An Acad Bras Cienc (2024) 96(1): e20220691 DOI 10.1590/0001-3765202420220691
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ECOSYSTEMS

How bird community responds to different ages of reforestation? Implications for restoration of a highly threatened Atlantic Forest phytophysiognomy

SÉRGIO ROBERTO POSSO, ROSIANI R.L. BRINCK, JOSÉ RAGUSA-NETTO, LUIZ U. HEPP & SILVIA V. MILESI

Abstract: We evaluated the bird composition, forest dependence, trophic guilds and avian representativeness associated with 7, 10 and 15 years old reforestations and mature forest patches in order to verify the successional process and avian contribution to the forest restoration. Analyses revealed a segregation of bird composition with a gradual increasing in forest dependent species from 7 years to mature forest. Detrended Correspondence Analysis ranged from those birds often present in semi-open habitats to forest birds, canopy frugivorous and understory insectivorous as the successional stages progressed from the most recent reforestation to the most mature. Although 7 and 10 years of reforestation had the largest composition range, the more generalist, granivorous and forest independent birds, three years were enough to have different bird diversity between them. Avifauna of 15 years patches resembled most closely that of mature forest but still lacked 18 species. In this way, we addressed: 1) planting of herbaceous/shrub and freshy-fruited species in reforestations and; 2) establish riparian forest corridors along the Paraná river to connect these reforestation patches with mature forest. These measures will allow higher avian beta-diversity to maximize the diaspores dispersed by birds to expand and accelerate the rehabilitation of this threatened for forest.

Key words: bird-plant interactions, community ecology, Neotropical forests, forest rehabilitation.

INTRODUCTION

The Brazilian Atlantic Forest is one of the most diverse and also one of the most devastated biomes of the planet given that only 12% of its original extension remains (Ribeiro et al. 2009). As a result, the Atlantic Forest is one of the three biodiversity hotspots most vulnerable to global change (Bellard et al. 2014), and many numerous endemics that are essential to ecological processes could be lost in the near future (Brooks et al. 2002). In addition to habitat loss, many remnants correspond to small, isolated, and/or unprotected forest fragments (Fonseca 1985, Silva & Tabarelli 2000), that make fragmentation-sensitive species to extinction (Whitmore & Sayer 1992, Brooks & Balmford 1996, Metzger et al. 2009). The Seasonal Deciduous Alluvial Forest, at type of Atlantic Forest located along the Parana River, has been highly fragmented due to anthropogenic activities and it is highly threatened with only 1% of the original forest remaining (IPARDES 1992).

We had an increase in initiatives to restore forests in the last decade, such as ecological restoration (i.e. the process of assisting ecosystems recovery – SER 2004), a main alternative to promote biodiversity renewal and to safeguard natural resources (Dobson et al. 1997, Young 2000, Lamb et al. 2005). However, it is essential to understand the plant-animal interactions in effective restoration strategies (Munro et al. 2007), indispensable and invaluable to establish a continuous process of regeneration, possible to sustain itself (Reis et al. 2003). In this regard, reforestation efficiency can be also measured by the environmental species values dependent on the vegetation quality, such as bird communities (Garcia 2016). Nevertheless, little is known about the complex interactions that maintain the stability of Neotropical ecosystems and their important connections between birds and vegetation (Ortega-Álvarez & Lindig-Cisneros 2012). Regarding the Atlantic Forest, only Melo et al. (2020) directed efforts to better understand how birds respond to different regeneration stages, but they did not included the highly threatened Seasonal Deciduous Alluvial Forest.

Moreover, most studies have focused on species richness and abundance of birds, but functional groups have been largely ignored (Coelho et al. 2016). Studies on functional groups of avifauna are important to assist decision-makers in managing landscape features that favor ecosystem functioning. They also contribute to catalyze the rehabilitation of current areas of forest loss and degradation (Child et al. 2009).

Thus, we addressed the following questions in this study:

(1) Are the avifauna composition, degree of forest dependence and bird trophic guilds associated to the reforestation stages?
(2) Is the avifauna composition of older reforestation patches more similar to that of mature forest?
(3) Are there bird species indicators for each reforestation stages?
(4) What measures can be applied to aid, expand and accelerate the reforestation of this Atlantic forest based on avian composition and functional groups?

MATERIALS AND METHODS

Study area

The studied was carried out in a protected area (RPPN Cisalpina, Companhia Energética de São Paulo) with 22,886.12 ha (21°16’43.3”S 51°58’29.7”W and 21°16’12.6”S 51°51’ 43.8”W) located on the drainage basin of Paraná River (Andrade et al. 2022) (Figure 1).

The focus of our study was the Seasonal Deciduous Alluvial Forest (from now SDAF) with 6,465 ha and distributed throughout the most eastern region of the RPPN Cisalpina, along to the Paraná River (Figure 1) (Andrade et al. 2022). The SDAF is in an alluvial plain area remaining from the low river terraces, dominated by pioneer vegetacional formation (floodplain or vegetation in areas subject to flooding), interspersed with areas of this alluvial forest (Campos & Souza 1997, 2002). This forest is composed of deciduous hydrophytic plants (20–50% of the tree community composed of deciduous trees), adapted to the alluvial environment, where mesophanerophytes and nanophanerophyte dominate (Andrade et al. 2022). The SDAF has three well-defined vegetation strata, with a canopy with an average height of ~13 m, tree cover between 50% and 90% and emergent individuals reaching ~18 m (Morante-Filho et al. 2014).

In the beginning of 2003, the RPPN Cisalpina was submitted to a reforestation program by adopting the high diversity of trees strategy (sensu Reis et al. 2003). Thus, the high-diversity plantation treatment was applied by planting

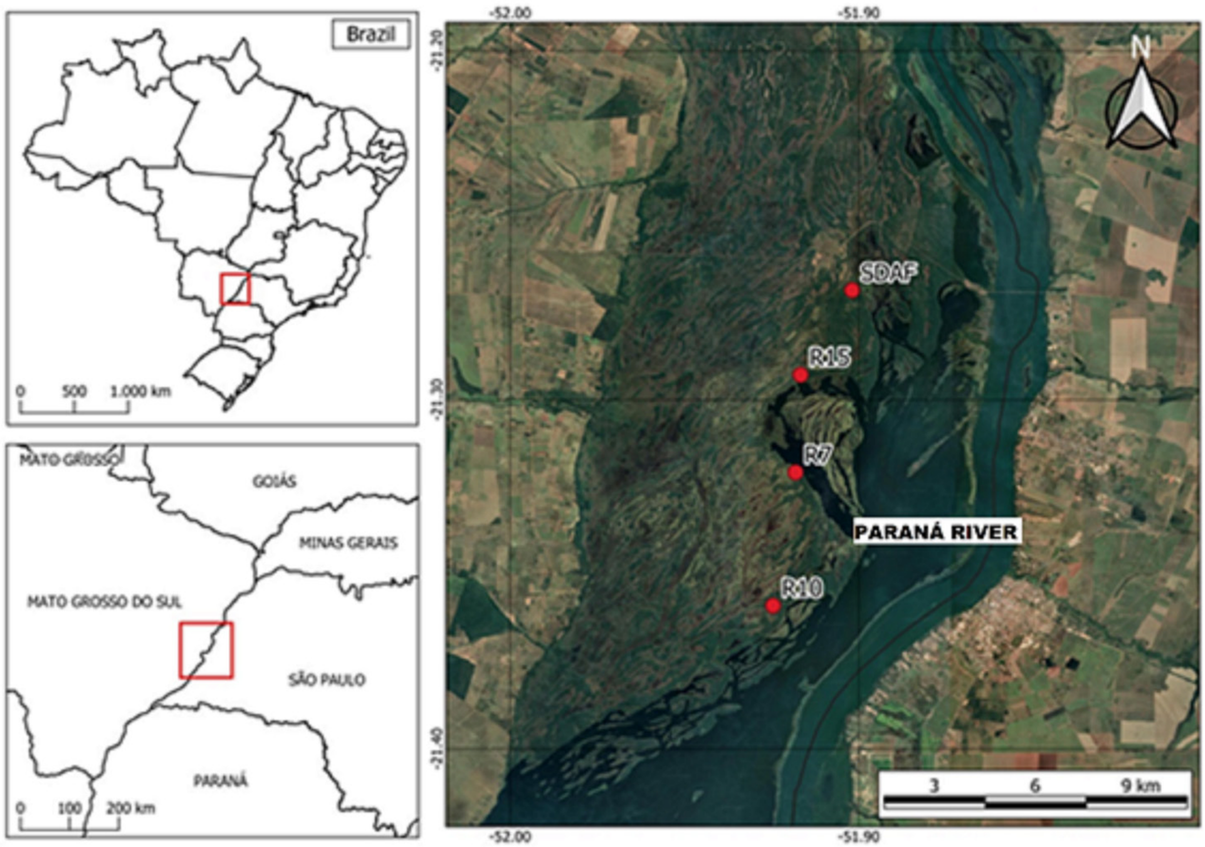

Figure 1. **RPPN Cisalpina (area of study) in Brasilândia, MS, Brazil. Caption: R7, R10, R15 = reforestation ages (7, 10 and 15 years) and SDAF = mature Seasonal Deciduous Alluvial Forest.**

104 native tree species, intercalating pioneer, fast-growing, shade species ("filling species") and slow-growing species ("diversity species") within planting lines. The most common species were *Trema micrantha*, *Croton urucurana*, *Guazuma ulmifolia*, *Cecropia pachystachya* and *Inga uruguensis* (Andrade 2011).

Birds were sampled in the reforestations areas of 7, 10 and 15 years of reforestation (R7, R10, and R15, respectively) and in the SDAF (Figure 1), according to the database from the area restoration program (Andrade et al. 2022). The R7, R10, R15 areas are similar in size (41.55, 44.1 and 43.6 ha, respectively) and the mature SDAF is larger (66,1 ha). The R7 had young trees (four to six meters high) and the canopy cover was very reduced, with large sunlight area on the ground (80-90%) (Figure 2a). This condition allowed the dominance of exotic grasses, particularly *Brachiaria decumbens* predominated among the planted trees (Andrade et al. 2022). The R10 presented taller trees (six to 10 meters) and the canopy cover was larger than R7 (Figure 2b). Thus, although the grassland in R10 was reduced in relation to R7 (Andrade et al. 2022) the tree canopy did not completely prevent sunlight, allowing the presence of invasive grasses. In these patches, as well as in R7, the herbaceous and arboreal strata showed low density. The R15 reforestation area presented more complex vegetation structure than R7 and R10, with a predominance of taller trees (10 to 15 meters), more canopy coverage (between 50% and 90%) and absence of exotic grasses (Figure 2c) (Andrade 2011), similar condition to the mature SDAF (*sensu* Morante-Filho et al. 2014). The main

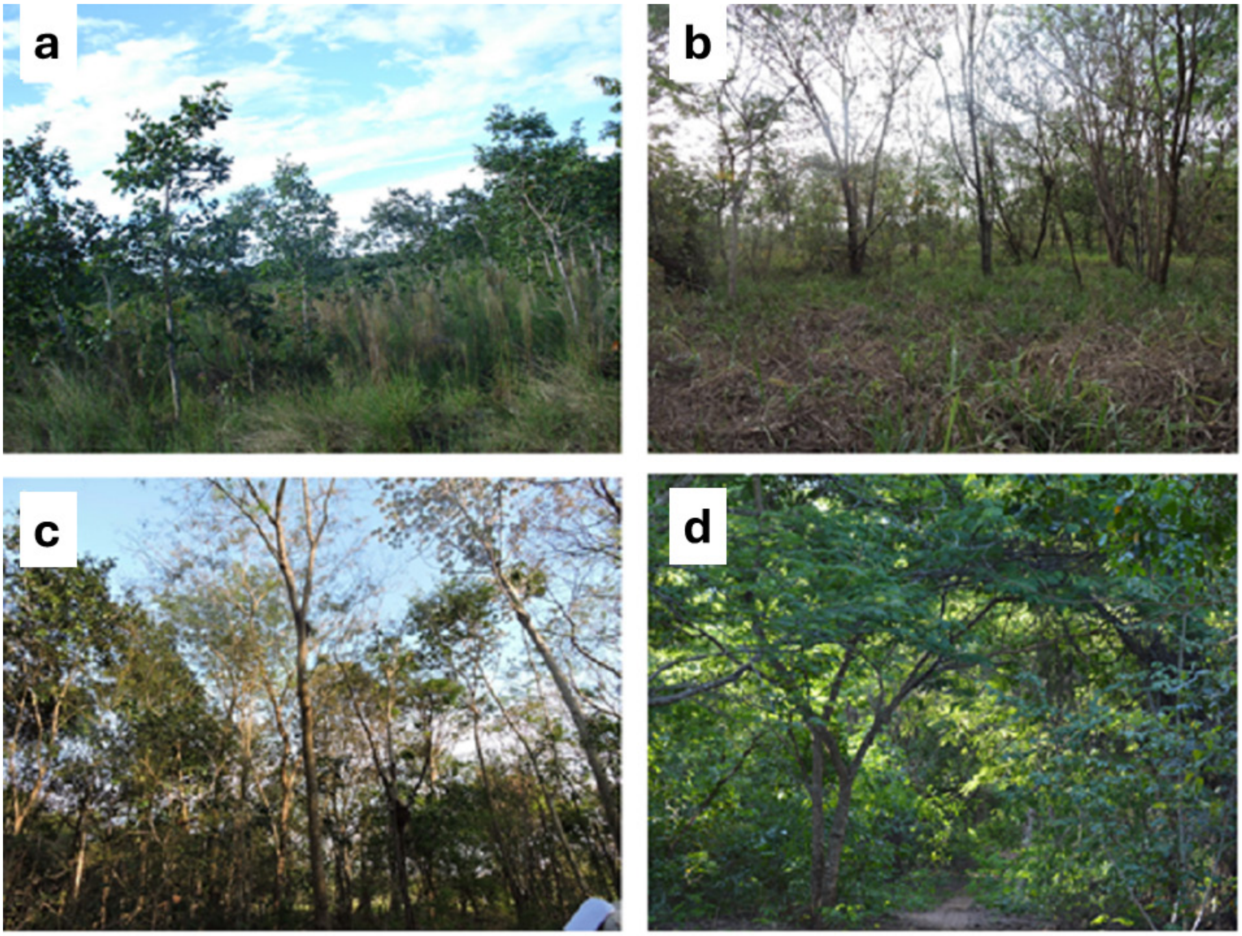

Figure 2. Areas of study of the RPPN Cisalpina (Brasilândia, MS, Brazil). Caption: a – 7 years of reforestation; b - 10 years of reforestation; c - 15 years of reforestation; d - SDAF = mature Seasonal Deciduous Alluvial Forest.

differences among these two areas were: 1) the mature SDAF had more complex vegetation structure (e.g. herbaceous and arboreal strata) (Figure 2d) and; 2) it showed taller tress with a height of ~13 meters and emergent individuals reaching ~18 meters (Morante-Filho et al. 2014).

Data collection

The avifauna was sampled during the rainy (October to December/2018) and dry (April to September/2019) seasons.

We used the point-counting method (Bibby et al. 2000) adapted to the Neotropical forests, as follows. The SDAF showed high dense vegetation occurring along the point counts which made difficult to detect birds at distances of > 50 meters, but SRP is highly familiarized with bird species in this area and easily detect birds within the short 30 meters of radius in every vegetation density. In this way, we established 30-m radius point count locations evenly spaced within each reforestation age and SDAF. As point count locations were at least 200 m apart, the counting areas for adjacent points did not overlap, helping to ensure that individual birds were not counted at more than one point (i.e. points were independent to each other with respect to birds). In each area of reforestation and mature SDAF, bird counting was conducted at eight points for 10 min each. All birds seen or heard were recorded. Results from the two counts (rainy and dry seasons) at each point were combined by using the maximum number of individuals recorded for each species as an estimate of the number of individuals of that species at that point.

The sampling was performed in the early morning (6:00 am to 8:00 am) and in the late afternoon (4:00 pm to 6:00 pm). We performed 16 point counts per day (eight in the morning and eight in the afternoon). The points were randomly selected by sampled area and the data were always obtained by the same observers (SRP and RRLB). We excluded birds that flew over the reforestations and the mature SDAF and we also did not perform the surveys on rainy days and/or strong winds. We adopted the avian nomenclature from the Brazilian Committee of Ornithological Records (Pacheco et al. 2021).

Data analysis

We estimated the sampling sufficiency by species accumulation per point counting during all the study period. We used a 1st order Jackknife richness estimator. Thus, we assessed the data normality with a Shapiro-Wilk test and compared the avifauna richness and abundance among the areas using a one-way ANOVA (Tukey-HDS *post hoc*). Additionally, we calculated the rarefied richness adjusted for the smallest abundance of birds observed.

The degree of forest dependence (DFD) of bird species was classified based on Silveira & Machado (2012), as it follows: 1 – independent species (open-country birds), 2 – semi-dependent species and 3 – dependent species. Then, we performed a Chi-square contingency analysis to compare the bird species proportions and abundance associated to DFD at each forest reforestation stage and SDAF. In the contingency table, rows represent the different states of reforestation stages and columns the states of DFD. Then, cells contain specific state occurrences (row, column) of the variables reforestation stages and DFD. The significance of the association between the two variables (based on chi-squared) is then given, with *p* values from the chi-squared distribution. In this analysis, we used the accumulated bird species and individual sampled by point at each reforestation stage. The trophic guild from each bird species were obtained from Motta Junior (1990) and Sick (1997).

We used an analysis of similarity (ANOSIM) to verify differences in the bird species composition among reforestation areas and SDAF (Clarke 1993). The ANOSIM procedure uses Monte Carlo randomization of observed data to assess whether rank similarities within groups (point counts = 8) are higher than among groups (habitat types: R7, R10, and R15 reforestation areas and SDAF). To further explore differences in bird community composition, we ran a non-metric multidimensional scaling ordination (NMDS; Bray-Curtis dissimilarity, Clarke 1993) using bird species abundance resulting from the bird survey at point counts.

We used a similarity percentages procedure (SIMPER, Clarke 1993) in order to explore the association between bird species and reforestation areas and SDAF. Additionally, we performed a Detrended Correspondence Analysis (DCA, Hill 1974) to analyze the association between bird species and habitat type. The DCA is an ordination method adequate for comparing associations between each bird species and a given habitat type (number of individuals recorded per site). Like other ordination methods, DCA attempts to place similar sampling sites in similar positions in the ordination plot. Bird species are positioned in the graph in accordance to their abundance in relation to other species` abundance. We included only 17 species that explained differences in community composition among each pair of habitat types (based on SIMPER results) (Clarke 1993) in the DCA.

RESULTS

We spent a total of 64 hours of observations (16 hours in each reforestation area and SDAF) during 24 days in 384 point counts, with 2 hours and 40 minutes (16 points) per day. We recorded 107 species (971 contacts), 18 of which were restricted to the mature SDAF (Supplementary Material - Table SI). We reached the asymptote from the 30th point count in the species accumulation curve (Figure 3a).

Abundance and richness in initial reforestation stages (R7 and R10 years) showed significantly lower values than the advanced reforestation stage (R15 years) and SDAF (Figure 3b and 3c). We recorded 178 contacts in R7, 199 in R10, 267 in R15 and 329 in SDAF (Table SI). The bird species richness was 39 species in R7, 42 in R10, 50 in R15 and 58 in SDAF (Figure 3c). As we observed a wide variation in bird abundance across the studied areas (178 in R7 and 329 in SDAF), we performed an interpolation to verify species richness corrected from the abundance. Thus, the rarefied richness maintained the pattern of observed richness, where we observed 39 species in R7, 42 in R10, 50.4 in R15 and 58.7 in SDAF (Figure 3d).

DFD 3 bird abundance was higher either at older reforestation stages, including the SDAF (χ^2 = 157.4, P < 0.0001, df = 6, Figure 4a), or when comparing only the reforestation stages (χ^2 = 105.6, P < 0.0001, df = 4, Figure 4a). DFD bird species distribution differed across reforestation stages, in which higher proportions of DDF 3 species occurred at older reforestation stages, including

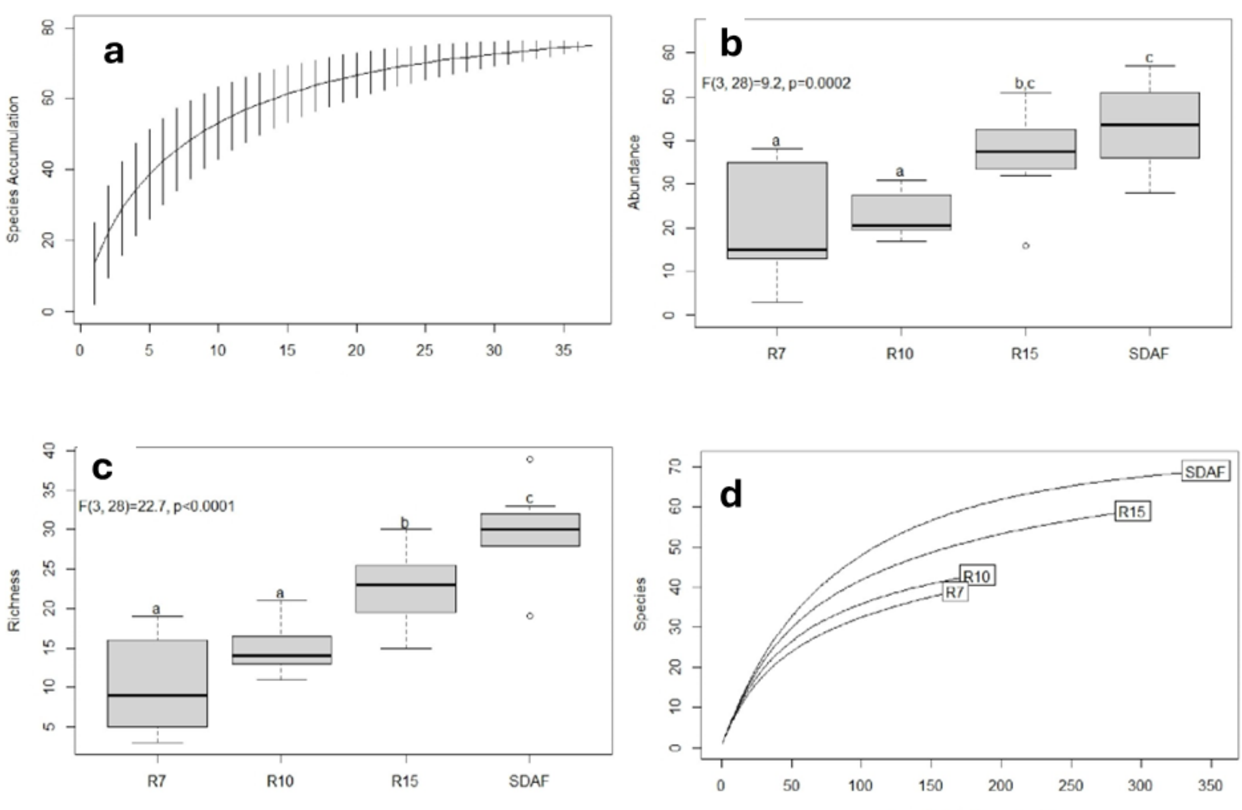

Figure 3. **a) Collector curve, b) abundance values, c) richness values and d) rarefy richness curve. R7, R10, R15 = reforestation ages (7, 10 and 15 years) and SDAF = mature Seasonal Deciduous Alluvial Forest.**

the SDAF (χ^2 = 25.6, P = 0.0003, df = 6, Figure 3b). The same trend persisted while comparing only reforestation stages (χ^2 = 11.9, P = 0.016, df = 4, Figure 4b).

Differences in bird species composition were greater between than within studied sites (ANOSIM, *r* = 0.63, *P* < 0.0001). This result reflected the coherence of sampling sites dispersion in the ordination plot according to bird

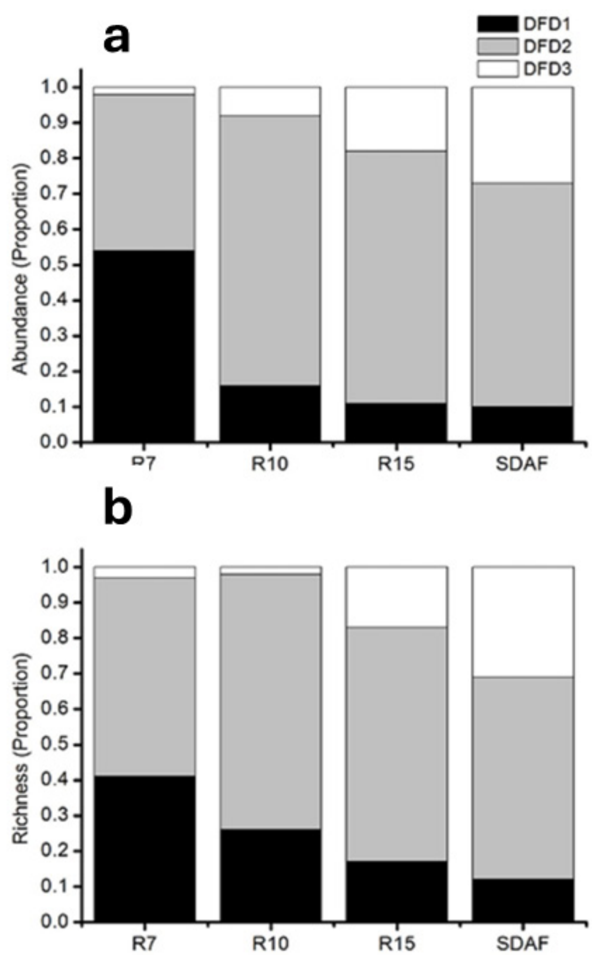

Figure 4. Proportion of both bird species (a) and number (b), according to the degree of forest dependence (DFD) along reforestation stages plus seasonal forest (SDAF), in the RPPN Cisalpina (Brasilândia, MS, Brazil). Degree of forest dependence for birds A) abundance and B) richness in R7, R10, R15 and SDAF. Caption: DFD 1= Degree of Forest D Dependence 1; DFD2 = Degree of Forest Dependence 2 and DFD3 = Degree of Forest Dependence 3. R7, R10, R15 = reforestation ages (7, 10 and 15 years) and SDAF = mature Seasonal Deciduous Alluvial Forest.

species composition in each area. Some species were entirely restricted to a given area which shared different complements of its avifauna with other sampling sites (Table SI). The most pronounced contrast in species composition was therefore between the bird assemblages of SDAF and R7, with R15 positioned close to SDAF (NMDS ordination, stress = 0.243, Figure 5).

The SIMPER analysis showed dissimilarities among the studied sites ranging from 64.91 (SDAF x R15) to 85.92 (SDAF x R7; intermediate values emerged within these extremes: R15 x R7 = 85.24, R10 x R7 = 82.60, SDAF x R10 = 73.28, R15 x R10 = 70.44). In this respect, dissimilarities in community composition were mostly due to species recorded more often or exclusively at a given area. The Axis 1 of DCA (eigenvalue = 0.56) described a species gradient that ranged from those ones often registered in semi-open habitats to forest dependent birds (Figure 6). Indeed, in one extreme of DCA 1 (most closely related to R7) were granivorous as *V. jacarina* and insectivorous of semi-opened habitats (*C. gujanensis* and *T. doliatus*) while in the opposite extreme (SDAF) were understory species as the insectivorous *M. flaveola* and *H. longirostris*, besides the nectarivorous *C. lucidus* and the omnivorous *I. cayanensis*. On the other hand (R15), DCA 2 (eigenvalue = 0.13) separated a gradient including canopy species such as *N. pileata, R. toco* (omnivorous) and *C. speciosum* (insectivorous) to the small understory insectivorous *C. rufus*. In fact, *C. speciosum* can explore all vertical gradients - from canopy to the ground (Ribon & Simon 1997) - and also it was frequently observed in both strata by SRP in the R15. In the intermediate values of Axis 1 and 2 (R10) the most representative were species of semi-opened habitats: the insectivorous *P. albosquamatus*, *H. margaritaceiventer* and *M. tyrannulus*, the omnivorous *T. sayaca*, the

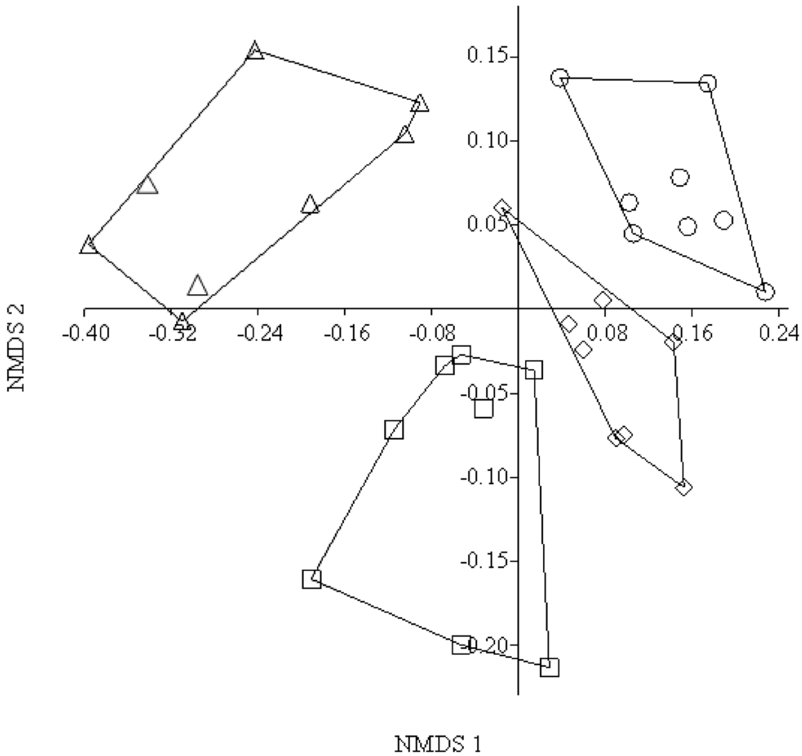

Figure 5. Non-metric multi-dimensional scaling (NMDS; stress = 0.243) ordination of bird communities' composition along a gradient of reforestation stage, plus seasonal forest (SDAF), recorded at point counts (n = 16, per habitat type) in the RPPN Cisalpina (Brasilândia, MS, Brazil). Caption: triangle = 7, square = 10, diamond = 15 years of reforestation stage, and circle = Seasonal Deciduous Alluvial Forest (SDAF).

nectarivorous *C. flaveola* and the frugivorous *T. leucomelas* (Figure 6).

DISCUSSION

According to the beta-diversity predictions (Baselga 2010), the vegetation structure is one of the main factors in determining animal species composition at the local level. Munro et al. (2011) found greater bird richness in old revegetation associated with high structural complexity of the vegetation in Australia. Our study revealed strong segregation of bird composition among the reforestation ages and a gradual increasing in forest dependent species, canopy frugivorous and understory insectivorous as the successional stages progressed. This is not surprising given the structural complexity in plantings increased with age: the vegetation gradient ranged from the young trees immersed in a grassland matrix (R7) to dense and tall trees in mature SDAF (Andrade 2011 and Andrade et al. 2022). In addition to serving as a food source for several bird species, plants contribute to several other aspects of Neotropical bird life, such as protection, roosting sites, nesting sites, among other factors (Garcia 2016). As a result, mature reforestation areas have birds more adapted to the forests and more homogeneous in composition, as found in the present study.

In R7 granivorous birds were attracted by colonization of opportunistic plant species (mainly grasses) growing among the planted trees, a common condition found in recent reforestations (Melo et al. 2020). So, these grasses harbor forest independent granivorous and/or omnivorous birds with high tolerance to environmental disturbance (Casas et al. 2016). This is confirmed by the fact that the most representative and the most exclusive species of R7 reforestation area were predominantly granivorous, including many species of Columbidae. In addition, we detected understory

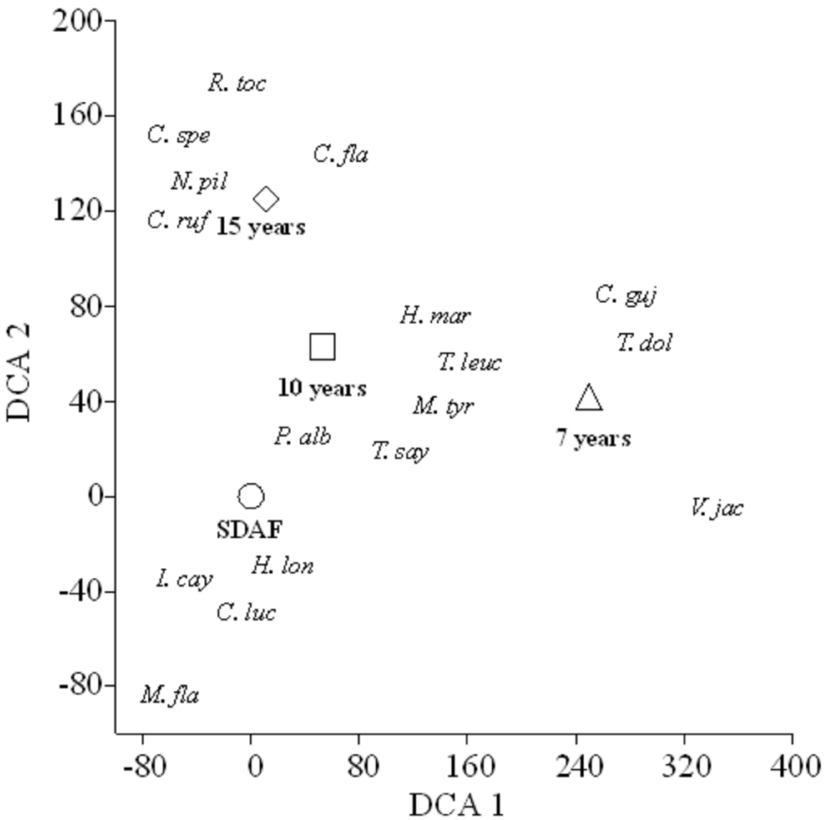

Figure 6. **Association between each reforestation stages (7, 10 and 15 years) and mature forest (SDAF). Detrended Correspondence Analysis axis 1 (eigenvalue = 0.26) and axis 2 (eigenvalue = 0.13). Caption: 7 years (*V. jac = V. jacarina; C. guj = C. gujanensis; T. dol = T. doliatus*); 10 years (*P. alb = P. albosquamatus, H. mar = H. margaritaceiventer; M. tyr = M. tyrannulus; T. leuc = T. leucomelas; T.say = T. sayaca*); 15 years (*C.fla = C. flaveola; N.pil = N. pileata; R. toc = R. toco; C. sp = C. speciosum, C. ruf = C. rufus*); SDAF = mature Seasonal Deciduous Alluvial Forest (*M. fla = M. flaveola; H. lon = H. longirostris, C. luc = C. lucidus; I. cay = I. cayanensis*).**

insectivores tolerant to more open areas, such as *L. angustirostris* and *T. doliatus*.

Our results indicated that an interval of three years is enough to make the avifauna dissimilar in composition among recent reforestations areas. In R10 the proportion of birds that are more forest dependent and able to feed on fruits (*T. sayaca* and *T. leucomelas*) and nectar (*C. lucidus*) increased. This last hummingbird fed intensely on the nectar of the *Inga uruguensis* flowers in September and October (SRP, pers. obs), a plant with high density in the RPPN Cisalpina reforestation areas (Andrade 2011, Andrade et al. 2022). Insectivorous birds from semi-dependent understory forests such as *P. albosquamatus, H. margaritaceiventer* and *M. tyrannulus* also appear as key species in R10. However, omnivorous/granivorous species, such as *Z. capensis*, are still present in R10. Although the grassland in R10 is reduced in comparison to R7 (Andrade 2011), at this stage the tree canopy does not completely prevent enough sunlight to avoid exotic grasses and thus, providing seeds to the granivorous birds.

Although there were rare frugivorous species in R7 and R10, omnivorous can also disperse seeds, such as *C. gujanensis, P. sulphuratus, N. pileata* and *I. cayanensis* (Camargo et al. 2020). The latter two were frequently observed feeding on fruits of *Cecropia pachystachya* (SRP, pers. obs.), a pioneer plant (Charles-Dominique 1986) widely used in these reforestations (Andrade 2011) and with strong mutualistic interactions with birds (Camargo et al. 2020). There were also some granivorous/omnivorous birds that can disperse seeds from the ground (Columbidae species and *C. parvirostris*), and from the understory (*T. leucomelas*). The high abundance of these dispersers bird species in recent reforestation areas is relevant because they play a key role during the early stages of forest regeneration, such as R10, by delivering seeds (Carlo et al. 2022).

The R15 reforestation area is more phytostructured than R7 and R10, with a predominance of taller trees, more canopy coverage and absence of exotic grasses (Andrade 2011, SRP pers. obs.). Older reforestations are expected to add more vegetation structure (e.g. herbaceous and arboreal strata) and they provide additional microhabitats that harbors higher bird diversity (Batisteli et al. 2018). This probably explains why R15 appears as a more cohesive bird group than the R7 and R10. In fact, R15 showed more homogeneous species assemblage compared to the bird assemblages in younger restoration areas. In addition, R15 harbors a more diverse bird community with higher forest dependent species than R7 and R10. Most probably R15 vegetation provides higher forested niches and additional resources for the bird community, especially higher diversity of insects (Tubelis & Cavalcanti 2000, Ramírez-Albores 2006, Posso et al. 2014). However, a test that adequately measure those attributes should be performed on further analysis to corroborate or not this assumption.

Our study showed a decline in seed-dispersing bird species as we considered the oldest to the most recent reforestation maturation. In R15, there are abundant frugivorous/omnivorous species (*T. leucomelas, N. pileata, M. momota, R. toco* and *M. pitangua*) responsible for distribution of seeds and expansion of second-growth forests (Camargo et al. 2020). According to Handel (1997), these birds introduce in reforestation areas a number of seeds much higher than the total produced by young plants. Thus, these abundant seed dispersers in R15 are strongly contributing to the recovery of the forest.

Although R15 had the most similar avifauna community in relation to the mature SDAF, it still had a bird assemblage with lesser diversity and different composition. In fact, 18 species found in SDAF were not detected in R15, so 15 years of reforestation are still insufficient to restore the SDAF avifauna. We have no Neotropical data to indicate how many years would be necessary to reforestations reach similar bird composition of a mature forest. According to Munro et al. (2011) it may take approximately 20-30 years for reforestations to show similar bird species richness as that of forest remnants in Australia. Many Neotropical bird species are relatively sensitive and dependent on mature forested environments (Korfanta et al. 2012), therefore, they probably do not find key ecological resources to support their colonization in these emerging forests. This fact is corroborated by the absence of several forest-dependent species in R15 when compared with the mature SDAF. Although there were abundant understory insectivorous birds in R15 (*C. speciosum* and *C. rufus*), they are semi-dependent of forests. In fact, there are not abundant understory insectivorous birds, dependent of forests in R15. We recorded these birds exclusively in SDAF: *A. polionotus, E. varius, G. ruficauda, L. leucophaius, M. viridicata, M. flaveola, P. polychopterus, S. griseicapillus* and *S. frontalis*. They are bioindicators of mature forest in Neotropical forest environments, as they are the most sensitive to environmental disturbances and the first to decline or disappear under such circumstances (Stouffer & Bierregaard 1995, Sekercioglu 2006). Moreover, hummingbirds (Trochilidae) presented high diversity with five key species for the mature SDAF; *C. mosquitus, P. pretrei* and *T. glaucopis* were found exclusively in SDAF. This mature forest harbors high angiosperms diversity in reproductive age, capable of offering nectar frequently and abundantly, especially species of Bromeliaceae, with closely co-evolving relationships with hummingbirds (Givnish et al. 2014). We also detected a high diversity of frugivorous species in mature SDFA. *A. galeata*, *E. penicilata, L. leucophaius, T. rufus, T. leucomelas* and *L. rufaxilla* are seed dispersers (Carlo et al. 2022) and they were found exclusively in mature SDAF. This high diversity of frugivorous is expected in mature Neotropical forests (Camargo et al. 2020).

Implications for reforestation programs

The crucial question about reforestation with native tree species is determine which parameters should be monitored to provide useful and cost-effective information on the development of biodiversity during the environmental recovery process (Piper et al. 2009). In this way, our results showed that birds constitute a reliable group to determine if the reforestation is in continuous ecological succession. They can rapidly recolonize many diverse reforestations habitats and they are also easily detected (Munro et al. 2011). Thus, the results indicate a natural and expected succession, starting from the most recent reforestations to the most mature. We recommended maintaining this system, in addition to preventive measures to avoid human actions such as fire, hunting and vegetation suppression in reforested areas.

The reforestation strategy that involves planting high diversity trees is the most common in Brazil and provides high diversity and floristic richness in the long term (Reis et al. 2003). This diversity and richness is optimized in environments where natural vectors, that promote pollen and seed dispersal, are available in the vicinity. This potential is pointed out in our study for the mature SDAF. Although we detected diaspore dispersing birds in the reforested areas, SDAF has higher diversity of frugivorous and, particularly, nectarivorous species . However, as reforestation ages and the canopy (and its resources) develop, there are still open spaces among plants, specially in the most recent reforestation. In this way, there will be a need to increase the number of vertical strata for plants to occupy this space. It consequently increases the bird species richness associated with this vertical stratum, especially seed and pollen dispersers. Thus, although the emergence of middle strata occurred naturally, we recommend the additional planting of herbaceous-shrubby species in the reforestation projects of the RPPN Cisalpina. These plants were neglected in the reforestation program of RPPN Cisalpina (Andrade et al. 2022) and they should be mixed with tree species. Munro et al. (2011) also recommended the woodlot plantings enhanced with shrubs in order to benefit bird community in restoration plantings. In fact, birds are recognized for their key role in pollination and seed dispersal, showing great effect on helping forest succession and ecosystem restructuring and provide a foundational ecosystem process that structure Neotropical plant communities (Sekercioglu 2006, Camargo et al. 2022). Bird species in different trophic levels represent essential allies in forest restoration management (McClanahan & Wolfe 1993, Ortega-Álvarez & Lindig-Cisneros 2012) as they are the most effective, abundant and diversified dispersers (Fleming & Kress 2011) and exploit a wide variety of plant species (Snow 1981, Wheelwright et al. 1984). In Neotropical forests, about 25-30% of the avifauna include fruits in their diet to a lesser or larger extent (Pizo & Galetti 2010). Through bird dispersal, seeds have a greater chance of surviving and reaching the site with more favorable conditions for their establishment and germination (Howe & Smallwood 1982, Galetti et al. 2006). In addition, by feeding on nectar (particularly hummingbirds) birds also contribute to the pollination of several species of these plants, a fact documented for Neotropical forests in general (Piacentini & Varassin 2007). Thus, planting of herbaceous-shrubby species, especially fleshy-fruited plants (Camargo et al. 2020), in these reforestations can accelerate and increase the structural complexity by promoting greater bird activity and seed dispersal, thus recruiting pollen and seeds of more plant species to reforestations patches.

In tropical regions, many frugivorous species perform movements for several reasons, such as structural change in habitat (Borghesio & Laiolo 2004) and mainly in relation to seasonality in fruit abundance (Camargo et al. 2020). Thus, mature forest areas are fundamental. They can offer a larger supply of food for a longer period of time, maintain frugivorous bird populations throughout the year, which can disperse seeds after rapid displacements over long distances, facilitated by the flight (Camargo et al. 2020). Godínez-Alvarez et al. (2020) demonstrated that small/medium birds, similar to those found in SDAF (*A. galeata*, *A. polionotus*, *D. cayana*, *S. similis* and *T. inquisitor*), are more effective dispersers of plants than large birds. Thus, the mature SDAF should be protected, mainly because frugivorous and nectarivorous birds will promote the reproduction process and acceleration of regeneration of the reforested areas (R7, R10 and R15). Nevertheless, many Neotropical bird species do not travel across open areas between patches, due to their high fidelity to the forest environment (Harris & Reed 2002). In this sense, the establishment of ecological corridors among the reforestation areas studied and the remaining mature and natural fragments of SDAF is crucial to restore this threatened Atlantic Forest. The RPPN Cisalpina is near to other protected SDAF areas, such as the Rio do Peixe State Park, the Aguapeí State Park and the RPPN Foz do Rio Aguapeí and they are located along the Paraná River. This situation represents a precious opportunity for conservation actions, cooperating to the formation of an ecological corridor of elementary biodiversity. In this way, we strongly recommend restoration measures to recover the Riparian vegetation of the Paraná River in order to guarantee higher species transit among these large areas of SDAF. The restoration of Riparian vegetation is one of the easiest, cheapest and most effective methods to promote connectivity (Corenblit et al. 2007); restored patches act as corridors to connect isolated fragments. They are also essential for the transit of forest bird species that disperse diaspores to new areas. Birds assist in the regulation of the new system, in the acceleration of the reproduction process and forest regeneration of the planted areas (Camargo et al. 2022).

As mentioned above, the SDAF is nearly decimated, as less than 1% of the original forest cover remains and it has high faunal richness including endangered animal species (Godoi et al. 2014). Thus, we hope that the insight from this study and the derived implications and recommendations for restoration will be useful for evaluation and decision making regarding future reforestation strategies of this highly threatened forest in Brazil.

Acknowledgments

Our appreciation and thankfulness to the Companhia Energética do Estado de São Paulo (CESP) for authorization and allowance of the studied area. RRLB received grants of Institutional Scientific Initiation Scholarship Program (PIBIC/UFMS-AF/PIBITI 2018-2019). LUH receives grants of Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, proc. #307212/2020-3). SVM participates in the Post-Doctoral Program at UFMS (PROPP/PROGEP/UFMS #41/2021) and receives scholarship from CNPq (proc. #150477/2021-0).

REFERENCES

ANDRADE FB. 2011. Plano de manejo como ferramenta de gestão para áreas naturais protegidas: avaliação dos resultados alcançados com a metodologia utilizada na reserva Cisalpina–Brasilândia MS. Master degree dissertation, Universidade Federal de Mato Grosso do Sul, Três Lagoas, 74 p. Available in https://repositorio.ufms.br/handle/123456789/993. (Unpublished).

ANDRADE FB, ALÉSSIO JD, RODRIGUES MLM, FEITOSA MV, PERETTI CL & MUSTAFÁ AL. 2022. Plano de manejo para a Reserva Cisalpina em Brasilândia/MS: metodologia e planejamento adotado. CESP, São Paulo, SP. 169 p. Available in https://www.imasul.ms.gov.br/wp-content/uploads/2022/04/Plano-de-Manejo-RPPN_Cisalpina_final.pdf.

BASELGA A. 2010. Partioning the turnover and nestedness componentes of beta diversity. Glob Ecol Biog 19: 134-143.

BATISTELI AF, TANAKA MO & SOUZA AL. 2018. Bird functional traits respond to forest structure in riparian areas undergoing active restoration. Diversity 10(3): 1-90.

BELLARD C, LECLERC C, LEROY B, BAKKENES M, VELOZ S, THUILLER, W & COURCHAMP F. 2014. Vulnerability of biodiversity hotspots to global change. Global Ecol Biogeogr 23: 1376-1386.

BIBBY CJ, BURGESS ND, HILLIS DM, HILL DA & MUSTOE S. 2000. Bird census techniques. Elsevier, London, 302 p.

BORGHESIO L & LAIOLO P. 2004. Seasonal foraging ecology in a forest avifauna of northern Kenya. J Trop Ecol 20(2): 145-155.

BROOKS TM & BALMFORD A. 1996. Atlantic forest extinctions. Nature 380(6570): 115-115.

BROOKS TM ET AL. 2002. Habitat loss and extinction in the hotspots of biodiversity. Cons Biol 16(4): 909-923.

CAMARGO PHSA, CARLO TA, BRANCALION PHS & PIZO MA. 2022. Frugivore diversity increases evenness in the seed rain on deforested tropical landscapes. Oikos: e08028.

CAMARGO PHSA, PIZO MA, BRANCALION PHS & CARLO TA. 2020. Fruit traits of pioneer trees structure seed dispersal across distances on tropical deforested landscapes: implications for restoration. J Ap Ecol 57: 2329-2339.

CAMPOS JB & SOUZA MC. 1997. Vegetação. In: Vazzoler AEAM, Agostinho AA & Hahn NS (Eds), A planície de inundação do alto rio Paraná: aspectos físicos, biológicos e socioeconómicos**.** Editora da Universidade Estadual de Maringá. Maringá, Paraná, p. 333-344.

CAMPOS JB & SOUZA MC. 2002. Arboreous vegetation of an alluvial riparian forest and their soils relations: Porto Rico island, Paraná River, Brazil. Braz Arch Biol Tec 45: 137-149.

CARLO TA, CAMARGO PH & PIZO MA. 2022. Functional ecology of Neotropical frugivorous birds. Ornit Res 30(2): 1-16.

CASAS G, DARSKI B, FERREIRA PM, KINDEL A & MÜLLER SC. 2016. Habitat structure influences the diversity, richness and composition of bird assemblages in successional Atlantic rain forests. Trop Con Sci 9(1): 503-524.

CHARLES-DOMINIQUE P. 1986. Inter-relations between frugivorous vertebrates and pioneer plants: Cecropia, birds and bats in French Guyana. In: Estrada A & Fleming TH (Eds), Frugivores and seed dispersal Dordrecht, Dr. W. Junk Publ., Springer Science & Business Media, Berlin, p. 119-135.

CHILD MF, CUMMING GS & AMANO T. 2009. Assessing the broad-scale impact of agriculturally transformed and protected area landscapes on avian taxonomic and functional richness. Biol Cons 142(11): 2593-2601.

CLARKE KR. 1993. Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18(1): 117-143.

COELHO MTP, RANIERO M, SILVA MI & HASUI E. 2016. The effects of landscape structure on functional groups of Atlantic forest birds. Wilson J Orni 128(3): 520-534.

CORENBLIT D, TABACCHI E, STEIGER J & GURNELL A. 2007. Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. Earth Sci Rev 84: 56-86.

DOBSON AP, BRADSHAW AD & BAKER AJM. 1997. Hopes for the future: restoration ecology and conservation biology. Science 277(5325): 515-522.

FLEMING TH & KRESS WJ. 2011. A brief history of fruits and frugivores. Acta Oecol 37(6): 521-530.

FONSECA GA. 1985. The vanishing Brazilian Atlantic Forest. Biol Cons 34(1): 17-34.

GALETTI M, DONATTI CI, PIRES AS, GUIMARÃES PR & JORDANO P. 2006. Seed survival and dispersal of an endemic Atlantic forest palm: the combined effects of defaunation and forest fragmentation. Bot J Lin Soc 151(1): 141-149.

GARCÍA D. 2016. Birds in ecological networks: insights from bird-plant mutualistic interactions. Ardeola 63(1): 151-180.

GIVNISH TJ, BARFUSS MH, VAN EE B, RIINA R, SCHULTE K, HORRES R & SYTSMA KJ. 2014. Adaptive radiation, correlated and contingent evolution, and net species diversification in Bromeliaceae. Mol Phyl Evol 71: 55-78.

GODÍNEZ-ALVAREZ H, RÍOS-CASANOVA L & PECO B. 2020. Are large frugivorous birds better seed dispersers than medium- and small-sized ones? Effect of body mass on seed dispersal effectiveness. Ecol Evol 10(12): 6136-6143.

GODOI MN, MORANTE-FILHO JC, MODENA ES, FAXINA C, TIZIANEL, FTT, BOCCHESE R, PIVATTO MAC, NUNES AP & POSSO SR. 2014. Birds of upper Paraná river basin in the southern Mato Grosso do Sul, Brazil. Braz J Ornit 21(3): 176-204.

HANDEL SN. 1997. The role of plant-animal mutualisms in the design and restoration of natural communities. In: Urbanska KM et al. (Eds), Restoration Ecology and Sustainable Development, Cambridge University Press, London, p. 111-132.

HARRIS RJ & REED JM. 2002. Behavioral barriers to non-migratory movements of birds. Ann Zool Fen 39(4): 275-290.

HILL MO. 1974. Correspondence analysis: a neglected multivariate method. J Roy Stat Soc: Series C 23: 340-350.

HOWE HF & SMALLWOOD J. 1982. Ecology of seed dispersal. Ann Rev Ecol Syst 13(1): 201-228.

IPARDES - INSTITUTO PARANAENSE DE DESENVOLVIMENTO ECONÔMICO E SOCIAL. 1992. Diagnóstico para a implantação de políticas para o setor florestal no Paraná. Fundação Ipardes, Curitiba, Paraná, 48 p.

KORFANTA NM, NEWMARK WD & KAUFFMAN MJ. 2012. Long-term demographic consequences of habitat fragmentation to a tropical understory bird community. Ecology 93(12): 2548-2559.

LAMB D, ERSKINE PD & PARROTTA JA. 2005. Restoration of degraded tropical forest landscapes. Science 310(5754): 1628-1632.

MCCLANAHAN TR & WOLFE RW. 1993. Accelerating forest succession in a fragmented landscape: the role of birds and perches. Cons Biol 7(2): 279-288.

MELO MA, DA SILVA MAG & PIRATELLI AJ. 2020. Improvement of vegetation structure enhances bird functional traits and habitat resilience in an area of ongoing restoration in the Atlantic Forest. An Acad Bras Cienc 92: e20191241. https://doi.org/10.1590/0001-3765202020191241.

METZGER JP, MARTENSEN AC, DIXO M, BERNACCI LC, RIBEIRO MC, TEIXEIRA AMG & PARDINI R. 2009. Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. Biol Cons 142(6): 1166-1177.

MORANTE-FILHO JC, POSSO SR, CUNHA NLD & BUENO FA. 2014. Tyrant flycatchers community in a mosaic of habitats of Cerrado, Brazil. North-Western J Zool 10(2): 425-434.

MOTTA-JUNIOR JC. 1990. Estrutura trófica e composição das avifaunas de três habitats terrestres na região central do estado de São Paulo. Ararajuba 1(1): 65-71.

MUNRO NT, LINDENMAYER DB & FISCHER J. 2007. Faunal response to revegetation in agricultural areas of Australia: a review. Ecol Man Rest 8(3): 199-207.

MUNRO NT, FISCHER J, BARRETT G, WOOD J, LEAVESLEY A & LINDENMAYER DB. 2011. Bird's response to revegetation of different structure and floristics—are "restoration plantings" restoring bird communities? Rest Ecol 19(201): 223-235.

ORTEGA-ÁLVAREZ R & LINDIG-CISNEROS R. 2012. Feathering the scene: the effects of ecological restoration on birds and the role birds play in evaluating restoration outcomes. Ecol Rest 30: 116-127.

PACHECO JF ET AL. 2021. Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee (2 edition). Ornit Res 29(2): 94-105.

PIACENTINI VQ & VARASSIN IG. 2007. Interaction network and the relationships between bromeliads and hummingbirds in an area of secondary Atlantic forest in southern Brazil. J Trop Ecol 23: 663-671.

PIPER SD, CATTERALL CP, KANOWSKI JJ & PROCTOR HC. 2009. Biodiversity recovery during rainforest reforestation as indicated by rapid assessment of epigaeic ants in tropical and subtropical Australia. Aust Ecol 34(4): 422-434.

PIZO MA & GALETTI M. 2010. Métodos e Perspectivas do Estudo de Frugivoria e Dispersão de Sementes por Aves. In: Accordi I, Straube FC & Von Matter S (Eds), Ornitologia e conservaçao: ciência aplicada, técnicas de pesquisa e levantamento. Technical Books Editora, Rio de Janeiro, Rio de Janeiro, p. 493-504.

POSSO SR, DE FREITAS MN, BUENO FA, MIZOBE RS, MORANTE-FILHO JC & NETO JR. 2014. Avian composition and distribution in a mosaic of cerrado habitats (RPPN Parque Ecológico João Basso) in Rondonópolis, Mato Grosso, Brazil. Braz J Ornit 21(4): 243-256.

RAMÍREZ-ALBORES JE. 2006. Variación en la composición de comunidades de aves en la Reserva de la Biosfera Montes Azules y áreas adyacentes, Chiapas, México. Biota Neo 6(2): 1-19.

REIS A, BECHARA FC, ESPÍNDOLA MB, VIEIRA NK & SOUSA LL. 2003. Restauração de áreas degradadas: a nucleação como base para incrementar os processos sucessionais. Nat & Cons 1: 28-36.

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 Cons 142(6): 1141-1153.

RIBON R & SIMON JE. 1997. The nest and eggs of the Chestnut-vented Conebill *Conirostrum speciosum* (Temmick, 1824). Ornit Neotropical 8: 71-72.

SEKERCIOGLU CH. 2006. Increasing awareness of avian ecological function. Trends Ecol Evol 21: 464-471.

SER - SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL SCIENCE & POLICY WORKING GROUP. 2004. The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International, 14 p.

SICK H. 1997. Ornitologia brasileira. Nova Fronteira. Rio de Janeiro, Porto Alegre, 863 p.

SILVA JMC & TABARELLI M. 2000. Tree species impoverishment and the future flora of the Atlantic forest of northeast Brazil. Nature 404(6773): 72-74.

SILVEIRA MHB & CG MACHADO. 2012. Estrutura da comunidade de aves em áreas de caatinga arbórea na bacia do Rio Salitre, Bahia, Brasil. Rev Bras Ornit 20(3): 161-172.

SNOW DW. 1981. Tropical frugivorous birds and their food plants: a world survey. Biotrop 13: 1-14.

STOUFFER PC & BIERREGAARD ROJR. 1995. Use of Amazonian forest fragment by understory insectivorous birds. Ecology 76(8): 2429-2445.

TUBELIS DP & CAVALCANTI RB. 2000. A comparison of bird communities in natural and disturbed non-wetland open habitats in the Cerrado's central region, Brazil. Bird Cons Intern 10(4): 331-350.

WHEELWRIGHT NT, HABER WA, MURRAY KG & GUINDON C. 1984. Tropical fruit-eating birds and their food plants: a survey of a Costa Rican lower montane forest. Biotropica 16: 173-192.

WHITMORE TC & SAYER J. 1992. Tropical deforestation and species extinction. Chapman & Hall, London, 153 p.

YOUNG TP. 2000. Restoration ecology and conservation biology. Biol Cons 92(1): 73-83.

How to cite

POSSO SR, BRINCK RRL, RAGUSA-NETTO J, HEPP LU & MILESI SV. 2024. How bird community responds to different ages of reforestation? Implications for restoration of a highly threatened Atlantic Forest phytophysiognomy. An Acad Bras Cienc 96: e20220691. DOI 10.1590/0001-3765202420220691.

Manuscript received on August 11, 2022;
accepted for publication on June 11, 2023

SÉRGIO ROBERTO POSSO[1]
https://orcid.org/0000-0002-7823-9068

ROSIANI R.L. BRINCK[1]
https://orcid.org/0009-0007-5892-9196

JOSÉ RAGUSA-NETTO[2]
https://orcid.org/0000-0001-9930-1548

LUIZ U. HEPP[3]
https://orcid.org/0000-0002-8499-9549

SILVIA V. MILESI[3]
https://orcid.org/0000-0002-9568-6476

[1]Universidade Federal de Mato Grosso do Sul – UFMS, LESCAN - Laboratório de Ecologia, Sistemática e Conservação de Aves Neotropicais, Av. Ranulpho Marques Leal, 3484, Distrito industrial, C.P. 210, 79620-080 Três Lagoas, MS, Brazil

[2]Universidade Federal de Mato Grosso do Sul – UFMS, LAMCON – Laboratório de Morfogenética e Conservação, Av. Ranulpho Marques Leal, 3484, Distrito industrial, C.P. 210, 79620-080 Três Lagoas, MS, Brazil

[3]Universidade Federal de Mato Grosso do Sul – UFMS, LABIND – Laboratório de Indicadores Ambientais, Av. Ranulpho Marques Leal, 3484, Distrito industrial, C.P. 210, 79620-080 Três Lagoas, MS, Brazil

Correspondence to: **Sérgio Roberto Posso**
E-mail: srposso@hotmail.com

Author's contribution

SRP, JRN, LUH and SVM conceived and designed the research; SRP and RRLB performed the bird surveys; SRP, JRN, LUH and SVM analyzed the data; SRP, JRN, LUH and SVM wrote and edited the manuscript.