Acta Brasiliensis 4(2): 91-98, 2020
http://revistas.ufcg.edu.br/ActaBra
Artigo Original
http://dx.doi.org/10.22571/2526-4338305

Bird assembly in reforested restinga areas

Erich de Freitas Mariano[a*], Arnaldo Honorato Vieira-Filho[b], Gustavo Alves Toledo da Costa[c], Helder Farias Pereira de Araujo[d], Malva Isabel Medina Hernández[e]

[a] *Laboratório de Pesquisa em Ensino, Zoologia e Conservação, Universidade Federal de Campina Grande, Patos, 58708-110, Paraíba, Brasil. *efmariano.ufcg@gmail.com*
[b] *Programa de Pós-Graduação em Ciências Biológicas, Universidade Federal da Paraíba, João Pessoa, 58051-900, Paraíba, Brasil.*
[c] *Programa de Pós-graduação em Psicobiologia, Universidade Federal do Rio Grande do Norte, Natal, 59.078-970, Rio Grande do Norte, Brasil.*
[d] *Programa de Pós-Graduação em Ecologia, Universidade Federal de Santa Catarina, 88040-900, Santa Catarina, Brasil.*
[e] *Programa de Pós-Graduação em Ciências Biológicas, Universidade Federal da Paraíba, Areia, , 58397-000, Paraíba, Brasil.*

Received: December 3, 2020 / Accepted: March 17, 2020 / Published online: May 25, 2020

Abstract

Landscape fragmentation is among the causes of environmental degradation and biodiversity reduction, mainly in Atlantic Forest areas. This study evaluates differences in avifauna richness and analyzes the structure of functional groups in a native restinga forest fragment (Control Area – CA) and four fragments with different reforestation ages, in Paraiba State. The latter fragments have undergone mining activities, and were reforested in 1989, 1997, 2001, and 2003. Four expeditions sampled the avifauna from November 2006 until April 2008. Each expedition had a sampling effort of 2700 net.m^2. Statistical tests verified richness differences between the studied areas, as well as in the composition of functional groups. The study recorded a total of 89 bird species. The area reforested longer ago showed the highest richness (n = 51 spp.). Species richness was not statistically significant among the CA and reforested areas. Similarity analysis indicated that reforested areas share a large amount of species, and species composition differ largely in CA. This differentiation is explained by the significant presence of frugivores, nectarivores, and leaf and understory insectivores. Changes in species richness and composition in degraded areas are expected. Reforested areas usually have a smaller number of forest-dependent species due to lower resource availability. Reforestation is an important conservation strategy for degraded restinga forest. However, there is a need of management measures promoting the enrichment of these areas and resource availability for forest-dependent species.

Keywords: Forest dependence, atlantic forest, environmental restoration, functional groups.

Comunidade de aves em áreas de restinga reflorestadas

Resumo

A fragmentação é uma das causas da diminuição da biodiversidade, principalmente em áreas de Floresta Atlântica. Este estudo avaliou as diferenças na riqueza e estrutura de grupos funcionais na ornitofauna de um fragmento nativo de floresta de restinga (Área Controle – AC) e quatro fragmentos com diferentes idades de reflorestamento (reflorestados em 1989, 1997, 2001 e 2003). O levantamento da avifauna ocorreu entre novembro de 2006 e abril de 2008 e totalizou um esforço de 2700 rede.m^2, por expedição. Foram registradas 89 espécies em todo o estudo. A área com a maior idade de reflorestamento deteve a maior riqueza (n = 51 spp.). As diferenças entre as riquezas de AC e as áreas reflorestadas não foi estatisticamente significante. A análise de similaridade apontou um grande compartilhamento de espécies entre as áreas reflorestadas e uma diferenciação em AC. Essa diferenciação é explicada pela presença de espécies dependentes de floresta em AC. Mudanças na riqueza e composição de espécies em áreas degradadas são esperadas. Áreas reflorestadas normalmente apresentam menos espécies dependentes de florestas devido à deficiência de recursos disponíveis. Reflorestamentos são estratégias de conservação importantes, contudo há a necessidade de medidas que promovam o enriquecimento destas áreas e disponibilização de recursos para espécies dependente de ambientes florestais.

Palavras-chave: Dependência de floresta, floresta atlântica, restauração ambiental, grupos funcionais.

Introduction

In Brazil, landscape fragmentation has been a major cause of environmental degradation and decreased biological diversity (Machado, Drummond & Paglia, 2008). The Brazilian Atlantic Forest has undergone a long process of fragmentation over the last centuries, resulting in loss of habitat and landscape change. As a consequence, approximately 84% of its fragments have an area smaller than 50 ha (Ribeiro, Metzger, Martensen, Ponzoni & Hirota, 2009; Melo, Arroyo-Rodriguez, Fahrig, Martinez-Ramos & Tabarelli, 2013).

The Atlantic Forest has only 11.45% of its original coverage (Ribeiro *et al.*, 2009). In northeast Brazil, original coverage is less than 5%. This region is highly fragmented, especially due to industrial sugarcane processing, real estate speculation, and mining activities (Ribeiro *et al.*, 2009). The main phytophysiognomies found are the restinga and board formations (Duré, Barbosa, Gadelha-Neto, Lima & Lima, 2018).

Historically, forest fragmentation and selective logging have been identified as the main causes of deleterious effects on bird communities (Bierregard & Lovejoy, 1989; Gimenes & Anjos, 2003; Moura *et al.*, 2014; Boesing, Nichols & Metzger, 2018). Strategies to reduce species loss in these fragments include their protection, enrichment, and restoration, besides actions that allow connectivity between them (Brancalion, Melo, Tabarelli & Rodrigues, 2013). In Brazil, the "Atlantic Forest Law" restricts the use of natural remnants of this biome and has a key role in restoring degraded areas (Calmon *et al*., 2011). Native forest fragments located close to restored areas prove to be important due to their potential to reduce edge effects and provide additional habitats, reducing the chances of future extinction (Santos-Junior, Marques, Lima & Anjos, 2016). Moreover, these areas provide propagules of colonizing plants, and animals capable of occupying reforested environments. However, several studies have pointed out different responses among different taxonomic groups (Gibson *et al*., 2011).

Regarding birds, studies on avifauna diversity, richness, and composition seek to analyze ecological factors that interfere with environmental dynamics, such as changing of habitats in a natural or anthropogenic way. Habitat heterogeneity and the complexity of the vegetation structure directly affect the richness of forest-dependent species (Munro *et al*., 2011) and species with different ecological needs (MacArthur & MacArthur, 1961). As a consequence of habitat loss, loss of variability in the vegetation structure leads to loss of diversity of this taxocenosis (Donner, Ribic & Probst, 2010). Species sensitive to habitat changes are rare in secondary forest environments (Stratford & Stouffer, 2013).

This study evaluates differences in avifauna richness and analyzes the structure of functional groups in a restinga forest fragment and four fragments with different reforestation ages, verifying the efficiency of reforestation actions conducted in the area.

Materials and Methods

Study area

The study was carried out in the mining area of the Cristal Mineração do Brasil LTDA Group, in a restinga area located in Mataraca city (6º29'40.01" S, 34º58'41.78" W), in the extreme northern coast of Paraíba State. The area is located in the drainage region of the Guaju River watershed, and covers 250 ha among portions of native forests, reforested areas, and sites subject to mining activities (Figure 1).

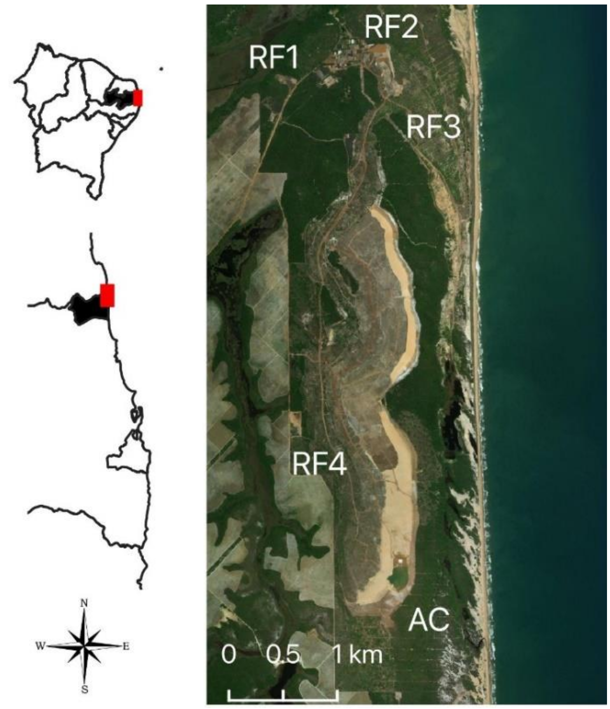

Figure 1. Restinga area on the northern coast of Paraíba State, with indications of the studied fragments (control area (CA) and reforested area (RF1 - RF4).

After mining, the dunes are rebuilt and the recovery program is applied. This process includes planting seedlings of selected tree species, implementing physical and biological windbreaks, sprinkler irrigation, soil enrichment, and addition of 40 cm of soil from already explored areas, which was stocked prior to mining (Duré *et al.*, 2018). The reforestation program started in 1989 with the planting of 27 tree species (native and exotic), without any pattern of spacing or number of individuals. Propagules of herbaceous species common in the locality were also planted (Cunha, Fontes, Oliveira & Oliveira-Filho, 2003).

Management of native species, including crowning, vine removal, and pruning, was carried out until plants reached a size that would allow them to overcome exotic species (Duré *et al*., 2018).

In the present study, we selected five areas within the mining complex, which consist of a native, unmined fragment, called the Control Area (CA), and four fragments subject to mining, with different reforestation ages (1989, 1997, 2001, and 2003), named, respectively, RF1, RF2, RF3, and RF4 (Figure 1). The fragments are characterized below.

Reports produced by the company itself point to the occurrence of 28 plant species exclusively in the control area, and 21 other species exclusively in the reforestation areas. Both the number of species and the number of plant individuals in the control area (average of 16.66 species and 66.33 individuals per 200 m^2 plot) are much higher than those observed in reforested areas (RF1: 10.00 spp. and 33.66 ind/200 m^2; RF2: 8.33 spp. and 26.66 ind/200 m^2; RF3: 5.00 spp. and 25.66 ind/200 m^2; RF4: 2.66 spp. and 13.00 ind/200 m^2). The main plant species found in reforested areas are *Anacardium occidentale* L. and *Tocoyena selloana* K. Schum., the latter not having been recorded in RF4. The Control Area does not contain the two most abundant species observed in reforested areas, having *Eugenia uniflora* L. and *Maytenus* sp. as the most abundant species, both of which occur exclusively in this fragment.

Reforested areas have an average area of 73 ha, while the control area measures 170 ha. The average distance between the centers of each area and the studied reforestation area was 3.71 km. The nearest forest fragment is the RPPN Mata da Estrela, in Baia Formosa city, Rio Grande do Norte State, located 16 km away from the studied area. Data regarding geometry and the distance between the central point of each studied area are presented in Table 1.

Table 1. Area (ha), perimeter (km), and distance (km) between forest fragments in a restinga area on the northern coast of Paraíba State. CA: Control area; RF1, RF2, RF3, and RF4: Areas reforested in 1989, 1997, 2001, and 2003, respectively.

Studied area	Area	Perim.	Distance				
			CA	RF1	RF2	RF3	RF4
CA	170	7.44	0				
RF1	45	5.49	5.56	0			
RF2	47	2.73	5.97	1.09	0		
RF3	67	4.45	5.08	1.39	0.97	0	
RF4	133	7.63	1.93	3.63	4.11	3.28	0

Data survey

The local avifauna was surveyed through four expeditions, two in the dry season (November 2006 and November 2007) and two in the rainy season (April 2007 and April 2008). The survey included direct observations with the aid of binoculars (7 X 35 mm), identification of vocalizations through recordings, and mist-net captures. For that purpose, three 1-ha sampling plots were established in each of the reforestation areas and in the control area. Sampling included 24 point counts in each sampling area, which lasted 10 minutes and were at least 150 meters apart. Additionally, 18 fog nets (12 m x 2.5 m and 36-mm mesh) were used, distributed in three rows with six nets each, randomly distributed within the plots, adding up to a total effort of 2700 net.m^2 per expedition. Field activities were duly authorized through the SNA/CEMAVE/SISBio-proj 3029 project.

Classification and categorization of species

The birds were identified with specialized field guides and marked with metal washers provided by the Brazilian National Center for Bird Research and Conservation - CEMAVE/ICMBIO. Species were classified according to the systematic order suggested by the Brazilian Ornithological Records Committee (Piacentini *et al*., 2015).

Species were categorized for their dependence on forest environments according to Parker *et al*. (1996), and for their functional groups according to Wilman *et al*. (2014) and Araujo & Silva (2017). Forest dependence is classified as follows: (1) dependent: species that occur only in forest environments; (2) semidependent: species that occur in the mosaic formed between forests and open and semiopen vegetation formations; (3) independent: species associated only with open areas.

Functional groups were defined from diet and foraging stratum. The defined categories were: carnivores (CAR), detritivores (SCV), small frugivores (weight $\leq$ 80.0 g; SFR), large frugivores (weight $\geq$ 80.1g; LFR), nectarivores (NEC), edge/open area granivores (EGR), terrestrial granivores (TGR), omnivores (OMN), omnivores/insectivores (OIN), canopy insectivores (CIN), trunk and branch insectivores (TTI), leaf insectivores (LIN), understory insectivores (UIN), terrestrial insectivores (TIN). Categorizations were based on Wilman *et al*. (2014) and Araujo & Silva (2017).

Data analysis

All statistical analyses were computed in R software. To test the differences between species richness in the studied areas, the “c2cv” function of the “rich” package was used, which verified the statistical significance of the values observed in the studied areas (see Rossi, 2011 for details). To test whether the avifauna composition in the reforested areas with the longest recovery time is similar to that of the control area, the Morisita-Horn similarity index was used through the “vegdist” function of the “vegan” package in R software (Oksanen *et al*., 2019). To visualize changes in the composition of functional groups between the studied areas, principal component analysis was used through the “fviz_pca” function of the “factoextra” package, also in R software (Kassambara & Mundt, 2016).

Results and Discussion

A total of 89 bird species were recorded in the five areas studied (Table 2). The area reforested in 1989 (RF1) had a higher species richness than the control area (51 and 48, respectively), and the area with the second longest reforestation time (1997 - RF2) showed 45 species, only three less than CA (Figure 2). The difference in the number of species between the Control Area (CA) and the reforested areas is within the limit expected by the null model hypothesis, i.e., it is not statistically significant (Table 3).

Principal component analysis revealed two important axes, which together explain 52.1% of the variance in the structure of functional groups (Figure 4). Positive values on axis 1 are associated with the areas with the largest number of leaf insectivores (LIN), understory insectivores (UIN), and trunk and branch insectivores (TTI), while negative values on this axis refer to areas with higher concentration of edge/open area granivores (EGR) and terrestrial insectivores (TIN).

In axis 2, positive values are associated with areas with the greatest richness of understory insectivores, nectarivores (NEC), and omnivores with a preference for insects (omnivores-insectivores - OIN). In turn, negative values are associated with areas having carnivores (CAR), omnivores (OMN), detritivores (SCV), and terrestrial and canopy insectivores (TIN and CIN, respectively). Species classified as terrestrial insectivores (TIN) are present only in the most recently reforested area (RF4). In contrast, no frugivores were recorded in this area. Species classified as frugivores (SFR or LFR) were more frequent in the control area (CA).

Table 2. Systematic list of bird species from a restinga area on the northern coast of Paraíba State, showing the number of records in the fragments in which they occur and their functional groups (FG).

Specie	CA	RF1	RF2	RF3	RF4	FG
Crypturellus parvirostris (Wagler, 1827)	0	0	3	0	2	TGR
Penelope superciliaris Temminck, 1815	3	0	1	0	0	LFR
Ortalis guttata (Spix, 1825)	2	2	0	0	0	LFR
Ardea alba Linnaeus, 1758	0	0	0	0	1	OMN
Cathartes aura (Linnaeus, 1758)	4	3	8	2	2	SCV
Coragyps atratus (Bechstein, 1793)	1	2	0	0	0	SCV
Rupornis magnirostris (Gmelin, 1788)	0	1	6	2	2	CAR
Buteo nitidus (Latham, 1790)	1	0	0	0	1	CAR
Aramides cajaneus (Statius Muller, 1776)	1	1	0	0	0	OMN
Vanellus chilensis (Molina, 1782)	0	0	0	0	4	TIN
Columbina passerina (Linnaeus, 1758)	0	1	0	2	19	EGR
Columbina talpacoti (Temminck, 1810)	1	6	6	17	32	EGR
Columbina squammata (Lesson, 1831)	0	0	1	0	0	EGR
Leptotila rufaxilla (Richard & Bernard, 1792)	9	10	8	6	0	TGR
Geotrygon montana (Linnaeus, 1758)	1	0	0	0	0	TGR
Piaya cayana (Linnaeus, 1766)	0	0	2	0	0	OMN
Coccyzus americanus (Linnaeus, 1758)	0	0	1	1	0	OMN
Crotophaga ani Linnaeus, 1758	0	0	0	4	11	OMN
Phaethornis ruber (Linnaeus, 1758)	4	0	0	0	0	NEC
Phaethornis pretrei (Lesson & Delattre, 1839)	1	0	0	1	0	NEC
Chrysolampis mosquitus (Linnaeus, 1758)	0	0	0	0	1	NEC
Chlorestes notata (Reich, 1793)	1	0	0	0	0	NEC
Chlorostilbon lucidus (Shaw, 1812)	0	3	0	2	0	NEC
Amazilia leucogaster (Gmelin, 1788)	0	0	0	1	0	NEC
Amazilia fimbriata (Gmelin, 1788)	0	0	0	0	2	NEC
Trogon curucui Linnaeus, 1766	3	0	0	0	0	SFR
Galbula ruficauda Cuvier, 1816	2	6	3	0	0	UIN
Nystalus maculatus (Gmelin, 1788)	0	3	2	2	0	UIN
Picumnus fulvescens Stager, 1961	0	0	1	0	0	TTI
Celeus flavescens (Gmelin, 1788)	2	2	4	0	0	TTI
Caracara plancus (Miller, 1777)	0	2	0	0	3	OMN
Milvago chimachima (Vieillot, 1816)	2	0	0	0	0	OMN
Formicivora grisea (Boddaert, 1783)	19	15	10	2	0	LIN
Dysithamnus mentalis (Temminck, 1823)	2	0	0	0	0	LIN
Herpsilochmus atricapillus Pelzeln, 1868	6	2	0	0	0	LIN
Herpsilochmus pectoralis Sclater, 1857	3	0	0	0	0	LIN
Thamnophilus pelzelni Hellmayr, 1924	6	3	1	0	0	LIN
Taraba major (Vieillot, 1816)	2	1	0	0	0	OIN
Conopophaga lineata (Wied, 1831)	0	2	0	0	0	OIN
Xiphorhynchus guttatus (Lichtenstein, 1820)	6	0	0	0	0	UIN
Dendroplex picus (Gmelin, 1788)	1	0	0	0	0	TTI
Xenops minutus (Sparrman, 1788)	9	3	2	0	0	TTI
Synallaxis frontalis Pelzeln, 1859	2	0	0	0	0	TTI
Crypturellus parvirostris (Wagler, 1827)	0	1	0	0	0	LIN

CA: Control area; RF1, RF2, RF3, and RF4: Areas reforested in 1989, 1997, 2001, and 2003, respectively. Functional groups: carnivores (CAR), detritivores (SCV), small frugivores (weight ≤ 80.0g; SFR), large frugivores (weight ≥ 80.1g; LFR), nectarivores (NEC), edge/open area granivores (EGR), terrestrial granivores (TGR), omnivores (OMN), omnivores/insectivores (OIN), canopy insectivores (CIN), trunk and branch insectivores (TTI), leaf insectivores (LIN), understory insectivores (UIN), terrestrial insectivores (TIN).

Table 2. *Continuation*.

Specie	CA	RF1	RF2	RF3	RF4	FG
Neopelma pallescens (Lafresnaye, 1853)	24	1	0	0	0	TTI
Chiroxiphia pareola (Linnaeus, 1766)	5	0	0	0	0	SFR
Pachyramphus polychopterus (Vieillot, 1818)	0	0	1	0	0	OIN
Platyrinchus mystaceus Vieillot, 1818	2	0	0	0	0	LIN
Tolmomyias flaviventris (Wied, 1831)	1	8	7	1	0	LIN
Todirostrum cinereum (Linnaeus, 1766)	0	5	5	0	0	LIN
Hemitriccus zosterops (Pelzeln, 1868)	1	0	0	0	0	LIN
Hemitriccus margaritaceiventer (d'Orbigny & Lafresnaye, 1837)	1	2	5	9	0	LIN
Camptostoma obsoletum (Temminck, 1824)	0	1	3	2	1	LIN
Elaenia flavogaster (Thunberg, 1822)	1	1	1	2	1	CIN
Elaenia cristata Pelzeln, 1868	0	1	3	0	2	CIN
Phaeomyias murina (Spix, 1825)	0	0	1	4	2	CIN
Myiarchus ferox (Gmelin, 1789)	0	2	1	0	0	CIN
Myiarchus tyrannulus (Statius Muller, 1776)	0	9	11	3	0	CIN
Pitangus sulphuratus (Linnaeus, 1766)	0	3	20	12	6	OMN
Myiozetetes similis (Spix, 1825)	0	0	2	0	0	CIN
Tyrannus melancholicus Vieillot, 1819	0	0	1	2	3	CIN
Lathrotriccus euleri (Cabanis, 1868)	1	3	0	1	0	UIN
Cyclarhis gujanensis (Gmelin, 1789)	6	8	5	3	0	OMN
Hylophilus amaurocephalus (Nordmann, 1835)	1	2	6	3	0	CIN
Vireo chivi (Vieillot, 1817)	11	17	18	14	3	LIN
Stelgidopteryx ruficollis (Vieillot, 1817)	0	1	4	0	0	UIN
Progne tapera (Vieillot, 1817)	3	12	0	0	0	CIN
Troglodytes musculus Naumann, 1823	0	1	0	0	0	LIN
Pheugopedius genibarbis (Swainson, 1838)	9	2	0	0	0	UIN
Cantorchilus longirostris (Vieillot, 1819)	0	0	1	0	0	UIN
Polioptila plumbea (Gmelin, 1788)	4	6	11	11	2	CIN
Turdus flavipes Vieillot, 1818	0	0	0	2	0	SFR
Turdus leucomelas Vieillot, 1818	2	17	5	1	1	OMN
Mimus gilvus (Vieillot, 1807)	0	0	0	0	2	OIN
Arremon taciturnus (Hermann, 1783)	7	0	0	0	0	UIN
Basileuterus culicivorus (Deppe, 1830)	0	1	2	1	0	LIN
Myiothlypis flaveola Baird, 1865	20	1	0	1	0	LIN
Icterus cayanensis (Linnaeus, 1766)	0	2	4	0	0	CIN
Tangara sayaca (Linnaeus, 1766)	0	9	3	3	0	OIN
Tangara palmarum (Wied, 1821)	0	3	2	6	0	OIN
Tangara cayana (Linnaeus, 1766)	0	8	3	3	0	OIN
Sicalis flaveola (Linnaeus, 1766)	0	1	0	0	0	TGR
Volatinia jacarina (Linnaeus, 1766)	0	0	4	3	10	EGR
Lanio cristatus (Linnaeus, 1766)	4	0	0	0	0	UIN
Tachyphonus rufus (Boddaert, 1783)	3	2	2	0	1	UIN
Dacnis cayana (Linnaeus, 1766)	4	1	14	5	3	NEC
Coereba flaveola (Linnaeus, 1758)	10	10	13	17	0	NEC
Saltator maximus (Statius Muller, 1776)	0	1	0	0	0	OIN
Thlypopsis sordida (d'Orbigny & Lafresnaye, 1837)	0	2	0	0	0	OIN
Euphonia chlorotica (Linnaeus, 1766)	1	0	0	0	0	SFR

CA: Control area; RF1, RF2, RF3, and RF4: Areas reforested in 1989, 1997, 2001, and 2003, respectively. Functional groups: carnivores (CAR), detritivores (SCV), small frugivores (weight $\leq$ 80.0g; SFR), large frugivores (weight $\geq$ 80.1g; LFR), nectarivores (NEC), edge/open area granivores (EGR), terrestrial granivores (TGR), omnivores (OMN), omnivores/insectivores (OIN), canopy insectivores (CIN), trunk and branch insectivores (TTI), leaf insectivores (LIN), understory insectivores (UIN), terrestrial insectivores (TIN).

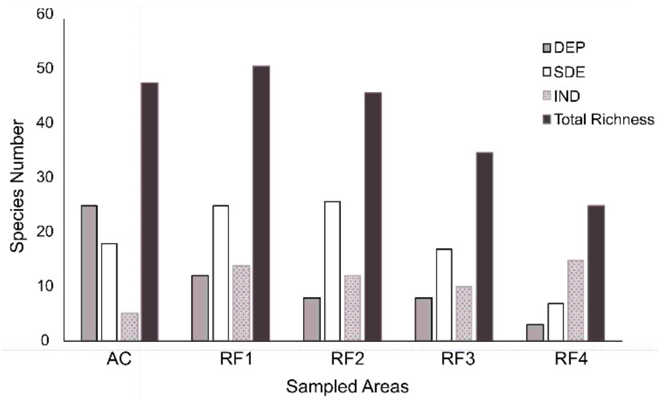

Figure 2. Total species richness and habitat use in reforested fragments and a control fragment in a restinga area on the northern coast of Paraíba State. CA: Control area; RF1 (reforested in 1989), RF2 (reforested in 1997), RF3 (reforested in 2001), and RF4 (reforested in 2003). DEP: Forest-dependent bird species; SDE: Semidependent forest bird species; IND: Forest-independent bird species.

Table 3. Permutation analysis of bird species richness in reforested fragments (RF1 to RF4) and a control fragment (CA) in a restinga area on the northern coast of Paraíba State.

Area	Differences in N	*p*
CA with All reforestations	25	0.891
CA with RF1	3	0.406
CA with RF2	3	0.406
CA with RF3	13	0.257
CA with RF4	23	0.139

N = Number of bird species.

Similarity analysis showed a faunal relationship between reforested areas, and a differentiation in the composition of CA species (Figure 3). This difference can be explained by the higher presence of forest-dependent species in CA, such as the pale-bellied Tyrant-Manakin (*Neopelma pallescens*), and the high presence of forest-independent species such as the great kiskadee (*Pitangus sulphuratus*) in reforested areas, especially those more recently reforested (see Figure 2).

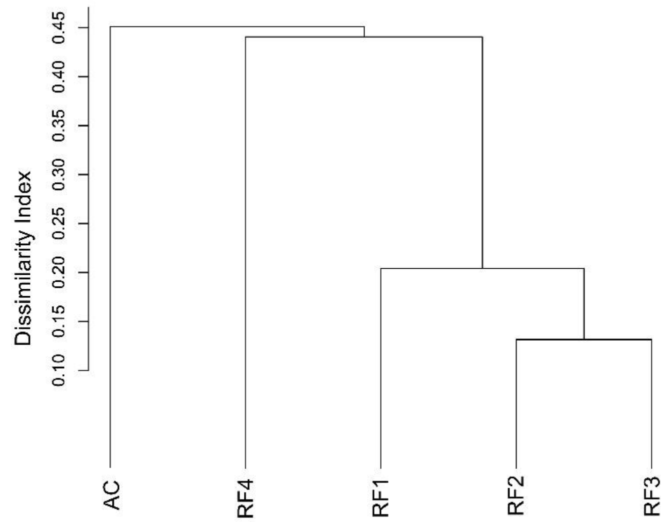

Figure 3. Hierarchical cluster analysis of the absence/presence of bird species (Morisita-Horn dissimilarity index) in the five areas studied. CA: Control area; RF1 (reforested in 1989), RF2 (reforested in 1997), RF3 (reforested in 2001), and RF4 (reforested in 2003).

Bird species richness was very close between the native forest fragment (CA) and the areas reforested longer ago (RF1 and RF2), being higher in RF1. However, similarity analysis showed differences in species composition between the studied areas. This is partly explained by the higher richness of forest-dependent species in CA as well as by the predominance of typical open-area species in reforested areas, mainly those most recently reforested. In general, species composition in reforested areas is different from the species composition prior to disturbance or when compared to a reference fragment. The main explanation is the time that reforested areas would need to recover specific microhabitats such as those needed for forest-dependent species (Stanturf, Palik & Dumroese, 2014).

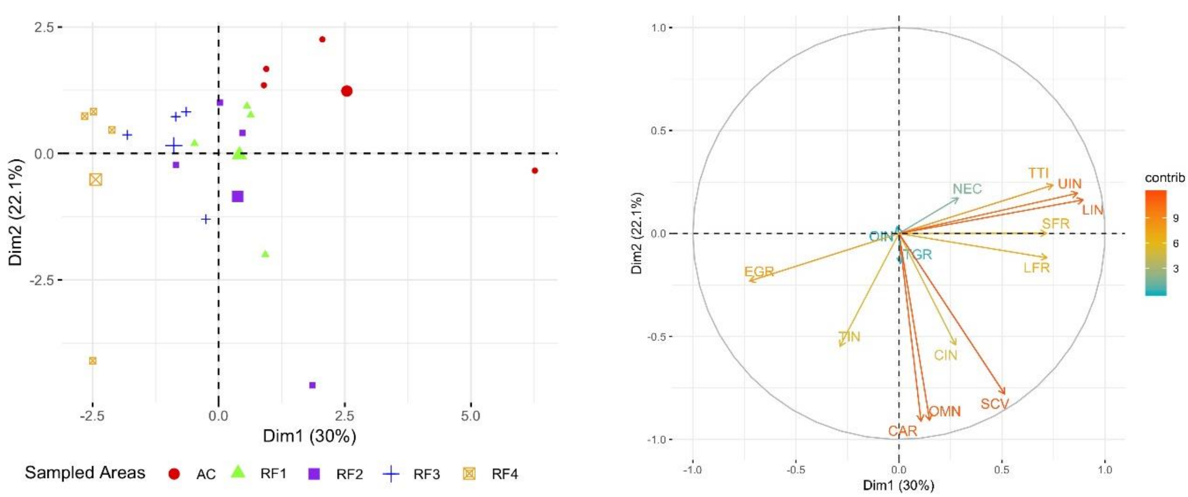

Figure 4. (A) Principal component analysis of the structure of functional groups of birds in the Control Area (CA) and reforested areas (RF1, RF2, RF3, and RF4). (B) Correlation circle indicating the importance of each functional group in the first and second

axes of the principal components. Functional groups as described in Table 1.

More specifically, birds tend to respond well in reforested areas, presenting a species richness close to that of the reference community, but with different taxocenosis (Munro *et al*., 2011; Catterall, Freeman, Kanowski & Freebody, 2012). The control area showed a predominance of forest-dependent over forest-independent species, while semidependent or independent species predominate in reforested areas.

Noticing changes in bird richness and composition in locations subject to high anthropogenic pressure, such as the studied areas, is no surprise. This is because we know that environmental changes directly affect the ecological traits of species in a given location and that the communities that live there respond in complex ways to these changes (Banks-Leite, Ewers & Metzger, 2013; Supp & Ernest, 2014). The community may respond to habitat decrease/fragmentation with species loss without a systematic decline in diversity (Banks-Leite *et al*., 2013; Supp & Ernest, 2014). This phenomenon occurs because species substitution changes the ecological functions of a community (Lepš, Bello, Šmilauer & Doležal, 2011). In this way, deforested areas can promote different ecological functions, but not necessarily less functions (De Coster, Banks-Leite & Metzger, 2015).

Reforested areas usually have a smaller number of forest-dependent species due to the lack of resources and adequate locations for building nests (Moura *et al*., 2014). Species that recolonize these areas tend to be opportunistic and generalist (Critescu, Frère & Banks, 2012; Santos-Junior *et al*., 2016). This aspect leads us to propose measures for environmental enrichment, thus increasing the availability of habitats for less generalist forest-dependent species.

It is important to remember that bird community composition changes along with reforestation time (Catterall *et al*., 2012). Notwithstanding, colonization of reforested areas by new species does not compensate for the absence of native species, since new species do not meet conservationist concerns (Moura *et al*., 2014). Therefore, monitoring actions should be prioritized to assess whether these areas are becoming capable of receiving a higher number of forest-dependent species (Santos-Junior *et al*., 2016).

Conclusion

Our results suggest that reforested areas can provide various habitats and resources, mainly in highly fragmented sites, but only for specific groups of birds. Bird species that prefer forest habitats are less frequent and less abundant in reforested areas, even when the reforestation time is long.

We understand that the recovery of areas through reforestation is an important conservation strategy in fragmented landscapes. However, there is a need for management measures that promote the enrichment of these areas and the availability of resources for forest-dependent species. In addition, the Atlantic Forest of northeastern Brazil is one of the most threatened landscapes in the world. That is why systematic mapping of ecological and conservation knowledge for this region, including threats and barriers to conservation, could identify preferences, flaws, and research priorities of value to researchers and conservationists.

References

Araujo, H.F.P. & Silva, J.M.C. (2017). The Avifauna of the Caatinga: Biogeography, Ecology, and Conservation. In J.M.C. Silva, I. Leal, & M. Tabarelli (Ed.). *Biodiversity, Ecosystems Services and Sustainable Development in Caatinga: The Largest Tropical Dry Forest Region in South America.* (pp. 181–210). Berlin: Springer-Verlag.

Banks-Leite, C., Ewers, R. M. & Metzger J. P. (2013). The confounded effects of habitat disturbance at the local, patch and landscape scale on understorey birds of the Atlantic Forest: Implications for the development of landscape-based indicators. *Ecological indicators*, 31, 82-88. doi: 10.1016/j.ecolind.2012.04.015

Bierregard, R. O. & Lovejoy, T. E. (1989). Effects of forest fragmentation on Amazonian understory bird communities. *Acta amazonica*, 19, 215-241. doi: 10.1590/1809-43921989191241

Boesing, A. L., Nichols, E. & Metzger, J. P. (2018). Biodiversity extinction thresholds are modulated by matrix type. *Ecography*, *41*(9), 1520-1533. doi: 10.1111/ecog.03365

Brancalion, P. H., Melo, F. P., Tabarelli, M. & Rodrigues, R. R. (2013). Restoration reserves as biodiversity safeguards in human-modified landscapes. *Natureza & Conservação*, *11*(2), 1-5. doi: 10.4322/natcon.2013.029

Calmon, M., Brancalion, P. H., Paese, A., Aronson, J., Castro, P., Silva, S. C. & Rodrigues, R. R. (2011). Emerging threats and opportunities for large-scale ecological restoration in the Atlantic Forest of Brazil. *Restoration Ecology*, *19*(2), 154-158. doi: 10.1111/j.1526-100X.2011.00772.x

Catterall, C. P., Freeman, A. N. D., Kanowski, J. & Freebody, K. (2012). Can active restoration of tropical rainforest rescue biodiversity? A case with bird community indicators. *Biological Conservation*, *146*(1), 53-61. doi: 10.1016/j.biocon.2011.10.033

Cristescu, R. H., Frère, C. & Banks, P. B. (2012). A review of fauna in mine rehabilitation in Australia: current state and future directions. *Biological Conservation*, *149*(1), 60-72. doi: 10.1016/j.biocon.2012.02.003

Cunha, L. O., Fontes, M. A. L., Oliveira, A. D. & Oliveira-Filho, A. T. (2003). Análise multivariada da vegetação como ferramenta para avaliar a reabilitação de dunas litorâneas mineradas em Mataraca, Paraíba, Brasil. *Revista Árvore*, *27*(4), 503-515. doi: 10.1590/S0100-67622003000400011

De Coster, G., Banks-Leite, C. & Metzger, J. P. (2015). Atlantic forest bird communities provide different but not fewer functions after habitat loss. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1811), 2014-2844. doi: 10.1098/rspb.2014.2844

Donner, D. M., Ribic, C. A. & PROBST, J. R. (2010). Patch dynamics and the timing of colonization–abandonment events by male Kirtland's Warblers in an early succession habitat. *Biological Conservation*, *143*(5), 1159-1167. doi: 10.1016/j.biocon.2010.02.023

Duré, R. C., Barbosa, M. R., Gadelha-Neto, P. C., Lima, I. B., & Lima, J. R. (2018). Reabilitação florestal de dunas litorâneas pós-mineração no nordeste brasileiro. *Gaia Scientia*, *12*(1). doi: 10.22478/ufpb.1981-1268.2018v12n1.36704

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J.,… & Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378-381. doi: 10.1038/nature10425

Gimenes, M. R. & Anjos, L. (2003). Efeitos da fragmentação florestal sobre as comunidades de aves. *Acta Scientiarum. Biological Sciences*, *25*(2), 391-402. doi: 10.4025/actascibiolsci.v25i2.2030

Kassambara, A. & Mundt, F. (2016). Factoextra: extract and visualize the results of multivariate data analyses. *R package version*, 1.3. Recovered from http://www.sthda.com/english/rpkgs/factoextra/.

Lepš, J., de Bello, F., Šmilauer, P., & Doležal, J. (2011). Community trait response to environment: disentangling species turnover vs intraspecific trait variability effects. *Ecography*, *34*(5), 856-863. doi: 10.1111/j.1600-0587.2010.06904.x

MacArthur, R. H. & MacArthur, J. W. (1961). On bird species diversity. *Ecology*, Washington, D.C., v. 42, n. 3, p. 594-598, 1961. doi: 10.2307/1932254

Machado, A. B. M., Drummond, G. M. & Paglia, A. P. (2008). Livro vermelho da fauna brasileira ameaçada de extinção. Belo Horizonte: Fundação Biodiversitas.

Melo, F. P. L., Arroyo-Rodriguez, V., Fahrig L., Martinez-Ramos, M. & Tabarelli, M. (2013). On the hope for biodiversity-friendly tropical landscapes. *Trends in ecology & evolution*, *28*(8), 462-468. doi: 10.1016/j.tree.2013.01.001

Moura, N. G., Lees, A. C., Aleixo, A., Barlow, J., Dantas, S. M., Ferreira, J., Lima, M. F. & Gardner, T. A. (2014). Two hundred years of local avian extinctions in Eastern Amazonia. *Conservation biology*, 28(5), 1271-1281. doi: 10.1111/cobi.12300

Munro, N. T., Fischer, J., Barrett, G., Wood, J., Leavesley, A., & Lindenmayer, D. B. (2011). Bird's response to revegetation of different structure and floristics—are "restoration plantings" restoring bird communities? *Restoration Ecology*, 19(201), 223-235. doi: 10.1111/j.1526-100X.2010.00703.x

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., O'Hara, R.B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Wagner, H. (2019). vegan: Community Ecology Package. *R package version 2.5-6.* Recovered from https://CRAN.R-project.org/package=vegan

Parker III, T.A., Stotz, D.F. & Fitzpatrick, J.W., 1996. Ecological and distributional databases. In: Stotz, D.F., Fitzpatrick, J.W., Parker III, T.A. & Moskovits, D.K. (Eds.), *Neotropical Birds: Ecology and Conservation*. The University of Chicago Press, Chicago, pp. 111–410.

Piacentini, V. Q., Aleixo, A., Agne, C. E., Maurício, G. N., Pacheco, J. F., Bravo, G. A., Brito, G. R. R., Naka, L. N., Olmos, F., Posso, S., Silveira. L. F., Betini, G. S., Carrano, E., Franz, I., Lees, A. C., Lima, L. M., Pioli, D., Schunck. F., Amaral, F. R., Bencke, G. A., Cohn-Haft, M., Figueiredo, L. F. A., Straube, F. C. & Cesari, E. (2015). Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee/Lista comentada das aves do Brasil pelo Comitê Brasileiro de Registros Ornitológicos. *Revista Brasileira de Ornitologia*, *23*(2), 91-298. Recovered from http://www.revbrasilornitol.com.br/BJO/article/view/1263

Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J. & Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological conservation*, *142*(6), 1141-1153. doi: 10.1016/j.biocon.2009.02.021

Rossi, J. P. (2011). rich: an R package to analyse species richness. *Diversity*, 3(1), 112-120. https://doi.org/10.3390/d3010112

Santos-Junior, P. C. A., Marques, F. C., Lima, M. R. & Anjos, L. (2016). The importance of restoration areas to conserve bird species in a highly fragmented Atlantic forest landscape. *Natureza & Conservação*, *14*(1), 1-7. doi: 10.1016/j.ncon.2016.03.001

Stanturf, J. A., PALIK, B. J. & Dumroesem R. K. (2014). Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management*, 331, 292-323. doi: 10.1016/j.foreco.2014.07.029

Stratford, J. A. & Stouffer, P. C. (2013). Microhabitat associations of terrestrial insectivorous birds in Amazonian rainforest and second-growth forests. *Journal of Field Ornithology*, *84*(1), 1-12. doi: 10.1111/jofo.12000

Supp, S. R. & Ernest, S. K. M. (2014). Species-level and community-level responses to disturbance: a cross-community analysis. *Ecology*, *95*(7), 1717-1723. doi: 10.1890/13-2250.1

Wilman, H., Belmaker, J., Simpson, J., Rosa, C., Rivadeneira, M. M. & Jetz, W. (2014). EltonTraits 1.0: Species-level foraging attributes of the world's birds and mammals. *Ecology*, 95, 2027-2027. doi:10.1890/13-1917.1