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ORIGINAL ARTICLE

Functional and conservation-related traits of bird communities in tropical restoration and second-growth forest patches

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Abstract

Forest restoration is an important strategy to recover biodiversity in degraded areas, though we know much more about its importance to the recovery of the vegetation than the associated animals and their ecological functions. We surveyed with 10-min point counts the bird communities in 12 natural forest fragments (0.6–79.0 ha) and nine restoration areas (5–60 years old, 8.3–305 ha) in a region of severe forest conversion in the Brazilian Atlantic Forest, focusing on the ecological functions performed by birds related to diet and foraging stratum, as well as traits pertinent to their conservation (capacity to cross open areas, sensitivity to forest disturbance, forest dependence, migratory status). Taking into account the potential confounding effects of the size of sampled areas, we tested for differences between forest fragments and restoration areas in the species richness and abundance of birds according to their functional and conservation-related traits. While the species richness of most of the trait-based bird groups did not differ between the two vegetation types, most of them had greater abundances in forest fragments. In general, some of the groups of greater conservation concern (e.g., birds with low capacity to cross open areas) had greater species richness in forest fragments, while the abundances of groups generally more resistant to forest disturbance (e.g., granivores, omnivores, non-forest birds) did not differ between vegetation types. We showed that although the species richness of bird groups defined by functional and conservation-related traits occurring in restoration areas were similar to forest fragments, their abundances were in general lower in restoration areas, except for groups that are more resilient to habitat disturbance and, therefore, of least conservation concern. But we also highlight that, except for the most sensitive species, restoration areas are serving as habitat for many forest bird species in landscapes dominated by sugar cane monocultures and pasturelands, which by itself lend importance to such areas.

Keywords Atlantic Forest · Bird community · Brazil · Diet · Forest fragments

Introduction

Forest restoration is a leading strategy to recover biodiversity in degraded tropical regions, with ambitious restoration targets proposed for national governments and conservation NGOs worldwide (Crouzeilles et al. 2019). In such regions, only considering legislation compliance, the area to be restored is enormous. In the Brazilian Atlantic Forest, one of the hot spots of biodiversity in the world, the area to be restored in the next decades exceeds 5 million hectares (Rezende et al. 2018).

In addition to restoring vegetation and its associated ecosystem services (e.g., carbon sequestration, soil stabilization, and water quality improvement), habitat restoration for fauna is another, often secondary objective of ecological restoration (Ditt et al. 2010; Hale et al. 2019). Moreover, to maintain its integrity and perpetuation through the many ecological functions performed by animals (e.g., nutrient cycling, pollination, seed dispersal), the colonization of restored forests may also have a conservation purpose when they serve as habitat for extinction-prone animals. Taking birds as an example, there are several potential benefits of restored areas for the conservation of species sensitive to degraded habitats (Ortega-Álvarez and Lindig-Cisneros 2012).

Active restoration (i.e., the planting of native trees) is one of the most often employed techniques to restore tropical

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forests. In Brazil, active restoration occupies 78.4% of the land allocated to restoration projects (Brancalion et al. 2016). Recurrent questions involved in active restoration is whether it can bring back the ecological functions that a native forest normally performs, how long does it take to do so, and which factors influence the recovery of ecological functions. One shortcut to answer such questions is to focus on the colonization of species to restored areas and the ecological functions they are expected to perform based on their traits. Birds have been extensively studied in this regard. In the Brazilian Atlantic Forest, for instance, older restoration sites (> 20 years) have bird communities that differ in composition from recent restoration sites (< 5 years) and a higher occurrence of more specialized functional groups (e.g., small frugivorous birds of superior stratum) (Adelino et al. 2020). Besides restoration age, forest structure also affects the functional profile of bird species in areas of the Atlantic Forest under restoration (Batisteli et al. 2018).

The study of animal responses to ecological restoration is still incipient in tropical regions, which is alarming since these are the regions where habitat restoration is most needed given their high rates of habitat conversion and rich biodiversity. As the outcomes of restoration for any target organism or ecological process often show great variability (Brancalion et al. 2016), it is important to multiply the efforts to learn about the responses of organisms to restoration efforts, especially in highly degraded areas where restoration is much needed. Notwithstanding, in the Brazilian Atlantic Forest where only a small fraction (9–28% depending on estimates) of the original forest cover remains, only a handful of studies has been conducted involving birds in restoration areas (Adelino et al. 2020).

In this study, we compared the bird communities in restoration areas and second-growth natural forest fragments in a region of severe forest conversion where several bird species disappeared from vast expanses in the last centuries, the semi-deciduous Atlantic Forest (Morellato and Haddad 2000; Cavarzere et al. 2023). Although one possible goal of any restoration project might be to make the biological community as similar as possible to well-preserved stretches of the original habitat, often used as reference areas for comparisons, the most realistic goal for a hyper-fragmented, severely disturbed biome as the Atlantic Forest is to compare restored areas with natural forest fragments. Such fragments are the predominant form of forest cover in the tropics worldwide, harboring a great part of the remaining biodiversity (Wintle et al. 2019). In the Atlantic Forest in particular, they form most of the remaining forest (Ribeiro et al. 2009).

Our comparison involved traits typically associated with the ecological functions performed by birds (diet, foraging stratum) as well as traits pertinent to their conservation (capacity to cross open areas, sensitivity to habitat disturbance, forest dependence of birds, and migratory status), though such separation between functional and conservation-related traits often is a blur. For example, we know that frugivores or understory insectivores are particularly prone to extinction following forest fragmentation (Willis 1979; Volpato et al. 2006), and birds able to cross open areas are likely to serve as mobile links between neighboring forest fragments, delivering their ecological functions (e.g., seed dispersal, pollination) between multiple fragments (Vélez et al. 2015). We focused specifically on bird species richness and abundance to characterize the profile of bird communities in relation to their functional and conservation-related traits. While species richness is the most direct measure of biodiversity and one that easily translate the conservation value of a forest patch, abundance weights such value and mediates several of the ecological functions that birds may perform (Pizo et al. 2022). In addition, species richness and abundance take less time to achieve restoration success (i.e., similarity to reference sites) than species composition (Chazdon 2014; Crouzeilles et al 2017). If the restoration process is achieving its overall goal of restoring the functionality of a forest and providing habitat for conservation-sensitive species, we expected no difference between forest fragments and restoration areas in the species richness and abundance of birds in each of the functional and conservation-related traits considered.

Methods

Study areas

Both restored areas and forest fragments were in the semi-deciduous Atlantic Forest domain in São Paulo state, SE Brazil (Morellato and Haddad 2000). We sampled nine restoration areas with little or no connection to native forest fragments, with ages and sizes ranging from 5 to 60 years and 8.3 to 305 ha (Table 1; Supplementary Material Table S1 and Fig. S1). These are mostly riparian areas, where most ecological restoration initiatives are concentrated in the Atlantic Forest to restore forests illegally cleared for agricultural use (Rodrigues et al. 2011). Such areas have a closed canopy and were planted following a 3 × 2m scheme with a high diversity (> 50 species) of both pioneer and non-pioneer tree species plus a few exotic species in some areas (Rodrigues et al. 2011; Rother et al. 2019). All the restoration areas are embedded in an agricultural matrix of sugarcane.

Twelve forest fragments ranging in size from 0.6 to 79.0 ha were sampled in the Corumbataí Basin (Table 1; Supplementary Material Table S1 and Fig. S1), whose native vegetation covers only 12% of the landscape (Valente and Vettorazzi 2003). Ten fragments had a matrix of active pastures, and two were in a sugarcane agricultural matrix. The minimum and maximum distances between restored areas

Table 1 The characteristics of restoration areas and forest fragments

Site name	Type of area [1]	Area (ha)	Age (year)	Number of point counts	Species richness
Fragment 1	FRAG	4.73	–	1	18
Fragment 2	FRAG	0.93	–	1	30
Fragment 3	FRAG	3.7	–	2	58
Fragment 4	FRAG	0.68	–	1	31
Fragment 5	FRAG	8.5	–	2	44
Fragment 6	FRAG	7.3	–	3	57
Fragment 7	FRAG	2.8	–	1	44
Fragment 8	FRAG	0.61	–	1	39
Fragment 9	FRAG	30.26	–	8	87
Fragment 10	FRAG	79	–	8	88
Fragment 11	FRAG	60.5	–	8	81
Fragment 12	FRAG	70	–	8	87
Represa São Luís	REST	30	17	7	49
Santa Ernestina	REST	15	13	2	34
Cruz do Vau	REST	34.63	5	2	24
Primavera 1	REST	10.37	7	4	23
Santa Eudóxia	REST	8.3	7	3	26
Usina Ester	REST	30	60	4	38
Parque Aimaratá	REST	9	9	4	35
Usina São João	REST	21	8.5	4	45
Guariroba	REST	305	10	6	40

[1]Type of area: *FRAG*, forest fragments; *REST*, restoration areas

and forest fragments were 22.1 km and 215.3 km, respectively, averaging 65.9 km.

Bird survey

From September to December 2015, censuses were carried out with 10-min unlimited radius point counts in which a record corresponded to an independent detection of a bird species irrespective of flock size. According to its size, each area had 1 to 8 sampling points 200 m apart from each other, which allowed us to sample all points in each area from 30 min before sunrise until about 11 am. We conducted three replicates for each of 44 sampling points in forest fragments and 36 points in restoration areas, resulting in 240 surveys. We did not record birds only detected flying over the areas.

Functional and conservation traits

We assigned birds to diet (carnivorous, frugivorous, granivorous, insectivorous, nectarivorous, omnivorous, piscivorous), sensitivity to habitat disturbance (low, medium, high), forest dependence (dependent, semi-dependent, independent), and foraging stratum (canopy, ground, mixed — i.e., birds occupying both canopy and understory strata — understory, and water) groups following Alexandrino et al. (2016), Stotz et al. (1996), Silva (1995), and Alexandrino (2015), respectively (Supplementary Table S2). Forest-dependent species are found mainly in forested habitats, semi-dependent species occur in forests but also in open habitats, usually with scattered trees, while independent species occur in open vegetation like pastures, grasslands, and marshes. The migratory status (resident × migratory) of birds was based on our experience with birds in the field and on over 21,000 eBird lists for the study region. Based on our experience, we also classified bird species in relation to their capacity to cross open areas as high, low, and medium capacity (Supplementary Material Table S2). As open areas, we considered non-forested, 100–200-m-wide areas composed by herbaceous vegetation such as active pastures and sugarcane plantations that form the dominant matrixes in the study areas.

Data analyses

Due to low occurrence, piscivorous birds and birds that forage on water were excluded from the analyses. We compared the species richness of functional and conservation-related bird groups in restoration areas and forest fragments by means of generalized linear mixed-effects models (GLMMs) with Poisson distribution. The number of species of each group recorded at each sampling point (the three replicates pooled together) was the response variable, with type of vegetation (restoration or fragment) as a fixed factor, and area as a random factor. Because bird species richness at each point may differ due to a number of unconsidered factors (e.g., historical processes) that would potentially affect the number of species in each group, the total species richness recorded at each sampling point was set as a covariate, as well as the size (ha) of each area. In this way, the GLMMs allowed us to contrast the proportional representation of bird groups defined by diet, migratory status, foraging strata, forest dependence, sensitivity to habitat disturbance, and capacity to cross open areas in the bird communities sampled in forest fragments and restoration areas.

Using the point count data, we calculated the point abundance index of each species at each sampling point by dividing the total number of records of the species by three, the number of replicates per point (Blondel et al. 1970). We then summed the point abundance index of all species belonging to a given functional and conservation-related bird group per sampling point as a proxy of the local abundance of each group. The summed abundance index for each group was then used as a response variable in linear mixed-effects models (LMMs), having again the type of vegetation (restoration or fragment) as a fixed factor, the size (ha) of the area as a covariate, and area identity as a random factor. Model assumptions were checked graphically. All analyses were done in R (R Core Team 2022).

Results

Species richness

We recorded 131 and 98 bird species in point counts at forest fragments and restoration areas, respectively, with 84 species in common between them (Supplementary Material Table S2; raw data available in https://zenodo.org/records/10126029). The species richness of only four out of the 20 functional groups differed between forest fragments and restoration areas. While species with low capacity to cross open areas, nectarivorous species, and species with medium sensitivity to forest disturbance occurred in greater numbers in forest fragments, the richness of species independent of forests was higher in restoration areas (Fig. 1A; Supplementary

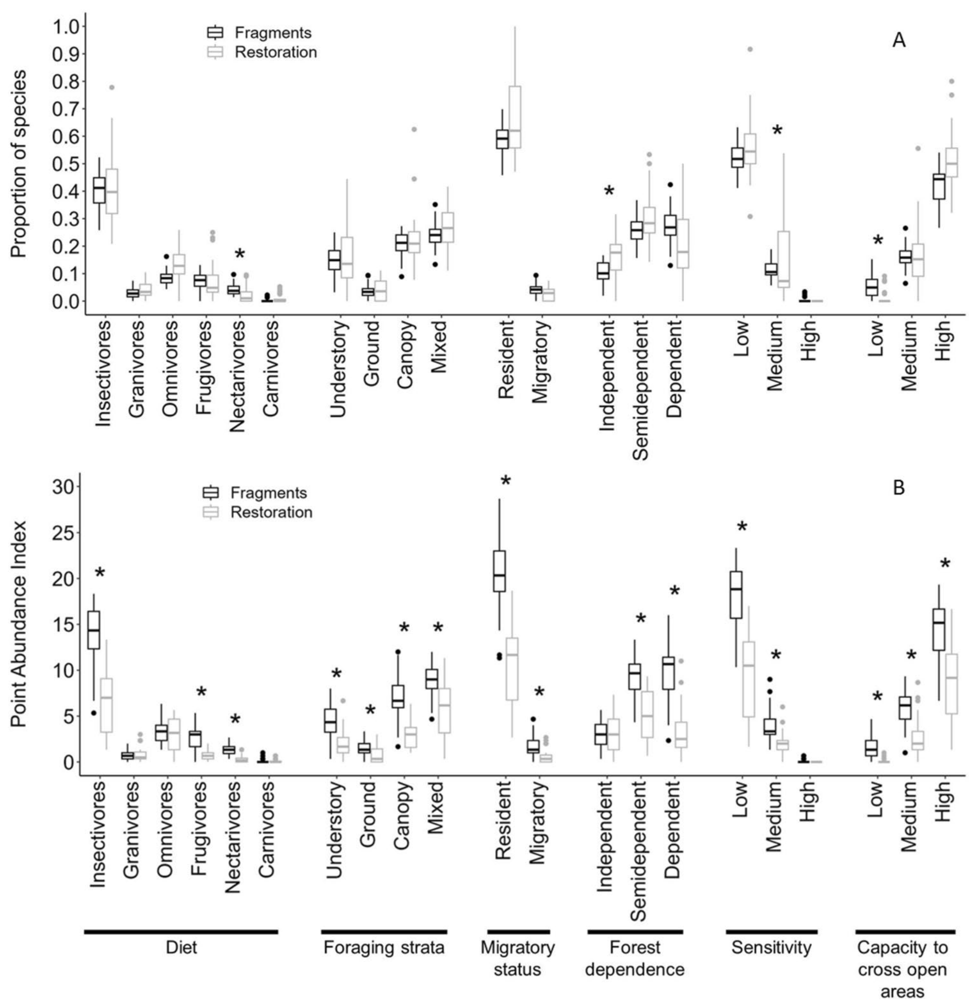

Fig. 1 Box plots showing the **A** species richness and **B** abundances of bird groups recorded in forest fragments and restoration areas. Bird groups were defined by functional and conservation-related traits. The species richness of each group is represented in proportion to the total number of species recorded in each vegetation type. The point abundance index was used as a proxy of abundance. Asterisks denote significant differences between vegetation types at $\alpha = 0.05$

Material Table S3). We highlight that only ten migratory species were recorded in the study areas, while the only two species highly sensitivity to habitat disturbance (*Dromococcyx pavoninus* and *Campylorhamphus falcularius*) were detected only in two of the largest forest fragments (Fragments 11 and 12 in Table 1).

Species abundances

Turdus leucomelas was the species that most frequently figured among the top 5 most abundant species (representing 5.9% and 8.4% of all the 2961 and 1148 records made in forest fragments and restored areas, respectively) in both vegetation types (Supplementary Material Table S4). Insectivorous birds that occupy mixed strata, birds that have a high capacity to cross open areas, have low sensitivity to disturbance or are semi-dependent on forests predominated among the most abundant species in both forest fragments and restoration areas (Supplementary Material Table S4).

For most of the functional groups, birds were more abundant in forest fragments. The only exceptions were carnivorous, granivorous, and omnivorous species, and birds that do not depend on forests, for which there were no differences in abundance between forest fragments and restoration areas (Fig. 1B; Supplementary Material Table S3).

Discussion

Considering the potential confounding effects of the size of sampled areas, the species richness of most functional and conservation-related bird groups did not differ between forest fragments and restoration areas. The exceptions involved nectarivores, birds that have low capacity to cross open areas, and birds that have a medium sensitivity to forest disturbance. We can only speculate about the underlying reasons leading to a lower number of nectarivorous species (mainly hummingbirds) in restoration areas, but it may have to do with the diversity of flowering plants. We know that the diversity of plant growth forms is important to provide flower resources in restoration areas (Garcia et al. 2014), but active restoration projects commonly plant only trees (Brancalion et al. 2018), which may preclude the year-round occupation of restoration areas by nectarivores. The other groups whose species richness was higher at forest fragments involve birds that are usually more sensitive to forest disturbance and isolation. For such species, the restoration areas may not constitute adequate habitats. It should be noted, however, that, except for the 60-year-old area, restoration areas were recently planted and may have not had enough time to develop more completed communities, which may take decades to occur (Catterall et al. 2012). We should highlight the low number of species highly sensitive to habitat disturbance, only detected in two of the largest forest fragments, which is indicative of the conservation concern that such species deserves to thrive in the highly fragmented landscapes typical of the semi-deciduous Atlantic forest (Cavarzere et al. 2023). It also suggests that most of the forest fragments (and restoration areas) in such landscapes indeed do not constitute habitat for such conservation-sensitive species.

Forest fragments had a higher overall abundance of birds than restoration areas, which was true for most functional and conservation-related groups. The groups whose abundances did not differ (carnivorous — only three species recorded, granivorous, omnivorous, and birds that do not depend on forests) are usually more resilient to forest disturbance (Morante-Filho et al. 2015). Once again, the issue of the age of restoration areas should be considered, since the abundance of birds in such areas has been shown to be influenced by the time since planting via the influence of restoration age on the development of forest structure (Noe et al. 2022).

In summary, we showed that although the species richness of bird groups defined by functional and conservation-related traits occurring in restoration areas were similar to forest fragments, their abundances were in general lower in restoration areas, except for groups that are more resilient to habitat disturbance and, therefore, of least conservation concern. These results may stem from the short time of forest development in most restoration areas (5–17 years), likely insufficient to permit the full development of vegetation structure, which usually positively influence bird communities in such areas (Melo et al. 2020). Future surveys of these areas are needed to address this possibility and, in an adaptive management approach (sensu Holling 1978), help to reframe restoration practices if needed (e.g., the inclusion of a more diverse array of plant growth forms in the original planting to promote a greater complexity of the vegetation structure). Anyway, to advance our understanding of the role of restoration areas for the recovery of ecological functions promoted by birds, future studies should refine the functional classification used here and commonly used in other similar studies (e.g., Batisteli et al. 2018; Adelino et al. 2020), which is important since different species in each functional group may perform slightly different their functions. For instance, insectivorous birds look for preys on different substrates (Gabriel and Pizo 2005), while frugivores go after different fruit species depending on their nutrients (Pizo et al. 2021).

We should note that the functional profile of the bird communities thriving in forest fragments, here used as reference sites, may differ from pristine forests. Therefore, it is likely that restoration areas depart even greatly from more preserved areas in what concerns the functional roles provided by birds (Barros et al. 2022). But, except for the most sensitive species, restoration areas are serving as habitat for many forest bird species in landscapes dominated by sugar cane monocultures and pasturelands, which by itself lend importance to such areas. Future studies should look at measures of fitness (i.e., breeding, survival) that will allow the development of self-sustaining breeding populations in them (Hale et al. 2019). In other words, it is necessary to understand whether restoration areas indeed serve as habitats for the species or act as ecological traps.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43388-023-00160-2.

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Author contribution C.O.A.G. and M.A.P. conceived the study; C.O.A.G. collected the data in the field; A.F.B. did the statistical analyses; and M.A.P. and A.F.B. wrote the manuscript. All authors read and approved the final manuscript.

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Data availability Raw data for this paper is available in https://zenodo.org/records/10126029.

Declarations

Consent to participate All the authors consent to participate in this study.

Conflict of interest The authors declare no competing interests.

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