UNIVERSIDADE ESTADUAL DE SANTA CRUZ

Departamento de Ciências Biológicas

Programa de Pós-Graduação em Ecologia e Conservação da Biodiversidade

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Number of forest fragments and understory plants affect multiple dimensions of bird diversity in eucalypt plantations

Ilhéus/BA
2022

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Dissertação apresentada ao Programa de Pós-Graduação em Ecologia e Conservação da Biodiversidade da Universidade Estadual de Santa Cruz como requisito para a obtenção do título de Mestre em Ecologia e Conservação, sob a orientação do Prof. Dr. José Carlos Morante Filho e coorientação do Prof. Dr. Anderson Saldanha Bueno.

Área de Concentração: Ecologia

Linha de Pesquisa: Ecologia e conservação de comunidades, ecossistemas e paisagens

Ilhéus/BA
2022

S586 Silva, Ivana Cardoso da.
Number of forest fragments and understory plants affect multiple dimensions of bird diversity in eucalypt plantations / Ivana Cardoso da Silva. – Ilhéus, BA: 2022.
67 f. : il.

Orientador: José Carlos Morante Filho.
Dissertação (mestrado) – Universidade Estadual de Santa Cruz. Programa de Pós-Graduação em Ecologia e Conservação da Biodiversidade.
Inclui referências e apêndices.

1. Eucalipto. 2. Avifauna. 3. Silvicultura. 4. Habitat (Ecologia). 5. Paisagens fragmentadas. I. Título.

CDD 634.973766

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28 de janeiro de 2022.

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AGRADECIMENTOS

Ao meu orientador, Dr. José Carlos Morante Filho, pela oportunidade, orientação, direcionamentos, ajuda e paciência. Por ter acompanhado, ao longo destes dois anos, a minha descoberta da jornada científica.

Ao meu coorientador, Dr. Anderson Saldanha Bueno, pelo apoio científico e profissional, e por todo encorajamento que me ajudou a viver as aventuras de desenvolver um mestrado durante uma pandemia.

A melhor parte do trabalho é a coleta de dados em campo, e fazer isso ao lado de amigos torna tudo muito melhor! Agradeço à nossa equipe Coala, por toda ajuda durante o campo: Rayssa, Ícaro, Luan, Joedno. Cada situação difícil que enfrentamos no campo foi divertida e engraçada ao lado de vocês! Agradeço, em especial, a minha amiga Rayssa Tormes, que saiu do Rio Grande do Sul para viver essa experiência comigo e virou especialista em anilhar beija-flores.

À Ilana, Júlia, Fernando e, em especial, Karol pelas pessoas maravilhosas que são e por sempre estarem dispostos a ouvir e me apoiar durante os altos e baixos do mestrado.

À minha família e, em especial, à minha mãe, Lusiana Cardoso, por apoiar minhas decisões e acreditar em minhas escolhas.

Ao meu querido companheiro, Luan Portella, por todo apoio, carinho e paciência. Compartilhar os dias de trabalho com você foram uma das melhores partes desta dissertação.

À Universidade Estadual de Santa Cruz (UESC) e ao Programa de Pós-Graduação em Ecologia e Conservação da Biodiversidade (PPGECB) pelo apoio financeiro, logístico e de infraestrutura necessários para a realização desta pesquisa.

À Fundação de Apoio a Pesquisa do Estado da Bahia (FAPESB) pela concessão da bolsa de mestrado.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pelo apoio financeiro necessário para realização da pesquisa.

À Veracel pelo apoio financeiro e permissão para amostrar suas áreas.

Ao SISBIO, CEUA-UESC e CEMAVE pela concessão das licenças de amostragem.

Ao Laboratório de Ecologia Aplicada a Conservação (LEAC) pelos equipamentos e livros necessários para a realização desta pesquisa.

Aos professores e alunos do PPGECB que contribuíram com seus ensinamentos, experiências e questionamentos.

SUMÁRIO

RESUMO

Diante da crescente destruição dos habitats naturais, diversos estudos buscam desvendar como ambientes antrópicos podem abrigar espécies nativas. Nesse contexto, plantações de eucalipto podem apresentar um papel ambíguo sob certas circunstâncias, pois podem atuar como desertos verdes (*i.e.* grandes áreas verdes que abrigam poucas espécies), habitat suplementar ou matriz amigável para a biodiversidade. Além de abrigar espécies nativas, essas plantações também podem manter comunidades funcionalmente diversas (*i.e.* diversidade funcional) e com uma rica história evolutiva (*i.e.* diversidade filogenética). Entretanto, a manutenção dessas diferentes dimensões da diversidade nesse ambiente antrópico pode depender da estrutura da paisagem onde a plantação está inserida e de características locais ligadas a complexidade da vegetação. Diante disso, avaliamos como variáveis da paisagem (*i.e.* cobertura florestal e de pastagem, densidade de bordas florestais e número de fragmentos florestais) e da vegetação local (*i.e.* número de árvores nativas, diâmetro médio a altura do peito (DBH) das árvores nativas, número de plantas no sub-bosque, altura do sub-bosque e número de poleiros) influenciam as dimensões taxonômica, funcional e filogenética de aves de sub-bosque em plantações de eucalipto. Para isso, coletamos nossos dados em 19 plantações de eucalipto inseridas em paisagens em um gradiente de cobertura florestal, localizadas no sul do estado da Bahia. Em cada plantação, utilizamos 20 redes de neblina para amostrar aves de sub-bosque durante três dias consecutivos. Utilizando modelos aditivos generalizados, avaliamos a influência das variáveis da paisagem e local sobre as diferentes dimensões da diversidade (*i.e.*, taxonômica, funcional e filogenética) de aves. Utilizamos o critério de informação de Akaike corrigido para pequenas amostras (AICc) para a seleção dos melhores modelos. Nossos resultados mostraram que (1) plantações de eucalipto inseridas em paisagens com maior número de fragmentos florestais abrigam assembleias de aves com menor diversidade taxonômica e funcional, e riqueza filogenética; e (2) plantações de eucalipto com maior número de plantas no sub-bosque abrigam maiores valores de riqueza taxonômica e filogenética e diversidade taxonômica e funcional de aves de sub-bosque. Para que as plantações de eucalipto abriguem maior diversidade de aves de sub-bosque, sugerimos que a indústria evite a fragmentação de remanescentes florestais já existentes na paisagem, e aqui destacamos que recomendar menos fragmentos não é o mesmo que recomendar menor cobertura florestal, e mantenha um sistema de rotação no corte da vegetação do sub-bosque de forma que, em uma mesma paisagem, exista uma plantação com vegetação do sub-bosque complexa atuando como habitat suplementar.

Palavras-chave: Avifauna, fragmentação, paisagens antrópicas, perda de habitat, silvicultura, traços funcionais

ABSTRACT

With the increasing destruction of natural habitats, several studies seek to unravel how anthropic environments can harbor native species. In this context, eucalypt plantations can play an ambiguous role under certain circumstances, as they can act as green deserts (*i.e.* large green areas that harbor few species), supplementary habitat or biodiversity-friendly matrix. In addition to harboring native species, these plantations can also maintain communities that are functionally diverse (*i.e.* functional diversity) and with a rich evolutionary history (*i.e.* phylogenetic diversity). However, the maintenance of these different dimensions of diversity in this anthropic environment may depend on the structure of the landscape where the plantation is inserted and on local characteristics linked to the complexity of the vegetation. Therefore, we evaluated how landscape (*i.e.* forest and pasture cover, density of forest edges and number of forest fragments) and local vegetation variables (*i.e.* number of native trees, mean diameter at breast height (DBH) of native trees, number of understory plants, understory height and number of perches) influence taxonomic, functional and phylogenetic dimensions of understory birds in eucalypt plantations. For this, we collected our data in 19 eucalypt plantations inserted in landscapes in a gradient of forest cover, located in the south of the state of Bahia. In each plantation, we used 20 mist nets to sample understory birds for three consecutive days. Using generalized additive models, we evaluated the influence of landscape and location variables on different dimensions of bird diversity (*i.e.* taxonomic, functional and phylogenetic). We used the Akaike information criterion corrected for small samples (AICc) to select the best models. Our results showed that (1) eucalypt plantations inserted in landscapes with a greater number of forest fragments harbor bird assemblages with less taxonomic and functional diversity, and phylogenetic richness; and (2) eucalypt plantations with a greater number of plants in the understory harbor higher values of taxonomic and phylogenetic richness and taxonomic and functional diversity of understory birds. For eucalypt plantations to shelter a greater diversity of understory birds, we suggest that the industry avoid the fragmentation of the existing remnants in the landscape, and here we emphasize that recommending fewer fragments is not the same as recommending less forest cover, and maintain a rotation system in the thinning of the understory vegetation so that, in the same landscape, there is a plantation with complex understory vegetation acting as a supplementary habitat.

Keywords: Anthropic landscapes; avifauna; fragmentation; functional traits; habitat loss; silviculture.

INTRODUÇÃO GERAL

A alteração de ambientes naturais em paisagens antrópicas vem ameaçando a biodiversidade através da perda e perturbação do habitat (Rios et al. 2021) decorrentes especialmente da urbanização (Marcacci et al. 2021), superexploração e atividades agrícolas (Maxwell et al. 2016). Essas pressões têm criado paisagens antrópicas que são, geralmente, caracterizadas por pequenos fragmentos de habitat, isolados pela imposição de outro ambiente antrópico adjacente (*i.e.* matriz; Haddad et al. 2015), com diferente capacidade de abrigar a biodiversidade (Prevedello & Vieira 2010; Hendershot et al. 2020). Entretanto, sob determinadas condições, paisagens antrópicas podem possibilitar o estabelecimento e permanência de espécies nativas. Por exemplo, paisagens antrópicas compostas por alta cobertura florestal podem apresentar uma maior disponibilidade de recursos, reduzindo a competição e permitindo a coexistência de um maior número de espécies (Arroyo-Rodríguez et al. 2020). Além disso, a matriz pode influenciar a persistência das populações nessas paisagens através de efeitos associados a movimentação das espécies, disponibilidade de recursos e condições abióticas do ambiente (Driscoll et al. 2013).

Em paisagens antrópicas, matrizes estruturalmente mais similares aos fragmentos florestais, como sistemas agroflorestais e plantações de árvores, podem facilitar a movimentação de espécies dependentes de florestas (Prevedello & Vieira 2010), abrigar uma porção significativa de espécies nativas e, portanto, ter alto valor para conservação da biodiversidade (Faria et al. 2006; Jacoboski et al. 2016). Além disso, a matriz pode disponibilizar recursos que ajudam as espécies dependentes de ambientes florestais (Driscoll et al. 2013), de forma que ela pode se tornar um habitat suplementar para as espécies (e.g. Faria et al. 2006; Lopes et al. 2015). Por fim, matrizes mais similares aos fragmentos florestais podem, ainda, alterar as condições abióticas dentro deles, amortecendo efeitos de borda como incidência de luz e penetração do vento (Laurance et al. 2002), podendo também abrigar maior diversidade de espécies do que matrizes abertas (Prevedello & Vieira 2010; Kennedy et al. 2010). Por exemplo, fragmentos florestais cercados por plantações de eucalipto estão sujeitos a efeitos de borda mais amenos e possuem uma comunidade de aves mais similar à floresta contínua quando comparado com os fragmentos cercados por pastagem (Hatfield et al. 2020). Ainda, em paisagens onde a matriz é dominada por eucalipto, pequenos fragmentos podem abrigar maior número de espécies de aves do que quando inseridos em paisagens onde a matriz predominante é pasto (Barbosa et al. 2017). Nesse caso, matrizes mais permeáveis, como plantações de eucalipto, podem facilitar a dispersão das espécies e, consequentemente, a utilização de diferentes fragmentos florestais dispersos na paisagem.

Mais do que manter riqueza e abundância de espécies, paisagens antrópicas também podem, sob determinadas condições, manter outras dimensões da diversidade, como a funcional e a filogenética. Especificamente, a diversidade funcional está ligada aos diferentes traços ecológicos de uma comunidade, sendo relacionada às funções ecológicas desempenhadas no ecossistema pelas espécies (Tilman 2001), enquanto a diversidade filogenética reflete a história evolutiva de uma comunidade (Cadotte et al. 2010). Essas dimensões da diversidade podem responder diferentemente a mudanças no ambiente de forma que uma não pode substituir a outra adequadamente (Díaz & Cabido 2001). Portanto, priorizar apenas uma dessas dimensões pode acarretar em conclusões equivocadas (Mazel et al. 2018). Por exemplo, considerando que no sítio "X" há duas espécies de aves frugívoras, duas insetívoras e duas granívoras (seis espécies representantes de três traços funcionais), e no sítio "Y" há uma espécie frugívora, uma insetívora e uma granívora, o número de espécies diminui pela metade (3 espécies), mas as funções desempenhadas pelas espécies são as mesmas quando comparamos os sítios. Ou seja, pode haver uma queda na diversidade taxonômica, mas uma manutenção da diversidade funcional (*e.g.* Matuoka et al. 2020). Nesse contexto, métricas ligadas a diversidade taxonômica são mais frequentemente utilizadas em estudos que avaliam os impactos de mudanças na estrutura da paisagem sobre a biodiversidade (Lopes et al. 2015c; Jacoboski et al. 2016), enquanto tais efeitos sobre a diversidade funcional e filogenética permanecem pouco compreendidos (Naeem et al. 2012; Van Meerbeek et al. 2014).

Em paisagens antrópicas, estudos têm avaliado os impactos da agricultura sob a biodiversidade (*e.g.* Edwards et al. 2014; Boesing et al. 2018; Hatfield et al. 2020). Um dos usos do solo classificado como agricultura é a plantação de árvores, que está aumentando em área no mundo todo (Payn et al. 2015) devido à crescente demanda por produtos madeireiros (Paquette & Messier 2010), e também por conta dos inúmeros projetos de restauração de habitats degradados (Brancalion et al. 2020). Tais plantações cobrem aproximadamente 3% da área total de floresta no mundo, equivalente a 131 milhões de hectares (FAO 2020a), mas são dominadas por poucas espécies de árvores, entre elas o eucalipto. Só no Brasil, 8 milhões de hectares (72% da área total de plantações de árvores) são destinados apenas a plantações de eucalipto (FAO 2020b). Apesar da sua grande representatividade, ainda não existe um consenso sobre a capacidade das plantações de eucalipto em abrigar a biodiversidade. Por exemplo, em estudo desenvolvido na Floresta Amazônica foi observado que plantações de eucalipto abrigaram menos espécies de aves e borboletas do que florestas, enquanto as assembleias de lagartos e morcegos tiveram valores similares entre esses ambientes (Barlow et al. 2007b). Por outro lado, outros estudos relatam que as plantações de eucalipto podem abrigar uma fração significativa das espécies florestais de aves (Lopes et al. 2015c) e borboletas (Barlow et al. 2008).

Alguns pesquisadores argumentam que as plantações de eucalipto são desertos verdes porque não fornecem os recursos necessários para o estabelecimento e permanência das espécies nativas, especialmente aquelas dependentes de habitats florestados (Barlow et al. 2007b; Paquette & Messier 2010; Pozo & Säumel 2018). Outros argumentam que as plantações podem servir como habitat suplementar para muitas espécies, mostrando que esses ambientes possuem capacidade para abrigar uma parcela da biodiversidade (Brockerhoff et al. 2008; Jacoboski et al. 2016). Contudo, ambos os lados desse debate nos mostram que o resultado pode depender tanto de características locais quanto da paisagem. Por exemplo, a presença da vegetação de sub-bosque nas plantações pode levar a uma maior riqueza e abundância de espécies dentro delas (Nájera and Simonetti 2010), assim como a maior cobertura florestal na paisagem pode contribuir para a diversidade local (Barlow et al. 2007a). Na verdade, ambos os fatores estão diretamente associados à disponibilidade de recursos (Nájera and Simonetti 2010; Jayathilake et al. 2021) e qualidade do habitat (Estavillo et al. 2013; Dagan and Izhaki 2019).

Diante da necessidade de entendermos o real papel das plantações de eucalipto em manutenção da biodiversidade em paisagens antrópicas, neste projeto buscamos avaliar como variáveis da paisagem (*i.e.* cobertura florestal e de pastagem, densidade de borda e número de fragmentos florestais) e da estrutura da vegetação local (*i.e.* número de árvores nativas, diâmetro médio a altura do peito (DBH) das árvores nativas, número de plantas no sub-bosque, altura do sub-bosque e número de poleiros) influenciam as dimensões taxonômica, funcional e filogenética de aves de sub-bosque em plantações de eucalipto inseridas em paisagens em um gradiente de cobertura florestal.

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Number of forest fragments and understory plants affect multiple dimensions of bird diversity in eucalypt plantations

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Abstract

Context The increase of area for tree plantations worldwide and the debate about the capacity of these plantations in maintaining biodiversity demonstrate the urgent need to create strategies allying biodiversity conservation and productivity.

Objectives We assessed the influence of landscape and local predictors on taxonomic, functional, and phylogenetic richness and diversity of birds in eucalypt plantations.

Methods We surveyed understory birds using mist-nets within 19 eucalypt stands, distributed in landscapes presenting a gradient of forest cover, located in northeast Brazilian Atlantic Forest. Adjacent to each site, we estimated landscape composition (*i.e.* forest cover and pasture cover) and configuration (*i.e.* number of forest fragments and edge density) metrics. We also collected five local variables (*i.e.* number of understory plants, native trees, perches, understory layer height and mean diameter at breast height) associated to understory vegetation in each site. Generalized Additive Models were constructed to assess the effects of landscape and local variables on each bird taxonomic, functional and phylogenetic dimensions.

Results Taxonomic and functional diversity, and phylogenetic richness were negatively influenced by an increase in the number of forest fragments at the landscape. Also, our findings indicated an increase in taxonomic richness and diversity, functional diversity, and phylogenetic richness with an increase in the number of plants in the understory of plantations. Indeed, this local variable was the most important to explain the bird diversity patterns in eucalyptus plantations.

Conclusions Our study indicated that the different dimensions of understory birds' diversity birds within eucalypt plantations are affected by both landscape and local predictors. To maintain this diversity in anthropic landscapes, we reinforce the need to avoid fragmenting the existing forest remnants in the landscape and the absence of understory vegetation in eucalypt plantations.

Keywords: avifauna, functional and phylogenetic diversity, habitat loss, human-modified landscapes, tree plantation, species richness.

1. INTRODUCTION

Most of tree plantations are monocultures of an exotic tree under intensively management, established primarily for productive purposes (Brockerhoff et al. 2008; Keenan et al. 2015), and usually providing harsh conditions for the maintenance of biodiversity. Tree plantations can act as green deserts or supplementary habitat according to local and/or adjacent landscape features (Bremer and Farley 2010). As green deserts, tree plantations cannot provide suitable conditions for the establishment and persistence of forest-dependent species (Pozo and Säumel 2018). For instance, eucalypt plantations with simplified understory vegetation present fewer resources for foraging and nesting, reducing habitat heterogeneity and harboring lower species richness and abundance, and different species composition of birds from that of the forest remnants (Marsden et al. 2001; Jacoboski et al. 2016). Furthermore, these plantations can harbor depauperate biological assemblages when inserted in highly managed landscapes or in landscapes dominated by harsh matrices, such as cattle pasture, as a result from features of the adjacent environment (Filloy et al. 2010; Pezda et al. 2021).

Conversely, as supplementary habitat and biodiversity-friendly matrix, tree plantations can provide resources for forest-dependent species (Faria et al. 2006; Driscoll et al. 2013; Lopes et al. 2015b), facilitate species movement (Prevedello and Vieira 2010), and buffer edge effects entering forest fragments, as incidence of light and wind penetration (Laurance et al. 2002). Eucalypt plantations composed by high understory plant diversity can harbor many vertebrate species (Castagneyrol and Jactel 2012) given the higher resource availability (Volpato et al. 2010). For instance, when young, eucalypt plantations are similar to shrublands (Calviño-Cancela et al. 2012), thus, insectivores birds that forage in tall shrub layers can be common in plantations (Loyn et al. 2007). Furthermore, these plantations can help forest fragments harbor higher bird species richness and a community of birds more similar to that of the continuum forest, due to the facilitated dispersion (Barbosa et al. 2017) in the landscape, and the weaker edge effects penetrating into the fragments (Hatfield et al. 2020), respectively.

Most of studies that examine the impact of tree plantations on biodiversity use metrics related only to taxonomic diversity, particularly species richness and abundance (*e.g.* Filloy et al., 2010; Fonseca et al., 2009; Jacoboski et al., 2016; Proença et al., 2010). However, other dimensions of diversity (*e.g.* functional and phylogenetic) indicate different patterns structuring biological communities, and improve our understanding about the maintenance of biodiversity in tree plantations (Pollock et al. 2017; Mazel et al. 2018; Jacoboski et al. 2019). Furthermore, distinct dimensions of diversity can be differently influenced by environmental changes. For instance, deforestation can lead to the loss of species in forest fragments, without affect the functional (Mayfield et al. 2010) and phylogenetic (Morante-Filho et al. 2018) diversity of the remaining assemblage. Conversely, other studies documented that even with the maintenance of species richness in disturbed habitats, there was a reduction in functional and phylogenetic diversity (Gerisch et al. 2012; Bae et al. 2018). These contrasting findings reinforce that considering only species richness in ecological studies may limit our understanding about the structure of biological assemblages in anthropogenic environments. In fact, species richness can be an inadequate substitute for functional diversity (Díaz and Cabido 2001), as well as phylogenetic metrics can be unable to fully predict the functional diversity of certain communities (Mazel et al. 2018). Thus, studies using different dimensions of diversity can create more accurate information on the effect of environmental disturbances on biodiversity.

Here, we investigated how landscape features (*i.e.* forest cover, pasture cover, edge density and number of fragments) and local vegetation characteristics (*i.e.* number of native trees, mean diameter at breast height (DBH) of native trees, number of understory plants, height of the understory layer and number of perches) influence taxonomic, functional and phylogenetic richness and diversity dimensions of understory birds in eucalypt plantations. For this, we tested the following hypotheses: (i) The increase in forest cover in the landscape will positively influence taxonomic, functional and phylogenetic richness and diversity, since it indicates the amount of available habitat for native species (Carrara et al., 2015; Estavillo et al., 2013). (ii) The increase in pasture cover in the landscape will negatively influence taxonomic, functional and phylogenetic bird richness and diversity because it can limit the movement of birds (Boesing et al. 2018b), increase the risk of predation (Biz et al. 2017), cause severe edge effect on eucalypt plantations, and present a drastic reduction in the availability of supplementary resources (Tscharntke et al. 2012). (iii) The increase in edge density in the landscape will positively influence taxonomic richness and diversity mainly due to the proliferation of habitat generalist species (Carrara et al. 2015; Morante-Filho et al. 2015), but negatively influence functional and phylogenetic richness and diversity as a result of a selection of species with similar ecological traits (high functional redundancy, *sensu* Mayfield et al., 2010), and belonging to a subset of clades adapted to disturbances (Matos et al. 2017). (iv) The increase in the number of forest fragments will positively influence taxonomic, functional and phylogenetic richness and diversity because forest patches can act as stepping stones, increasing movement of species in the landscape (Lees and Peres 2009). Also, some species can move across the landscape to use the resources in these fragments (Stouffer and Bierregaard, 1995). (v) The increase in local vegetation complexity (*i.e.* greater number of understory plants, higher understory layer height, presence of native trees with greater DBH and greater number of perches) in eucalypt plantations will be positively associated with taxonomic, functional and phylogenetic richness and diversity, since these features can promote shelter and food resources for birds, including forest-specialist species (Nájera and Simonetti 2010; Dagan and Izhaki 2019).

2. METHODS

2.1 Study area

We conducted this study in the southern Bahia State, Brazil (Fig. 1A; between 15°38’ – 16°00’ S and 39°22’ – 39°26’ W), a region originally dominated by the Atlantic Forest, but that changes in the land use for the last four decades created anthropic landscapes composed by secondary forests, eucalypt plantations, and open areas dominated by cattle pasture (Fig. 1B; Pardini et al. 2009, Morante-Filho et al. 2016). According to the Köppen classification, the regional climate is tropical without dry season (Af), presenting annual mean temperature and precipitation ranging from 22-24°C and 1300-1600 mm, respectively (Alvares et al. 2013). Although there is no defined seasonality, a dryer period can occur from December to March (Thomas et al. 1998).

2.2 Sampling design

We created a land use map of the study area (Fig. 1B) using QGIS software (QGIS Development Team 2019) to clip a previous mapping of land cover in Bahia (Forum Florestal da Bahia and Universidade Federal do Sul da Bahia 2018). In addition, we conducted a field validation campaign to confirm the land use types, location and age of eucalypt plantations. Then, we randomly selected 19 eucalypt stands between 4-7 years, separated by at least 2 km from each other, and located in landscapes presenting a gradient of native forest amount (from 3.5% to 68.5%, calculated in landscapes of 1000-m radius).

2.3 Landscape structure

We used *rgeos* package (Bivand and Rundel 2020) in the R software (R Core Team 2021) to estimate two metrics related to landscape composition – forest (old-growth and secondary forest) and pasture cover – and two metrics related to landscape configuration – forest edge density and number of forest fragments. All metrics were estimated in 9 different-sized landscapes, ranging from 200 to 1000 m radius (Fig. 1C). To estimate landscape composition metrics, we calculated the area of the polygons of forest and pasture present in the landscapes. To determine edge density, we obtained the perimeter (m) of forest polygons divided by the total area (m^2) of the landscape. Then, we conducted a multi-scale analysis (Jackson and Fahrig 2015) to determine which landscape size was most appropriate to assess the effect of each landscape predictor on bird taxonomic, functional, and phylogenetic metrics (see results in Appendix S1).

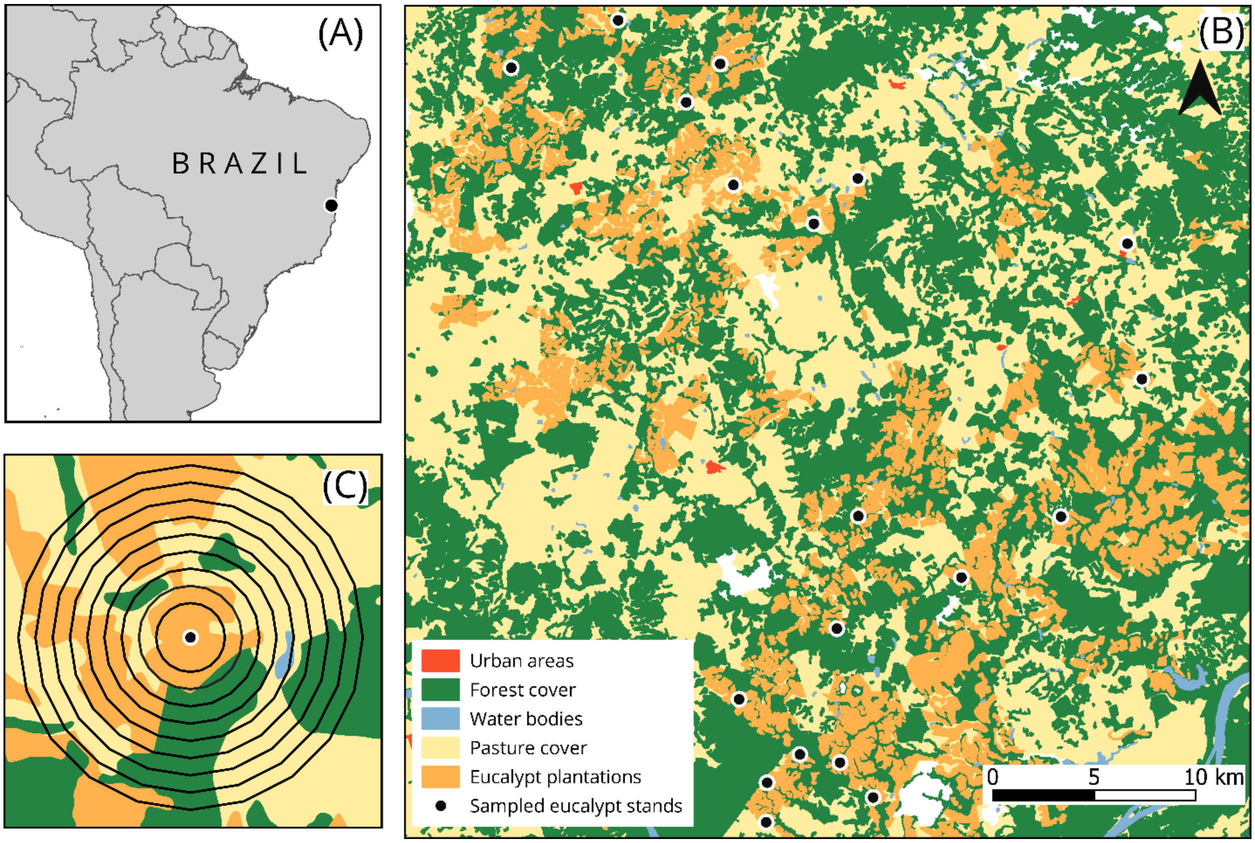

Figure 1. (A) Location of study area, in Bahia State, Brazil, showing (B) Land cover types adjacent to 19 sampled eucalypt stands. (C) Buffers ranging from 200 to 1000-m radius used to conduct the multiscale analysis.

2.4 Local vegetation features

Within each sampling site, we placed four 25 × 4 m plots at least 30 m from the mist-nets used for sampling birds. In each plot, we recorded the number of native trees with a diameter at breast height (DBH) ≥ 1.6 cm and calculated the mean DBH of the trees. We also recorded the number of understory plants (60-250 cm in height), number of tree perches with at least 40 cm of length and 5 cm of circumference at the base of the trunk until 250 cm in height, and mean height of understory layer estimated in ten points spaced by 2.5 m within the plot (Fig. 2). These variables are associated to local vegetation structure, and can exert influence on bird diversity via increase resource availability (Chapman et al. 1992; Watson et al. 2004).

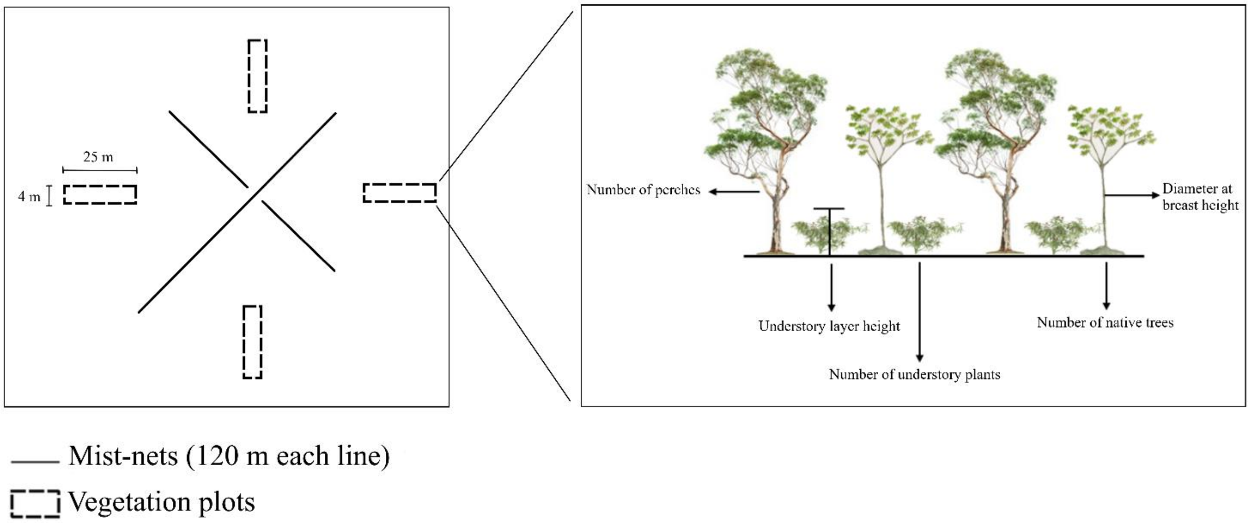

Figure 2. Representation of the spatial distribution of the mist-nets and vegetation plots used in our study. In each plot, we collected five variables related to vegetation structure.

2.5 Avian surveys

We sampled birds from April to June 2021 using mist nets. In each site, we opened 20 mist-nets (Ecotone®; 12 × 2.5 m, 32 mm mesh) to capture birds during three consecutive days. The mist-nets were placed in the understory of the eucalypt plantations and arranged following a cross-shaped net-line design, totaling 240 m of net-lines (Fig. 2). The mist-nets were opened from 05:00 to 17:00 h, except on the third day when the nets were open until 11:00 h, and checked every 30 min to reduce the catching stress. We avoided sampling birds on rainy and windy days because such conditions can reduce the bird movement, thereby interfering in the capture rate. We used a standardized effort of 600 net-hours at each site, totaling 11,400 net-hours (20 mist-nets × 30 h × 19 sampled sites). The captured birds were identified using field guide (Ridgely et al. 2015) and banded following the protocols of the Centro Nacional de Pesquisa e Conservação de Aves Silvestres (CEMAVE). The license for bird capture was granted by Comissão de Ética no Uso dos Animais (CEUA) of the Universidade Estadual de Santa Cruz (UESC); Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) and Sistema de Autorização e Informação em Biodiversidade (SISBIO/license number 75678). Additionally, the license for bird banding was granted by Instituto Chico Mendes de Conservação da Biodiversidade/Sistema Nacional de Anilhamento (ICMBio/SNA license number 6569995).

2.6 Taxonomic, functional and phylogenetic metrics

We used Hill numbers of order 0 and 1 with the *iNEXT 3D* package (Hu and Chao 2021a) for R software (R Core Team 2021) to estimate multiple dimensions of bird diversity. This method provides an unified framework for measuring biodiversity that can be generalized to taxonomic, functional and phylogenetic richness and diversity (Chao et al. 2014). Specifically, order 0 is not sensitive to species abundance and gives the same weight to rare and abundant species, representing therefore taxonomic, functional, and phylogenetic *richness*. Additionally, order 1 weights each species according to its abundance in the assemblage (*i.e.*, exponential of Shannon entropy), favoring more abundant species because they will have higher weight than rare species (Jost 2007, Chao and Jost 2012), representing the taxonomic, functional and phylogenetic *diversity*.

To estimate functional richness and diversity, we selected 12 avian traits related to the acquisition of food resources and sensitivity to disturbances: (1) body mass, (2) body length, (3) bill length, (4) bill width, (5) bill depth, (6) tarsus length, (7) tail length, (8) wing length, (9) diet type, (10) forest dependency, (11) Kipp's distance, (12) foraging stratum. Indeed, these traits may influence the growth, reproduction, or survival of bird species (see details in Appendix S2). In particular, body mass and length are related to fecundity, longevity, and species sensitivity to human disturbances (Pigot et al. 2020). Bill measures indicate the size and type of food consumed by birds (Miles et al. 1987), while tarsus, tail, and wing length, as well as Kipp's distance, are locomotor traits linked to foraging behavior and dispersal capacity of birds (Tobias et al. 2014; Bregman et al. 2016; Pigot et al. 2020). Traits related to diet and foraging strata were obtained from the EltonTraits database (Wilman et al. 2014), forest dependency (*i.e.* high, medium, low, does not normally occur in forest) was obtained in the BirdLife Datazone, while all morphometric traits were collected during fieldwork. Kipp's distance was calculated as the differences of the length of the first and the secondary feathers of the left wing divided by wing length. Then, we estimated functional richness and diversity using a distance-based approach, which is calculated based on a functional pairwise distance matrix (Chao et al. 2019). According to Bello et al. (2021), this matrix allows specifying groups of functional traits that can be correlated and provide similar biological information by calculating the dissimilarity inside the group specified and, thus, comparing with the dissimilarity of the other traits or group of traits. In this context, we grouped our 12 traits in six uncorrelated groups that provide similar biological meaning: (1) Body mass and length, (2) Bill length, width, and depth, (3) Tarsus, tail and wing length and Kipp's distance, (4) Diet type, (5) Forest dependency and (6) Foraging stratum.

To estimate phylogenetic metrics, we used the website BirdTree (www.birdtree.org) - global phylogeny of birds - to download 1,000 phylogenetic trees based on Ericson All Species backbone. Each phylogenetic tree is an evolutionary hypothesis about the relationship among species recorded in the study area. Thus, we estimated the phylogenetic richness and diversity for each phylogenetic tree and calculated the mean values for these metrics, which incorporates species evolutionary history, taking into account phylogenetic distances between species (Chao et al. 2010).

2.7 Data analyses

Using the *entropart* package (Marcon and Herault 2015), we observed that the sampling effort was able to record on average (± standard deviation) 0.57 ± 0.31 sample coverage per site (Appendix S3. Table S3). Given that sampling coverage values showed high variation among sites, we calculated the taxonomic, functional and phylogenetic richness and diversity for each site using coverage-based standardization (Appendix S4. Table S4). Thus, we estimated this metrics using a sample coverage of 0.88 for all sampled sites with the iNEXT.*3D* package (Hu and Chao 2021). This value corresponds to twice the lowest sample coverage value found in our study (Appendix S3, Table S3). We excluded four sampled sites from subsequent analysis because these sites had sample coverage values equal to zero. Thus, the final dataset was comprised of 15 sampling sites.

We assessed the effects of landscape and local predictors on each dimension of bird diversity using Generalized Additive Models (GAMs) with Gaussian distribution (Guisan et al. 2002). GAMs are semi-parametric extensions of Generalized Linear Models, although do not assume any *a priori* form of the relationship between response and predictor variables. We tested the correlation between all environmental predictors using a Pearson test to reduce collinearity within the same model and excluded variables with r-values ≥ 0.70 (Appendix S5. Dormann et al., 2013). We constructed models containing from one to three predictor variables. In particular, the full model was composed by two landscape variables (composition and configuration landscape variables), and one local descriptor. In addition, we constructed the null models for each response variable to check if the models were better than expected at random.

We ranked a set of models based on Akaike Criterion corrected for small samples (AICc) and considered equally plausible models with ΔAICc ≤ 2. When the null model was among the plausible models, it was always selected as the best model. We also evaluated the fit of the plausible models using a ratio between residual deviance and residual degrees of freedom, where values greater than 1 indicate overdispersion (Crawley 2002) (Appendix S6. Table S10). Given that plausible models for species richness presented overdispersion, we used Box-Cox transformation to account for that. Finally, we evaluated the spatial autocorrelation in the residuals of the plausible models using Moran's I test (Appendix S7. Table S11). Considering all the models included in the set of candidate models, we calculated the relative importance of each predictor by summing the models' weigh where each predictor was present (Appendix S8. Table S12). All statistical analyses were conducted in R software (R Core Team 2021) using the packages *MuMIn* (Barton 2020), *mgcv* (Wood 2011), *MASS* (Venables and Ripley 2002), and *ape* (Paradis and Schliep 2019).

3. RESULTS

We captured a total of 274 individuals belonging to 53 species, 41 genera and 18 families across 19 eucalypt plantations (Appendix S9. Table S13). The number of species per site varied from 1 to 24 (mean ± SD = 7.95 ± 6), and the number of individuals from 1 to 44 (13.89 ± 12.42). The most abundant species were *Tolmomyias flaviventris* (n = 31), *Capsiempis flaveola* (n = 21) and *Elaenia flavogaster* (n = 18). 12 species were captured only once.

Our results highlighted several plausible models (ΔAICc ≤ 2) for explaining the influence of landscape and local variables on bird taxonomic, functional and phylogenetic metrics (Table 1). Furthermore, we did not detect spatial autocorrelation in the residuals of the most parsimonious models (Appendix S7). Among all the created models, we observed that the number of forest fragments and the number of understory plants showed greater relative importance to explain species richness and diversity, functional diversity and phylogenetic richness (Fig. 3).

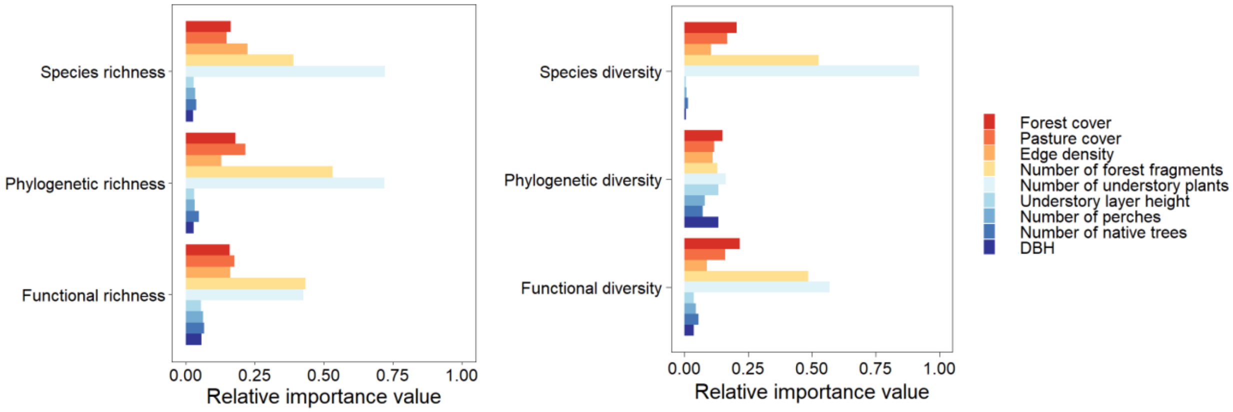

Figure 3. Relative importance value of each landscape and local predictor used to explain multiple dimensions of bird diversity in eucalypt plantations. The relative importance value was calculated by summing the weights of the models where each predictor was present.

Some plausible models were composed by other environmental predictors (e.g., forest cover and edge density estimated in 200 m and 900 m- sized landscapes, respectively), although these did not significantly influence the evaluated metrics (Appendix S10. Table S14). In particular, we observed that number of forest fragments in 900 m landscapes negatively affects taxonomic and functional diversity of birds, as well as phylogenetic richness. Conversely, our findings indicated that the increase of number of understory plants positively affects the taxonomic and phylogenetic richness (Fig. 4). In addition, we observed that eucalypt plantations with greater number of understory plants presented higher taxonomic and functional diversity (Fig. 4).

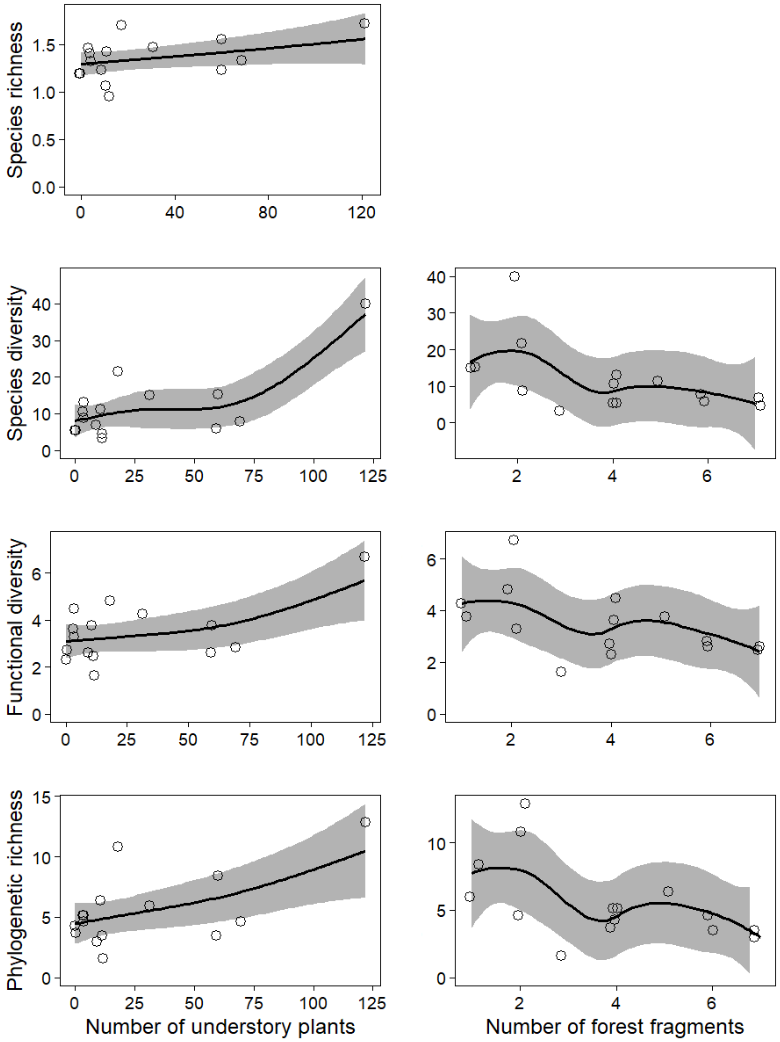

Figure 4. Relationship between landscape (number of forest fragments) and local (number of understory plants) predictors and bird taxonomic, functional, and phylogenetic metrics (richness and diversity). We presented only significant relationships indicated in the best models (Appendix S10). The solid black lines represent the relation between the predictor variables and the metrics of richness and diversity. The shaded area represents the 95% confidence interval. The values of species richness were transformed using the Box-Cox transformation.

Table 1. Parsimonious models (ΔAICc $\leq$ 2) used to explain the relationship between the landscape and local predictors and the bird taxonomic, functional and phylogenetic metrics.

Species richness			
Models	ΔAICc	k	W_i
Number of forest fragments	0.00	2	0.16

Number of forest fragments + Number of understory plants	0.08	4	0.16
Number of understory plants	1.25	2	0.09
Species diversity			
Models	ΔAICc	k	W_i
Number of forest fragments + Number of understory plants	0	4	0.34
Number of understory plants	1.64	2	0.15
Functional richness			
Models	ΔAICc	k	W_i
Number of forest fragments + Number of understory plants	0.00	4	0.12
Number of forest fragments	0.16	2	0.12
Number of understory plants	0.47	2	0.10
Edge density + Number of understory plants	0.80	4	0.08
Null model	1.67	1	0.05
Functional diversity			
Models	ΔAICc	k	W_i
Number of forest fragments + Number of understory plants	0.00	4	0.17
Number of understory plants	0.57	2	0.13
Number of forest fragments	1.09	2	0.10
Forest cover + Number of understory plants	1.76	3	0.07

Forest cover + Number of forest fragments + Number of understory plants	1.82	5	0.07
Phylogenetic richness			
Models	ΔAICc	k	W_i
Number of forest fragments + Number of understory plants	0.00	4	0.26
Phylogenetic diversity			
Models	ΔAICc	k	W_i
Null model	0.00	1	0.20
Number of understory plants	1.66	2	0.09

ΔAICc: difference in AICc between the best model and the ith model; k: parameter number of the model; Wi: AICc weight. Models are ranked by AICc values.

4. DISCUSSION

Our study assessed how landscape and local contexts of eucalypt plantations can influence taxonomic, functional and phylogenetic richness and diversity of understory birds within these plantations. Our results indicated that multiple dimensions of bird diversity in eucalyptus plantations can be influenced by both contexts, highlighting the following patterns: i) eucalypt plantations inserted in landscapes with higher number of forest fragments harbor impoverished bird assemblages; and ii) eucalypt plantations composed by high number of understory plants can maintain higher species richness and diversity, functional diversity and phylogenetic richness.

Contrary to our predictions, we observed an impoverishment of all dimensions of bird diversity in eucalypt plantations located in landscapes with the increase in the number of forest fragments, which may indicate that the remaining bird assemblages perform a reduced number of functional roles and present a low capability to resist further disturbances. In fact, these landscapes were also composed by low forest cover and high amount of cattle pasture, creating harsh conditions for maintain the bird diversity in eucalypt plantations. As it has been shown in previous studies, habitat loss and the resulting fragmentation increase isolation between habitat remnants leading to a decrease in the connectivity of the habitat (Fahrig 2003; Uezu and Metzger 2016). These changes in landscape structure can cause unsuccessful recolonization events and higher extinction rates in the remaining habitat (Boscolo et al. 2008). For instance, bird species richness can be higher on plantations connected to native remnants compared to isolated ones (Castaño-Villa et al. 2019). Similarly, previous study conducted in Brazilian Amazon Forest observed that oil palm plantations connected to riparian reserves can harbor high avian phylogenetic diversity, reducing local extinctions in fragmented landscapes (Cardoso et al. 2021). Furthermore, it was also shown that pasture cover is a harsh matrix that can difficult the movement of species (Prevedello and Vieira 2010; Biz et al. 2017). In particular, landscapes dominated by pasture can reduce supplementary and complementary resources and increase edge effects, creating impoverished species assemblages (Laurance et al. 2002; Hendershot et al. 2020; Cabral et al. 2021). In fact, more fragmented landscapes can also harbor more functionally similar species (i.e. functional homogenization; Devictor et al. 2008, 2010; Lôbo et al. 2011) and promote the dominance of species clades more adapted to survive in disturbed environments (Matos et al. 2017). Additionally, functional diversity can be lower in fragmented landscapes because there are environmental filters that select species able to survive in disturbed environments (Munguía-Rosas et al. 2014). In our study, eucalypt plantations inserted in landscapes with higher number of forest fragments harbored predominantly species with low forest dependency and diet composed of invertebrates.

According to our predictions, we observed an increase in taxonomic richness and diversity, functional diversity, and phylogenetic richness in eucalypt plantations composed by high number of understory plants. Specifically, understory vegetation is associated to the availability of food resources, shelter, refuges, breeding sites and, therefore, is often considered an important predictor of bird diversity in plantations (Aratrakorn et al. 2006), including forest-specialist species. Thus, plantations with more complex understory vegetation harbor a greater number of species, including different dietary groups (Nájera and Simonetti 2010; Millan et al. 2015). In eucalypt plantations where the regeneration of the vegetation is taking place (*i.e.* unmanaged plantations), taxonomic and functional diversity of ants approximates the ones in native forests, while in managed plantations (*i.e.* where the understory is thinned) the values are reduced, leading to species taxonomic and functional homogenization (Martello et al. 2018). For birds, when eucalypt plantations have a dense understory, and coexist in a mosaic with native stands, it can have higher understory species richness than native forests, although the composition of ecological traits are similar between these habitats (Lopes et al. 2015b). Furthermore, it was observed that rubber plantations presenting high density of fruit trees and herbaceous plants in the understory harbor a higher functional and phylogenetic diversity of birds due to an increase in the resource availability (Jayathilake et al. 2021).

Although some of the sampled eucalypt plantations harbored high values of taxonomic, functional and phylogenetic richness and diversity, bird species composition of these plantations was not similar to that observed in native forests in the same region. (Appendix S11. Fig. S1). In particular, from 17 species recorded in forest fragments, 13 (76%) were exclusively observed in fragments. In fact, we captured mainly individuals of the Dendrocolaptidae family in forest fragments (47%), while in eucalypt plantations we captured mainly individuals of the Rhynchocyclidae (11%) and Tyrannidae (28%) families. Several studies demonstrated that woodcreepers (Dendrocolaptidae) needs vertical vegetation stratification for foraging (Orians, 1969), being hence more sensitive to changes in forest structure (Rodrigues et al. 2016). Indeed, these bird species are negatively affected by the reduction of number of native trees (Thiollay 1992), habitat fragmentation and isolation (Maldonado-Coelho 2000). In contrast, two of the species most commonly recorded in studied eucalypt plantations are birds capable of occupying different environments, including highly disturbed areas. For instance, *Tolmomyias flaviventris* is quite common, being able to occupy almost every forested habitats in Neotropics (Fitzpatrick 1980), including coffee plantations, shade trees and mangroves (Haverschmidt 1974), as well as *Elaenia flavogaster*, which inhabit semi-open areas, forest borders and clearings (Camargo 1986). In fact, the species registered in eucalypt plantations are more generalist in the use of the habitat and generally unaffected by changes in the environment (Faria et al. 2006; Nájera and Simonetti 2010), while in the forest fragments we captured mainly forest-dependent species, which are usually considered highly sensitive to anthropic disturbances (Carrara et al. 2015; Morante-Filho et al. 2015). This result raises an alert about the real role of eucalyptus plantations for conservation, because although this system may harbor a rich bird assemblage, their species composition strongly differs from those commonly recorded in remaining forests.

4.1 Conclusions

By assessing taxonomic, functional and phylogenetic bird richness and diversity within eucalypt plantations with different landscape and local contexts, we addressed the following question: under which landscape and local characteristics eucalypt plantations could harbor high diversity of understory birds? Our findings evidenced that eucalypt plantations harbor an impoverished understory bird assemblage when located in highly fragmented landscapes. Conversely, when presenting higher number of understory plants, these plantations can harbor a diverse assemblage of birds, including species with distinct ecological traits and a rich evolutionary history. Therefore, higher levels of multiple dimensions of bird diversity can be maintained if eucalypt plantations present high number of understory plants and when inserted in landscapes composed by low number of forest fragment.

Given the increase of areas designated to tree plantations worldwide, it is essential to define effective strategies that ally biological conservation and economic return. We suggest that the industry avoid the fragmentation of the existing remnants in the landscape, and highlight that recommending fewer forest fragments is not the same as recommending less forest since it can increase the amount of habitat and favor landscape connectivity (Biz et al. 2017). Furthermore, we encourage a rotation system in the thinning of the understory vegetation within plantations inserted in the same landscape. This management mechanism will allow plantations with high complexity of understory vegetation to be always maintained in the landscape, and act as supplementary habitat especially in heavily deforested landscapes. We also discourage the thinning during birds' breeding season, from October to February, because in this period birds have a higher demand for food resources due to the egg laying and parental care (Ewald et al. 1982).
Finally, we conclude that both landscape and local context influence the diversity of birds within eucalypt plantations, therefore, to ally biological conservation and economic return an effective strategy should contemplate both contexts.

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APÊNDICES

APPENDIX S1. Results of multi-scale analysis

We used a site-landscape approach (Fahrig 2013) to estimate our landscape metrics (*i.e.* forest cover, pasture cover, edge density and number of forest fragments) within 9 different-sized buffers surrounding each eucalyptus site, ranging from 200 to 1000 m radius. We did not use the 100 m buffer because of the low variation of the landscape metrics surrounding the sampled sites. In addition, we did not use buffers largest than 1000 m to avoid spatial overlapping given that each site was distant, at least, 2 km from one another. Therefore, we obtained landscapes of 200 m (12.6 ha), 300 m (28.3 ha), 400 m (50.3 ha), 500 m (78.5 ha), 600 m (113.1 ha), 700 m (153.9 ha), 800 m (201.1 ha), 900 m (254.5 ha), 1000 m (314.2 ha). We tested the effect of landscape metrics on each response variables using the *stats* package in R software. We constructed linear models to identify the best scale in which the association between landscape metrics and different bird diversity dimensions showed highest R^2 and lowest p-value (Table S1).

Table S1. Result of association between spatial scale and the strength of relationship between landscape metrics and each dimension of bird diversity. Best scales are indicated in bold.

Response variable	Landscape metric	Buffer size (m)	R^2	p-value
Species richness	Forest cover	200	0.00	0.98
Species richness	Forest cover	300	0.00	0.95
Species richness	Forest cover	400	0.01	0.74
Species richness	Forest cover	500	0.02	0.61
Species richness	Forest cover	600	0.02	0.56
Species richness	Forest cover	700	0.03	0.47
Species richness	Forest cover	800	0.04	0.42
Species richness	Forest cover	900	0.05	0.38
Species richness	**Forest cover**	**1000**	**0.06**	**0.33**
Species diversity	Forest cover	200	0.00	0.98
Species diversity	Forest cover	300	0.00	0.88
Species diversity	Forest cover	400	0.01	0.66
Species diversity	Forest cover	500	0.03	0.53
Species diversity	Forest cover	600	0.04	0.48
Species diversity	Forest cover	700	0.04	0.42
Species diversity	Forest cover	800	0.05	0.40
Species diversity	Forest cover	900	0.05	0.38
Species diversity	**Forest cover**	**1000**	**0.06**	**0.34**
Functional richness	Forest cover	200	0.01	0.67
Functional richness	Forest cover	300	0.01	0.75
Functional richness	Forest cover	400	0.00	0.95
Functional richness	Forest cover	500	0.00	0.91
Functional richness	Forest cover	600	0.00	0.86

Functional richness	Forest cover	700	0.01	0.77
Functional richness	Forest cover	800	0.01	0.71
Functional richness	Forest cover	900	0.01	0.66
Functional richness	**Forest cover**	**1000**	**0.02**	**0.60**
Functional diversity	**Forest cover**	**200**	**0.02**	**0.61**
Functional diversity	Forest cover	300	0.01	0.72
Functional diversity	Forest cover	400	0.00	0.93
Functional diversity	Forest cover	500	0.00	0.92
Functional diversity	Forest cover	600	0.00	0.86
Functional diversity	Forest cover	700	0.00	0.82
Functional diversity	Forest cover	800	0.00	0.82
Functional diversity	Forest cover	900	0.01	0.79
Functional diversity	Forest cover	1000	0.01	0.76
Phylogenetic richness	Forest cover	200	0.00	0.86
Phylogenetic richness	Forest cover	300	0.00	0.99
Phylogenetic richness	Forest cover	400	0.01	0.76
Phylogenetic richness	Forest cover	500	0.02	0.60
Phylogenetic richness	Forest cover	600	0.03	0.55
Phylogenetic richness	Forest cover	700	0.03	0.48
Phylogenetic richness	Forest cover	800	0.04	0.44
Phylogenetic richness	Forest cover	900	0.05	0.40
Phylogenetic richness	**Forest cover**	**1000**	**0.06**	**0.35**
Phylogenetic diversity	**Forest cover**	**200**	**0.09**	**0.23**
Phylogenetic diversity	Forest cover	300	0.07	0.30
Phylogenetic diversity	Forest cover	400	0.05	0.38
Phylogenetic diversity	Forest cover	500	0.04	0.47
Phylogenetic diversity	Forest cover	600	0.02	0.55
Phylogenetic diversity	Forest cover	700	0.03	0.51
Phylogenetic diversity	Forest cover	800	0.04	0.47
Phylogenetic diversity	Forest cover	900	0.04	0.46
Phylogenetic diversity	Forest cover	1000	0.04	0.46
Species richness	**Pasture cover**	**200**	**0.14**	**0.14**
Species richness	Pasture cover	300	0.13	0.16
Species richness	Pasture cover	400	0.10	0.22
Species richness	Pasture cover	500	0.08	0.28
Species richness	Pasture cover	600	0.07	0.32
Species richness	Pasture cover	700	0.07	0.30
Species richness	Pasture cover	800	0.07	0.31
Species richness	Pasture cover	900	0.07	0.31
Species richness	Pasture cover	1000	0.07	0.30
Species diversity	Pasture cover	200	0.10	0.21

Species diversity	**Pasture cover**	**300**	**0.12**	**0.18**
Species diversity	Pasture cover	400	0.11	0.20
Species diversity	Pasture cover	500	0.09	0.25
Species diversity	Pasture cover	600	0.08	0.28
Species diversity	Pasture cover	700	0.08	0.27
Species diversity	Pasture cover	800	0.08	0.29
Species diversity	Pasture cover	900	0.07	0.32
Species diversity	Pasture cover	1000	0.06	0.33
Functional richness	**Pasture cover**	**200**	**0.11**	**0.20**
Functional richness	Pasture cover	300	0.10	0.22
Functional richness	Pasture cover	400	0.07	0.30
Functional richness	Pasture cover	500	0.06	0.37
Functional richness	Pasture cover	600	0.04	0.42
Functional richness	Pasture cover	700	0.05	0.40
Functional richness	Pasture cover	800	0.05	0.41
Functional richness	Pasture cover	900	0.04	0.43
Functional richness	Pasture cover	1000	0.04	0.43
Functional diversity	Pasture cover	200	0.04	0.42
Functional diversity	**Pasture cover**	**300**	**0.07**	**0.32**
Functional diversity	Pasture cover	400	0.06	0.36
Functional diversity	Pasture cover	500	0.04	0.42
Functional diversity	Pasture cover	600	0.04	0.44
Functional diversity	Pasture cover	700	0.04	0.43
Functional diversity	Pasture cover	800	0.04	0.47
Functional diversity	Pasture cover	900	0.03	0.52
Functional diversity	Pasture cover	1000	0.02	0.55
Phylogenetic richness	Pasture cover	200	0.13	0.15
Phylogenetic richness	**Pasture cover**	**300**	**0.15**	**0.12**
Phylogenetic richness	Pasture cover	400	0.12	0.17
Phylogenetic richness	Pasture cover	500	0.10	0.22
Phylogenetic richness	Pasture cover	600	0.09	0.24
Phylogenetic richness	Pasture cover	700	0.10	0.22
Phylogenetic richness	Pasture cover	800	0.09	0.23
Phylogenetic richness	Pasture cover	900	0.09	0.25
Phylogenetic richness	Pasture cover	1000	0.09	0.24
Phylogenetic diversity	**Pasture cover**	**200**	**0.01**	**0.76**
Phylogenetic diversity	Pasture cover	300	0.00	0.97
Phylogenetic diversity	Pasture cover	400	0.00	0.91
Phylogenetic diversity	Pasture cover	500	0.00	0.93
Phylogenetic diversity	Pasture cover	600	0.00	0.90
Phylogenetic diversity	Pasture cover	700	0.00	0.94
Phylogenetic diversity	Pasture cover	800	0.00	0.97

Phylogenetic diversity	Pasture cover	900	0.00	0.97
Phylogenetic diversity	Pasture cover	1000	0.00	0.93
Species richness	Edge density	200	0.00	0.82
Species richness	Edge density	300	0.00	0.92
Species richness	Edge density	400	0.01	0.75
Species richness	Edge density	500	0.01	0.71
Species richness	Edge density	600	0.03	0.53
Species richness	Edge density	700	0.05	0.41
Species richness	Edge density	800	0.06	0.36
Species richness	**Edge density**	**900**	**0.09**	**0.25**
Species richness	Edge density	1000	0.07	0.32
Species diversity	Edge density	200	0.01	0.69
Species diversity	Edge density	300	0.00	0.83
Species diversity	Edge density	400	0.01	0.67
Species diversity	Edge density	500	0.01	0.75
Species diversity	Edge density	600	0.01	0.66
Species diversity	Edge density	700	0.02	0.61
Species diversity	Edge density	800	0.02	0.58
Species diversity	**Edge density**	**900**	**0.04**	**0.44**
Species diversity	Edge density	1000	0.03	0.53
Functional richness	Edge density	200	0.00	0.80
Functional richness	Edge density	300	0.00	0.85
Functional richness	Edge density	400	0.02	0.64
Functional richness	Edge density	500	0.02	0.60
Functional richness	Edge density	600	0.04	0.46
Functional richness	Edge density	700	0.07	0.32
Functional richness	Edge density	800	0.08	0.26
Functional richness	**Edge density**	**900**	**0.13**	**0.16**
Functional richness	Edge density	1000	0.11	0.20
Functional diversity	Edge density	200	0.01	0.67
Functional diversity	Edge density	300	0.01	0.73
Functional diversity	Edge density	400	0.03	0.52
Functional diversity	Edge density	500	0.02	0.61
Functional diversity	Edge density	600	0.02	0.58
Functional diversity	Edge density	700	0.03	0.51
Functional diversity	Edge density	800	0.04	0.45
Functional diversity	**Edge density**	**900**	**0.07**	**0.32**
Functional diversity	Edge density	1000	0.05	0.37
Phylogenetic richness	Edge density	200	0.01	0.74
Phylogenetic richness	Edge density	300	0.01	0.74
Phylogenetic richness	Edge density	400	0.02	0.59

Phylogenetic richness	Edge density	500	0.02	0.61
Phylogenetic richness	Edge density	600	0.03	0.55
Phylogenetic richness	Edge density	700	0.04	0.44
Phylogenetic richness	Edge density	800	0.05	0.39
Phylogenetic richness	**Edge density**	**900**	**0.08**	**0.26**
Phylogenetic richness	Edge density	1000	0.07	0.32
Phylogenetic diversity	Edge density	200	0.01	0.76
Phylogenetic diversity	**Edge density**	**300**	**0.01**	**0.70**
Phylogenetic diversity	Edge density	400	0.00	0.87
Phylogenetic diversity	Edge density	500	0.00	1.00
Phylogenetic diversity	Edge density	600	0.00	0.88
Phylogenetic diversity	Edge density	700	0.01	0.70
Phylogenetic diversity	Edge density	800	0.01	0.78
Phylogenetic diversity	Edge density	900	0.01	0.79
Phylogenetic diversity	Edge density	1000	0.01	0.72
Species richness	Number of forest fragments	200	0.01	0.76
Species richness	Number of forest fragments	300	0.00	0.97
Species richness	Number of forest fragments	400	0.03	0.50
Species richness	Number of forest fragments	500	0.11	0.20
Species richness	Number of forest fragments	600	0.14	0.14
Species richness	Number of forest fragments	700	0.20	0.08
Species richness	Number of forest fragments	800	0.15	0.12
Species richness	**Number of forest fragments**	**900**	**0.22**	**0.06**
Species richness	Number of forest fragments	1000	0.14	0.13
Species diversity	Number of forest fragments	200	0.01	0.73
Species diversity	Number of forest fragments	300	0.00	0.86
Species diversity	Number of forest fragments	400	0.04	0.46
Species diversity	Number of forest fragments	500	0.14	0.15
Species diversity	Number of forest fragments	600	0.17	0.10

Species diversity	Number of forest fragments	700	0.20	0.07
Species diversity	Number of forest fragments	800	0.15	0.13
Species diversity	**Number of forest fragments**	**900**	**0.22**	**0.06**
Species diversity	Number of forest fragments	1000	0.14	0.14
Functional richness	Number of forest fragments	200	0.02	0.62
Functional richness	Number of forest fragments	300	0.01	0.74
Functional richness	Number of forest fragments	400	0.01	0.75
Functional richness	Number of forest fragments	500	0.06	0.34
Functional richness	Number of forest fragments	600	0.11	0.20
Functional richness	Number of forest fragments	700	0.14	0.15
Functional richness	Number of forest fragments	800	0.11	0.19
Functional richness	**Number of forest fragments**	**900**	**0.17**	**0.10**
Functional richness	Number of forest fragments	1000	0.12	0.17
Functional diversity	Number of forest fragments	200	0.03	0.51
Functional diversity	Number of forest fragments	300	0.01	0.71
Functional diversity	Number of forest fragments	400	0.00	0.87
Functional diversity	Number of forest fragments	500	0.06	0.36
Functional diversity	Number of forest fragments	600	0.10	0.21
Functional diversity	Number of forest fragments	700	0.10	0.22
Functional diversity	Number of forest fragments	800	0.08	0.28
Functional diversity	**Number of forest fragments**	**900**	**0.14**	**0.14**
Functional diversity	Number of forest fragments	1000	0.09	0.23

Phylogenetic richness	Number of forest fragments	200	0.01	0.67
Phylogenetic richness	Number of forest fragments	300	0.00	0.91
Phylogenetic richness	Number of forest fragments	400	0.02	0.59
Phylogenetic richness	Number of forest fragments	500	0.10	0.22
Phylogenetic richness	Number of forest fragments	600	0.17	0.10
Phylogenetic richness	Number of forest fragments	700	0.20	0.07
Phylogenetic richness	Number of forest fragments	800	0.17	0.10
Phylogenetic richness	**Number of forest fragments**	**900**	**0.24**	**0.05**
Phylogenetic richness	Number of forest fragments	1000	0.19	0.09
Phylogenetic diversity	Number of forest fragments	200	0.00	0.91
Phylogenetic diversity	Number of forest fragments	300	0.00	0.99
Phylogenetic diversity	**Number of forest fragments**	**400**	**0.01**	**0.68**
Phylogenetic diversity	Number of forest fragments	500	0.00	0.93
Phylogenetic diversity	Number of forest fragments	600	0.00	0.87
Phylogenetic diversity	Number of forest fragments	700	0.00	0.98
Phylogenetic diversity	Number of forest fragments	800	0.00	0.96
Phylogenetic diversity	Number of forest fragments	900	0.00	0.84
Phylogenetic diversity	Number of forest fragments	1000	0.00	0.90

APPENDIX S2. Bird traits used to estimate bird functional richness and diversity.

Functional metrics measure the different ecological traits of a community, being directly linked to ecological functions performed by species in the ecosystem (Tilman 2001). Therefore, greater values of functional richness and diversity may indicate a community with more distinct ecological functions, and thus greater functional stability facing human disturbances (*e.g.* Carvalho et al. 2021, Palmeirim et al. 2021). We selected twelve functional traits commonly used in avian studies of functional diversity and that influence growth, reproduction, or survival of bird species (Table S2).

Table S2. List of the ecological traits used in this study, indicating their functional significance.

Functional trait	**Type of data**	**Functional significance** [1]
Body mass Body length	Numerical continuous	Related to fecundity, longevity, and sensitivity to human disturbances
Bill length Bill width Bill depth	Numerical continuous	Indicate the type and size of food consumed by birds
Tarsus length Tail length Wing length Kipp's distance	Numerical continuous	Linked to foraging behavior and dispersal capacity of birds
Diet type	Numerical continuous	Type of food consumed; linked to the contribution of species to ecological functions (carnivore, frugivore, granivore, insectivore, nectarivore, omnivore, scavenger)
Forest dependency	Categorical	Forest habitat requirement of species (low, medium, high, does not normally occur in forest)
Foraging strata	Numerical continuous	Where the bird species use the resource in vertical strata (ground, understory, midstory, canopy)

[1] Miles et al. 1987, Tobias et al. 2014, Bregman et al. 2016, Pigot et al. 2016, 2020

The morphological traits obtained in the field were body mass, body length, bill length, bill width, bill depth, tarsus length, tail length and wing length. Body mass was the difference between the mass (g) of the holding bag with the individual inside and the mass of the empty holding bag, obtained with the assistance of a Pesola scale. Body length was the length from the tip of the tail to the tip of the bill (mm) measured with the assistance of a caliper. Bill length was the length from the edge of the nostrils to the tip of the beak (mm), bill width was the length (mm) from the left join of the mandibles to the right join, and the bill depth was the vertical length of the beak. Tarsus length was measured from the rear ankle joint to the last scale of the acrotarsium. Tail length was measured from the uropygium to the tip of the tail. Wing length was measured in the right open wing of the birds, from the shoulder to the tip of the first primary feathers. Kipp’s distance was measured as the difference from the length of the primary and secondary feathers, divided by total wing length. Diet type and foraging strata was obtained in EltonTraits (Wilman et al. 2014) as the percentage of the diet constituted by the types of food and the percentage of foraging in determinate vertical strata. Forest dependency was obtained in the Birdlife DataZone.

APPENDIX S3. Sample coverage recorded in each sampled site.

Table S3. Number of species, individuals and sample coverage of each sampled site. Sites with sample coverage equal zero were excluded from the statistical analysis.

Site	**Number of species**	**Number of individuals**	**Sample coverage**
Adeus	10	15	0.63
Aratombo	4	6	0.58
Beija_flor	3	5	0.73
Carapana	9	20	0.87
Carrapato	7	17	0.90
Irara	6	9	0.75
Lagrimas	24	38	0.56
Limbo	3	3	0
Meliante	4	6	0.80
Morro_oculto	10	17	0.74
Reencontro	7	10	0.67
Saudade	18	44	0.75
Sinistro	4	6	0.58
Sofrimento	8	10	0.44
Sucuarana	16	33	0.73
Trilha_do_boi	11	18	0.68
Urtiga	1	1	0
Verdade	5	5	0
Zumbido	1	1	0

APPENDIX S4. Estimated values of the bird richness and diversity metrics

Table S4. Estimated values of taxonomic, functional and phylogenetic richness and diversity for each sampled site. NAs indicate the four sites with only singletons that were excluded from statistical analysis.

Sites	Species Richness	Species Diversity	Functional Richness	Functional Diversity	Phylogenetic Richness	Phylogenetic diversity
Adeus	14.00	13.13	4.50	4.47	5.10	4.33
Aratombo	6.18	5.32	2.94	2.70	3.68	2.71
Beija-flor	3.66	3.17	1.70	1.63	1.59	1.36
Carapanã	9.14	7.80	3.14	2.82	4.63	2.03
Carrapato	6.91	5.91	2.83	2.60	3.48	1.56
Irara	6.89	6.84	2.55	2.60	2.96	2.16
Lágrimas	57.92	39.89	8.30	6.70	12.88	5.79

Limbo	NA	NA	NA	NA	NA	NA
Meliante	4.59	4.56	2.45	2.46	3.48	3.20
Morro oculto	11.72	10.57	3.77	3.63	5.13	3.37
Reencontro	8.76	8.77	3.18	3.30	4.61	3.29
Saudade	48.24	21.60	8.34	4.81	10.80	0.59
Sinistro	6.18	5.32	2.50	2.30	4.25	2.62
Sofrimento	14.92	15.08	4.15	4.27	5.97	4.52
Suçuarana	21.35	15.27	4.62	3.75	8.39	2.11
Trilha do boi	12.32	11.27	3.94	3.75	6.37	1.63
Urtiga	NA	NA	NA	NA	NA	NA

Verdade	NA	NA	NA	NA	NA	NA
Zumbido	NA	NA	NA	NA	NA	NA

APPENDIX S5. Correlation between landscape and local predictors using Pearson test. Where the best landscape scale was the same for more than one diversity metric, it was specified on the table title.

Table S5. Correlation between landscape variables to species richness, functional richness

	Forest cover 1000 m	Pasture cover 200 m	Edge density 900 m	Number of forest fragments 900 m
Forest cover 1000 m	1			
Pasture cover 200 m	-0.56	1		
Edge density 900 m	0.82	-0.29	1	
Number of forest fragments 900 m	-0.21	0.58	-0.01	1

Table S6. Correlation between landscape variables to species diversity, phylogenetic richness

	Forest cover 1000 m	Pasture cover 300 m	Edge density 900 m	Number of forest fragments 900 m
Forest cover 1000 m	1			
Pasture cover 300 m	-0.70	1		
Edge density 900 m	0.82	-0.48	1	
Number of forest fragments 900 m	-0.21	0.53	-0.01	1

Table S7. Correlation between landscape variables to functional diversity

	Forest cover 200 m	Pasture cover 300 m	Edge density 900 m	Number of forest fragments 900 m
Forest cover 200 m	1			
Pasture cover 300 m	-0.48	1		
Edge density 900 m	0.56	-0.48	1	
Number of forest fragments 900 m	-0.05	0.53	-0.01	1

Table S8. Correlation between landscape variables to phylogenetic diversity

	Forest cover 200 m	Pasture cover 200 m	Edge density 300 m	Number of forest fragments 400 m
Forest cover 200 m	1			
Pasture cover 200 m	-0.35	1		
Edge density 300 m	0.79	-0.29	1	
Number of forest fragments 400 m	0.37	0.25	0.51	1

Table S9. Correlation between local variables

	Number of trees	DBH	Number of understory plants	Understory layer height	Number of perches
Number of trees	1				
DBH	0.94	1			
Number of understory plants	0.83	0.84	1		
Understory layer height	0.82	0.82	0.60	1	
Number of perches	-0.15	-0.16	-0.27	-0.09	1

APPENDIX S6. Adjustment tests for plausible models using the ratio between residual deviance and residual degrees of freedom.

Table S10. Results of adjustment test for plausible models used to explain the relationship between landscape and local predictors and bird taxonomic, functional, and phylogenetic metrics.

Species richness	
Models	Residual deviance / degrees of freedom
Number of forest fragments	0.01
Number of forest fragments + Number of understory plants	0.01
Number of understory plants	0.01
Species diversity	
Models	Residual deviance / degrees of freedom
Number of forest fragments + Number of understory plants	0.51
Number of understory plants	0.54
Functional Richness	
Models	Residual deviance / degrees of freedom
Number of forest fragments + Number of understory plants	0.13
Number of forest fragments	0.13
Number of understory plants	0.13
Edge density + Number of understory plants	0.14
Null model	0.14
Functional diversity	
Models	Residual deviance / degrees of freedom

Number of forest fragments + Number of understory plants	0.08
Number of understory plants	0.08
Number of forest fragments	0.09
Forest cover + Number of understory plants	0.09
Forest cover + Number of forest fragments + Number of understory plants	0.09
Phylogenetic richness	
Models	Residual deviance / degrees of freedom
Number of forest fragments + Number of understory plants	0.18
Phylogenetic diversity	
Models	Residual deviance / degrees of freedom
Null model	0.10
Number of understory plants	0.10

APPENDIX S7. Test for spatial autocorrelation using Moran’s I test

Table S11. Spatial autocorrelation test of plausible models used to explain the relationship between landscape and local predictors and bird taxonomic, functional and phylogenetic metrics.

Species richness		
Models	Moran’s I p-value	Std. Moran’s I
Number of forest fragments	0.36	0.08
Number of forest fragments + Number of understory plants	0.3	0.08
Number of understory plants	0.55	0.08
Species diversity		
Models	Moran’s I p-value	Std. Moran’s I
Number of forest fragments + Number of understory plants	0.57	0.08
Number of understory plants	0.81	0.08
Functional Richness		
Models	Moran’s I p-value	Std. Moran’s I
Number of forest fragments + Number of understory plants	0.89	0.08
Number of forest fragments	0.2	0.08
Number of understory plants	0.9	0.07
Edge density + Number of understory plants	0.66	0.08
Null model	0.29	0.08
Functional diversity		
Models	Moran’s I p-value	Std. Moran’s I
Number of forest fragments + Number of understory plants	0.57	0.08
Number of understory plants	0.89	0.08
Number of forest fragments	0.02	0.08
Forest cover + Number of understory plants	0.71	0.08
Forest cover + Number of forest fragments + Number of understory plants	0.6	0.08
Phylogenetic richness		
Models	Moran’s I p-value	Std. Moran’s I
Number of forest fragments + Number of understory plants	0.89	0.08

Phylogenetic diversity		
Models	Moran’s I p-value	Std. Moran’s I
Null model	0.45	0.08
Number of understory plants	0.68	0.09

APPENDIX S8. Relative importance values of each predictor.

Table S12. Relative importance (varying of 0 and 1) of the landscape and local predictor used to explain multiple dimensions of bird diversity.

	Species richness	**Species diversity**	**Functional richness**	**Functional diversity**	**Phylogenetic richness**	**Phylogenetic diversity**
Forest cover	0.164	0.206	0.160	0.218	0.181	0.151
Pasture cover	0.148	0.168	0.176	0.161	0.216	0.117
Edge density	0.224	0.105	0.161	0.090	0.129	0.112
Number of forest fragments	0.390	0.527	0.433	0.486	0.533	0.131
Number of understory plants	0.720	0.920	0.427	0.571	0.719	0.163
Number of native trees	0.038	0.015	0.067	0.056	0.048	0.072
Number of perches	0.035	0.010	0.063	0.046	0.032	0.080
DBH	0.027	0.007	0.057	0.038	0.029	0.135
Understory layer height	0.028	0.007	0.056	0.038	0.031	0.134

APPENDIX S9. Abundance matrix of the bird species recorded in 19 eucalyptus plantations located in Brazilian Atlantic Forest from April to June 2021 using 20 mist-nets.

Table S13 – Abundance matrix of bird species following the taxonomy of Jetz et al. 2012.

Species	Adeus	Aratombo	Beija-flor	Carapanã	Irara	Lágrimas	Limbo	Meliante	Morro oculto	Reencontro	Saudade	Sinistro	Sofrimento	Suçuarana	Trilha do boi
Camptostoma obsoletum	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Capsiempis flaveola	0	0	0	2	4	0	2	0	0	0	0	5	1	2	2
Ceratopipra rubrocapilla	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chlorestes cyanus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Chlorestes notata	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Chlorostilbon lucidus	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0
Chrysuronia versicolor	0	0	1	1	0	2	3	0	0	2	2	1	0	1	0
Coereba flaveola	1	0	0	2	0	0	1	0	0	0	0	5	0	0	4
Columbina talpacoti	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Crotophaga ani	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Elaenia chiriquensis	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Elaenia flavogaster	0	0	0	1	0	2	3	0	0	4	0	5	0	0	1
Elaenia mesoleuca	0	0	0	0	0	1	1	0	0	1	0	6	0	0	0
Eupetomena macroura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphonia chlorotica	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Euphonia violacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Formicivora grisea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Furnarius figulus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Furnarius leucopus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glaucis hirsutus	0	1	3	0	0	0	1	0	2	0	1	0	0	1	0
Hylocharis sapphirina	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Machaeropterus regulus	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Manacus manacus	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Megarynchus pitangua	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Myiarchus ferox	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
Myiarchus swainsoni	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Myiophobus fasciatus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Myiozetetes similis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Nyctidromus albicollis	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Nystalus maculatus	0	3	0	0	0	0	1	0	2	0	0	0	0	0	0
Pachyramphus viridis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Phaeomyias murina	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Phaethornis pretrei	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Phaethornis ruber	0	1	1	2	0	0	2	0	0	0	1	0	0	1	1
Picumnus exilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Pitangus sulphuratus	2	0	0	0	1	0	0	0	0	1	2	1	0	0	0
Setophaga pitiayumi	0	0	0	1	0	0	3	0	0	0	0	1	1	0	0

Sporophila caerulescens	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sporophila falcirostris	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sporophila nigricollis	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Stilpnia cayana	3	0	0	0	2	0	0	0	0	0	0	3	0	0	0
Synallaxis frontalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tangara seledon	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Tapera naevia	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Thalurania glaucopis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Thamnophilus ambiguus	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Thraupis palmarum	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thraupis sayaca	0	0	0	0	2	0	1	0	0	0	2	1	0	0	1
Tolmomyias flaviventris	0	0	0	5	2	2	1	0	0	2	1	7	3	1	7
Troglodytes musculus	1	0	0	0	0	0	6	0	0	1	0	1	0	2	1
Turdus leucomelas	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Tyrannus melancholicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Vireo chivi	0	0	0	4	0	0	0	0	0	1	0	1	0	0	5

APPENDIX S10. Parameters of the best models (ΔAIC ≤ 2) used for explaining the patterns of taxonomic, functional and phylogenetic richness and diversity of birds in 19 eucalyptus plantations located in Brazilian Atlantic Forest. The significative predictors (P ≤ 0.05) are highlighted in bold.

Table S14. Best models (ΔAIC ≤ 2) for each richness and diversity metric.

Species Richness				
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	21.51	7.77	2.77	0.02
Number of forest fragments	-3.24	1.60	-2.03	0.06
Number of understory plants	0.24	0.09	2.57	**0.02**
Model 2				
	Estimate	Std. Error	t-value	p-value
Intercept	-7.15	8.76	-0.82	0.43
Edge density	0.33	0.17	1.94	0.08
Number of understory plants	0.30	0.09	3.20	**0.008**
Model 3				
	Estimate	Std. Error	t-value	p-value
Intercept	7.97	4.43	1.80	0.09
Number of understory plants	0.27	0.10	2.70	**0.02**
Species diversity				
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	14.50	3.97	3.65	0.003
Number of forest fragments	-1.88	0.82	-2.30	**0.04**
Number of understory plants	0.16	0.05	3.38	**0.006**
Model 2				
	Estimate	Std. Error	t-value	p-value
Intercept	6.66	2.34	2.85	0.01
Number of understory plants	0.18	0.05	3.37	**0.005**

Functional richness				
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	4.92	1.03	4.76	<0.001
Number of forest fragments	-0.42	0.21	-1.99	0.07
Number of understory plants	0.02	0.01	1.91	0.08
Model 2				
	Estimate	Std. Error	t-value	p-value
Intercept	5.86	0.99	5.89	<0.001
Number of forest fragments	-0.50	0.23	-2.18	**0.05**
Model 3				
	Estimate	Std. Error	t-value	p-value
Intercept	3.15	0.58	5.38	<0.001
Number of understory plants	0.03	0.01	2.10	**0.05**
Model 4				
	Estimate	Std. Error	t-value	p-value
Intercept	1.29	1.18	1.09	0.30
Edge density	0.04	0.02	1.77	0.10
Number of understory plants	0.03	0.01	2.47	**0.03**
Null model				
	Estimate	Std. Error	t-value	p-value
Intercept	3.93	0.05	7.74	<0.001
Functional diversity				
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	4.03	0.64	6.26	<0.001
Number of forest fragments	-0.27	0.13	-2.02	0.07
Number of understory plants	0.02	0.01	2.16	**0.05**

Model 2				
	Estimate	Std. Error	t-value	p-value
Intercept	2.91	0.37	7.94	<0.001
Number of understory plants	0.02	0.01	2.32	**0.04**
Model 3				
	Estimate	Std. Error	t-value	p-value
Intercept	4.70	0.64	7.33	**<0.001**
Number of forest fragments	-0.32	0.15	-2.18	**0.05**
Model 4				
	Estimate	Std. Error	t-value	p-value
Intercept	2.55	0.42	5.99	<0.001
Forest cover	0.03	0.02	1.52	0.15
Number of understory plants	0.02	0.01	2.62	**0.02**
Model 5				
	Estimate	Std. Error	t-value	p-value
Intercept	3.63	0.67	5.45	<0.001
Forest cover	0.03	0.02	1.51	0.16
Number of forest fragments	-0.25	0.13	-1.98	0.07
Number of understory plants	0.02	0.01	2.48	**0.03**
Phylogenetic richness				
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	7.01	1.40	5.01	<0.001
Number of forest fragments	-0.69	0.29	-2.39	**0.03**
Number of understory plants	0.04	0.02	2.65	**0.02**
Phylogenetic diversity				
Null model				
	Estimate	Std. Error	t-value	p-value

Intercept	2.75	0.35	7.77	<0.001
Model 1				
	Estimate	Std. Error	t-value	p-value
Intercept	2.42	0.45	5.38	<0.001
Number of understory plants	0.01	0.01	1.18	0.26

APPENDIX S11. Bird assemblage in two surveyed forest fragments

Each forest fragment was sampled during 3 consecutive days using 20 mist-nets (Ecotone®; 12 × 2.5 m, 32 mm mesh) placed in the understory following a cross-shaped net-line design. The mist-nets were opened from 05:00 to 17:00 h, except on the third day when the nets were open until 11:00h, and checked every 1 hour. The number of species in the forest fragments varied from 9 to 14 (11.5 ± 3.54) and the number of individuals varied from 23 to 30 (26.5 ± 4.95). Interestingly, we recorded 13 exclusive species (76%) to forest fragments, with high and medium forest dependency. The most abundant species in the forest fragments were *Dendrocincla turdina* (n = 11), *Pseudopipra pipra* (n = 8), *Glyphorynchus spirurus* (n = 8) and *Xiphorhynchus fuscus* (n = 6). Furthermore, we registered similar values of the multiple dimensions of bird diversity between the forest fragments and eucalypt plantations (Table S15), although the species composition strongly differs between these environments.

Table S15. Estimated values of taxonomic, functional and phylogenetic richness and diversity for the sampled forest fragments

Sites	Species Richness	Species Diversity	Functional Richness	Functional Diversity	Phylogenetic Richness	Phylogenetic diversity
Jitai	9.02	7.24	2.48	2.19	3.49	1.22
Taquara	19.55	13.46	3.44	2.86	6.31	0.70

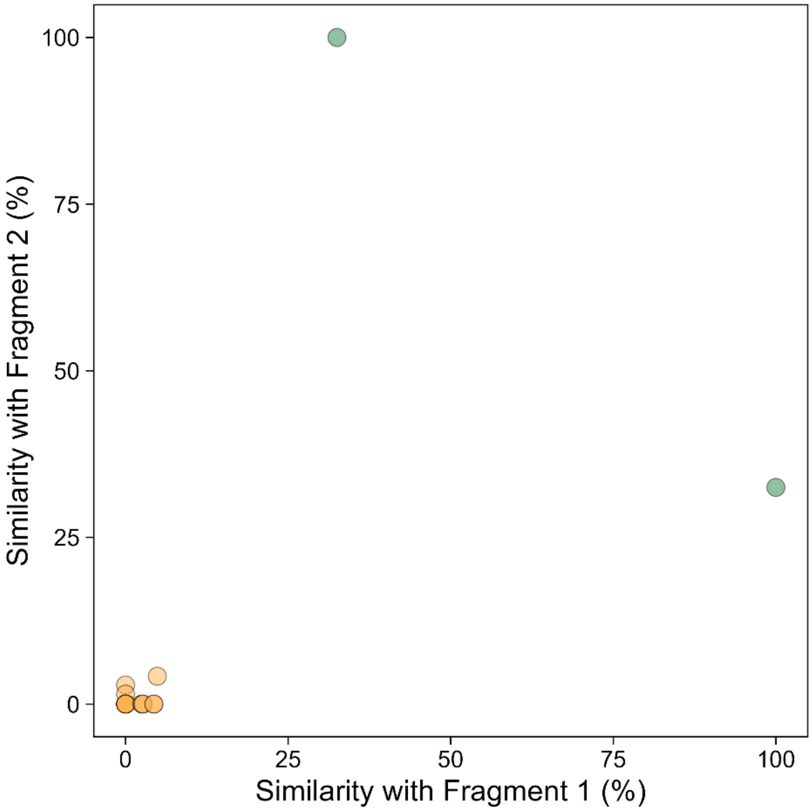

Figure S1. Similarity between each fragment and eucalypt plantations, where the forest fragments are represented in green, and the eucalypt plantations in orange, using Jaccard index.