



# Promoting Bird Functional Diversity on Landscapes with a Matrix of Planted *Eucalyptus* spp. in the Atlantic Forest

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## Abstract

Promoting the diversity of biological communities in areas of agricultural production is a very current debate since protected areas may not be sufficient to ensure biodiversity conservation. Among the biological communities affected by the production areas are birds, which show rapid responses to changes in the landscape. Here we seek to understand how landscape planning, concerning its composition and configuration, in areas with a matrix of planted *Eucalyptus* spp. forests influences the functional diversity of bird assemblages in the Atlantic Forest. Our results show that the spatial distribution design of planted forests in terms of age, land cover and clone types have effects on bird diversity with regard to functional divergence, functional evenness and species richness. These results reinforce the importance of good management for the maintenance of bird diversity. We found that bird functional diversity in planted forest matrices increased with the proximity index, proportion of native vegetation and age importance value, and is negatively influenced by edge density and proportion of forest plantation. For bird conservation, it is thus better to associate *Eucalyptus* spp. with other cover types in the landscape. These results corroborate that, to increase bird functional diversity, it is possible to associate conservation and production in the same landscape. Mosaic landscapes have great potential to contribute to the conservation of bird biodiversity outside protected areas. However, decisions regarding the management of planted forests and planning of improved areas intended for conservation seem to be decisive to ensure the maintenance of bird biodiversity.

**Keywords** Landscape structure · Forest planning · Community ecology · Conservation biology · *Eucalyptus* spp.

## Introduction

Intensely managed planted forests occupy 131 million hectares worldwide (FAO 2020). In Brazil, they cover an area of 7.83 million hectares, with a predominance of *Eucalyptus* spp. plantations, which make up 72.41% of this total (IBÁ 2019). Widely spread in the Atlantic Forest region, planted *Eucalyptus* spp. forests (here called planted forests) are cultivated by adopting strategies that generate forms of land use and landscapes with distinct structures capable of influencing local biodiversity (e.g.: Jacoboski et al. 2016; Millan et al. 2015). Planning of new areas is considered key in the implementation phase, and there may be plantations in mosaics of ages and clone types, which contribute to increasing the resilience of the plantations and controlling pests and diseases (Gonçalves et al. 2013). When performed at large scales, the harvesting phase generates simplified landscapes, but when performed in mosaics of smaller plots, it increases landscape complexity (Franklin and Forman 1987; Pawson et al. 2013).

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The complexity of the landscapes is also influenced by the presence of native vegetation, located mainly close to rivers or on steeper terrain, commonly found as fragments amid the agricultural/forestry matrix. Those areas can easily assume the role of biodiversity conservation areas (Lamb et al. 2005; Bowen et al. 2007). In the Atlantic Forest, those areas occupy about 28% of the landscape, composed mainly of small fragments that are distant from each other (Ribeiro et al. 2009; Rezende et al. 2018). However, considering the landscape dominated by forest plantations, the occupied proportion is higher, reaching about 41% (IBÁ 2019).

Native vegetation areas result from compliance with the Brazilian Native Vegetation Protection Law (Brasil 2012) which obliges properties to protect areas on sloping land and around rivers and springs (“Permanent Preservation Areas”) in addition to more 20% at the choice of the owner to compose the “Legal Reserve” (LR). In the case of the LR category, it becomes possible to choose the areas to be protected or restored (Banks-Leite et al. 2011; Tambosi et al. 2014) aiming at improving the structure of the landscape itself and/or for the fauna and water quality.

Regarding landscape planning for *Eucalyptus* spp. production, one of the current objectives of forest companies is to establish landscapes that provide ecosystem services and consequently the sustainability of production. In Brazil, for instance, almost half of planted forests are certified by the Forest Stewardship Council standard (IBÁ 2019), and the certification process and maintenance require indicators evidencing that silvicultural practices are not negatively affecting the wildlife and flora of the region.

Among the biological communities affected by agricultural/forestry management are birds, which are used in ecological surveys due to their potential for rapid response to changes in the landscape (Tschardt et al. 2005; Gardner et al. 2008). However, each species has a different behavior according to its characteristics, such as feeding guild and foraging stratum (Martensen et al. 2008; Boscolo and Metzger 2011; Alexandrino et al. 2017). Because of that, the functional diversity approach is the strategy used to aggregate the particularities of each species expressed by bird traits, for example. Then, the functional diversity makes it possible to understand in more detail the effects of landscape structure on the traits of the biodiversity elements being considered (e.g.: Dias et al. 2016; Leitão et al. 2016).

Therefore, the maintenance of the functional diversity of biological communities in forest production ecosystems, concomitantly with increased productivity, brings the need for studies that elucidate ways to achieve these objectives (Tschardt et al. 2005; Bennett et al. 2006; Brockerhoff et al. 2008, 2013). Considering that there is a risk that areas intended for conservation cannot guarantee biodiversity conservation by themselves, it is necessary to investigate and adopt techniques that promote the conservation of

biodiversity beyond protected areas (Daily 2001; Fischer et al. 2006).

Within this context, our objective was to understand how landscape planning in planted forests areas can influence bird assemblages’ functional diversity. For this, we characterized the assemblage of birds present in areas of native vegetation located in landscapes of planted forest matrix, the landscape structure of the mosaic formed by planted forests and areas intended for conservation, and we also evaluated the relationship between landscape structure and bird functional diversity. We hypothesized that there is greater functional diversity of birds in landscapes of planted forests with a higher proportion of native vegetation, conserved and formed by contiguous areas.

## Material and methods

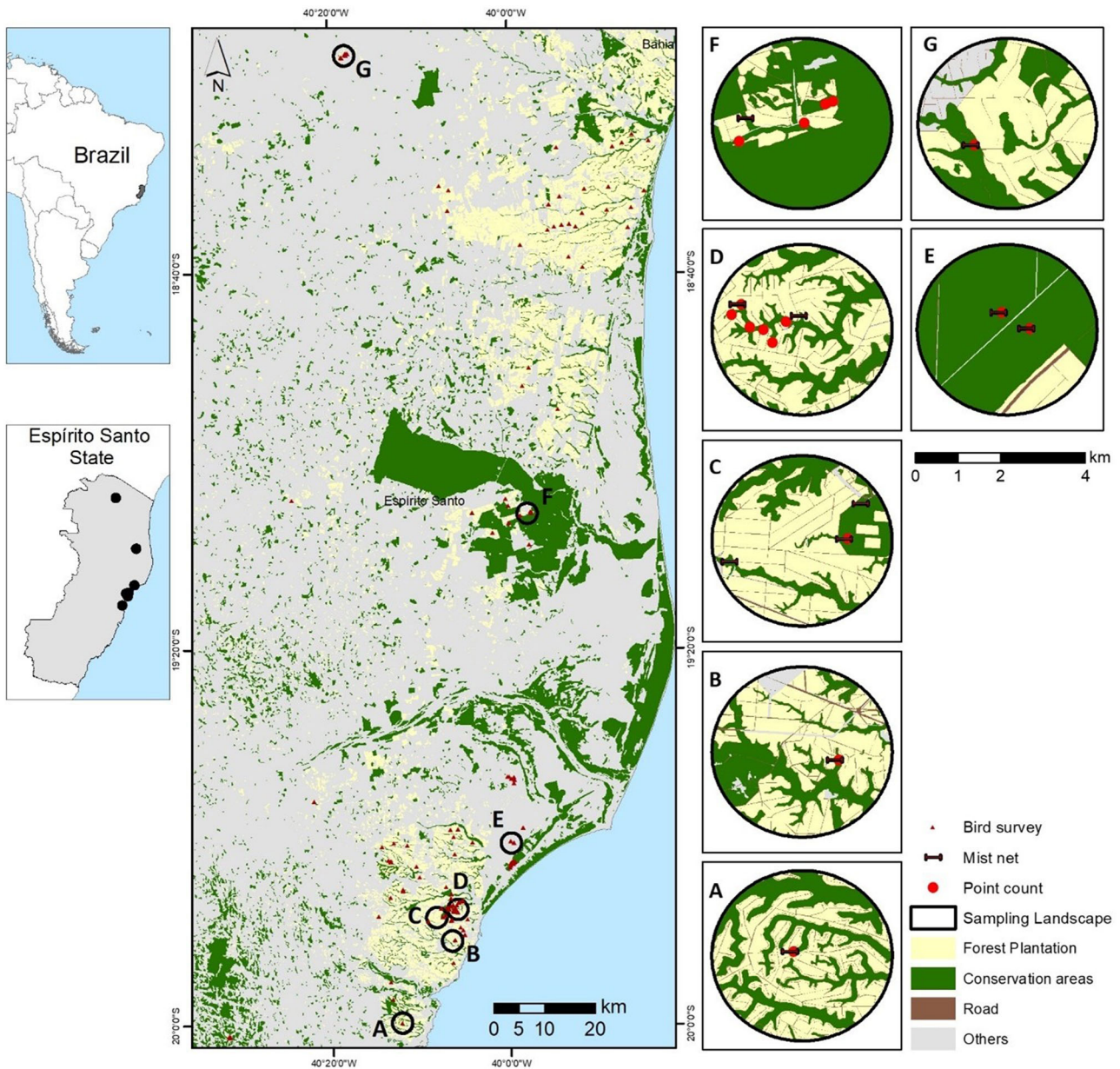
### Study Area

The study was conducted in areas of north-central Espírito Santo, Brazil, a state with more than 220,000 ha of planted forests bordered by areas intended for conservation (IBÁ 2019). It has a tropical climate with dry winters (Aw in Köppen’s classification). The average annual temperature ranges between 20.2 and 26.1 °C, and the average annual precipitation is around 1290 mm (Alvares et al. 2013). The predominant soil is Ultisol (dos Santos et al. 2011). The study area is located at an average altitude of 43 m above sea level and with a mean slope of 7% (SRTM 1).

This region is part of the Atlantic Forest biome, which is considered a world hotspot – it is one of the most biodiversity-rich areas on the planet, with the highest degree of endemism in the world, but also very threatened due mainly to deforestation (Myers et al. 2000). The north-central Espírito Santo state (Brazil) was intensely occupied between the 1920s and 1940s for coffee production and livestock farming. In the 1950s, the need for coal to produce iron and steel intensified the opening of new areas and in the late 1960s, forestry began in the region, becoming one of the main activities (Loureiro 2006). Currently, there is about 23% of native vegetation left in the state (Rezende et al. 2018), formed by Dense Ombrophilous Forests (IBGE 2004). In this region, in several localities where planted forests are present, they form clusters and become the landscape matrix, because of their predominance in area and before being considered non-habitat (Forman and Godron 1986).

### Sampling Design

The companies responsible for these planted forests periodically survey biodiversity in native vegetation in these areas, meeting requirements to obtain and maintain forest



**Fig. 1** Sampling landscapes located in the state of Espirito Santo, Brazil, in areas of matrix composed of planted *Eucalyptus* spp. forests (left). Land use in the sampling landscapes and the location of bird

surveys (right). Source: Remnants of Atlantic Forest—SOS Mata Atlântica 2013/2014; Planted Forest—MapBiomias Collection 5

certification (FSC 2014). Based on the information about the places where the company carried out bird surveys in this region (database belonging to Suzano Papel e Celulose), we allocated 7 points in the places with the highest cumulative sampling effort. From the centroids of the surveys, we created buffers with 2 km radius, which formed the sampling landscapes (SL), so that they could represent the existing ecological processes and their size was in accordance with what is recommended in the literature (Boscolo and Metzger 2009; Smith et al. 2011). In addition, the sampling landscapes have variations in land cover which we measured through selected landscape metrics (Fig. 1).

### Landscape Structure

We used a land cover map of the year 2010 at 1:10,000 scale prepared by the company responsible for the study area resulting from a topography survey. Some SLs covered areas with no company operation, so there was a gap in information about land use. In these cases, we used images from LANDSAT 5 TM satellite with 30 meters of spatial resolution and high-resolution images from Google Earth for 2010 to manually complement information on land use in these areas. As the areas we needed to complement were not large enough to justify an image classification and to maintain the land



cover classes and map information provided by the company, a manual land cover complement was the best option.

We obtained the metrics for each of the seven SLs defined. We calculated three metrics to measure the landscape matrix (i.e., planted forests) and six metrics for the native vegetation. We selected most of the metrics for being widely applied in similar studies (e.g.: Thies and Tschamtkke 1999; Villard et al. 1999; Banks-Leite et al. 2011; Dias et al. 2016), and others we developed to check landscapes particularities as explained hereafter.

For the landscape matrix we obtained: (i) the proportion it covered the landscape (Peuc) as a way to check whether its presence can influence the bird assemblage; (ii) the diversity of *Eucalyptus* spp. clones present in the landscape (DCLeuc), considering that planted forests with low clone diversity form more homogeneous landscapes than forests with high clone diversity; and (iii) the development stages of the planted forest (AIVeuc), weighted according to the planting age (<1.5 years) (w: 0.2), 1.6 to 3.0 years (w: 0.4), 3.1 to 4.5 years (w: 0.6), 4.6 to 6.0 years (w: 0.8) and > 6.1 years (w: 1.0); see Online Resource 2 for more details.

For the areas of native vegetation we obtained: (iv) the proportion covering the landscape (Pnat); (v) the proportion of core area in the remnants relative to the total area of native vegetation (Core), considering core areas as those at 50 m away from the edge of the fragment (Murcia 1995); (vi) the diversity of classes of native vegetation (Dnat), considering that there is a greater possibility of high biodiversity when there is a greater variety of ecosystems present in the landscape (McGarigal and McComb 1995); (vii) the potential for biodiversity conservation according to the types of native vegetation importance value (TIVnat), giving greater weight to native vegetation areas that are in more advanced stages of development and/or had less anthropic alteration, factors that influence the assemblage of birds (e.g.: Alexandrino et al. 2017) - the weights are presented in Online Resource 1 of the supplementary material; (viii) the edge density (ED), which reflects the degree of influence of external factors such as wind, heat and humidity on native vegetation (Murcia 1995); and finally (ix) the Proximity Index (PROX), which reflects the chance of an individual finding a resource within a search radius, taking into account the distance and size of native vegetation areas (Gustafson and Parker 1992; Belcik et al. 2020). The calculation was performed with a search for patches whose edges are within a 1,00 m radius from the focal patch. We present the equations used to calculate each metric in Online Resource 2. We calculated all metrics using ArcGIS software v. 10.3 and the V-Late extension to calculate the proximity index.

## Bird Survey

We used data from bird surveys carried out in the areas of native vegetation by the company responsible for the

planted forests from 2010 to 2014, totaling 5 years of data. Companies from the Brazilian forest sector usually survey the fauna and flora in their area of operation to assess the maintenance of local diversity through the biological community that is directly affected by the amount of native vegetation and the condition in which the remnants are (e.g.: Martensen et al. 2012; Turner 1996; Uezu and Metzger 2011). We considered the surveys carried out by fixed points and mist nets since using the two procedures is considered an effective approach for bird assemblage investigation (e.g.: Wang and Finch 2002; Maas et al. 2015).

Mist nets were used for the samplings of understory birds. Each sample consisted of 10 nets, five with 36 mm mesh and 2.5 m height and the other five with 61 mm mesh and 3.25 m height, forming a 134-m-long line open at sunrise and exposed until midday, checked every hour. We oriented the mist nets in a way that they are completely inside/alongside the native fragments, following the relief when it was possible, and occupied different proportions of the height of the forest, but focused on the understory. We adopted the pattern of 35 h of sampling effort per SL; that is, SLs with greater effort had the excess amount randomly eliminated and the SLs with less effort were not used. After standardization, the average sampling effort was  $33.28 \pm 1.71$  h per sample, which totaled 232.97 h of mist nets exposed in areas intended for conservation.

Samplings by fixed points were carried out at least 50 m away from the edges of the native vegetation remnants and 200 m away from each other to avoid overlapping sampling units. The observations were made half an hour after sunrise, lasting up to two hours after this time. The sampling interval was 20 min, and we recorded all species seen or heard, then, the number of contacts was used as a measure of abundance. As performed with the data of mist nets, it was also necessary to standardize the sampling effort per fixed point between the SLs. We adopted the sampling effort of 6 h per SL. The SLs with greater number of hours had the excess amount randomly eliminated. After standardization, the average sampling effort was  $5.67 \pm 0.00$  h per sample, which totaled 39.67 h of sampling per fixed point in native vegetation areas. With the combination of these two types of survey we obtained the species richness and abundance. We used the nomenclature and taxonomic order adopted by the Brazilian Committee of Ornithological Records (Piacentini et al. 2015).

## Functional Traits

We used four traits to functionally describe the bird species recorded in the study area. The traits address the acquisition and use of the resources consumed in terms of the food aspect regarding (1) diet (feeding guild), (2) position of the

**Table 1** Traits used to calculate functional diversity indices for birds

Trait	Categories or Variation	Scale	Reference
Feeding Guild	carnivore, frugivore, granivore, herbivore, insectivore, nectarivore, broad omnivore, restricted omnivore, scavenger	Categorical (9 classes)	Wilman et al. 2014 with approach of Alexandrino et al. 2017
Foraging strata	water, ground, understory, midstory, canopy, aerial	Categorical (multichoice)	Parker III et al. 1996
Habitat of occurrence	aerial, forest, non-forest		
Body Mass	2.6 to 3994.9 g	Continuous	Collecting data and literature revision (del Hoyo et al. 2015; Magalhães et al. 2007; Wilman et al. 2014)

vertical stratum birds use to forage (foraging stratum), (3) type of habitat in which birds are found and (4) energy resource available to the birds (average body mass shown by the species) (Table 1). These traits were selected because they are related to the role of the species in the community, the energy flows involved and the structure of the ecosystem (Peters 1983), and also to allow comparison with other studies that have used similar attributes (e.g.: De Coster et al. 2015; Leitão et al. 2016; Petchey et al. 2007).

### Functional Diversity Indices

From the species with the functional traits and the abundance recorded in the selected SLs, we calculated three independent metrics to quantitatively represent functional diversity: Functional Richness (FRic), Functional Evenness (FEve) and Functional Divergence (FDiv). The advantage of applying these indices lies in using data of abundance and various traits of the species. In addition, functional traits can be on different measurement scales without the indices being related. Thus, it is possible to evaluate the functional diversity present in a given landscape more comprehensively way than evaluating only species richness (Flynn et al. 2009).

To calculate these indices, we standardized the functional traits and abundances of the species. Regarding functional traits, we initially calculated the adapted matrix of Gower's distance between each pair of species because it standardizes each variable type independently. Next, we constructed the global distance matrix and thus calculated the contribution and correlation of each trait (Pavoine et al. 2009). After that, we performed a principal coordinate analysis (PCoA). We used the first seven axes to construct a multidimensional space because they showed the best quality of multidimensional space based on the lowest mean square deviation between the initial functional distance and the scaled distance in the functional space between pairs of species (Maire et al. 2015). We used the axes to compute the three indices of functional diversity. The first of these, FRic, represents the functional volume occupied by the bird assemblage, and it can be said that the

higher the value, the greater the number of functions performed in the assemblage. The second index, FEve, describes the evenness of the distribution of abundance in a space of functional traits and it decreases when abundance is not evenly distributed among species and/or when the functional distance between traits is not regular (Villéger et al. 2008). The third and last index, FDiv, is related to the divergence of the distribution of abundance in the functional volume occupied by the species; the greater the FDiv, the lower the competition for resources because there is an indication that there was a high degree of differentiation of niches in that assemblage (Mason et al. 2005). We calculated the functional diversity of the bird assemblage using the statistical software R and the functions `quality_funcn_space` and `multidimFD` (R 2022).

### Statistical Analyses

The four response variables of the bird assemblage (functional diversity indices - FRic, FEve, FDiv and species richness - SRic) were modeled separately by linear regressions (LM) using landscape metrics related to planted forests and areas intended for conservation as explanatory variables. First, we checked the assumptions of the model regarding data normality. Transformations were necessary for the variables FRic, Peuc, DCLeuc, Pnat and Dnat, because they were not normally distributed, so they were transformed using the Box-Cox method because it suggests the better transformation of the data. After the regressions, we checked the distribution of the residuals, which did not show asymmetry. For each response variable, we constructed a set of candidate models using landscape metrics as explanatory variables, which resulted in 9 models per response variable. We compared the candidate models using Akaike's Information Criterion (AIC) adjusted for small samples (AICc); models with the lowest AICc are considered the most parsimonious in a set of candidate models (Burnham and Anderson 2002). For all models, we also calculated Akaike weights ( $w_i$ , which can be interpreted as the probability of a model being the one with the best support in a set; Burnham and Anderson

(2002)) and the coefficient of determination ( $R^2$ ) to evaluate the quality of fit of the model. For the interpretation of the best models, we considered those with better support,  $\Delta AICc \leq 2$  (Burnham and Anderson 2002), and  $R^2$  greater than 0.20. Statistical analyses were carried out using R software (R Core Team 2022).

## Results

### Bird Biodiversity at Forest Plantation Landscapes

A total of 859 contacts resulted in 175 species of birds found in the studied areas. The lowest richness found was 34 species, and the highest was 75 species (Online Resource 3 in Supplementary Material).

Most detected birds feed preferably on insects (63.0%), have a forest habit (62.3%) and forage in the understory and midstory strata (17.7%) (Fig. 2). The contacted birds had body masses varying from 2.6 to 3994.9 grams, with an average of 32.6 grams. Although a high amplitude in species richness was found among the sampling landscapes, the functional diversity indices did not show great variation. The difference between the highest and the lowest value was 0.063 for FRic, 0.100 for FEve and 0.164 for FDiv. The presence of planted forests in the sampling landscapes ranged from 10 to 64%, and the presence of native vegetation areas ranged from 20 to 86% (SM Fig. 2).

The silviculture practices in planted forests showed a high level of mixed clones in the landscape since DCLeuc remained above 0.9 and the maximum was 1.0. AIVEuc showed lower values than DCLeuc, ranging from 0.28 to 0.60. The values evidenced the presence of homogeneous forests in terms of age and the predominance of young forests. The native vegetation metrics showed a high range

for Core an average value slightly above 0.5, demonstrating that more than half of native vegetation did not have influence of edges. In contrast, ED also had high variation in its values and an average of 49.8 m/ha. Despite that, Dnat had distinct values among sampling landscapes, but tended to have considerable diversity in types of native vegetation, and the areas intended for conservation in general had good conservation quality (see TIVnat—SM Fig. 2). PROX index oscillated more than 30 times between the lowest and the highest value, and all sampling landscapes showed values above 100 thousand.

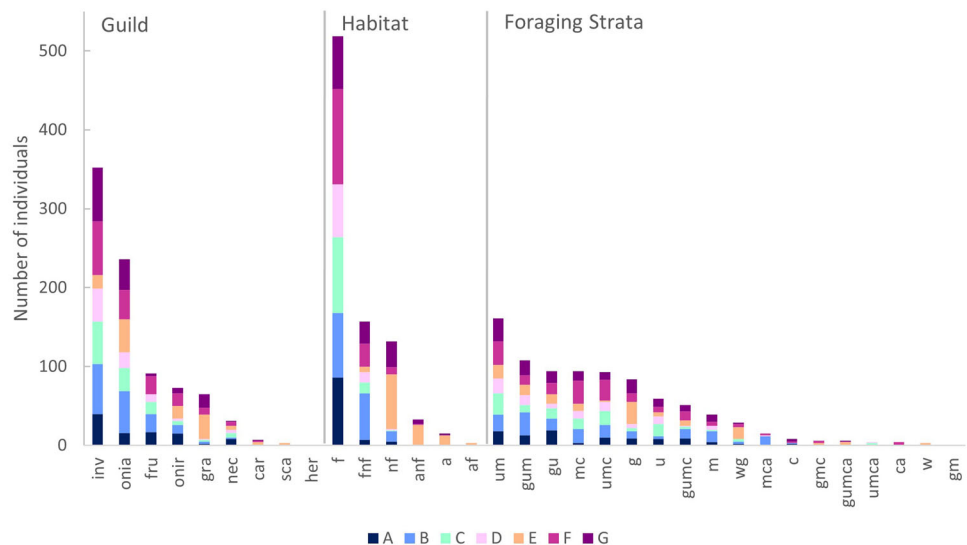
### Effects of Landscape Structure on Bird Biodiversity

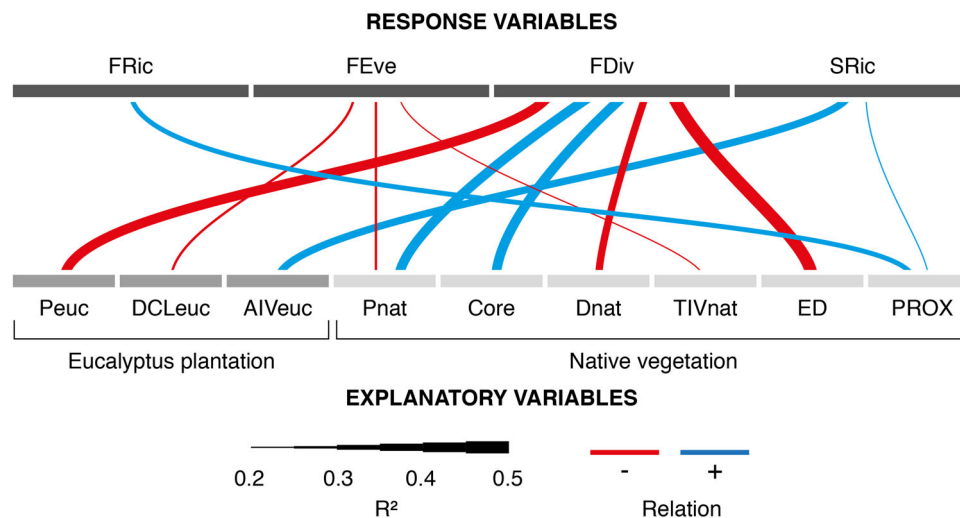
The composition and configuration of the landscape matrix formed by planted forests, represented here by the metrics proportion of planted *Eucalyptus* spp. forests (Peuc), diversity of clones (DCLeuc) and age importance value (AIVEuc), influenced the functional divergence (FDiv) present in areas intended for conservation, functional evenness (FEve) and species richness (SRic), respectively (Fig. 3 and Online Resource 3).

The composition and configuration of the areas intended for conservation occupying the planted forest landscapes were also related to bird functional diversity. Species richness (SRic) and functional diversity (FRic) were positively correlated with proximity index (PROX). The regularity of the functions performed by the species (FEve) decreased as the proportion of native vegetation increased and in cases in which it had a higher degree of conservation (Pnat and TIVnat) (Fig. 3 and Online Resource 3).

Functional divergence (FDiv), the index that showed the highest number of better-supported relations, increases when there is a lower overlap of niches or competition for resources, and this condition was favored when there was a

**Fig. 2** Distribution of bird individuals by sampling landscapes (letters A–G) and by categorical characteristics used to compute functional diversity indices. (Guild: car: carnivore; fru: frugivore; gra: granivore; her: herbivore; inv: insectivore; nec: nectarivore; onia: broad omnivore; onir: restricted omnivore; sca: scavenger. Habitat: a: aerial; f: forest; nf: non-forest. Foraging Strata: w: water; g: ground; u: understory; m: midstory; c: canopy; a: aerial)





**Fig. 3** Results of linear regression models for bird functional diversity indices and landscape metrics as explanatory variables. Line thickness represents the coefficient of determination and color represents the signal of the relation. (FRic: Functional Richness; FEve: Functional Evenness; FDiv: Functional Divergence; SRic: Species Richness;

Peuc: Proportion of *Eucalyptus* spp. plantation; DCLeuc: Diversity of Clones; AIveuc: Age Importance Value; Pnat: Proportion of native vegetation; Core: Core area proportion; Dnat: Diversity of classes of native vegetation; TIVnat: Types of native vegetation importance value; ED: Edge density; PROX: Proximity index)

higher proportion of native vegetation (Pnat). In addition, this vegetation must have lower edge density (ED), greater core area proportion (Core) and lower diversity of classes of native vegetation (Dnat).

## Discussion

### Bird Assemblage at Forest Plantation Landscapes

The bird assemblage observed here, composed predominantly of insectivores and omnivores, corroborates the results of other studies which surveyed birds in landscapes with planted forests matrix (Tejeda-Cruz and Sutherland 2004; Volpato et al. 2010; Lopes et al. 2015) and in other anthropic landscapes (Martin et al. 2012; Alexandrino et al. 2019). Studies in planted forests have also identified the presence of a greater number of species that forage in the forest canopy (Tejeda-Cruz and Sutherland 2004; Cockle et al. 2005), whereas in the present study there was a predominance of birds which foraged in the understory and midstory, reinforcing the importance of the presence of understory in native vegetation. As for the predominance of forest-dwelling species in this study, some studies report the same pattern (e.g.: John and Kabigumila 2011; Zurita et al. 2006), while other studies identified the predominance of generalist species (e.g.: Jacoboski et al. 2016; Volpato et al. 2010). Understory and midstory strata may have become important because of the predominance of forest individuals, which prefer more developed native forests that can have understory and mid-story strata, increasing the support capacity for birds.

### Effects of Landscape Structure on Bird Biodiversity

The native vegetation proportion in the studied landscapes was higher than that found in this region (Rezende et al. 2018; Ribeiro et al. 2009). All the SLs analyzed have more than 20% of native forest, with an average of 45% (see Pnat—SM Fig. 2), a value above that found for the extensive fragmentation of the Atlantic Forest in the region where the study was conducted, i.e., biogeographical sub-regions of Bahia, where the proportion is 17.7% (Ribeiro et al. 2009). The values of the present study are higher than the thresholds indicated for the maintenance of ecological functions, 30% according to Banks-Leite et al. (2014), and for conserving species of forest habitats, 40% according to Arroyo-Rodríguez et al. (2020). However, two of the seven SLs analyzed did not reach this vegetation cover threshold, indicating that even this landscape with a good quantity of native vegetation cover still has areas which require more attention and need to be eventually restored.

However, the structure of this landscape can also affect biodiversity positively with the major presence of native vegetation core areas compared to edge areas (Banks-Leite et al. 2010). Our results also highlight the contribution of the native vegetation core area of the patches present in landscapes for maintaining of bird biodiversity. Those areas increase niche differentiation, which does not occur when the patch is only influenced by edge effects. Studies suggest that the presence of core areas is paramount for the permanence of species that are sensitive to disturbances, and corridors favor mainly the generalist species, so the presence of these two landscape components is important (Banks-Leite et al. 2010; Hansbauer et al. 2008).

Concerning the production areas, we were able to assess a wide variation of forest plantation land cover. In areas where *Eucalyptus* spp. trees have been cultivated for a long time, and near the pulp mill, there is a predominance of *Eucalyptus* spp. plantation on the landscape, mainly to reduce the transportation costs of raw materials to the plant pulp mill (Ferreira et al. 2019). On the other hand, the diversity of clones (DCLeuc) showed a low data variability but with high values, mainly because the high diversity of clones planted in a mosaic system is one of the techniques adopted to control the dissemination of pests and diseases and to promote resilience to extreme climatic events (Burdon and Aimers-Halliday 2006; Martins et al. 2017). The age importance value of the forest plantation showed that most of the studied areas have young forests under six years old. This is because in this region, the forests intended for cellulose pulp production are cultivated in short rotations and reach the optimal cutting age at around six years of age (Gonçalves et al. 2013; McMahan and Jackson 2019).

## Relationship Between Bird Functional Diversity and Landscape Structure

### Planted *Eucalyptus* spp. Forests

Our results show that the spatial distribution design of planted forests in terms of age, land cover and choice of clones (metrics AIVeuc, Peuc, DCLeuc, respectively) has effects on bird diversity (FDiv, FEve, SRic) in areas intended for conservation in the matrix, which reinforces the importance of good landscape management for the maintenance of bird diversity. Although the landscape matrix has already been pointed out as modulator in the composition of the bird assemblage (Dunford and Freemark 2005; Kennedy et al. 2010; Aben et al. 2012; Alexandrino et al. 2019), little was known, until now, about the influence of the management of planted forests, reinforcing the importance of economic decisions that affect the land cover of a landscape and its characteristics influencing biodiversity.

The higher proportion of planted forests in the landscape (Peuc) caused a decrease in the functional divergence of the bird assemblage (FDiv). This is because intensively cultivated landscapes tend to be more homogeneous than those with a lower proportion of cultivated areas. Consequently, the amount of functions performed by the bird assemblage is also smaller, that is, there is no major differentiation of niches (Mason et al. 2005). This relationship is corroborated by a study that found a decrease in FDiv in areas of overstocked pine trees compared to less densely stocked plantations (Lee and Carroll 2018).

The relative abundance of species with different functional characteristics (FEve) was more uniform in areas with lower diversity of clones (DCLeuc), since this generates a

homogenization in the forest profile, in the landscape and, consequently, in the supply of resources, directly influencing the avifauna. In addition to the fact that there is no differentiation of niches (FDiv), with an increase in the proportion of planted forest (Peuc), if it also has no variety in its planting regarding species or clones (DCLeuc), there will be stability in the supply of resources and consequently in the uniformity of functions being represented by the bird assemblage (FEve), as observed in other studies (Leaver et al. 2019; Jacoboski and Hartz 2020). On the other hand, the increase in the complexity of the landscape by natural agents, diversity of crops or ages of forest plantations can influence the composition of fauna species, which responds according to the functional traits that they have (Bennett et al. 2006; Burgess and Maron 2016).

### Areas Intended for Conservation

With the results found in this study, we confirmed that both the structure and composition of the areas intended for conservation and also of the landscape matrix formed by planted forests directly influence bird assemblages, so adequate planning of the landscape can positively aid biodiversity. To increase the components of bird functional diversity (FRic, FEve, FDiv), our results corroborate the land-sharing proposal, showing that it is possible to associate conservation and production in the same landscape (Phalan et al. 2011).

The increments in bird richness (SRic) and in the number of functions performed (FRic) were mainly influenced by the landscape forest availability (PROX). Our results support previous research, emphasizing that forest connectivity facilitates the movement of birds, influencing species richness, in addition to enabling their presence and higher abundance than less connected landscapes (Alexandrino et al. 2019; Boscolo and Metzger 2011; Holbech 2009; John and Kabigumila 2011; Laube et al. 2008; Martin et al. 2012; Uezu et al. 2005; Zurita et al. 2006). Also, the proximity of production areas to native vegetation has been recognized as a way to promote the presence of a greater richness of bird species and increase of key species that prey on pests (Maas et al. 2015). In this context, birds with certain traits may be more affected than others. Understorey frugivores, nectarivores and insectivores decrease their richness when there is less native forest, while granivores are favored, but not where *Eucalyptus* spp. plantation is the matrix (Tschardt et al. 2008; Clough et al. 2009; Jacoboski et al. 2016). Therefore, the amount of native forest becomes an important factor for the balance and management of landscapes in which biodiversity conservation is sought.

In addition, in this study, we identified that when the remnants are very irregular (high ED), and the proportion of native vegetation in the landscape under edge effect increases (low Core), it leads to reductions in the divergence of functions (FDiv) performed by the bird assemblages,



limiting birds to specific traits or traits associated with a given location. The edge effect, given the size of the fragment, is the main agent of the landscape structure that changes the inner forest structure, changing the composition of the bird community since it limits the existence of mature interior forests (Banks-Leite et al. 2010). Studies show that greater bird richness is found in core areas when compared to areas where the edge effect is predominant (Watson et al. 2004). A similar relationship was found in palm oil plantations and in urban environments where the amount of native forest prevented the loss of functional diversity (Schütz and Schulze 2015; Prescott et al. 2016). So, landscapes that favor fewer possibilities of different niches lead to lower functional diversity of birds.

Functional Evenness (FEve) is influenced on a fine scale by the homogeneity of the structure of the native vegetation present, determining its ecosystem function for the landscape, such as seed dispersal and insect control (Sitters et al. 2016). The types of native vegetation (ex. Online Resource 1) present in a given location increase through natural disturbances or anthropic landscape management processes, which also cause an increase in the richness of bird species (Fairbanks 2004; Bennett et al. 2006). However, this richness may be distributed unevenly among the various functional traits (Willson 1974; Hudson and Bouwman 2007; Burgess and Maron 2016).

On the other hand, the functional divergence of the bird community (FDiv) tends to increase when specialist species are present (Boyer and Jetz 2014). This corroborates the result found for the positive relationship between functional diversity and stage of forest succession (TIVnat), since it is known that specialist bird species have a preference for occurring in preserved habitat as opposed to degraded fragments, which have a low value for this index (Jiguet et al. 2007; Pardini et al. 2009). Furthermore, biodiversity and the presence of varied functions in the biological community promote the capacity for resilience (Tschamtko et al. 2008). Diversity of characteristics makes it possible for the bird communities to restructure themselves after extreme events, external pressures or incorrect actions adopted in management more easily than other communities with low functional diversity (Fischer et al. 2006; Jiguet et al. 2007).

### Implications for Landscape Management

Due to the differentiated conditions found in landscapes with forest plantation, with a higher proportion of areas of native vegetation compared to the condition found in agricultural landscapes of the Atlantic Forest (Ribeiro et al. 2009; Rezende et al. 2018), it is possible to adopt practices in these landscapes to increase their conservation potential in a way that adds to the established roles of protected areas (Daily 2001). Implementing single plantations in the landscape is one of the first aspects to be observed since the

homogenization of large areas reduces the differentiation of niches in the bird assemblages. Production should be sought through the increase of productivity in areas already occupied instead of expanding into new areas. This point can be achieved by identifying growth restrictions and adopting strategies to overcome the limitations, e.g. choosing adequate genetic material, adopting the best quantity of trees per hectare, performing good soil management, identifying the deficiencies of nutrients and controlling weeds, pests and diseases (Gonçalves et al. 2013; Elli et al. 2019), or alternating the covers of landscapes already homogenized by silviculture, seeking to diversify the landscape. The richness of bird species can benefit from the increase in rotation cycles, which would contribute to the reduction of constant management activities in the area and the possibility of understory formation, which contributes to the permanence of bird assemblages (Calviño-Cancela 2013; Luck and Korodaj 2008). In addition, agglomeration in the landscape of genetically close clonal groups may favor the balanced distribution of functions performed by the bird assemblage. On the other hand, clonal mixtures are recommended for maintaining the resilience of plantations in recovering from damage caused by pests, diseases and extreme weather events (Carnus et al. 2006).

Regarding areas intended for conservation, because of the evolution in stages of forest succession, it is natural that there is a tendency of homogenization. Still, in this case, it is expected that there will be an increase in the conservation value of these areas, offsetting the losses in the diversity of vegetation types (Bengtsson et al. 2003). Thus, areas intended for conservation should become similar to the natural forest structural patterns of the region through the protection of native vegetation, natural regeneration, restoration and/or increase of areas, considering that the heterogeneity of the landscape is particularly important (Fischer et al. 2006). Protecting areas intended for conservation can be achieved by different techniques, such as maintaining marginal *Eucalyptus* spp. forest strips without management around remnants of native vegetation (Margules and Pressey 2000; Fischer et al. 2006; Brockerhoff et al. 2008). In areas in early regeneration, it is necessary to protect against fires, livestock, invasion of exotic species or other disturbances (Zavaleta et al. 2001; Fischer et al. 2006) and adopt strategies that can accelerate the natural recovery of the area at landscape level (Lamb et al. 2005).

At the landscape planning scale, it is necessary to increase the amount of native vegetation and it would be better to have a higher proportion of core area than areas under edge effects and that the remnants of native vegetation are close to each other. For this purpose, one may consider the elimination of roads bordering areas of native vegetation, reallocating them in such a way as to increase cultivation areas, which can act as a barrier, or the adoption of buffer zones (Murcia 1995). Eliminating this type of road

would reduce the costs of road maintenance and limit the influence of vehicles that, with their noise, interfere with the fauna potentially present in these remnants and hinder the access of hunters (Kleinschroth et al. 2016).

Increased proximity between areas of native vegetation and production areas can be achieved by restoring and maintaining permanent preservation areas around watercourses, which can form corridors, increasing landscape connectivity (Bennett 2003; Şekercioğlu et al. 2015). When this strategy has been implemented, another possibility in areas with intense forestry production is to identify isolated remnants so that ecological stepping stones can be implemented to improve the permeability of the landscape matrix (Uezu et al. 2008), which is important in biodiversity conservation (Rösch et al. 2015).

Landscapes formed by mosaics of forest plantation and native vegetation have great potential to contribute to the conservation of bird biodiversity outside protected areas. However, decisions regarding the management of forest plantations and planning areas intended for conservation seem to be decisive in ensuring the maintenance of bird biodiversity in these landscapes.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

## References

- Aben J, Adriaensen F, Thijs KW et al. (2012) Effects of matrix composition and configuration on forest bird movements in a fragmented Afrotropical biodiversity hot spot. *Anim Conserv* 15:658–668. <https://doi.org/10.1111/j.1469-1795.2012.00562.x>
- FAO (2020) Global Forest Resources Assessment 2020. FAO, Rome
- Alexandrino ER, Buechley ER, Karr JR et al. (2017) Bird based Index of Biotic Integrity: assessing the ecological condition of Atlantic Forest patches in human-modified landscape. *Ecol Indic* 73:662–675. <https://doi.org/10.1016/j.ecolind.2016.10.023>
- Alexandrino ER, Buechley ER, Forte YA et al. (2019) Highly disparate bird assemblages in sugarcane and pastures: implications for bird conservation in agricultural landscapes. *Neotrop Biol Conserv* 14:169–194. <https://doi.org/10.3897/neotropical.14.e37602>
- Alvares CA, Stape JL, Sentelhas PC et al. (2013) Köppen's climate classification map for Brazil. *Meteorol Z* 22:711–728. <https://doi.org/10.1127/0941-2948/2013/0507>
- Arroyo-Rodríguez V, Fahrig L, Tabarelli M et al. (2020) Designing optimal human-modified landscapes for forest biodiversity conservation. *Ecol Lett* 23:1404–1420. <https://doi.org/10.1111/ele.13535>
- Banks-Leite C, Ewers RM, Metzger JP (2010) Edge effects as the principal cause of area effects on birds in fragmented secondary forest. *Oikos* 119:918–926. <https://doi.org/10.1111/j.1600-0706.2009.18061.x>
- Banks-Leite C, Ewers RM, Kapos V et al. (2011) Comparing species and measures of landscape structure as indicators of conservation importance. *J Appl Ecol* 48:706–714. <https://doi.org/10.1111/j.1365-2664.2011.01966.x>
- Banks-Leite C, Pardini R, Tambosi LR et al. (2014) Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science* (80-) 345:1041–1045. <https://doi.org/10.1126/science.1255768>
- Belcik M, Lenda M, Amano T, Skórka P (2020) Different response of the taxonomic, phylogenetic and functional diversity of birds to forest fragmentation. *Sci Rep*. 10:20320. <https://doi.org/10.1038/s41598-020-76917-2>
- Bengtsson J, Angelstam P, Elmqvist T et al. (2003) Reserves, resilience and dynamic landscapes. *Ambio* 32:389–396. <https://doi.org/10.1579/0044-7447-32.6.389>
- Bennett AF (2003) Linkages in the landscape: the role of corridors and connectivity in wildlife conservation, 2nd edn. IUCN, Victoria, Australia
- Bennett AF, Radford JQ, Haslem A (2006) Properties of land mosaics: implications for nature conservation in agricultural environments. *Biol Conserv* 133:250–264. <https://doi.org/10.1016/j.biocon.2006.06.008>
- Boscolo D, Metzger JP (2009) Is bird incidence in Atlantic forest fragments influenced by landscape patterns at multiple scales? *Landsc Ecol* 24:907–918. <https://doi.org/10.1007/s10980-009-9370-8>
- Boscolo D, Metzger JP (2011) Isolation determines patterns of species presence in highly fragmented landscapes. *Ecography* (Cop) 34:1018–1029. <https://doi.org/10.1111/j.1600-0587.2011.06763.x>
- Bowen ME, McAlpine CA, House APN, Smith GC (2007) Regrowth forests on abandoned agricultural land: A review of their habitat values for recovering forest fauna. *Biol Conserv* 140:273–296. <https://doi.org/10.1016/j.biocon.2007.08.012>
- Boyer AG, Jetz W (2014) Extinctions and the loss of ecological function in island bird communities. *Glob Ecol Biogeogr* 23:679–688. <https://doi.org/10.1111/geb.12147>
- Brasil (2012) Lei nº 12.651, de 25 de maio de 2012. *Diário Of da União* 1–32
- Brockerhoff EG, Jactel H, Parrotta JA et al. (2008) Plantation forests and biodiversity: oxymoron or opportunity? *Biodivers Conserv* 17:925–951. <https://doi.org/10.1007/s10531-008-9380-x>
- Brockerhoff EG, Jactel H, Parrotta JA, Ferraz SFB (2013) Role of eucalypt and other planted forests in biodiversity conservation and the provision of biodiversity-related ecosystem services. *Ecol Manag* 301:43–50. <https://doi.org/10.1016/j.foreco.2012.09.018>
- Burdon RD, Aimers-Halliday J (2006) Managing risk in clonal forestry. *CAB Rev Perspect Agric Vet Sci Nutr Nat Resour* 1: <https://doi.org/10.1079/PAVSNNR20061035>

- Burgess EE, Maron M (2016) Does the response of bird assemblages to fire mosaic properties vary among spatial scales and foraging guilds? *Landsc Ecol* 31:687–699. <https://doi.org/10.1007/s10980-015-0275-4>
- Burnham KP, Anderson DR (2002) *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd edn. Springer, New York
- Calviño-Cancela M (2013) Effectiveness of eucalypt plantations as a surrogate habitat for birds. *For Ecol Manage* 310:692–699. <https://doi.org/10.1016/j.foreco.2013.09.014>
- Carnus J-M, Parrotta J, Brockerhoff E et al. (2006) Planted forests and biodiversity. *J* 104:65–77
- Clough Y, Dwi Putra D, Pitopang R, Tschardt T (2009) Local and landscape factors determine functional bird diversity in Indonesian cacao agroforestry. *Biol Conserv* 142:1032–1041. <https://doi.org/10.1016/j.biocon.2008.12.027>
- Cockle KL, Leonard ML, Bodrati AA (2005) Presence and abundance of birds in an Atlantic forest reserve and adjacent plantation of shade-grown yerba mate, in Paraguay. *Biodivers Conserv* 14:3265–3288. <https://doi.org/10.1007/s10531-004-0446-0>
- De Coster G, Banks-Leite C, Metzger JP (2015) Atlantic forest bird communities provide different but not fewer functions after habitat loss. *Proc R Soc B Biol Sci* 282:20142844. <https://doi.org/10.1098/rspb.2014.2844>
- Daily GC (2001) Ecological forecasts. *Nature* 411:245–245. <https://doi.org/10.1038/35077178>
- Dias DFC, Ribeiro MC, Felber YT et al. (2016) Beauty before age: landscape factors influence bird functional diversity in naturally regenerating fragments, but regeneration age does not. *Restor Ecol* 24:259–270. <https://doi.org/10.1111/rec.12293>
- Dunford W, Freemark K (2005) Matrix matters: Effects of surrounding land uses on Forest Birds Near Ottawa, Canada. *Landsc Ecol* 20:497–511. <https://doi.org/10.1007/s10980-004-5650-5>
- Elli EF, Sentelhas PC, de Freitas CH et al. (2019) Assessing the growth gaps of Eucalyptus plantations in Brazil – Magnitudes, causes and possible mitigation strategies. *For Ecol Manage* 451:117464. <https://doi.org/10.1016/j.foreco.2019.117464>
- Fairbanks DH (2004) Regional land-use impacts affecting avian richness patterns in Southern Africa—insights from historical avian atlas data. *Agric Ecosyst Environ* 101:269–288. <https://doi.org/10.1016/j.agee.2003.09.009>
- Ferreira MA, Silva CSJe, Gomide LR et al. (2019) Wood supply optimization in Brazilian pulp industry involving forestry out-grower scheme. *Rev Árvore* 43:1–10. <https://doi.org/10.1590/1806-90882019000500004>
- Fischer J, Lindenmayer DB, Manning AD (2006) Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. *Front Ecol Environ* 4:80–86
- Flynn DFB, Gogol-Prokurat M, Nogeire T et al. (2009) Loss of functional diversity under land use intensification across multiple taxa. *Ecol Lett* 12:22–33. <https://doi.org/10.1111/j.1461-0248.2008.01255.x>
- Forman RTT, Godron M (1986) *Landscape ecology*. Wiley, New York
- Franklin JF, Forman RTT (1987) Creating landscape patterns by cutting: biological consequences and principles. *Landsc Ecol* 1:5–18
- FSC (2014) Avaliação de plantações florestais na República Federativa do Brasil: Padrão Harmonizado entre as Certificadoras. 53
- Gardner TA, Barlow J, Araujo IS et al. (2008) The cost-effectiveness of biodiversity surveys in tropical forests. *Ecol Lett* 11:139–150. <https://doi.org/10.1111/j.1461-0248.2007.01133.x>
- Gonçalves JLdeM, Alvares CA, Higa AR et al. (2013) Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. *For Ecol Manage* 301:6–27. <https://doi.org/10.1016/j.foreco.2012.12.030>
- Gustafson EJ, Parker GR (1992) Relationships between landcover proportion and indices of landscape spatial pattern. *Landsc Ecol* 7:101–110. <https://doi.org/10.1007/BF02418941>
- Hansbauer MM, Storch I, Leu S et al. (2008) Movements of neotropical understory passerines affected by anthropogenic forest edges in the Brazilian Atlantic rainforest. *Biol Conserv* 141:782–791. <https://doi.org/10.1016/j.biocon.2008.01.002>
- Holbech LH (2009) The conservation importance of luxuriant tree plantations for lower storey forest birds in south-west Ghana. *Bird Conserv Int* 19:287. <https://doi.org/10.1017/S0959270909007126>
- Hudson A, Bouwman H (2007) Different land-use types affect bird communities in the Kalahari, South Africa. *Afr J Ecol* 45:423–430. <https://doi.org/10.1111/j.1365-2028.2006.00750.x>
- IBÁ (2019) Report 2019. Rep. 2019 80
- IBGE - Instituto Brasileiro de Geografia e Estatística (2004) Mapa de vegetação do Brasil
- Jacoboski LI, Hartz SM (2020) Using functional diversity and taxonomic diversity to assess effects of afforestation of grassland on bird communities. *Perspect Ecol Conserv* 18:103–108. <https://doi.org/10.1016/j.pecon.2020.04.001>
- Jacoboski LI, Mendonça-Lima Ade, Hartz SM (2016) Structure of bird communities in eucalyptus plantations: nestedness as a pattern of species distribution. *Braz J Biol* 76:583–591. <https://doi.org/10.1590/1519-6984.18614>
- Jiguet F, Gador A-S, Julliard R et al. (2007) Climate envelope, life history traits and the resilience of birds facing global change. *Glob Chang Biol* 13:1672–1684. <https://doi.org/10.1111/j.1365-2486.2007.01386.x>
- John JRM, Kabigumila JDL (2011) The use of bird species richness and abundance indices to assess the conservation value of exotic Eucalyptus plantations. *Ostrich* 82:27–37. <https://doi.org/10.2989/00306525.2011.556799>
- Kennedy CM, Marra PP, Fagan WF, Neel MC (2010) Landscape matrix and species traits mediate responses of Neotropical resident birds to forest fragmentation in Jamaica. *Ecol Monogr* 80:651–669. <https://doi.org/10.1890/09-0904.1>
- Kleinschroth F, Gourlet-Fleury S, Sist P et al. (2016) Logging roads in tropical forests: Synthesis of literature written in French and English highlights environmental impact reduction through improved engineering. *Bois Forêts des Trop* 328:13–26
- Lamb D, Erskine P, Parrotta J (2005) Restoration of degraded tropical forest landscapes. *Science* (80-) 310:1628–1632. <https://doi.org/10.1126/science.1111773>
- Laube I, Breitbach N, Böhning-Gaese K (2008) Avian diversity in a Kenyan agroecosystem: effects of habitat structure and proximity to forest. *J Ornithol* 149:181–191. <https://doi.org/10.1007/s10336-007-0258-6>
- Leaver J, Mulvaney J, Ehlers Smith DA et al. (2019) Response of bird functional diversity to forest product harvesting in the Eastern Cape, South Africa. *For Ecol Manage* 445:82–95. <https://doi.org/10.1016/j.foreco.2019.04.054>
- del Hoyo J, Elliott A, Vicens JS, Christie DA (eds) (2015) *Handbook of the Birds of the World Alive*. Lynx Edicions, Barcelona
- Lee MB, Carroll JP (2018) Effects of patch size and basal area on avian taxonomic and functional diversity in pine forests: Implication for the influence of habitat quality on the species–area relationship. *Ecol Evol* 8:6909–6920. <https://doi.org/10.1002/ece3.4208>
- Leitão RP, Zuanon J, Villéger S et al. (2016) Rare species contribute disproportionately to the functional structure of species assemblages. *Proc R Soc B Biol Sci* 283:20160084. <https://doi.org/10.1098/rspb.2016.0084>
- Lopes IT, Gussoni COA, Demarchi LO et al. (2015) Diversity of understory birds in old stands of native and Eucalyptus plantations. *Restor Ecol* 23:662–669. <https://doi.org/10.1111/rec.12216>
- Loureiro K (2006) A instalação da empresa Aracruz Celulose s/a e a “moderna” ocupação das terras indígenas Tupiniquim e Guarani Mbya. *Rev Ágora* 0:1–32



- Luck GW, Korodaj TN (2008) Stand and landscape-level factors related to bird assemblages in exotic pine plantations: Implications for forest management. *For Ecol Manag* 255:2688–2697. <https://doi.org/10.1016/j.foreco.2008.01.029>
- Maas B, Tschamtk T, Saleh S et al. (2015) Avian species identity drives predation success in tropical cacao agroforestry. *J Appl Ecol* 52:735–743. <https://doi.org/10.1111/1365-2664.12409>
- Magalhães VS, Azevedo Júnior SMde, Lyra-Neves RMde et al. (2007) Biologia de aves capturadas em um fragmento de Mata Atlântica, Igarassu, Pernambuco, Brasil. *Rev Bras Zool* 24:950–964. <https://doi.org/10.1590/S0101-81752007000400011>
- Maire E, Grenouillet G, Brosse S, Villéger S (2015) How many dimensions are needed to accurately assess functional diversity? A pragmatic approach for assessing the quality of functional spaces. *Glob Ecol Biogeogr* 24:728–740. <https://doi.org/10.1111/geb.12299>
- Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* 405:243–253. <https://doi.org/10.1038/35012251>
- Martensen AC, Pimentel RG, Metzger JP (2008) Relative effects of fragment size and connectivity on bird community in the Atlantic Rain Forest: Implications for conservation. *Biol Conserv* 141:2184–2192. <https://doi.org/10.1016/j.biocon.2008.06.008>
- Martensen AC, Ribeiro MC, Banks-Leite C et al. (2012) Associations of forest cover, fragment area, and connectivity with neotropical understory bird species richness and abundance. *Conserv Biol* 26:1100–1111. <https://doi.org/10.1111/j.1523-1739.2012.01940.x>
- Martin EA, Viano M, Ratsimisetra L et al. (2012) Maintenance of bird functional diversity in a traditional agroecosystem of Madagascar. *Agric Ecosyst Environ* 149:1–9. <https://doi.org/10.1016/j.agee.2011.12.005>
- Martins TV, Gomide LR, Ferraz Filho AC et al. (2017) Eucalyptus clonal mosaics in forest planning and their effects on wood production and economy. *Sci* 45:727–737. <https://doi.org/10.18671/scifor.v45n116.13>
- Mason NWH, Mouillot D, Lee WG, Wilson JB (2005) Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos* 111:112–118. <https://doi.org/10.1111/j.0030-1299.2005.13886.x>
- McGarigal K, McComb WC (1995) Relationships between landscape structure and breeding birds in the Oregon Coast Range. *Ecol Monogr* 65:235–260. <https://doi.org/10.2307/2937059>
- McMahon DE, Jackson RB (2019) Management intensification maintains wood production over multiple harvests in tropical Eucalyptus plantations. *Ecol Appl* 29:1–15. <https://doi.org/10.1002/eap.1879>
- Millan CH, Develey PF, Verdade LM (2015) Stand-level management practices increase occupancy by birds in exotic Eucalyptus plantations. *For Ecol Manag* 336:174–182. <https://doi.org/10.1016/j.foreco.2014.10.005>
- Murcia C (1995) Edge effects in fragmented forests: implications for conservation. *Trends Ecol Evol* 10:58–62. [https://doi.org/10.1016/S0169-5347\(00\)88977-6](https://doi.org/10.1016/S0169-5347(00)88977-6)
- Myers N, Mittermeier RA, Mittermeier CG et al. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403:853–858. <https://doi.org/10.1038/35002501>
- Pardini R, Faria D, Accacio GM et al. (2009) The challenge of maintaining Atlantic forest biodiversity: a multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. *Biol Conserv* 142:1178–1190. <https://doi.org/10.1016/j.biocon.2009.02.010>
- Parker III TA, D F. Stotz, J W. Fitzpatrick (1996) Ecological and Distributional Databases. In: Stotz DF, John W. Fitzpatrick, Theodore A. Parker III, Moskovits DK (eds) *Neotropical birds: ecology and conservation*. University of Chicago Press, Chicago, pp 111–410
- Pavoine S, Vallet J, Dufour A-B et al. (2009) On the challenge of treating various types of variables: application for improving the measurement of functional diversity. *Oikos* 118:391–402. <https://doi.org/10.1111/j.1600-0706.2008.16668.x>
- Pawson SM, Brin A, Brockerhoff EG et al. (2013) Plantation forests, climate change and biodiversity. *Biodivers Conserv* 22:1203–1227. <https://doi.org/10.1007/s10531-013-0458-8>
- Petchey OL, Evans KL, Fishburn IS, Gaston KJ (2007) Low functional diversity and no redundancy in British avian assemblages. *J Anim Ecol* 76:977–985. <https://doi.org/10.1111/j.1365-2656.2007.01271.x>
- Peters RH (1983) *The ecological implications of body size*, 1a. Cambridge University Press, Cambridge
- Phalan B, Onial M, Balmford A, Green RE (2011) Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. *Science* (80-) 333:1289–1291. <https://doi.org/10.1126/science.1208742>
- Piacentini V, de Q, Aleixo A, Agne CE et al. (2015) Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee. *Rev Bras Ornitol* 23:91–298
- Prescott GW, Gilroy JJ, Haugeaasen T et al. (2016) Reducing the impacts of Neotropical oil palm development on functional diversity. *Biol Conserv* 197:139–145. <https://doi.org/10.1016/j.biocon.2016.02.013>
- R Core Team (2022) R: A language and environment for statistical computing
- Rezende CL, Scarano FR, Assad ED et al. (2018) From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. *Perspect Ecol Conserv* 16:208–214. <https://doi.org/10.1016/j.pecon.2018.10.002>
- Ribeiro MC, Metzger JP, Martensen AC et al. (2009) The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biol Conserv* 142:1141–1153. <https://doi.org/10.1016/j.biocon.2009.02.021>
- Rösch V, Tschamtk T, Scherber C, Batáry P (2015) Biodiversity conservation across taxa and landscapes requires many small as well as single large habitat fragments. *Oecologia* 179:209–222. <https://doi.org/10.1007/s00442-015-3315-5>
- dos Santos HG, Jr de W C, de O Dart R et al (2011) O novo mapa de solos do Brasil: legenda atualizada. 67
- Schütz C, Schulze CH (2015) Functional diversity of urban bird communities: effects of landscape composition, green space area and vegetation cover. *Ecol Evol* 5:5230–5239. <https://doi.org/10.1002/ece3.1778>
- Şekercioğlu ÇH, Loarie SR, Oviedo-Brenes F et al. (2015) Tropical countryside riparian corridors provide critical habitat and connectivity for seed-dispersing forest birds in a fragmented landscape. *J Ornithol* 156:343–353. <https://doi.org/10.1007/s10336-015-1299-x>
- Sitters H, Di Stefano J, Christie F et al. (2016) Bird functional diversity decreases with time since disturbance: Does patchy prescribed fire enhance ecosystem function? *Ecol Appl* 26:115–127. <https://doi.org/10.1890/14-1562>
- Smith AC, Fahrig L, Francis CM (2011) Landscape size affects the relative importance of habitat amount, habitat fragmentation, and matrix quality on forest birds. *Ecography (Cop)* 34:103–113. <https://doi.org/10.1111/j.1600-0587.2010.06201.x>
- Tambosi LR, Martensen AC, Ribeiro MC, Metzger JP (2014) A framework to optimize biodiversity restoration efforts based on habitat amount and landscape connectivity. *Restor Ecol* 22:169–177. <https://doi.org/10.1111/rec.12049>
- Tejeda-Cruz C, Sutherland WJ (2004) Bird responses to shade coffee production. *Anim Conserv* 7:169–179. <https://doi.org/10.1017/S1367943004001258>
- Thies C, Tschamtk T (1999) Landscape Structure and Biological Control in Agroecosystems. *Science* (80-) 285:893–895. <https://doi.org/10.1126/science.285.5429.893>
- Tschamtk T, Klein AM, Kruess A et al. (2005) Landscape perspectives on agricultural intensification and biodiversity - ecosystem



- service management. *Ecol Lett* 8:857–874. <https://doi.org/10.1111/j.1461-0248.2005.00782.x>
- Tscharntke T, Sekercioglu CH, Dietsch TV et al. (2008) Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. *Ecology* 89:944–951. <https://doi.org/10.1890/07-0455.1>
- Turner IM (1996) Species loss in fragments of tropical rain forest: A review of the evidence. *J Appl Ecol* 33:200–209
- Uezu A, Metzger JP (2011) Vanishing bird species in the Atlantic Forest: relative importance of landscape configuration, forest structure and species characteristics. *Biodivers Conserv* 20:3627–3643. <https://doi.org/10.1007/s10531-011-0154-5>
- Uezu A, Metzger JP, Vielliard JME (2005) Effects of structural and functional connectivity and patch size on the abundance of seven Atlantic Forest bird species. *Biol Conserv* 123:507–519. <https://doi.org/10.1016/j.biocon.2005.01.001>
- Uezu A, Beyer DD, Metzger JP (2008) Can agroforest woodlots work as stepping stones for birds in the Atlantic forest region? *Biodivers Conserv* 17:1907–1922. <https://doi.org/10.1007/s10531-008-9329-0>
- Villard M-A, Trzcinski MK, Merriam G (1999) Fragmentation effects on forest birds: Relative influence of woodland cover and configuration on landscape occupancy. *Conserv Biol* 13:774–783. <https://doi.org/10.1046/j.1523-1739.1999.98059.x>
- Villéger S, Mason NWH, Moullot D (2008) New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89:2290–2301. <https://doi.org/10.1890/07-1206.1>
- Volpato GH, Prado VM, dos Anjos L (2010) What can tree plantations do for forest birds in fragmented forest landscapes? A case study in southern Brazil. *For Ecol Manag* 260:1156–1163. <https://doi.org/10.1016/j.foreco.2010.07.006>
- Wang Y, Finch DM (2002) Consistency of mist netting and point counts in assessing landbird species richness and relative abundance during migration. *Condor* 104:59–72. <https://doi.org/10.1093/condor/104.1.59>
- Watson JEM, Whittaker RJ, Dawson TP (2004) Habitat structure and proximity to forest edge affect the abundance and distribution of forest-dependent birds in tropical coastal forests of southeastern Madagascar. *Biol Conserv* 120:311–327. <https://doi.org/10.1016/j.biocon.2004.03.004>
- Willson MF (1974) Avian community organization and habitat structure. *Ecology* 55:1017–1029
- Wilman H, Belmaker J, Jennifer S et al. (2014) EltonTraits 1.0: Species-level foraging attributes of the world's birds and mammals. *Ecology* 95:2027
- Zavaleta ES, Hobbs RJ, Mooney HA (2001) Viewing invasive species removal in a whole-ecosystem context. *Trends Ecol Evol* 16:454–459. [https://doi.org/10.1016/S0169-5347\(01\)02194-2](https://doi.org/10.1016/S0169-5347(01)02194-2)
- Zurita GA, Rey N, Varela DM et al. (2006) Conversion of the Atlantic Forest into native and exotic tree plantations: Effects on bird communities from the local and regional perspectives. *Ecol Manag* 235:164–173. <https://doi.org/10.1016/j.foreco.2006.08.009>

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