	0.59	25.00	MI
Coereba flaveola (Linnaeus, 1758)	13	0.16	100.00	RE
Saltator maximus (Statius Muller, 1776)	12	0.15	75.00	RE
Nemosia pileata (Boddaert, 1783)	3	0.04	87.50	RE
Lanio cristatus (Linnaeus, 1766)	8	0.10	50.00	RE
Tangara palmarum (Wied, 1823)	7	0.09	87.50	RE
Dacnis cayana (Linnaeus, 1766)	7	0.09	75.00	RE
Hemithraupis guira (Linnaeus, 1766)	3	0.04	75.00	RE
Ammodramus humeralis (Bosc, 1792)	2	0.03	12.50	WA
Volatinia jacarina (Linnaeus, 1766)	2	0.03	12.50	WA
Arremon taciturnus (Hermann, 1783)	3	0.04	37.50	RE
Basileuterus culicivorus (Deppe, 1830)	5	0.06	62.50	RE
Euphonia chlorotica (Linnaeus, 1766)	1	0.01	25.00	OC
Euphonia violacea (Linnaeus, 1758)	11	0.14	75.00	RE

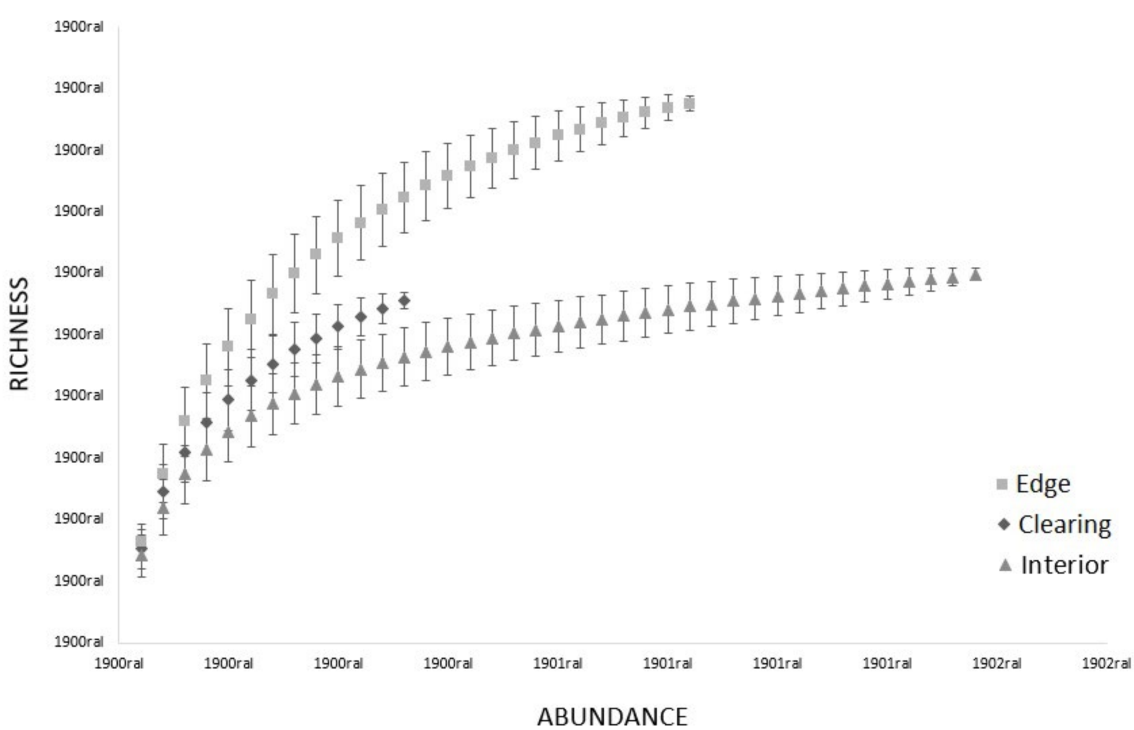

Fig. 1. Rarefaction curve based at Mata do Cedro abundance and richness, state of Alagoas, Brazil.

Insectivores (46% n = 51) and frugivorous (23% n = 26) were the most significant trophic categories with other categories accounting for 31% of species.

Intermediate and superior strata were most used, with 80% of the species occupying these two strata. The soil stratum was occupied by 14 species (13%) with eight species (7%) using the vertical stratum. Of all species registered, 11 (10%) showed high, 39 (35%) had average and 61 (55%) had low sensitivity to human disturbance. Twelve species are classified as threated and 11 are considered endemic to the PCE and the Atlantic Forest.

The dendrogram separated one species (the Common Waxbill *Estrilda astrild* Linnaeus, 1758) by its grazing habit; and grouped the others according to their different diets and foraging habits (Fig. 2).

DISCUSSION

The bird community of Mata de Cedro is highly diverse, with the presence of endemic and threatened taxa, balanced trophic categories: characteristics of communities in well preserved tropical forests. Our results therefore reinforce the importance of Mata do Cedro for the maintenance of local biodiversity and highlight their probable role as stepping stones for birds moving through this highly fragmented region. Previous studies in Mata do Cedro identified 45 forest dependent species, 11 PCE endemics and 12 threatened taxa (Pereira *et al*. 2016), strongly corroborating the results of the present work.

Compared to previous studies in the PCE, the present study found higher species richness than Lyra-Neves *et al*. (2004), and Lobo-Araújo *et al*. (2013), probably due to particularities of different forest types, the small sizes of the fragments or differences in sampling effort and methodologies. Conversely, Roda (2004), Magalhães *et al*. (2007) and Farias *et al*. (2007) recorded higher values of 125, 151 and 140 species, respectively, in contrast to the 111 found in this study. In Alagoas, Daher *et al*. (2013) registered 150 and 110 species in Madeiras and Fazenda Brejo, respectively. The application of long term studies and the adoption of different sampling methods may further improve our knowledge of species richness in highly diverse areas such as the Atlantic Forest (Moraes *et al*., 2007).

The observed abundance patterns are consistent with the literature, with few species showing high values and large number of species showing intermediate and low values (Donatelli *et al*., 2004; Lyra-Neves *et al*., 2004; Dario, 2010). These results are typical of bird communities in tropical forests, with high species richness and low number of individuals in each species, except for some naturally abundant taxa (Donatelli *et al*., 2004). Likewise, the diversity and evenness indices indicate that most species are equally abundant in the environment (Magurran, 1988), supporting similar findings by Vielliard & Silva (1990) (H' = 3.89 and E = 0.83 for a forest fragment of 592 ha) - considered normal for effectively sampled neotropical forest environments. Indeed, the larger the forest fragment, the greater its diversity indices due to the complexity of the environment and availability of niches (Roda, 2004). In fragments smaller than 100 ha, diversity is reduced dramatically due to edge effects and the strong inflow of generalist species.

Several resident and forest dependent species were registered in Mata do Cedro. However, most were classified as wandering, occasional or migratory species. In addition, we recorded several species that are typically found in open areas such as fields and wetlands (24%), demonstrating the importance of this fragment for reducing isolation and therefore increasing persistence across wider spatial and temporal scales (Saura *et al*., 2014).

Forest fragments are both directly and indirectly affected by their isolation, size and shape, type of surrounding matrix and edge effect (Bierregaard *et al*., 1992; Ranta *et al*., 1998). As a consequence, birds populations can be reduced or become locally extinct; processes that particularly effect insectivorous understory taxa, large frugivores and raptors (Aleixo & Vielliard, 1995; Offerman *et al*., 1995; Jullien & Thiollay, 1996). In 2002, Silveira *et al*. (2003) recorded 78 species for the Mata do Cedro, 15 of which were not sampled in this study. Among these is the Bearded Bellbird *Procnias averano* (Hermann, 1783) and Lettered Aracari *Pteroglossus inscriptus* Swainson, 1822, both large frugivores. Their absence may be evidence of local extinction caused by pressures in the area such as hunting, captivity and other effects discussed above.

A total of 10 recorded species were classified as highly sensitive to human disturbance. Although this number is lower than that found by Lyra-Neves *et al*. (2004) (16) and Rodrigues *et al*. (2007) (17) in other areas of the PCE, the presence of these species indicate good conservation conditions (Roda, 2004) of the Mata do Cedro. The low abundance (mean IPA = 0.3 ± 0.3) of these species may be related to a greater sensitivity to forest fragmentation (Anjos, 2006). Besides that, such sensitivity can increase the risk of local extinction (e.g. Purvis *et al*., 2000) and their presence should be used to assign conservation priorities (Anjos *et al*., 2011). The presence of these species also demonstrates the importance of the Mata do Cedro for local conservation of these populations. It is also important to note that even such an isolated forest fragment can provide an important refuge for sensitive species, facilitating long-distance dispersal and functioning as stepping stones to other forest patches (Uezu *et al*., 2008; Kramer-Schadt *et al*., 2011).

Similarly, mapping trophic relationships is important for evaluating a bird community (Rodrigues *et al*., 2007). Most species in Mata do Cedro were insectivores or frugivores. These results corroborate previous studies (Piratelli & Pereira, 2002; Donatelli *et al*., 2004; Roda, 2004; Roda & Pereira, 2005), who claim that this distribution is characteristic of well-preserved tropical forests. Other authors, however, have shown a predominance of insectivores and omnivores in tropical bird communities (Telino-Jr *et al*., 2005; Rodrigues *et al*., 2007; Dario, 2008).

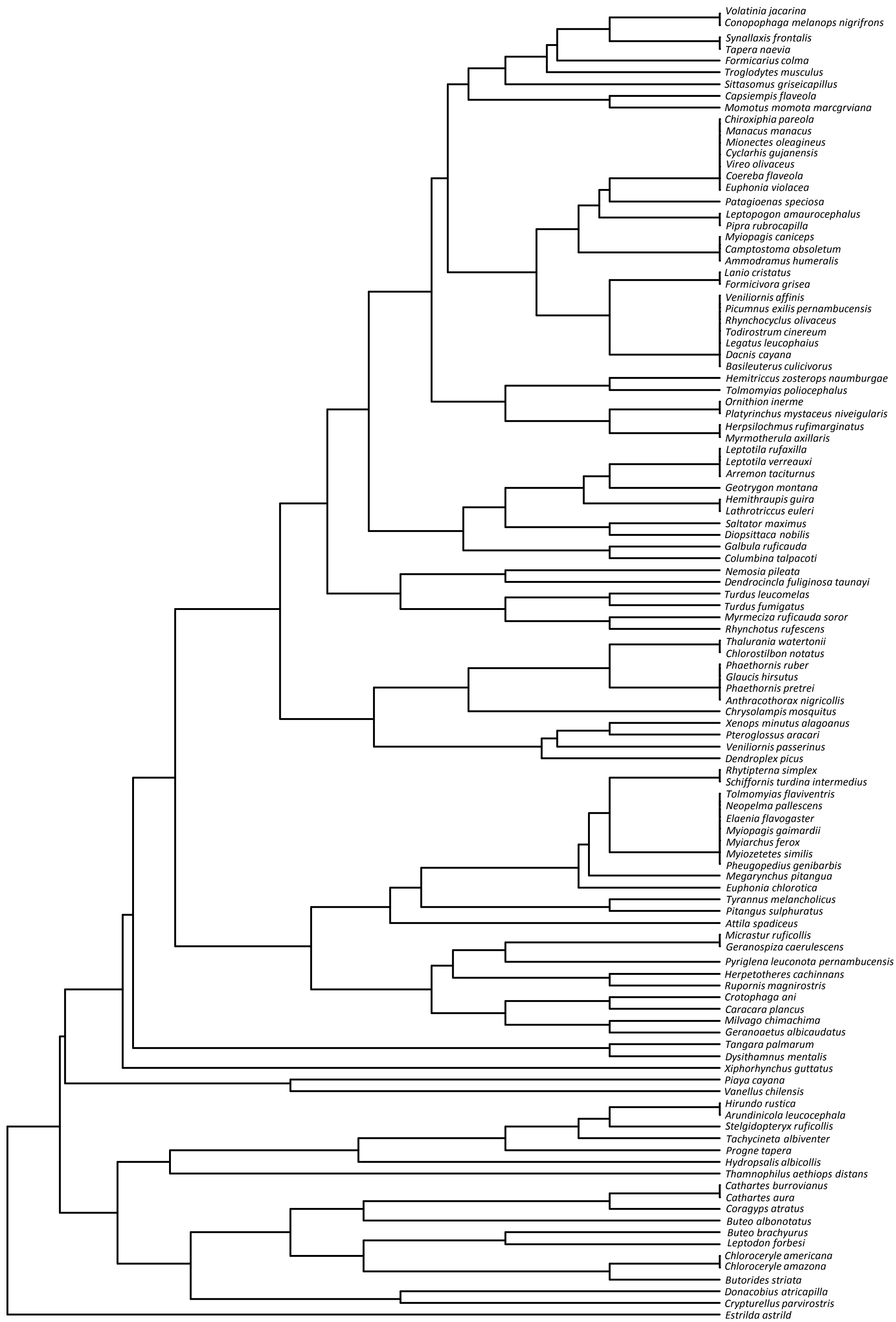

Fig. 2. Functional dendrogram of species of birds found at Mata do Cedro, state of Alagoas, Brazil.

In this study approximately 57% (n = 29) of insectivores were forest dependent, particularly climbers of trunks and branches or relying on understory and soil strata. The latter comprise the forest dependent species with limited dispersal ability and so are strongly affected by fragmentation, changes in vegetation structure and loss of associated organisms, such as ants (Silveira *et al.*, 2003). According to Willis (1979) environmental changes can lead to increases in omnivorous birds and less specialized insectivores and a decrease of more specialized frugivores and insectivores.

The Bearded Bellbird *Procnias averano* (Hermann, 1783) seems to be locally extinct and *Pteroglossus aracari* (Linnaeus, 1758) was only registered with one individual. In addition, of the three recorded terrestrial frugivores, two (Small-billed Tinamou *Crypturellus parvirostris* (Wagler, 1827) and Red-winged Tinamou *Rhynchotus rufescens* (Temmick, 1815)) are forest independent and the third (the Ruddy Quail-Dove *Geotrygon montana* (Linnaeus, 1758)) is forest dependent and is restricted to the area and neighboring fragments. In fact, despite being able to move between fragments in search of food, large frugivores may not be able to cross the surrounding matrix (Roda, 2004). So, the reduction in habitat may be responsible for the loss of species that require large areas of forest (Aleixo & Vielliard, 1995), such as the large frugivores and large predators (S. A. Roda, dados inéditos).

We recorded 10 species of raptors, among them *Leptodon forbesi*, an endemic of the Atlantic Forest and severely threatened in northeast Brazil (F. V. Dénes, dados inéditos). Predators have high influence on prey distributions, since perceived risk of predation can affect prey behavior (Sodhi, 1990), stabilize predator-prey dynamics (Ives & Dobson, 1987) and lead to higher species richness via competitive coexistence (Brown *et al*., 1988). Furthermore, predator species have a functional role related to the recycling of carcasses and limiting the spread of diseases and undesirable mammalian scavengers (Prakash *et al*., 2003). Therefore, once again, the data obtained in this study demonstrates the importance of these species for the ecological functioning and conservation of the habitat and for the PCE in general, where the situation of birds of prey is very worrying (see Roda & Pereira, 2006).

In addition, we recorded ten species of granivores and omnivores, with six forest dependents and one (Red-shouldered Macaw *Diopsittaca nobilis* Linaeus, 1758) with medium sensitivity to disturbances. All others were classified as having low sensitivity. Granivory plays a crucial role in the regeneration, colonization ability and spatial distribution of plants. In addition, granivores have been suggested as agents of natural selection, influencing seed trait and seed production strategies (chemical compounds, growth rate) (Hulme & Benkman, 2002). Therefore, the dispersal of seeds by birds facilitates the regeneration of deforested and other marginal habitats (Sekercioglu, 2006), and the presence of these species in the fragment is therefore important for ecosystem functioning.

Similarly, the presence of seven species of nectarivores in the study site is a positive signal for conservation. Bird species pollinate approximately 500 genera of vascular plants (Sekercioglu, 2006). In addition, to meet their high energy needs, they visit numerous flowers regularly, which increases gene flow among plants (Schuchmann, 1999). Avian pollination has ecological, economic, evolutionary and conservation significance in species-rich communities such as tropical forests. Amongst the nectarivores at the study site, the Long-tailed Woodnymph *Thalurania watertonii* (Bourcier, 1847) is considered a vulnerable species endemic to the Atlantic forest, with medium sensitivity to disturbances. Its conservation, along with the other species responsible for this functional role, will help to maintain the local plant community and the conservation of the fragment. Recently, the hummingbird *Phaethornis margarettae camargoi* Grantsau, 1988 was recorded in the Mata do Cedro (G. A. Pereira, dados inéditos). This hummingbird is considered critically endangered, and there is little information about its natural history and geographical distribution (G. A. Pereira, dados inéditos).

The functional groups responsible for the consumption of insects (gleaning, gleaning on air, gleaning on soil and vegetation, probing soil and vegetation, pouncing on soil and vegetation) are extremely important for the maintenance of the fragment, due to their effects on herbivorous arthropods, since these strongly impact plants and their associated nutritional cycles (Bohm *et al*., 2011). In addition, herbivorous arthropods can reduce leaf area through feeding activities and hence affect the biomass of trees (Bohm *et al*., 2011). Van Bael *et al*. (2008) fond that foliage-gleaning birds can limit herbivorous arthropod densities and their damage to plants in tropical forests. In tropical systems, species richness of insectivorous birds is the main controlling factor for arthropods, because species richness of predators correlates with functional richness (Van Bael *et al*., 2008). Hence, higher species richness of predators increases the probability that highly efficient species are present (Perfecto, 2004; Philpott *et al*., 2009). At our study site, 75 insectivorous and omnivorous bird species were recorded, including species that adopted gleaning, probing and pouncing strategies. Ten of these species are threatened and all of these are restricted to the PCE and have medium and high sensitivity to disturbances and occupy various strata.

Bohm *et al*. (2011) showed that top-down control of leaf damage depends on predator diversity. Changes in species richness and abundance of birds through human induced changes in land use might therefore have far-reaching consequences for ecosystem functioning and services, as a decrease in species richness is likely to lead to a steep increase in the abundance of arthropod herbivores. In turn, this might influence the intensity of leaf damage and, ultimately, forest productivity. Hence, the maintenance of insectivorous birds at Mata do Cedro is crucial for its long-term conservation.

The function of predators in food webs is assumed to be positively related with species richness and abundance (Bohm *et al*., 2011). Habitat fragmentation causes local extinction and has long-term effects on populations through changes in ecological processes. As a result, fragmented ecosystems usually fail to support species assemblages found in intact ecosystems (Lovejoy *et al*., 1984). Due to its complex ecological structure and high species diversity, species loss through fragmentation is especially high in tropical forests (Wilcove *et al*., 1986). In addition, declines in bird populations, even before they are well studied, can rapidly diminish certain ecosystem processes, such as seed dispersal, plant growth and nutrient cycling (Sekercioglu, 2006). The Atlantic Forest currently exists as isolated fragments. Conservation efforts must focus on the remaining fragments, such as the Mata do Cedro, which are important in reducing regional isolation, functioning as stepping stones. (Schelhas & Greenberg, 1996; Ribeiro *et al*., 2009).

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