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Landscape composition is more important than local characteristics for understory birds in cocoa agroforest systems

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Índice

Resumo

Agrofloresta de cacau é uma plantação em que o sub-bosque das florestas nativas é raleado para o plantio de cacaueiros, que são sombreados por árvores de grande porte. Esses sistemas têm grande importância para a conservação da biodiversidade, pois mantêm parte da vegetação nativa. No sul da Bahia, possuímos uma grande região produtora de cacau, com altos níveis de riqueza e endemismo de espécies, dentre elas o grupo de aves que se destaca pela alta diversidade e importância ecológica. Entretanto, a persistência de suas populações depende das características locais e da estrutura da paisagem na qual esse sistema está inserido. Testamos quatro hipóteses: (i) Riqueza e abundância da assembleia de aves de subosque são negativamente influenciadas pela simplificação da estrutura local da agrofloresta e pela diminuição da quantidade de cobertura florestal na paisagem. (ii) Aves dependentes-florestais têm forte resposta negativa à intensidade de manejo local e perda de floresta na paisagem, enquanto as não-dependentes-florestais respondem positivamente a essas perturbações. (iii) Guildas tróficas reagem de maneira diferente a distúrbios locais e de paisagem, sendo os insetívoros os mais sensíveis. (iv) A similaridade na composição de espécies é diferente entre agroflorestas altamente manejadas e inseridas em paisagens severamente desmatadas, compostas especialmente por pastagens e em áreas menos antropizadas. Foram coletados dados de aves de subosque em 18 agroflorestas de cacau em diferentes paisagens e com diferentes intensidades de manejo local. Em cada agrofloresta, foram utilizadas 10 redes de neblina com total de 120m de comprimento, por seis dias. Utilizando modelos lineares generalizados, avaliamos como riqueza, abundância e composição da assembléia completa e dos grupos ecológicos são influenciadas pela composição da paisagem e características locais da agrofloresta. Usamos o critério de informação de Akaike para selecionar os modelos mais plausíveis. Nossos resultados mostraram que a paisagem circundante à agrofloresta é mais importante para a assembléia de aves que a estrutura local dos agrossistemas. Das variáveis de paisagem, o pasto foi o preditor que mais influenciou negativamente a avifauna, refletindo o cenário atual de perda e fragmentação de florestas nativas do sul da Bahia. Das variáveis locais, área basal das árvores sombreadoras, abundância de cacaueiros e fechamento de dossel influenciaram os grupos de não-florestais e insetívoros. É importante a manutenção de árvores grandes para assegurar a viabilidade desses grupos nas agroflorestas de cacau. Os sistemas agroflorestais presentes na região de estudo fornecem habitats complementares para muitas espécies, inclusive para dependentes-florestais, e, portanto, podem atenuar os efeitos da perda de habitat.
Palavras-chave: Agrofloresta de cacau; Avifauna; Fragmentação; Paisagens antropogênicas; Perda de habitat.

Abstract

Cocoa agroforestry is a plantation in which the understory of native forests is thinned for planting cocoa trees, which are shaded by large old-grow trees. These systems are of great importance for the conservation of biodiversity, as they maintain part of the native vegetation. In the south of Bahia, we have a large cocoa-producing region, with high levels of species richness and endemism, among them the group of birds that stands out for their high diversity and ecological importance. However, the persistence of their populations depends on local characteristics and structure of the landscape in which this system is inserted. We tested four hypothesis: (i) Richness and abundance of the assemblage of understory birds are negatively influenced by simplification of local structure of cocoa agroforestry and by decrease in the amount of forest cover in the landscape. (ii) Forest-dependent birds have a strong negative response to intensity of local management and forest loss in landscape, while non- forest-dependent birds respond positively to these disturbances. (iii) Trophic guilds react differently to local and landscape disturbances, with insectivores being the most sensitive. (iv) Similarity in species composition will be different between highly managed agroforestry and inserted in disturbed landscapes composed especially for cattle pastures and in less anthropized areas. Understory bird data were collected from 18 cocoa agroforestry in different landscapes and with different intensities of local management, using mist nets. In each agroforestry, 10 mist nets with a total length of 120m were used for six days. Using generalized linear models, we evaluate how richness, abundance and composition of complete community and ecological groups are influenced by landscape composition and local characteristics of cocoa agroforestry. We use Akaike information criterion to select the most plausible models. Our results showed that landscape surrounding agroforestry is more important for the assemblage of birds than local structure of the agrosystems. Of the landscape variables, pasture was the predictor that most negatively influenced avifauna, reflecting the current scenario of loss and fragmentation of native forests in southern Bahia. From the local variables, basal area of shading trees, abundance of cocoa trees and canopy closure influenced the groups of non-forest and insectivores. Maintaining large trees is important to ensure the viability of these groups in cocoa agroforestry. Cocoa agroforestry systems provide complementary habitats for many species, including forest-dependent birds, and therefore can mitigate the effects of habitat loss to some extent, but cocoa agroforestry is not a substitute for forests.
Keywords: Anthropogenic Landscapes; Avifauna; Cocoa Agroforestry; Fragmentation; Habitat Loss.

Introdução geral

As florestas tropicais abrigam uma das maiores biodiversidades do mundo. Contudo, mais da metade desses ecossistemas já foram perdidos ou alterados (Brandon, 2014). Essa contínua perda de biodiversidade se deve ao aumento na intensidade de perturbações antrópicas (Mouillot et al., 2013; Newbold et al., 2015), a qual impacta diretamente uma série de funções e serviços ecossistêmicos em escala global (Brandon, 2014). As principais ameaças estão relacionadas à superexploração, onde a retirada de espécies supera a capacidade de reestabelecimento das mesmas, e às atividades agrícolas, relacionadas à aquisição de recursos naturais para a humanidade (Maxwell et al., 2016). Aliados a outros processos antrópicos, como a urbanização, essas perturbações determinam os padrões de intensificação do uso do solo, e consequentemente a estrutura da paisagem remanescente (Gardner et al., 2009). Atualmente, a maioria das florestas tropicais se encontra fortemente alterada e ameaçada, inserida em paisagens dominadas por diferentes usos agrícolas (Harvey et al., 2006; Vandermeer and Perfecto, 2007). Assim, um dos maiores desafios é conciliar a crescente demanda de recursos pela população humana com a manutenção da biodiversidade nessas paisagens (Foley et al., 2005; Laurance et al., 2014).

Diante da atual dinâmica de uso da terra, as agroflorestas vêm sendo reconhecidas como um tipo de matriz importante para a gestão dos recursos naturais. Os sistemas agroflorestais são práticas do uso da terra em que cultivos agrícolas são plantados e manejados associados com espécies de árvore ou arbusto nativo (May et al., 2008). Devido à manutenção de parte da estrutura arbórea da floresta nativa, as agroflorestas são uma excelente oportunidade para aliar desenvolvimento agrícola e conservação da biodiversidade em paisagens modificadas pelo homem (Bhagwat et al., 2008). Com a intensa conversão de florestas em áreas com grandes perturbações antrópicas (FAO, 2007), as agroflorestas podem ser as únicas áreas com árvores nativas em paisagens antropizadas (Greenberg et al., 2008). Por apresentarem uma necessidade reduzida de desmatamento, tais cultivos podem proporcionar uma atividade econômica mais sustentável que as monoculturas (Schroth et al., 2000). Nesse contexto, as agroflorestas ganham destaque, especialmente as que mantêm sistemas sombreados pela floresta alterada, cuja complexidade estrutural é maior. Assim, podem ocorrer comunidades mais similares com as florestas adjacentes e manter maior heterogeneidade de habitat na paisagem (Bhagwat et al., 2008).

Dentre as diferentes formas de agroflorestas, os sistemas agroflorestais de cacau (*Theobroma cacao*) constituem um sistema de alta importância ambiental e econômica. Particularmente, essas agroflorestas foram amplamente estabelecidas na Mata Atlântica do sul da Bahia, onde se encontra uma das principais regiões cacaueiras do Brasil (Alger e Caldas, 1994; Dietz et al., 1996). Neste sistema de plantio, há a supressão do sub-bosque da floresta nativa para estabelecer o cultivo sob o sombreamento do dossel (Sambuichi, 2006; Schroth et al., 2011; Rice and Greenberg, 2000; Faria e Baumgarten, 2007). Apesar de sua semelhança com uma floresta original, os sistemas agroflorestais de cacau são sistemas estruturalmente mais simples (Rice e Greenberg, 2000), resultando em uma redução das espécies de plantas (Sambuichi, 2002), especialmente em função da retirada das árvores de sub-bosque. O cultivo do cacau entre as árvores é muito menos impactante para a biodiversidade quando comparado a outros tipos de cultivo que necessitam da retirada de todas as espécies nativas (Setenta et al., 2005), como monoculturas a pleno sol e áreas de pastagens (Schroth et al., 2011).

Assim como outros sistemas agroflorestais (Vandermeer e Perfecto, 2007), as agroflorestas de cacau mantêm a cobertura arbórea com espécies nativas para o sombreamento da plantação (Sambuichi, 2006), retendo parte da estrutura, das condições ambientais e dos recursos presentes nas florestas da região e, consequentemente possibilitam que parte significativa de espécies que compõem as assembléias florestais nativas de vários grupos taxonômicos possa habitá-las (Pardini, 2004; Faria et al., 2006, 2007; Delabie et al., 2007; Harvey e Villalobos, 2007; Van Bael et al., 2007; Cassano et al., 2009). Além disso, essas áreas podem ser utilizadas como corredores e trampolins ecológicos permitindo a algumas espécies se deslocarem entre os fragmentos florestais (Cassano et al., 2009), diminuindo as extinções locais (Pardini et al., 2005). Ainda, como parte dos remanescentes florestais ocorre inserida em uma matriz predominantemente composta por agrofloresta de cacau, estes sistemas agroflorestais reduzem o efeito de borda (Pardini, 2004; Faria et al., 2007; Cassano et al., 2009), um dos principais processos responsáveis pela degradação de remanescentes em paisagens fragmentadas (Murcia, 1995).

É sabido que os sistemas agroflorestais do sul da Bahia mantêm alta riqueza de plantas arbóreas (Sambuichi, 2006; Sambuichi et al., 2012), bem como de muitos grupos animais (Pardini et al., 2009). Raboy et al. (2004) concluíram que as agroflorestas de cacau são importantes locais de alimentação e abrigo para o mico-leão-da-cara-dourada (*Leontopithecus chrysomelas*), espécie endêmica da Mata Atlântica do sul da Bahia. Outra espécie para a qual os sistemas agroflorestais de cacau constituem um habitat-chave é a preguiça-de-coleira (*Bradypus torquatus),* espécie ameaçada de extinção que utiliza tais cultivos como parte significativa de sua área de vida e se alimenta de folhas de árvores de dossel como parte da sua dieta (Cassano et al., 2010). Faria e Baumgarten (2007) relataram uma diversa comunidade de morcegos em sistemas agroflorestais de cacau. Segundo os autores, as agroflorestas apresentam riqueza, diversidade e equitabilidade superiores a fragmentos florestais. Por fim, Delabie et al. (2007) demonstraram a importância das agroflorestas de cacau para a conservação de formigas na região da Mata Atlântica do Brasil. Portanto, embora habitats agroflorestais sejam estruturalmente mais simples do que as florestas nativas (Sambuichi, 2002; Cassano et al., 2009), tais sistemas são importantes na conservação de uma parcela significativa da biodiversidade regional.

Outro grupo que pode ocorrer nas áreas de agrofloresta de cacau e que iremos focar neste estudo são as aves, que, junto aos morcegos, formam os dois grupos de vertebrados que possuem a maior riqueza de espécies nas agroflorestas de cacau do sul da Bahia (Faria et al., 2006, 2007; Pardini et al., 2009). De acordo com Pardini et al. (2009), isto ocorre devido ao acréscimo de espécies generalistas nas agroflorestas de cacau que supera a perda de espécies especialistas florestais. Entrentanto, a manutenção de diversidade de aves em agroflorestas de cacau depende das condições da matriz circundante, sendo que as aves dependentes de floresta são extremamente afetadas de acordo com a quantidade de floresta no entorno (Van Bael et al., 2007; Clough et al., 2009). Além da paisagem, outro fator importante para a manutenção de aves em agroflorestas de cacau é a condição local desse sistema, de modo que a retirada do sub-bosque tem impacto direto maior em alguns grupos específicos, como os insetívoros. Aves insetívoras tendem a ser mais sedentárias e, portanto, mais dependentes do habitat local (Neuschulz et al., 2013). Assim, a simplificação do sub-bosque promove dificuldades para forragear e se esconder de predadores (Castellón e Sieving, 2006; Hansbauer et al., 2010). Segundo resultados de um estudo desenvolvido por Cordeiro (2002) no sul da Bahia, a região de Una é uma das áreas prioritárias para a conservação de espécies endêmicas e ameaçadas de psitacídeos. Os sistemas agroflorestais de cacau também são habitats importantes para a ave conhecida como acrobata (*Acrobatornis fonsecai)*, um gênero da família Furnariidae descoberta nas agroflorestas, e, aparentemente, endêmica do sul da Bahia (Pacheco et al., 1996).

Modificações econômicas ocorridas na região cacaueira do sul da Bahia, resultantes da crise do cacau nos anos 1980 (Alger e Caldas, 1994), causaram a transformação das áreas de agrofloresta de cacau. Essas transforamções se deram principalmente pelo abandono das áreas, pela substituição por pastagens para gado, plantações de seringa (*Hevea brasiliensis*) (Araújo et al., 1998; Cassano et al., 2009; Schroth et al., 2011) e pela redução da densidade de árvores de sombra para adensamento das árvores de cacau para tornar a produção mais rentável. Este raleamento das plantações tem sido resultado da introdução de variedades clonadas, resistentes a pragas e ao sol, o que aumentou a produtividade e, portanto, o retorno financeiro (Schroth et al., 2011). Tais mudanças podem afetar toda biodiversidade que usa ou depende das áreas de agrofloresta de cacau para sobreviver. Desta forma, a conservação da biota nessas paisagens depende da complexidade e composição das áreas cultivadas e, sobretudo, da heterogeneidade estrutural mantida nos sistemas agrícolas.

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Landscape composition is more important than local characteristics for understory birds in cocoa agroforest systems

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Abstract

Cocoa agroforestry is a plantation in which the understory of native forests is thinned for planting cocoa trees, which are shaded by large old-grow trees. These systems are of great importance for the conservation of biodiversity, as they maintain part of the native vegetation. In the south of Bahia, we have a large cocoa-producing region, with high levels of species richness and endemism, among them the group of birds that stands out for their high diversity and ecological importance. However, the persistence of their populations depends on local characteristics and structure of the landscape in which this system is inserted. We tested four hypothesis: (i) Richness and abundance of the assemblage of understory birds are negatively influenced by simplification of local structure of cocoa agroforestry and by decrease in the amount of forest cover in the landscape. (ii) Forest-dependent birds have a strong negative response to intensity of local management and forest loss in landscape, while non- forest-dependent birds respond positively to these disturbances. (iii) Trophic guilds react differently to local and landscape disturbances, with insectivores being the most sensitive. (iv) Similarity in species composition will be different between highly managed agroforestry and inserted in disturbed landscapes composed especially for cattle pastures and in less anthropized areas. Bird data were collected from 18 cocoa agroforestry in different landscapes and with different intensities of local management, using mist nets. In each agroforestry, 10 mist nets with a total length of 120m were used for six days. Using generalized linear models, we evaluate how richness, abundance and composition of complete community and ecological groups are influenced by landscape composition and local characteristics of cocoa agroforestry. We use Akaike information criterion to select the most plausible models. Our results showed that landscape surrounding agroforestry is more important for the assemblage of understory birds than local structure of the agrosystems. Of the landscape variables, pasture was the predictor that most negatively influenced avifauna, reflecting the current scenario of loss and fragmentation of native forests in southern Bahia. From the local variables, basal area of shading trees, abundance of cocoa trees and canopy closure influenced the groups of non-forest and insectivores. Maintaining large trees is important to ensure the viability of these groups in cocoa agroforestry. Cocoa agroforestry systems provide complementary habitats for many species, including forest-dependent birds, and therefore can mitigate the effects of habitat loss to some extent, but cocoa agroforestry is not a substitute for forests.

Keywords: Anthropogenic Landscapes; Avifauna; Cocoa Agroforestry; Fragmentation; Habitat Loss; Thinning.

1. Introduction

Natural environments are being converted by human-modified landscapes (Rios, 1995; Fahrig, 2003; Hoekstra et al., 2005), especially in the tropics, were climatic conditions favor agriculture and livestock (Malhi et al., 2014). Such changes in land use affect the natural ecosystems, mainly due to fragmentation and habitat loss (Fahrig, 2003) that create smaller and more isolated forest remnants (Andrade and Romeiro, 2009). Although habitat loss and fragmentation are different processes and have different adverse effects on species, population persistence in human-modified landscapes is a result of the interaction these factors (Andren, 1994; Fahrig, 2003). Indeed, these processes can form anthropogenic landscapes composed of forest fragments of different sizes and disturbance levels, inserted in the homogeneous matrix dominated especially by agricultural systems (Lord and Norton, 1990; Andren, 1994). This transformation of landscape may cause harsh effects on biodiversity, being associated with population declines and increased risk of extinction of species, mainly because of the changes in the availability and quality of the remaining habitat (Laurance et al., 1997). Therefore, in highly deforested landscapes, the characteristic of the matrix can act as a primordial factor, facilitating the species dispersal among fragments and serving of supplementary habitat in periods of scarce resources (Malhi et al., 2014).

In tropical landscapes, the expansion of cattle pastures and agricultural lands are the most frequent cause of population decline, species extinction and alteration of ecological processes (Fahrig, 2003; Morante-Filho et al., 2016). Additionally, habitat loss and increases in the isolation of natural habitats hamper species biological flows in anthropogenic matrices, which may lead to additional stochastic losses (Saunders et al., 1991; Rosenzweig, 1995). Several studies have documented that habitat generalist species are more able to use anthropized matrices to maintain their fundamental activities, such as foraging and reproduction, than forest specialist species (Daniels et al., 1990; Waltert et al., 2005; Bonier et al., 2007; Weyland et al., 2014; da Silva et al., 2015). Indeed, forest-dweller species present high specialization in the habitat use and low vagility (Petit and Petit, 2003; Clough et al., 2009). Therefore, the type and the quantity of the matrix can affect the dynamics of native species populations in fragmented landscapes (Fischer et al., 2013). In this context, agroforest systems can perform a key role for maintaining biodiversity in these landscapes (Perfecto et al., 1996; Reitsma et al., 2001). These systems provide a more structurally complex habitat compared with land uses devoid of arboreal vegetation (Rice and Greenberg, 2000; Sherry, 2000; Estrada and Coates-Estrada, 2002; Schroth et al., 2004), conferring a greater permeability to local biotas and allowing forest-dependent species can inhabit them.

Therefore, agroforests can be a crucial element of matrix in tropical fragmented landscapes (Perfecto et al., 1996), especially because this system is composed of native species that retain part of the local structure of a forest, although canopy and understory layers dominated by fewer native species (Greenberg et al., 2008). These characteristics allow the maintenance of species diversity (Schroth et al., 2011) and ecological processes, such as carbon storage (Saj et al., 2013; Somarriba et al., 2013; Schroth et al., 2014) in agroforest systems, being hence considered more biodiversity-friendly than conventional farming systems (Perfecto and Vandermeer, 2008). However, management intensification of agroforestry through the removal of large native trees may reduce the capacity of these systems to maintain biodiversity, especially due to the simplification of vegetation structure that decreases the local resources to species (Laps et al., 2003; Steffan-Dewenter et al., 2007). In fact, some studies have documented that local intensification to bust coffee (Vandermeer, 2011) and cocoa (Wade et al., 2010; Ruf, 2011) production has altered vegetation characteristics, especially native tree richness and shade levels, putting at risk the animal species that use these systems. In addition, agroforest systems inserted in highly deforested landscapes are unable to maintain regional species diversity. Thus, species diversity is expected to decrease as the amount of forest cover is reduced in the landscape (Faria et al., 2006, 2007; Schroth and Harvey, 2007; Van Bael et al., 2007; Rizali et al., 2012; Tscharntke et al., 2015).

Although many studies have shown that several bird species can occur in agroforestry (Faria et al., 2006; Van Bael et al., 2008; Cassano et al., 2009; Clough et al., 2009), the persistence of their populations depends on the local characteristics and the landscape composition in which this system are inserted (Harvey and Villalobos, 2007). Bird responses may vary according to specific ecological traits, even among those groups of species, such as forest-dependent birds, that are usually considered to be sensitive to anthropogenic disturbance (Clough et al., 2009). Also, some studies have highlighted the importance of dietary niche and trophic level as factors that influence the sensitivity of species to disturbance (Bregman et al., 2014; Murphy and Romanuk, 2012). For instance, specific trophic guilds, such as understory insectivorous birds (Sekercioglu et al., 2002) and large frugivorous birds (Sekercioglu et al., 2004), are likely to be the first groups to disappear in deforested landscapes. However, the proneness to extinction can diverge even in sensitive species. For example, frugivorous species show a greater capacity for dispersal and a greater ability to use complementary habitats to obtain food (Moran and Catterall, 2014) compared with insectivorous species, which require specific local forest characteristics (Stouffer and Bierregaard, 1995; Develey and Stouffer, 2003; Laurance and Gómez, 2005).

Here, we evaluated the potential contribution of cocoa agroforestry inserted in landscapes with different land use changes for maintained understory bird diversity. Our study was conducted in 18 cocoa agroforest systems located in the southern Bahia state, Brazil, a region dominated by Atlantic Forest (Araújo et al., 1998). Specifically, our data were collected in three distinct regions with different amounts of forest cover, cocoa agroforestry and open areas, especially intended for cattle pasture. We evaluated whether richness, abundance and composition of bird complete community and specific ecological groups are influenced by increased local management of cocoa agroforestry and by land use changes in the surrounding landscape. For this, we tested four hypotheses: (i) Richness and abundance of the complete community would be negatively influenced by simplification of local structure of cocoa agroforestry and decrease of forest cover amount at the landscape. (ii) Forest-dependent birds would show a strong negative response to management intensity and forest loss in the landscape, while non-forest dependent birds would respond positively to these perturbations. (iii) Trophic guilds may respond differently to local and landscape disturbances, with forest insectivores being the most sensitive to such disturbances. Previous studies emphasize that habitat loss can be extremely harmful to forest insectivorous birds due to their low dispersal capacity and habitat specificity (Stouffer and Bierregaard, 1995; Sekercioglu et al., 2002, 2004). Conversely, other bird groups, such as omnivores, can benefit from local modification, mainly in agroforest systems inserted in highly deforested landscapes (García et al., 2007). (iv) We expect that similarity in species composition will be different between highly managed agroforestry and inserted in disturbed landscapes composed especially for cattle pastures. Such changes in species composition can occur in these landscapes due to the drastic reduction in species richness, surviving only species best adapted to disturbed habitats, such as non-forest-dependent birds (Devictor et al., 2007).

2. Methods

2.1 Study area

This study was conducted in southern Bahia state, northeastern Brazil, a region dominated by Brazilian Atlantic forest. However, changes in land use over the last 40 years in this region, induced by anthropic actions, created human-modified landscapes especially composed of a mosaic of secondary forests, cocoa (*Theobroma cacao*), rubber tree (*Hevea brasiliensis*) and eucalyptus plantations (*Eucalyptus sp*.), as well as cattle pastures (Pardini et al., 2009; Morante-Filho et al., 2016). The average annual temperature is 24 °C, and annual rainfall averages 2,000 mm/yr. Although no occur significant seasonal climatic variation, a rainless period may occur from December to March (Thomas et al., 1998).

Using the ArcGIS software and satellite images (QuickBird and WorldView from 2011; RapidEye from 2009 to 2010), we created digital maps with a scale of 1:10 000, which is adequate for identifying land cover patches based on the visual inspection of differences in colour, texture, shape, location and context. The remaining patches were classified according to different forest types following the typologies provided by IBGE (2006). Then, we selected three regions that present different land use patterns, located in the municipalities of Ilhéus, Una and Belmonte (Fig. 1). The Ilhéus region is composed especially by cacao agroforest systems interspersed with forest remnants (high agroforesty cover (HAC) region, hereafter). In the central portion of the study area is located Una region that presents high forest cover amount (high forest cover (HFC) region, hereafter), which corresponds to native old-growth and secondary forest, principally concentrated around the Una Biological Reserve and the Una Wildlife Refuge – two federally protected conservation units that have a total area of 34 804 ha. This region is highly heterogeneous although dominated by cacao agroforest systems and rubber trees plantations. In contrast, Belmonte region is highly deforested, and the matrix is notably more homogeneous, being dominated by cattle pastures, *Eucalyptus sp.* plantations, and a small amount of cacao agroforestry (low forest cover (LFC) region, hereafter) (Fig. 1).

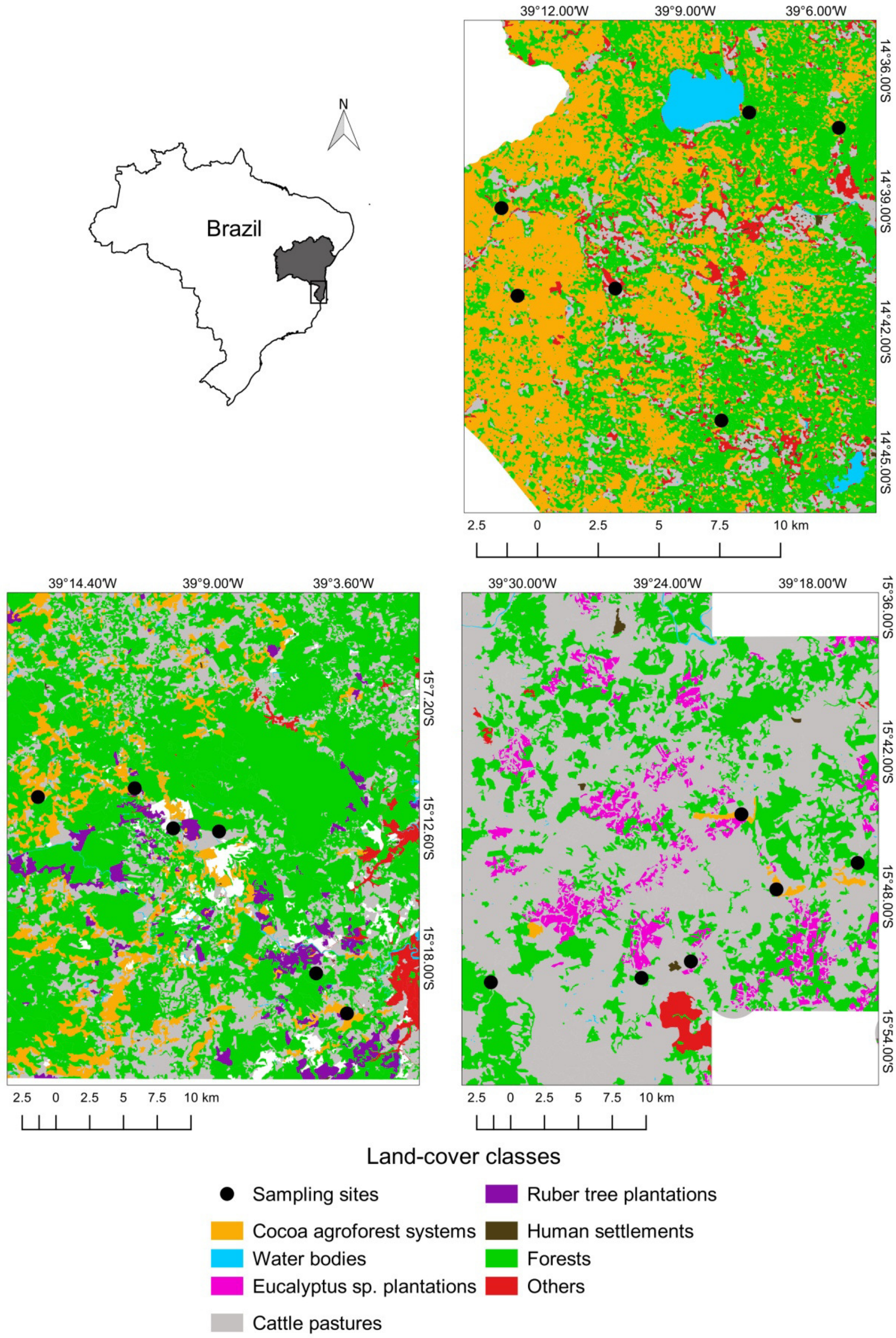

Figure 1 – Study area in southern Bahia, Brazil. In (A), we show HAC region, predominantly formed by cocoa agroforestry. In (B) we show the HFC region, composed especially by forest patches. In (C), we highlight the LFC region, composed of small forest patches surrounding by cattle pasture and eucalyptus plantations. We indicate the studied sites within each region with black dots.

We select 80 cocoa agroforestry, the forest cover was calculated in a landscape with a radius of 1km surrounding each site. Subsequently, 18 agroforest systems were selected randomly with at least 2km distance between them controlling greater gradient in the forest cover at the landscape (from 3.45% to 66.74%). For these sites, land use corrections were made after on-site visits with the help of Google Earth imagery. This adjustment was made to correct the temporal effects of land use and achieve a more realistic and current landscape context.

2.2 Landscape metrics and their scales of effect

We used patch-landscape approach which response variables were evaluated within cocoa agroforest sites, and landscape attributes surrounding sites were measured within a specific radius (buffer) from the centre of each focal site (McGarigal and Cushman, 2002; Fahrig, 2013). We used the software ArcGIS (McGarigal et al., 2012) to estimate the percentage of mature and secondary forest (forest cover, hereafter), cocoa agroforestry and cattle pasture around each site, both metrics related to the landscape composition. These metrics were chosen because can to influence the richness and the composition of bird in human-modified landscapes (Villard et al., 1999; Radford et al., 2005; Reino et al., 2009).

Because the effect of landscape variables on biodiversity depends on the spatial scale at which predictors are measured (i.e. the so-called "scale of effect", Fahrig, 2013; Jackson and Fahrig, 2015), we calculate each landscape metric within 9 different-sized buffers from the center of each site, ranging from 200 to 1000m radius (Appendix A in Supporting Information). We used linear models to identify the landscape size most appropriate to assess the effect of each landscape predictor on richness, abundance and composition of bird (see results in Appendix A).

2.3 Local vegetation structure

We established a 100 x 25m plot in the center each cocoa agroforest system, which local environmental variables were sampled (March to June 2019). Within each plot, we recorded all old-growth trees with a diameter at breast height (DBH) ≥ 10 cm and basal area

(m^2/ha) these trees, and all cacao trees, regardless of height or DBH. We also estimated the percentage of canopy closure inside the plots with five hemispherical photographs (Nikon Coolpix 4300 digital camera equipped with hemispherical fisheye lens [Nikon Corp, Tochigi, Japan]), taken 1.3m from the ground and 20m apart from each other. The photos were taken between cocoa individuals, as our objective was to estimate the shading only of the canopy trees. These data were analyzed with Gap Light Analyzer software (Frazer et al., 1999), and then was considered the mean value of the fives photos as our estimate of canopy closure.

These variables were considered as a proxy of the intensity of local management in each agroforest system. Therefore, we expected that systems highly local management should present low number of old-growth trees and low basal area these trees, high canopy oppeness and a high number of cocoa individuals.

2.4 Bird survey

We sampled understory birds in two field seasons (January to July 2019), using mist nets method (Karr, 1981). In each agroforestry, we used 10 mist nets with a total of 120m long (12m long, 2.5m high, 31mm mesh) for the capture of birds during three consecutive days per season. The mist nets were opened from 06:00 a.m. to 04:00 p.m., covering the period of activity of the diurnal birds, and reviewed every 30 minutes in order to reduce the catch stress (Banks-Leite et al., 2010). We avoided sampling on rainy and windy days because such conditions reduce bird movement and therefore may interfere in the capture success. Each captured bird was temporarily marked on one of the right-wing primary feathers with non-toxic material to avoid recounting the same individual during sampling, and individuals were identified following the scientific nomenclature of the South American Committee for classification (Remsen et al., 2014). In this study, we used a sampling effort of 60 hours per site.

We classified birds either as forest-dependent or non-forest-dependent species (hereafter, forest birds and non-forest birds) based on Stotz et al., 1996 and Bregman et al., 2014 (Appendix B). Forest birds are considered highly specialized on forest resources, and included endemic species of the Atlantic forest and those inhabiting forest interiors. Yet, non-forest birds do not depend on forest resources, and comprised those species reported in a variety of habitat types including secondary forest, forest edges, open vegetation and anthropogenic areas, such as crop plantations. Also, bird species were grouped according to their trophic guild (i.e., insectivores, frugivores, nectivores, omnivores, and granivores) (Appendix B). Trophic categories reflect the main food source of the species, and birds were categorized as omnivores if their dietis composed of different classes of food items. These classifications were based on our prior knowledge about the ecology of the species and information available on the literature (Wilman, 2014). For subsequent analyses, we used the information only of the three most commonly observed guilds - insectivores, frugivores, and omnivores.

2.5 Statistical Analyses

We first performed Spearman's test to assess the correlation between all environmental variables, i.e. local and landscape variables (Appendix C). Based on this result, variables highly correlated ($r \geq 0.70$) were not included in the same model in further analysis. Then, we used generalized linear models to evaluate how richness, abundance and composition of bird complete communities and different ecological groups are influenced by environmental variables. In particular, we performed non-metric multidimensional scaling (NMDS) ordinations based on the Bray-Curtis similarity matrix to obtain species composition (axis 1 from NMDS).

Our models were composed of only three predictor variables that included two environmental descriptors (local and landscapes predictors) and study region as a categorical factor due to contrasting land-use change patterns observed. Finally, we created non-interactive models due to our limited sample size. We also fitted a nullmodel for each response variable to verify if the models were better than would be expected by chance. We subsequently used Akaike Information Criterion corrected for small samples (AICc) and Akaike weights (i.e. the normalized relative likelihood of each model) to select the best model for each response variable. The model presenting the lowest AIC value was considered the most plausible one, and all models presenting a lower than two unities difference in AIC with similar Akaike weights were considered parsimonious. In this case, we selected the simplest model, that is, the model with fewer parameter estimates. Yet, we always selected the null model when it was among the most plausible models, because we believe that there is no simpler model to explain a given pattern than chance.

We also evaluated the fit of the best models using ratio between residual deviation and residual degrees of freedom, where values > 1 indicate overdispersion, i.e. variation in the data is larger than the mean (Zuur et al., 2009). We further fitted the models that presented overdispersion using the Quasi-poisson family. Furthermore, we evaluated the spatial autocorrelation in the residuals of the best models based on the Moran's I autocorrelation coefficient (Appendix E). All statistical analyses and graphs were carried out in R software version 3.5.3 (R Core Team 2019) using the packages lme4 (Bates et al., 2019), MASS (Ripley et al., 2019), mgcv (Wood, 2019), nlme (Pinheiro et al., 2019), bbmle (Bolker, 2017), AICcmodavg (Mazerolle and Linden, 2019) and ape (Paradis et al., 2019).

3. Results

We captured 625 birds in 18 cocoa agroforest systems, belonging to 24 families and 64 bird species. The families Thraupidae (10 species), Trochilidae (9 species) and Tyrannidae (8 species) showed higher species richness and Pipridae (n = 173), Turdidae (n = 113) and Trochilidae (n = 110) presented higher individual numbers. The most abundant specie captured was *Manacus manacus*, with 103 individuals, followed by *Glaucis hirsutus* (n = 88), *Turdus leucomelas* (n = 68) and *Euphonia violacea* (n = 47). We captured 365 forest birds belonging to 34 species and 260 non-forest birds belonging to 30 species. Additionally, in our study insectivorous birds were trophic guild most commonly recorded (22 species, n = 86), followed by omnivores (15 species, n = 174), and frugivores (13 species, n = 243).

Our model selection highlighted several parsimonious models (ΔAICc $\leq$ 2) for explaining the effect of environmental predictors on understory bird communities (Table 1). Additionally, we did not detect spatial autocorrelation in the residual of all best models (Appendix E). We observed that the study region affects some groups of birds, especially the species most adapted to disturbances (Fig. 2). Specifically, our results showed that the most deforested region (LFC region) has lower richness of complete community, richness and abundance of omnivores and non-forest species. Also, we observed a distinct composition of non-forest species in LFC region when compared from the other regions.

Table 1. Parsimonious models (ΔAICc ≤ 2) used to explain the relationship between richness, abundance and composition of bird ecological groups and several environmental variables recorded in 18 agroforest systems located in the Brazilian Atlantic forest.

Bird group	Response variable	Models	ΔAICc	*df*	weight
Complete bird community	Richness	Abundance of cocoa trees + Cattle pasture	0	3	0.21
		Cattle pasture	0.71	2	0.15
		Abundance of trees + Cattle pasture + Region	0.84	5	0.14
		Cattle pasture + Region	1.17	4	0.12
	Abundance	Abundance of cocoa trees + Cattle pasture + Region	0	5	0.98
	Composition	Cocoa agroforestry	0	3	0.14
		Nullmodel	0	2	0.14
		Forest cover	1.24	3	0.07
		Cattle pasture	1.36	3	0.07
Forest-dependent birds	Richness	Cattle pasture	0	2	0.36
		Abundance of cocoa trees + Cattle pasture	1.75	3	0.15
	Abundance	Canopy closure + Forest cover + Region	0	5	0.67
	Composition	Abundance of cocoa trees + Cattle pasture	0	4	0.31
		Cattle pasture	0.26	3	0.27
Non-forest dependent birds	Richness	Cattle pasture	0	2	0.11
		Canopy closure + Cattle pasture	0.4	3	0.09
		Canopy closure	0.51	2	0.09
		Abundance of cocoa trees + Cattle pasture	1.15	3	0.06
		Region	1.33	3	0.06
		Basal area + Cattle pasture	1.41	3	0.06
		Abundance of trees + Cattle pasture	1.77	3	0.05
		Canopy closure + Region	1.92	4	0.04
	Abundance	Abundance of cocoa trees + Cocoa agroforestry + Region	0	5	1
	Composition	Basal area + Cattle pasture	0	4	0.2
		Basal area + Region	0.32	5	0.17
		Region	1.24	4	0.11
Frugivorous birds	Richness	Cattle pasture	0	2	0.18
		Forest cover	1.25	2	0.1
		Cocoa agroforestry	1.41	2	0.09
	Abundance	Abundance of cocoa trees + Forest cover + Region	0	5	0.43
		Abundance of cocoa trees + Forest cover	0.63	3	0.31
	Composition	Cattle pasture	0	3	0.2
		Cocoa tree abundance + Cattle pasture	0.4	4	0.16
		Canopy closure + Cattle pasture	1.02	4	0.12
Insectivorous birds	Richness	Abundance of trees + Cattle pasture	0	3	0.19
		Canopy closure + Cattle pasture	0.07	3	0.19

		Cattle pasture	0.29	2	0.17
		Abundance of cocoa trees + Cattle pasture	1.77	3	0.08
	Abundance	Canopy closure + Cattle pasture	0	3	0.52
	Composition	Cattle pasture	0	3	0.25
		Abundance of cocoa trees + Cattle pasture	1.42	4	0.13
Omnivorous birds	Richness	Region	0	3	0.12
		Cattle pasture	0.2	2	0.11
		Basal area + Cattle pasture	1.15	3	0.07
		Abundance of trees + Region	1.17	4	0.07
		Basal area + Region	1.61	4	0.06
		Canopy closure + Cattle pasture	1.65	3	0.05
		Cattle pasture + Region	1.95	4	0.05
	Abundance	Basal area + Cattle pasture + Region	0	5	0.86
	Composition	Cattle pasture	0	3	0.25
		Abundance of cocoa trees + Cattle pasture	1.42	4	0.13

Our findings highlight that landscape compposition is more important predictor than local variables. Indeed, we found that cocoa agroforestry inserted in more forested landscapes present greater richness and abundance of frugivorous birds. Similar pattern was observed for abundance of forest birds. We also observed that the amount of agroforestry at the landscape has a weak effect on understory birds, being only observed a decrease of the abundance of non-forest species and richness of frugivores in the studied sites. Conversely, the increase of the amount of cattle pasture at the landscape has a negative effect for most bird groups evaluated (Appendix D). For instance, we found a lower richness in all evaluated ecological groups, including the complete community, in agroforestry surrounded by higher pasture amount. In addition, we observed a decrease of similarity of species composition of forest-dependent, frugivores, insectivores, and omnivores in landscapes dominated for cattle pasture. In contrast, our result indicated that the enhance of pasture amount led to increase of similarity of non-forest species composition.

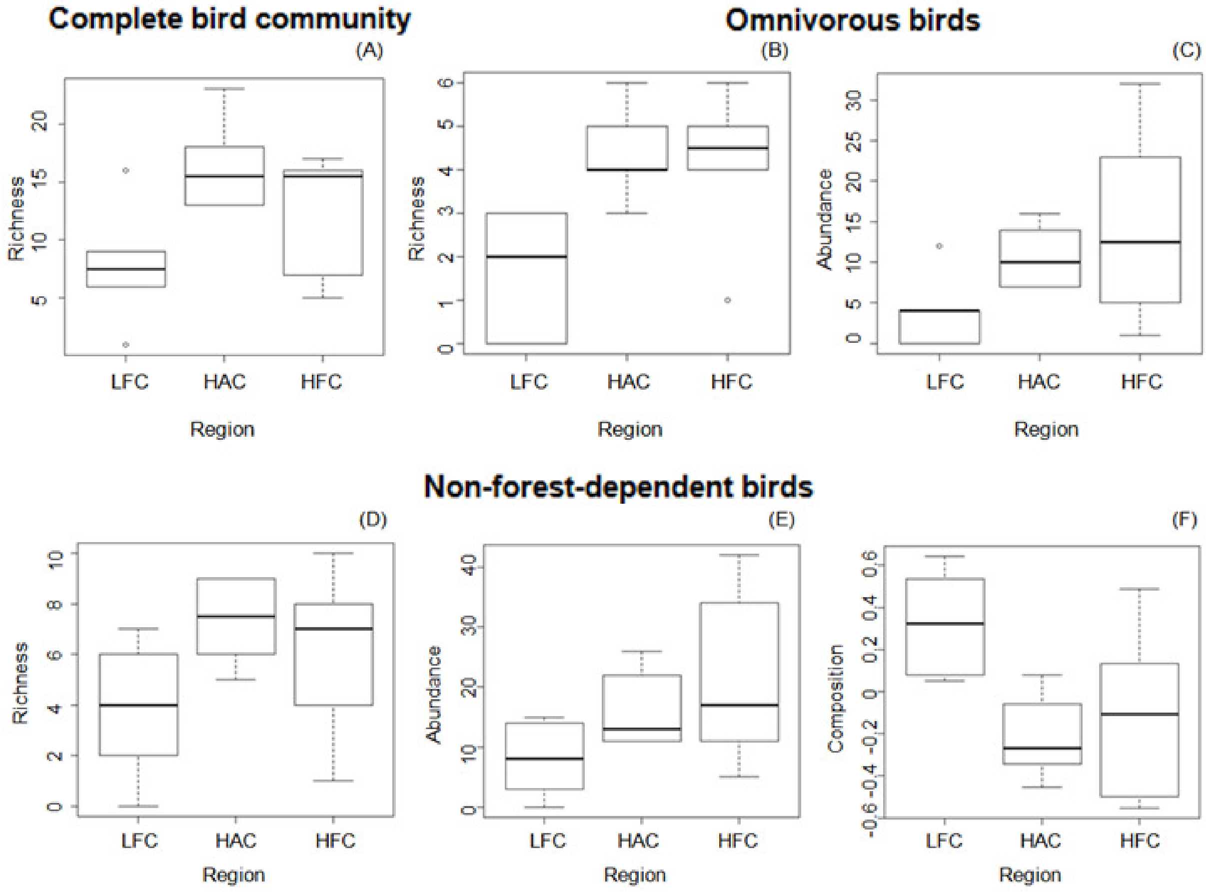

Figure 2 – Richness, abundance and species composition of different bird groups observed in cocoa agroforest sites located in three distinct regions: low forest cover (LFC), high agroforestry cover (HAC) and high forest cover (HFC).

We finally verified that local vegetation has a weak effect on understory bird communities. In fact, our finding demonstrated that the increase of canopy closure drives an increase in the abundance of insectivorous birds in agroforest systems. Similarly, abundance of non-forest species increases in the agroforestry with higher number of cocoa plants. In addition, we observed an increase of similarity of non-forest species composition in agroforest systems composed of larger trees (Appendix D).

4. Discussion

Our results revealed some interesting patterns. First, we observed that landscape predictors had more influence on understory bird commuties than local variables. Second, regarding landscape variables, we observed that pasture had a negative effect on most groups of birds evaluated. Probabily this result is related to the fact that the availability of habitat and food is lower in in pastures, therefore hindering the occurrence of certain bird species. Threfore, cocoa agroforest system can act as a supplementary habitat for several bird species in agricultural landscapes. Indee, cocoa agroforest systems are modified forms of tropical forests that result in changes in microhabitats (Greenberg, 2014). Thus, these systems have higher importance for the conservation of biodiversity when compared to intensive monocultures or pastures (Cassano et al., 2009; Schroth et al., 2011).

Our results demonstrated that the low forest cover region had lower species richness from the complete community. This region is dominated by cattle pasture, and other land use that could be used for birds, such as forests and agroforestry, are located in decreased and isolated patches indicating that even adapted birds to disturbed sites are negatively affect by land use change in this region.. The homogeneous feature of the pastures added to the structural gap and low availability of resources on *Eucalyptus sp.* plantation in LFC region provides more than a low-usable territory (Arnold and Weeldenburg, 1998; Zurita et al., 2006). In addition many forest sites in LFC region are being burned and converted to pasture and *Eucalyptus sp.* plantations (Fundação SOS Mata Atlântica 2017). This disturbed can harsh consequences for bird, especially because the amount of forest cover at the landscape is identified as determining factors for the bird richness shaded plantations, such cocoa agroforestry (Faria et al., 2006; Sambuichi and Haridasan, 2007; Clough et al., 2009; Schroth et al., 2011; Tscharntke et al., 2012).

We also observed that LFC region has a distinct species composition, mainly non-forest species, when compared other ones. The low dispersibility of some birds species is what can explains why the composition of LFC region is different from the other regions. Bird assemblages in disturbed sites can be similar because the species that occur on those sites are a subset of local community, whose most adapted species survives. This variation in the composition is the result of deterministic processes driven by environmental changes and/or stochastic processes of local colonization and extinction (Baselga et al., 2015). Laps et al. (2003) highlighted that the bird composition found in the cocoa agroforestry located souther Bahia could be associated with the large forest remnants present in the landscape. According to the authors, forests would be the source of birds that would use cocoa agroforestry systems as corridors or feeding habitats. Additionally, Ranganathan et al. (2010) pointed out that agricultural areas and nearby forests show greater similarities in the composition of species, and this similarity becomes smaller as the habitats distance themselves. Fahrig and Merriam (1994) highlighted the importance of the agricultural matrix in which the forest remnants are inserted. Therefore, a constant conversation of native forests in agricultural habitats and the high level of forest fragmentation requires that the matrix be able to allow the migration of species between fragments, and not only just able to hold and house these especies (Vandermeer and Perfecto, 2007). A region with a permeable agricultural matrix with a very low percentage of forest cover and highly disturbed forest fragments may not be able to support a high diversity of birds, and, consequently, ecological functions can stop working (Faria et al., 2007).

Our study demonstraded that landscape composition is a more important predictor than local variables. As expected, agroforestry inserted in more forested landscapes has greater richness of frugivores and abundance of frugivores and forest species. Fruit-eating birds depend more on forest cover (Neuschulz et al., 2013), while forest species benefit from matrix permeability (Bisseleua et al., 2009). That diversity will be higher in cocoa agroforestry adjacent to forests (Greenberg, 1998) because some organisms that use theses systems probably need the forest to complete part of their life cycle (Schroth and Harvey, 2007). Clough et al. (2009) also found a lower richness of frugivorous birds when the distance between agroforest and forest increased. Forest patches can act as a source of resource for species that inhabiting agroforests, with species using agroforest systems as part of their home range, but they do not necessarily receive everything they need to maintain their populations (Rice and Greenberg, 2000). The diversity of birds in cocoa agroforestry depends on the percentage of forests present in the landscape. Faria et al. (2006) highlighted that cocoa agroforestry in southern Bahia can perform as shelters for birds and bats communities, but this key characteristic depend to forest cover amount at the landscape. Some species are no able to reach agroforest but those that do, probably adapt well, fix their populations or are able to move between forest and cocoa agroforestry sites (Uezu et al., 2008; Van Bael et al., 2008; Maas et al., 2016).

Also, we observed that the abundance of non-forest species decreases with the increase of cocoa agroforestry in the landscape. Perhaps that specific ecological group needs a more heterogeneous landscape, including forest and open areas (Goulart et al., 2013). Non-forest birds are able to survive in more disturberd landscapes dominated by open areas (Kupsch et al., 2019). In addition, the increase in agroforestry systems also showed a negative relationship with the richness of frugivores, which is probably related to the simplification of the understory of these systems (Bleher and Böhning-Gaese, 2001; Clough et al., 2009; Goulart et al., 2011; Bomfim et al., 2013). The simplification of the understory and the scarcity of food resources cause a reduction in richness of frugivorous birds of this stratum in cocoa agroforestry systems (Laps et al., 2003). The periodic thining of understory in cocoa agroforestry prevents plant recruit, therefore reducing the availability of fruits in this system (Laps et al., 2003).

It is known that pastures have a harsh effect on several ecological groups (Kohler et al., 2006). In fact, in our study the bird richness of the all groups decreased with the increase of pasture amount at the landscape. This result demonstrates that pastures can hamper bird dispersion and hence decrease the number of species capable of colonizing cocoa agroforestry (Harvey et al., 2006). In addition, pasture has very limiting conditions and resources for birds, such as very high temperatures, lack of hiding places, difficulty in finding food and sexual partners (Wegner and Merriam, 1979; Sieving et al., 1996; Kohler et al., 2006; Munkhtsetseg et al., 2007; Ibarra-Macias et al., 2011). All of these characteristics generate very adverse conditions, allowing that only a subset of species to be able to use or transverse pasture areas (Pizo and dos Santos, 2011; Carrara et al., 2015; Carlo and Morales, 2016). Perhaps for this reason, we also observed decrease in the similarity of the composition of forest species, frugivores, insectivores and omnivores in sites inserted in landscapes with high pasture amount. These groups have biological limitations to move across this matrix, reducing the possibility to reach cocoa agroforest (Sieving et al., 1996; Pizo and dos Santos, 2011).

In contrast, we observed high similarity of of non-forest species composition in sites located in landscapes dominated by pastures. These birds area biologically able to cross and move through cattle pastures (Sieving et al., 1996; Pizo and dos Santos, 2011). In addition to the difficulties in dispersing pasture matrix, cattle have a direct impact on plant communities. Stomping and grazing compact the soil, which may prevent the vegetation from maintaining its integrity (Heady et al., 1975; Davies et al., 2009), which reduces micro-habitats usable by several species of birds. The compaction of the soil by livestock makes the habitat unsuitable for some animals, with harmful effects for small insectivorous animals affecting the use of these areas as areas for foraging (Sanderson, 1989). Like many pesticides, the use of certain chemical compounds in the treatment of bovine parasites and diseases also directly affects microorganisms and microfauna associated with the decomposition of organic matter (Kolpin et al., 2002; Boxall, 2008), which can lead to a cascade effect in the entire associated ecosystem.

Although local variables have not influenced the most bird ecological groups, we have some interesting results. The increase in canopy closure generates an increase in the abundance of insectivorous birds in agroforestry systems, which may be related to the fact that insectivorous birds tend to be more sedentary and thus more dependent on the local habitat (Neuschulz et al., 2013). Indeed a closed canopy cover would be structurally similar to a forest, having more resources for this group of birds, mainly for hiding since they are birds that are not very dispersed and foraging (Castellón and Sieving, 2006; Hansbauer et al., 2010). Van Bael et al. (2007) in a study of bird diversity in cocoa plantations in Panama found low diversity of understory insectivorous species. Also these authors observed that the more intense the plantation management, the lesser the diversity of birds. For non-forest birds, abundance increases in cocoa agroforestry composed by more cocoa trees. Also, we observed that non-forest bird composition is more similar in cocoa agroforest compound by larger trees. These results can demonstrated that local characteristics are important for non-forest species, which can benefit in more disturbed or simplified sites, such as cocoa agroforesty. In fact, Tejeda-Cruz and Sutherland (2004) highlighted that the replacement of native understory with trees of economic interest block many bird species from using this stratum for foraging. Thus, non-forest species, which benefit from non-forest habitat structures (Kupsch et al., 2019) are able to use these environments more easily than other groups, such as forest-dependent birds.

5. Conclusions

Our results partially corroborate our hypothesis, since we expected that the intensification of local management of cocoa agroforestry and the loss of forests in the landscape would express strongly in relation to the loss of birds. Our study showed that landscape variables are more important predictors of understory bird assemblages than the local variables in the cocoa agroforestry, where the cattle pastures mainly contributed to bird species loss. The scenario of habitat loss and fragmentation in southern Bahia, concomitant with the increase of pasture amount, has a harshy negative effect on the group of birds. Currently, the remaining forest cover of the Brazilian Atlantic Forest is only 11% of its original extension (Ribeiro et al., 2009). Yet, the best preserved areas are located in the southern states of Serra do Mar, which has 36.5% of its original vegetation, and the remnants that still exist in the State of Bahia (17.7%) (Ribeiro et al., 2009). Our work has shown that cocoa agroforestry is able to retain a considerable part of avifauna, especially when these systems have nearby forests and when they are less managed. Therefore, in a scenario of increasing fragmentation and loss of habitat of the Atlantic Forest, such agroforestry may represent an additional habitat for birds in the south of Bahia, and thus contribute to their conservation. The conversion of areas of native vegetation to agricultural production is a topic widely discussed by scientists and rural producers due to the limited availability of more areas for agricultural expansion. Therefore, reconciling productivity and environmental conservation is a challenge that must be achieved to i) maintain production without causing major impacts on native forests, ii) prevent new natural areas from becoming agricultural areas and iii) use these agroforestry as allies in the conservation of species.

Although local conditions are not the most significant, the vegetation structure is very important. As our results, some ecological groups such as non-forest and insectivores are affected by local agroforesty conditions. In general, it is important to maintain these areas with large trees to ensure the viability of these groups in the cocoa agroforestry. However, the decree No. 15,180 of June 2, 2014 provides for the maintenance of only 40 individuals of species of native trees per hectare, enabling the removal of native species for the planting of cocoa (thinning). Therefore, simplifying the vegetation structure of cocoa agroforestry can decrease- the amount of resources and, consequently, prevents the occurrence of species (Van Bael et al. 2007). The agroforestry systems present in the study region provide complementary habitats for many species, including forest-dependent birds, and therefore can mitigate the effects of habitat loss to some extent, but cocoa agroforestry is not a substitute for forests.

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Appendices

Appendix A. The scale of landscape effects on response variables

Because the effect of landscape variables on biodiversity depends on the spatial scale at which predictors are measure (i.e. the so-called "scale of landscape effects"; sensu Jackson and Fahrig, 2012; Fahrig, 2013), we estimated the amount of cocoa agroforestry, forest cover and cattle pastures within nine different-sized buffers (i.e., landscapes), ranging from 200 to 1000m radius. We do not use the 100m scale due to the small variation in the amount of forest cover, cocoa agroforestry and cattle pasture measured in the landscapes. Also, we decided not to use buffers larger than 1000m to avoid landscape overlap, and hence to avoid potential problems of independence among landscapes (see Eigenbrod et al., 2011). Thus, we obtained landscapes of 200m (12.6 ha), 300m (28.3 ha), 400m (50.2 ha), 500m (78.5 ha), 600m (113 ha), 700m (153.9 ha), 800m (201 ha), 900m (254.3 ha) and 1,000m radius (314 ha). We tested the effect of the landscape metrics scale on the response variables using the *multifit* function proposed by Huais (2018) for multi-scale analyzes. We used linear models to identify the landscape size most appropriate to analyze the effect of each landscape variable on response variables. Following Fahrig (2013) and Jackson and Fahrig (2015), the scale of effect of each landscape predictor was simply defined as the landscape size within which the landscape-response relationship was strongest (i.e., with highest R^2 and lowest P-value). Our results, presented in table A.1, highlight that the best-scale of effect of each landscape predictor varies according to the response variable evaluated.

Table A.1 Results of association between landscape size (scale) and the strength of the relationship (Pseudo-R^2 and P-value) between landscape composition variables (cocoa agroforestry, forest cover and cattle pastures) and several response variables. The landscape size used in this study for each landscape metric is indicated in bold.

Response variable	Landscape metric	Scale	R^2	P-value
Richness of complete bird community	Cocoa agroforestry	200	-0.01	0.38
Richness of complete bird community	**Cocoa agroforestry**	**300**	**0.06**	**0.17**
Richness of complete bird community	Cocoa agroforestry	400	0.02	0.26
Richness of complete bird community	Cocoa agroforestry	500	-0.01	0.36
Richness of complete bird community	Cocoa agroforestry	600	-0.02	0.45
Richness of complete bird community	Cocoa agroforestry	700	-0.04	0.57
Richness of complete bird community	Cocoa agroforestry	800	-0.05	0.72
Richness of complete bird community	Cocoa agroforestry	900	-0.06	0.88
Richness of complete bird community	Cocoa agroforestry	1000	-0.06	0.95
Richness of complete bird community	Forest cover	200	0.16	0.06
Richness of complete bird community	**Forest cover**	**300**	**0.18**	**0.04**
Richness of complete bird community	Forest cover	400	0.17	0.05
Richness of complete bird community	Forest cover	500	0.14	0.07
Richness of complete bird community	Forest cover	600	0.14	0.07
Richness of complete bird community	Forest cover	700	0.14	0.07
Richness of complete bird community	Forest cover	800	0.13	0.08
Richness of complete bird community	Forest cover	900	0.13	0.08
Richness of complete bird community	Forest cover	1000	0.12	0.09
Richness of complete bird community	**Cattle pasture**	**200**	**0.30**	**0.01**
Richness of complete bird community	Cattle pasture	300	0.27	0.02
Richness of complete bird community	Cattle pasture	400	0.25	0.02
Richness of complete bird community	Cattle pasture	500	0.22	0.03
Richness of complete bird community	Cattle pasture	600	0.22	0.03
Richness of complete bird community	Cattle pasture	700	0.23	0.03
Richness of complete bird community	Cattle pasture	800	0.24	0.02
Richness of complete bird community	Cattle pasture	900	0.26	0.02
Richness of complete bird community	Cattle pasture	1000	0.29	0.01
Abundance of complete bird community	Cocoa agroforestry	200	0.09	0.13
Abundance of complete bird community	**Cocoa agroforestry**	**300**	**0.23**	**0.03**
Abundance of complete bird community	Cocoa agroforestry	400	0.19	0.04
Abundance of complete bird community	Cocoa agroforestry	500	0.16	0.06
Abundance of complete bird community	Cocoa agroforestry	600	0.13	0.08
Abundance of complete bird community	Cocoa agroforestry	700	0.08	0.13
Abundance of complete bird community	Cocoa agroforestry	800	0.05	0.19
Abundance of complete bird community	Cocoa agroforestry	900	0.02	0.28
Abundance of complete bird community	Cocoa agroforestry	1000	-0.01	0.39
Abundance of complete bird community	Forest cover	200	0.33	0.01
Abundance of complete bird community	**Forest cover**	**300**	**0.38**	**0.004**

Abundance of complete bird community	Forest cover	400	0.36	0.01
Abundance of complete bird community	Forest cover	500	0.35	0.01
Abundance of complete bird community	Forest cover	600	0.36	0.01
Abundance of complete bird community	Forest cover	700	0.35	0.01
Abundance of complete bird community	Forest cover	800	0.34	0.01
Abundance of complete bird community	Forest cover	900	0.32	0.01
Abundance of complete bird community	Forest cover	1000	0.30	0.01
Abundance of complete bird community	**Cattle pasture**	**200**	**0.31**	**0.01**
Abundance of complete bird community	Cattle pasture	300	0.29	0.01
Abundance of complete bird community	Cattle pasture	400	0.23	0.03
Abundance of complete bird community	Cattle pasture	500	0.20	0.04
Abundance of complete bird community	Cattle pasture	600	0.20	0.04
Abundance of complete bird community	Cattle pasture	700	0.20	0.03
Abundance of complete bird community	Cattle pasture	800	0.21	0.03
Abundance of complete bird community	Cattle pasture	900	0.23	0.03
Abundance of complete bird community	Cattle pasture	1000	0.26	0.02
Composition of complete bird community	**Cocoa agroforestry**	**200**	**0.09**	**0.12**
Composition of complete bird community	Cocoa agroforestry	300	0.03	0.23
Composition of complete bird community	Cocoa agroforestry	400	-0.03	0.52
Composition of complete bird community	Cocoa agroforestry	500	-0.06	0.76
Composition of complete bird community	Cocoa agroforestry	600	-0.06	0.90
Composition of complete bird community	Cocoa agroforestry	700	-0.06	0.99
Composition of complete bird community	Cocoa agroforestry	800	-0.06	0.93
Composition of complete bird community	Cocoa agroforestry	900	-0.06	0.90
Composition of complete bird community	Cocoa agroforestry	1000	-0.06	0.93
Composition of complete bird community	Forest cover	200	0.00	0.32
Composition of complete bird community	**Forest cover**	**300**	**0.03**	**0.25**
Composition of complete bird community	Forest cover	400	0.02	0.26
Composition of complete bird community	Forest cover	500	0.01	0.31
Composition of complete bird community	Forest cover	600	0.00	0.33
Composition of complete bird community	Forest cover	700	0.01	0.31
Composition of complete bird community	Forest cover	800	0.00	0.32
Composition of complete bird community	Forest cover	900	0.01	0.31
Composition of complete bird community	Forest cover	1000	0.01	0.28
Composition of complete bird community	Cattle pasture	200	-0.03	0.46
Composition of complete bird community	Cattle pasture	300	-0.06	0.89
Composition of complete bird community	Cattle pasture	400	-0.04	0.59
Composition of complete bird community	Cattle pasture	500	-0.02	0.43
Composition of complete bird community	Cattle pasture	600	-0.01	0.37
Composition of complete bird community	Cattle pasture	700	0.01	0.31
Composition of complete bird community	Cattle pasture	800	0.02	0.27

Composition of complete bird community	**Cattle pasture**	**900**	**0.02**	**0.26**
Composition of complete bird community	Cattle pasture	1000	0.02	0.28
Richness of forest-dependent birds	Cocoa agroforestry	200	0.04	0.22
Richness of forest-dependent birds	**Cocoa agroforestry**	**300**	**0.15**	**0.06**
Richness of forest-dependent birds	Cocoa agroforestry	400	0.12	0.09
Richness of forest-dependent birds	Cocoa agroforestry	500	0.08	0.13
Richness of forest-dependent birds	Cocoa agroforestry	600	0.05	0.19
Richness of forest-dependent birds	Cocoa agroforestry	700	0.03	0.25
Richness of forest-dependent birds	Cocoa agroforestry	800	0.00	0.33
Richness of forest-dependent birds	Cocoa agroforestry	900	-0.02	0.44
Richness of forest-dependent birds	Cocoa agroforestry	1000	-0.04	0.55
Richness of forest-dependent birds	Forest cover	200	0.28	0.02
Richness of forest-dependent birds	**Forest cover**	**300**	**0.32**	**0.01**
Richness of forest-dependent birds	Forest cover	400	0.31	0.01
Richness of forest-dependent birds	Forest cover	500	0.29	0.01
Richness of forest-dependent birds	Forest cover	600	0.29	0.01
Richness of forest-dependent birds	Forest cover	700	0.29	0.01
Richness of forest-dependent birds	Forest cover	800	0.27	0.02
Richness of forest-dependent birds	Forest cover	900	0.26	0.02
Richness of forest-dependent birds	Forest cover	1000	0.25	0.02
Richness of forest-dependent birds	**Cattle pasture**	**200**	**0.34**	**0.01**
Richness of forest-dependent birds	Cattle pasture	300	0.30	0.01
Richness of forest-dependent birds	Cattle pasture	400	0.23	0.03
Richness of forest-dependent birds	Cattle pasture	500	0.20	0.04
Richness of forest-dependent birds	Cattle pasture	600	0.20	0.04
Richness of forest-dependent birds	Cattle pasture	700	0.20	0.04
Richness of forest-dependent birds	Cattle pasture	800	0.20	0.04
Richness of forest-dependent birds	Cattle pasture	900	0.21	0.03
Richness of forest-dependent birds	Cattle pasture	1000	0.23	0.03
Abundance of forest-dependent birds	Cocoa agroforestry	200	0.22	0.03
Abundance of forest-dependent birds	**Cocoa agroforestry**	**300**	**0.38**	**0.004**
Abundance of forest-dependent birds	Cocoa agroforestry	400	0.26	0.02
Abundance of forest-dependent birds	Cocoa agroforestry	500	0.15	0.06
Abundance of forest-dependent birds	Cocoa agroforestry	600	0.10	0.11
Abundance of forest-dependent birds	Cocoa agroforestry	700	0.05	0.19
Abundance of forest-dependent birds	Cocoa agroforestry	800	0.01	0.29
Abundance of forest-dependent birds	Cocoa agroforestry	900	-0.01	0.39
Abundance of forest-dependent birds	Cocoa agroforestry	1000	-0.03	0.51
Abundance of forest-dependent birds	Forest cover	200	0.56	0.0002
Abundance of forest-dependent birds	**Forest cover**	**300**	**0.65**	**0.00003**
Abundance of forest-dependent birds	Forest cover	400	0.61	0.0001

Abundance of forest-dependent birds	Forest cover	500	0.54	0.0003
Abundance of forest-dependent birds	Forest cover	600	0.51	0.001
Abundance of forest-dependent birds	Forest cover	700	0.48	0.001
Abundance of forest-dependent birds	Forest cover	800	0.44	0.002
Abundance of forest-dependent birds	Forest cover	900	0.40	0.003
Abundance of forest-dependent birds	Forest cover	1000	0.37	0.004
Abundance of forest-dependent birds	Cattle pasture	200	0.33	0.01
Abundance of forest-dependent birds	**Cattle pasture**	**300**	**0.35**	**0.01**
Abundance of forest-dependent birds	Cattle pasture	400	0.30	0.01
Abundance of forest-dependent birds	Cattle pasture	500	0.29	0.01
Abundance of forest-dependent birds	Cattle pasture	600	0.27	0.02
Abundance of forest-dependent birds	Cattle pasture	700	0.26	0.02
Abundance of forest-dependent birds	Cattle pasture	800	0.24	0.02
Abundance of forest-dependent birds	Cattle pasture	900	0.25	0.02
Abundance of forest-dependent birds	Cattle pasture	1000	0.26	0.02
Composition of forest-dependent birds	Cocoa agroforestry	200	-0.06	0.89
Composition of forest-dependent birds	Cocoa agroforestry	300	-0.05	0.72
Composition of forest-dependent birds	Cocoa agroforestry	400	-0.06	0.88
Composition of forest-dependent birds	Cocoa agroforestry	500	-0.05	0.73
Composition of forest-dependent birds	Cocoa agroforestry	600	-0.05	0.68
Composition of forest-dependent birds	Cocoa agroforestry	700	-0.04	0.59
Composition of forest-dependent birds	Cocoa agroforestry	800	-0.03	0.48
Composition of forest-dependent birds	Cocoa agroforestry	900	-0.01	0.40
Composition of forest-dependent birds	**Cocoa agroforestry**	**1000**	**0.004**	**0.32**
Composition of forest-dependent birds	Forest cover	200	0.17	0.05
Composition of forest-dependent birds	**Forest cover**	**300**	**0.24**	**0.02**
Composition of forest-dependent birds	Forest cover	400	0.19	0.04
Composition of forest-dependent birds	Forest cover	500	0.15	0.07
Composition of forest-dependent birds	Forest cover	600	0.12	0.09
Composition of forest-dependent birds	Forest cover	700	0.12	0.09
Composition of forest-dependent birds	Forest cover	800	0.11	0.10
Composition of forest-dependent birds	Forest cover	900	0.11	0.10
Composition of forest-dependent birds	Forest cover	1000	0.10	0.11
Composition of forest-dependent birds	**Cattle pasture**	**200**	**0.56**	**0.0002**
Composition of forest-dependent birds	Cattle pasture	300	0.49	0.001
Composition of forest-dependent birds	Cattle pasture	400	0.40	0.003
Composition of forest-dependent birds	Cattle pasture	500	0.32	0.01
Composition of forest-dependent birds	Cattle pasture	600	0.25	0.02
Composition of forest-dependent birds	Cattle pasture	700	0.22	0.03
Composition of forest-dependent birds	Cattle pasture	800	0.20	0.04
Composition of forest-dependent birds	Cattle pasture	900	0.21	0.03

Composition of forest-dependent birds	Cattle pasture	1000	0.23	0.03
Richness of non-forest-dependent birds	Cocoa agroforestry	200	-0.06	0.86
Richness of non-forest-dependent birds	Cocoa agroforestry	300	-0.05	0.71
Richness of non-forest-dependent birds	Cocoa agroforestry	400	-0.06	0.92
Richness of non-forest-dependent birds	Cocoa agroforestry	500	-0.06	0.93
Richness of non-forest-dependent birds	Cocoa agroforestry	600	-0.06	0.86
Richness of non-forest-dependent birds	Cocoa agroforestry	700	-0.05	0.73
Richness of non-forest-dependent birds	Cocoa agroforestry	800	-0.04	0.59
Richness of non-forest-dependent birds	Cocoa agroforestry	900	-0.03	0.48
Richness of non-forest-dependent birds	**Cocoa agroforestry**	**1000**	**-0.004**	**0.35**
Richness of non-forest-dependent birds	**Forest cover**	**200**	**-0.03**	**0.47**
Richness of non-forest-dependent birds	Forest cover	300	-0.03	0.48
Richness of non-forest-dependent birds	Forest cover	400	-0.04	0.53
Richness of non-forest-dependent birds	Forest cover	500	-0.05	0.65
Richness of non-forest-dependent birds	Forest cover	600	-0.05	0.66
Richness of non-forest-dependent birds	Forest cover	700	-0.05	0.66
Richness of non-forest-dependent birds	Forest cover	800	-0.05	0.64
Richness of non-forest-dependent birds	Forest cover	900	-0.05	0.62
Richness of non-forest-dependent birds	Forest cover	1000	-0.05	0.62
Richness of non-forest-dependent birds	Cattle pasture	200	0.07	0.14
Richness of non-forest-dependent birds	Cattle pasture	300	0.08	0.14
Richness of non-forest-dependent birds	Cattle pasture	400	0.11	0.10
Richness of non-forest-dependent birds	Cattle pasture	500	0.09	0.13
Richness of non-forest-dependent birds	Cattle pasture	600	0.09	0.12
Richness of non-forest-dependent birds	Cattle pasture	700	0.11	0.10
Richness of non-forest-dependent birds	Cattle pasture	800	0.12	0.09
Richness of non-forest-dependent birds	Cattle pasture	900	0.14	0.07
Richness of non-forest-dependent birds	**Cattle pasture**	**1000**	**0.17**	**0.05**
Abundance of non-forest-dependent birds	Cocoa agroforestry	200	-0.06	0.87
Abundance of non-forest-dependent birds	Cocoa agroforestry	300	-0.06	0.88
Abundance of non-forest-dependent birds	Cocoa agroforestry	400	-0.05	0.63
Abundance of non-forest-dependent birds	Cocoa agroforestry	500	-0.02	0.43
Abundance of non-forest-dependent birds	**Cocoa agroforestry**	**600**	**-0.01**	**0.35**
Abundance of non-forest-dependent birds	Cocoa agroforestry	700	-0.01	0.36
Abundance of non-forest-dependent birds	Cocoa agroforestry	800	-0.01	0.39
Abundance of non-forest-dependent birds	Cocoa agroforestry	900	-0.03	0.46
Abundance of non-forest-dependent birds	Cocoa agroforestry	1000	-0.04	0.54
Abundance of non-forest-dependent birds	Forest cover	200	-0.06	0.87
Abundance of non-forest-dependent birds	Forest cover	300	-0.06	0.88
Abundance of non-forest-dependent birds	Forest cover	400	-0.06	0.78
Abundance of non-forest-dependent birds	Forest cover	500	-0.05	0.62

Abundance of non-forest-dependent birds	Forest cover	600	-0.03	0.48
Abundance of non-forest-dependent birds	Forest cover	700	-0.02	0.40
Abundance of non-forest-dependent birds	Forest cover	800	0.00	0.34
Abundance of non-forest-dependent birds	Forest cover	900	0.01	0.31
Abundance of non-forest-dependent birds	**Forest cover**	**1000**	**0.01**	**0.29**
Abundance of non-forest-dependent birds	Cattle pasture	200	0.00	0.33
Abundance of non-forest-dependent birds	Cattle pasture	300	0.00	0.35
Abundance of non-forest-dependent birds	Cattle pasture	400	-0.02	0.40
Abundance of non-forest-dependent birds	Cattle pasture	500	-0.03	0.47
Abundance of non-forest-dependent birds	Cattle pasture	600	-0.02	0.41
Abundance of non-forest-dependent birds	Cattle pasture	700	0.00	0.35
Abundance of non-forest-dependent birds	Cattle pasture	800	0.01	0.28
Abundance of non-forest-dependent birds	Cattle pasture	900	0.04	0.22
Abundance of non-forest-dependent birds	**Cattle pasture**	**1000**	**0.07**	**0.16**
Composition of non-forest-dependent-birds	Cocoa agroforestry	200	0.03	0.25
Composition of non-forest-dependent-birds	**Cocoa agroforestry**	**300**	**0.05**	**0.19**
Composition of non-forest-dependent-birds	Cocoa agroforestry	400	0.03	0.23
Composition of non-forest-dependent-birds	Cocoa agroforestry	500	0.02	0.28
Composition of non-forest-dependent-birds	Cocoa agroforestry	600	0.00	0.33
Composition of non-forest-dependent-birds	Cocoa agroforestry	700	-0.01	0.39
Composition of non-forest-dependent-birds	Cocoa agroforestry	800	-0.02	0.45
Composition of non-forest-dependent-birds	Cocoa agroforestry	900	-0.04	0.53
Composition of non-forest-dependent-birds	Cocoa agroforestry	1000	-0.05	0.64
Composition of non-forest-dependent-birds	**Forest cover**	**200**	**0.18**	**0.05**
Composition of non-forest-dependent-birds	Forest cover	300	0.13	0.08
Composition of non-forest-dependent-birds	Forest cover	400	0.12	0.09
Composition of non-forest-dependent-birds	Forest cover	500	0.12	0.09
Composition of non-forest-dependent-birds	Forest cover	600	0.13	0.08
Composition of non-forest-dependent-birds	Forest cover	700	0.14	0.07
Composition of non-forest-dependent-birds	Forest cover	800	0.15	0.06
Composition of non-forest-dependent-birds	Forest cover	900	0.14	0.07
Composition of non-forest-dependent-birds	Forest cover	1000	0.12	0.08
Composition of non-forest-dependent-birds	Cattle pasture	200	0.25	0.02
Composition of non-forest-dependent-birds	**Cattle pasture**	**300**	**0.25**	**0.01**
Composition of non-forest-dependent-birds	Cattle pasture	400	0.19	0.04
Composition of non-forest-dependent-birds	Cattle pasture	500	0.15	0.06
Composition of non-forest-dependent-birds	Cattle pasture	600	0.15	0.06
Composition of non-forest-dependent-birds	Cattle pasture	700	0.17	0.05
Composition of non-forest-dependent-birds	Cattle pasture	800	0.18	0.05
Composition of non-forest-dependent-birds	Cattle pasture	900	0.20	0.04
Composition of non-forest-dependent-birds	Cattle pasture	1000	0.22	0.03

Richness of frugivorous birds	Cocoa agroforestry	200	-0.01	0.37
Richness of frugivorous birds	Cocoa agroforestry	300	0.17	0.05
Richness of frugivorous birds	Cocoa agroforestry	400	0.27	0.02
Richness of frugivorous birds	**Cocoa agroforestry**	**500**	**0.28**	**0.01**
Richness of frugivorous birds	Cocoa agroforestry	600	0.26	0.02
Richness of frugivorous birds	Cocoa agroforestry	700	0.22	0.03
Richness of frugivorous birds	Cocoa agroforestry	800	0.17	0.05
Richness of frugivorous birds	Cocoa agroforestry	900	0.12	0.09
Richness of frugivorous birds	Cocoa agroforestry	1000	0.08	0.14
Richness of frugivorous birds	Forest cover	200	0.17	0.17
Richness of frugivorous birds	Forest cover	300	0.23	0.03
Richness of frugivorous birds	Forest cover	400	0.28	0.01
Richness of frugivorous birds	Forest cover	500	0.29	0.01
Richness of frugivorous birds	**Forest cover**	**600**	**0.32**	**0.01**
Richness of frugivorous birds	Forest cover	700	0.31	0.01
Richness of frugivorous birds	Forest cover	800	0.30	0.01
Richness of frugivorous birds	Forest cover	900	0.29	0.01
Richness of frugivorous birds	Forest cover	1000	0.28	0.01
Richness of frugivorous birds	**Cattle pasture**	**200**	**0.31**	**0.01**
Richness of frugivorous birds	Cattle pasture	300	0.21	0.03
Richness of frugivorous birds	Cattle pasture	400	0.14	0.07
Richness of frugivorous birds	Cattle pasture	500	0.10	0.11
Richness of frugivorous birds	Cattle pasture	600	0.09	0.13
Richness of frugivorous birds	Cattle pasture	700	0.09	0.12
Richness of frugivorous birds	Cattle pasture	800	0.10	0.11
Richness of frugivorous birds	Cattle pasture	900	0.12	0.09
Richness of frugivorous birds	Cattle pasture	1000	0.15	0.06
Abundance of frugivorous birds	Cocoa agroforestry	200	0.13	0.08
Abundance of frugivorous birds	**Cocoa agroforestry**	**300**	**0.30**	**0.01**
Abundance of frugivorous birds	Cocoa agroforestry	400	0.28	0.02
Abundance of frugivorous birds	Cocoa agroforestry	500	0.23	0.03
Abundance of frugivorous birds	Cocoa agroforestry	600	0.19	0.04
Abundance of frugivorous birds	Cocoa agroforestry	700	0.14	0.07
Abundance of frugivorous birds	Cocoa agroforestry	800	0.10	0.11
Abundance of frugivorous birds	Cocoa agroforestry	900	0.07	0.16
Abundance of frugivorous birds	Cocoa agroforestry	1000	0.03	0.23
Abundance of frugivorous birds	Forest cover	200	0.37	0.01
Abundance of frugivorous birds	**Forest cover**	**300**	**0.44**	**0.002**
Abundance of frugivorous birds	Forest cover	400	0.42	0.002
Abundance of frugivorous birds	Forest cover	500	0.38	0.004
Abundance of frugivorous birds	Forest cover	600	0.39	0.004

Abundance of frugivorous birds	Forest cover	700	0.36	0.01
Abundance of frugivorous birds	Forest cover	800	0.34	0.01
Abundance of frugivorous birds	Forest cover	900	0.32	0.01
Abundance of frugivorous birds	Forest cover	1000	0.30	0.01
Abundance of frugivorous birds	Cattle pasture	200	0.21	0.03
Abundance of frugivorous birds	**Cattle pasture**	**300**	**0.22**	**0.03**
Abundance of frugivorous birds	Cattle pasture	400	0.15	0.06
Abundance of frugivorous birds	Cattle pasture	500	0.13	0.08
Abundance of frugivorous birds	Cattle pasture	600	0.12	0.09
Abundance of frugivorous birds	Cattle pasture	700	0.12	0.09
Abundance of frugivorous birds	Cattle pasture	800	0.11	0.09
Abundance of frugivorous birds	Cattle pasture	900	0.12	0.09
Abundance of frugivorous birds	Cattle pasture	1000	0.14	0.07
Composition of frugivorous birds	Cocoa agroforestry	200	-0.03	0.52
Composition of frugivorous birds	Cocoa agroforestry	300	0.01	0.29
Composition of frugivorous birds	**Cocoa agroforestry**	**400**	**0.27**	**0.02**
Composition of frugivorous birds	Cocoa agroforestry	500	0.04	0.22
Composition of frugivorous birds	Cocoa agroforestry	600	0.04	0.20
Composition of frugivorous birds	Cocoa agroforestry	700	0.03	0.25
Composition of frugivorous birds	Cocoa agroforestry	800	0.001	0.33
Composition of frugivorous birds	Cocoa agroforestry	900	-0.02	0.44
Composition of frugivorous birds	Cocoa agroforestry	1000	-0.04	0.57
Composition of frugivorous birds	Forest cover	200	0.10	0.10
Composition of frugivorous birds	Forest cover	300	0.10	0.09
Composition of frugivorous birds	Forest cover	400	0.10	0.10
Composition of frugivorous birds	Forest cover	500	0.10	0.11
Composition of frugivorous birds	**Forest cover**	**600**	**0.11**	**0.09**
Composition of frugivorous birds	Forest cover	700	0.10	0.10
Composition of frugivorous birds	Forest cover	800	0.10	0.10
Composition of frugivorous birds	Forest cover	900	0.10	0.10
Composition of frugivorous birds	Forest cover	1000	0.10	0.10
Composition of frugivorous birds	**Cattle pasture**	**200**	**0.26**	**0.02**
Composition of frugivorous birds	Cattle pasture	300	0.23	0.03
Composition of frugivorous birds	Cattle pasture	400	0.16	0.05
Composition of frugivorous birds	Cattle pasture	500	0.10	0.11
Composition of frugivorous birds	Cattle pasture	600	0.08	0.14
Composition of frugivorous birds	Cattle pasture	700	0.07	0.14
Composition of frugivorous birds	Cattle pasture	800	0.09	0.13
Composition of frugivorous birds	Cattle pasture	900	0.11	0.10
Composition of frugivorous birds	Cattle pasture	1000	0.15	0.07
Richness of insectivorous birds	Cocoa agroforestry	200	-0.06	0.83

Richness of insectivorous birds	**Cocoa agroforestry**	**300**	**-0.05**	**0.64**
Richness of insectivorous birds	Cocoa agroforestry	400	-0.06	0.86
Richness of insectivorous birds	Cocoa agroforestry	500	-0.06	0.90
Richness of insectivorous birds	Cocoa agroforestry	600	-0.06	0.92
Richness of insectivorous birds	Cocoa agroforestry	700	-0.06	1.00
Richness of insectivorous birds	Cocoa agroforestry	800	-0.06	0.90
Richness of insectivorous birds	Cocoa agroforestry	900	-0.06	0.80
Richness of insectivorous birds	Cocoa agroforestry	1000	-0.05	0.72
Richness of insectivorous birds	Forest cover	200	0.04	0.21
Richness of insectivorous birds	**Forest cover**	**300**	**0.05**	**0.19**
Richness of insectivorous birds	Forest cover	400	0.02	0.26
Richness of insectivorous birds	Forest cover	500	0.00	0.34
Richness of insectivorous birds	Forest cover	600	-0.01	0.35
Richness of insectivorous birds	Forest cover	700	0.00	0.35
Richness of insectivorous birds	Forest cover	800	0.00	0.34
Richness of insectivorous birds	Forest cover	900	0.00	0.32
Richness of insectivorous birds	Forest cover	1000	0.01	0.30
Richness of insectivorous birds	**Cattle pasture**	**200**	**0.17**	**0.05**
Richness of insectivorous birds	Cattle pasture	300	0.12	0.09
Richness of insectivorous birds	Cattle pasture	400	0.08	0.13
Richness of insectivorous birds	Cattle pasture	500	0.07	0.15
Richness of insectivorous birds	Cattle pasture	600	0.08	0.14
Richness of insectivorous birds	Cattle pasture	700	0.08	0.13
Richness of insectivorous birds	Cattle pasture	800	0.08	0.13
Richness of insectivorous birds	Cattle pasture	900	0.08	0.13
Richness of insectivorous birds	Cattle pasture	1000	0.09	0.12
Abundance of insectivorous birds	Cocoa agroforestry	200	-0.01	0.40
Abundance of insectivorous birds	**Cocoa agroforestry**	**300**	**0.00**	**0.34**
Abundance of insectivorous birds	Cocoa agroforestry	400	-0.04	0.56
Abundance of insectivorous birds	Cocoa agroforestry	500	-0.05	0.67
Abundance of insectivorous birds	Cocoa agroforestry	600	-0.06	0.76
Abundance of insectivorous birds	Cocoa agroforestry	700	-0.06	0.85
Abundance of insectivorous birds	Cocoa agroforestry	800	-0.06	0.93
Abundance of insectivorous birds	Cocoa agroforestry	900	-0.06	0.97
Abundance of insectivorous birds	Cocoa agroforestry	1000	-0.06	0.90
Abundance of insectivorous birds	**Forest cover**	**200**	**0.10**	**0.11**
Abundance of insectivorous birds	Forest cover	300	0.08	0.14
Abundance of insectivorous birds	Forest cover	400	0.03	0.23
Abundance of insectivorous birds	Forest cover	500	0.00	0.32
Abundance of insectivorous birds	Forest cover	600	-0.01	0.36
Abundance of insectivorous birds	Forest cover	700	-0.01	0.38

Abundance of insectivorous birds	Forest cover	800	-0.02	0.40
Abundance of insectivorous birds	Forest cover	900	-0.02	0.42
Abundance of insectivorous birds	Forest cover	1000	-0.02	0.40
Abundance of insectivorous birds	**Cattle pasture**	**200**	**0.08**	**0.13**
Abundance of insectivorous birds	Cattle pasture	300	0.04	0.22
Abundance of insectivorous birds	Cattle pasture	400	0.01	0.31
Abundance of insectivorous birds	Cattle pasture	500	0.01	0.31
Abundance of insectivorous birds	Cattle pasture	600	0.02	0.28
Abundance of insectivorous birds	Cattle pasture	700	0.02	0.26
Abundance of insectivorous birds	Cattle pasture	800	0.02	0.26
Abundance of insectivorous birds	Cattle pasture	900	0.02	0.26
Abundance of insectivorous birds	Cattle pasture	1000	0.02	0.26
Composition of insectivorous birds	**Cocoa agroforestry**	**200**	**0.17**	**0.05**
Composition of insectivorous birds	Cocoa agroforestry	300	-0.02	0.40
Composition of insectivorous birds	Cocoa agroforestry	400	-0.05	0.69
Composition of insectivorous birds	Cocoa agroforestry	500	0.01	0.31
Composition of insectivorous birds	Cocoa agroforestry	600	0.05	0.20
Composition of insectivorous birds	Cocoa agroforestry	700	0.07	0.16
Composition of insectivorous birds	Cocoa agroforestry	800	0.09	0.13
Composition of insectivorous birds	Cocoa agroforestry	900	0.10	0.11
Composition of insectivorous birds	Cocoa agroforestry	1000	0.10	0.11
Composition of insectivorous birds	**Forest cover**	**200**	**0.34**	**0.01**
Composition of insectivorous birds	Forest cover	300	0.28	0.02
Composition of insectivorous birds	Forest cover	400	0.19	0.04
Composition of insectivorous birds	Forest cover	500	0.16	0.06
Composition of insectivorous birds	Forest cover	600	0.12	0.09
Composition of insectivorous birds	Forest cover	700	0.11	0.10
Composition of insectivorous birds	Forest cover	800	0.10	0.11
Composition of insectivorous birds	Forest cover	900	0.07	0.14
Composition of insectivorous birds	Forest cover	1000	0.06	0.17
Composition of insectivorous birds	Cattle pasture	200	0.14	0.07
Composition of insectivorous birds	Cattle pasture	300	0.38	0.004
Composition of insectivorous birds	Cattle pasture	400	0.41	0.003
Composition of insectivorous birds	**Cattle pasture**	**500**	**0.43**	**0.002**
Composition of insectivorous birds	Cattle pasture	600	0.41	0.002
Composition of insectivorous birds	Cattle pasture	700	0.40	0.003
Composition of insectivorous birds	Cattle pasture	800	0.39	0.004
Composition of insectivorous birds	Cattle pasture	900	0.36	0.01
Composition of insectivorous birds	Cattle pasture	1000	0.33	0.01
Richness of omnivorous birds	**Cocoa agroforestry**	**200**	**-0.02**	**0.43**
Richness of omnivorous birds	Cocoa agroforestry	300	-0.02	0.45

Richness of omnivorous birds	Cocoa agroforestry	400	-0.06	0.77
Richness of omnivorous birds	Cocoa agroforestry	500	-0.06	0.98
Richness of omnivorous birds	Cocoa agroforestry	600	-0.06	0.91
Richness of omnivorous birds	Cocoa agroforestry	700	-0.06	0.80
Richness of omnivorous birds	Cocoa agroforestry	800	-0.05	0.69
Richness of omnivorous birds	Cocoa agroforestry	900	-0.04	0.59
Richness of omnivorous birds	Cocoa agroforestry	1000	-0.03	0.48
Richness of omnivorous birds	Forest cover	200	0.03	0.25
Richness of omnivorous birds	Forest cover	300	0.02	0.26
Richness of omnivorous birds	Forest cover	400	0.01	0.28
Richness of omnivorous birds	Forest cover	500	0.00	0.32
Richness of omnivorous birds	Forest cover	600	0.01	0.29
Richness of omnivorous birds	Forest cover	700	0.02	0.25
Richness of omnivorous birds	Forest cover	800	0.04	0.22
Richness of omnivorous birds	Forest cover	900	0.04	0.21
Richness of omnivorous birds	**Forest cover**	**1000**	**0.04**	**0.20**
Richness of omnivorous birds	Cattle pasture	200	0.04	0.20
Richness of omnivorous birds	Cattle pasture	300	0.12	0.09
Richness of omnivorous birds	Cattle pasture	400	0.19	0.04
Richness of omnivorous birds	Cattle pasture	500	0.18	0.05
Richness of omnivorous birds	Cattle pasture	600	0.19	0.04
Richness of omnivorous birds	Cattle pasture	700	0.21	0.03
Richness of omnivorous birds	Cattle pasture	800	0.23	0.03
Richness of omnivorous birds	Cattle pasture	900	0.25	0.02
Richness of omnivorous birds	**Cattle pasture**	**1000**	**0.27**	**0.02**
Abundance of omnivorous birds	Cocoa agroforestry	200	-0.06	1.00
Abundance of omnivorous birds	Cocoa agroforestry	300	-0.06	0.80
Abundance of omnivorous birds	Cocoa agroforestry	400	-0.04	0.60
Abundance of omnivorous birds	Cocoa agroforestry	500	-0.02	0.42
Abundance of omnivorous birds	Cocoa agroforestry	600	-0.003	0.35
Abundance of omnivorous birds	**Cocoa agroforestry**	**700**	**-0.004**	**0.34**
Abundance of omnivorous birds	Cocoa agroforestry	800	-0.01	0.38
Abundance of omnivorous birds	Cocoa agroforestry	900	-0.02	0.42
Abundance of omnivorous birds	Cocoa agroforestry	1000	-0.03	0.49
Abundance of omnivorous birds	Forest cover	200	-0.05	0.72
Abundance of omnivorous birds	Forest cover	300	-0.06	0.76
Abundance of omnivorous birds	Forest cover	400	-0.05	0.67
Abundance of omnivorous birds	Forest cover	500	-0.04	0.52
Abundance of omnivorous birds	Forest cover	600	-0.01	0.39
Abundance of omnivorous birds	Forest cover	700	0.01	0.31
Abundance of omnivorous birds	Forest cover	800	0.03	0.25

Abundance of omnivorous birds	Forest cover	900	0.04	0.22
Abundance of omnivorous birds	**Forest cover**	**1000**	**0.04**	**0.20**
Abundance of omnivorous birds	Cattle pasture	200	0.01	0.29
Abundance of omnivorous birds	Cattle pasture	300	0.01	0.31
Abundance of omnivorous birds	Cattle pasture	400	0.00	0.35
Abundance of omnivorous birds	Cattle pasture	500	-0.02	0.44
Abundance of omnivorous birds	Cattle pasture	600	-0.02	0.41
Abundance of omnivorous birds	Cattle pasture	700	-0.01	0.36
Abundance of omnivorous birds	Cattle pasture	800	0.01	0.30
Abundance of omnivorous birds	Cattle pasture	900	0.03	0.24
Abundance of omnivorous birds	**Cattle pasture**	**1000**	**0.05**	**0.18**
Composition of omnivorous birds	**Cocoa agroforestry**	**200**	**0.17**	**0.05**
Composition of omnivorous birds	Cocoa agroforestry	300	-0.02	0.40
Composition of omnivorous birds	Cocoa agroforestry	400	-0.05	0.69
Composition of omnivorous birds	Cocoa agroforestry	500	0.01	0.31
Composition of omnivorous birds	Cocoa agroforestry	600	0.05	0.20
Composition of omnivorous birds	Cocoa agroforestry	700	0.07	0.16
Composition of omnivorous birds	Cocoa agroforestry	800	0.09	0.13
Composition of omnivorous birds	Cocoa agroforestry	900	0.10	0.11
Composition of omnivorous birds	Cocoa agroforestry	1000	0.10	0.11
Composition of omnivorous birds	**Forest cover**	**200**	**0.34**	**0.01**
Composition of omnivorous birds	Forest cover	300	0.28	0.02
Composition of omnivorous birds	Forest cover	400	0.19	0.04
Composition of omnivorous birds	Forest cover	500	0.16	0.06
Composition of omnivorous birds	Forest cover	600	0.12	0.09
Composition of omnivorous birds	Forest cover	700	0.11	0.10
Composition of omnivorous birds	Forest cover	800	0.10	0.11
Composition of omnivorous birds	Forest cover	900	0.07	0.14
Composition of omnivorous birds	Forest cover	1000	0.06	0.17
Composition of omnivorous birds	Cattle pasture	200	0.14	0.07
Composition of omnivorous birds	Cattle pasture	300	0.38	0.004
Composition of omnivorous birds	Cattle pasture	400	0.41	0.003
Composition of omnivorous birds	**Cattle pasture**	**500**	**0.43**	**0.002**
Composition of omnivorous birds	Cattle pasture	600	0.41	0.002
Composition of omnivorous birds	Cattle pasture	700	0.40	0.003
Composition of omnivorous birds	Cattle pasture	800	0.39	0.004
Composition of omnivorous birds	Cattle pasture	900	0.36	0.01
Composition of omnivorous birds	Cattle pasture	1000	0.33	0.01

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Appendix B. Classification of bird species

Table B.1 List of bird species recorded in 18 agroforest systems. We classified birds either as forest-dependent or non-forest-dependent species, and according to their trophic guild (i.e., insectivores, frugivores, nectivores, omnivores, and granivores).

Bird specie	Habitat	Trophic guild
Anthracotorax nigricollis	Non-forest-dependent	Nectarivore
Aphantochroa cirrochloris	Non-forest-dependent	Nectarivore
Arremon taciturnus	Forest-dependent	Insectivore
Attila rufus	Forest-dependent	Omnivore
Cacicus cela	Non-forest-dependent	Frugivore
Celeus flavescens	Forest-dependent	Insectivore
Celeus flavus	Non-forest-dependent	Insectivore
Ceratopipra rubrocapilla	Forest-dependent	Frugivore
Chloceryle inda	Forest-dependent	Omnivore
Chlorestes notata	Forest-dependent	Nectarivore
Coereba flaveola	Non-forest-dependent	Nectarivore
Columbina talpacoti	Non-forest-dependent	Granivore
Cyanerpes cyaneus	Forest-dependent	Omnivore
Dacnis cayana	Non-forest-dependent	Omnivore
Dendrocincla turdina	Forest-dependent	Insectivore
Dendroplex picus	Non-forest-dependent	Insectivore
Dixiphia pipra	Forest-dependent	Frugivore
Empidonomus varius	Non-forest-dependent	Insectivore
Eupetomena macroura	Non-forest-dependent	Nectarivore
Euphonia pectoralis	Forest-dependent	Frugivore
Euphonia violácea	Non-forest-dependent	Frugivore
Euphonia xanthogaster	Forest-dependent	Frugivore
Furnarius leucopus	Non-forest-dependent	Insectivore
Glaucidium minutissimum	Forest-dependent	Insectivore
Glaucis dohrnii	Forest-dependent	Nectarivore
Glaucis hirsutus	Forest-dependent	Nectarivore
Hylocharis cyanus	Non-forest-dependent	Nectarivore
Lathotriccus euleri	Forest-dependent	Insectivore
Leptopogon amaurocephalus	Forest-dependent	Insectivore
Leptotila rufaxilla	Forest-dependent	Granivore
Leptotila verreauxi	Non-forest-dependent	Granivore
Machaeropterus regulus	Forest-dependent	Frugivore
Malacoptila striata	Forest-dependent	Insectivore
Manacus manacus	Forest-dependent	Frugivore
Megarynchus pitangua	Non-forest-dependent	Omnivore

Myiobius barbatus	Forest-dependent	Insectivore
Myiozetes similis	Non-forest-dependent	Omnivore
Myrmotherula axillaris	Forest-dependent	Insectivore
Pachyramphus marginatus	Forest-dependent	Omnivore
Piaya cayana	Forest-dependent	Insectivore
Pitangus sulphuratus	Non-forest-dependent	Omnivore
Pteroglossus aracari	Forest-dependent	Frugivore
Ramphocelus bresilius	Non-forest-dependent	Omnivore
Rhytipterna simplex	Forest-dependent	Insectivore
Rupornis magnirostris	Non-forest-dependent	Omnivore
Saltator maximus	Non-forest-dependent	Omnivore
Sittasomus griseicapillus	Forest-dependent	Insectivore
Tangara cayana	Non-forest-dependent	Frugivore
Tangara palmarum	Non-forest-dependent	Frugivore
Tangara sayaca	Non-forest-dependent	Omnivore
Tangara seledon	Forest-dependent	Frugivore
Thalurania furcata	Non-forest-dependent	Nectarivore
Thalurania glaucopis	Forest-dependent	Nectarivore
Thamnophilus ambiguus	Forest-dependent	Insectivore
Thamnophilus palliatus	Non-forest-dependent	Insectivore
Tiaris fuliginosus	Non-forest-dependent	Granivore
Tolmomyias flaviventris	Forest-dependent	Insectivore
Turdus amaurochalinus	Non-forest-dependent	Frugivore
Turdus leucomelas	Non-forest-dependent	Omnivore
Turdus rufiventris	Non-forest-dependent	Omnivore
Vireo olivaceus	Non-forest-dependent	Omnivore
Xenops minutus	Forest-dependent	Insectivore
Xenops rutilans	Forest-dependent	Insectivore
Xiphorynchus fuscus	Forest-dependent	Insectivore

Appendix C. Spearman's correlation test between each environmental predictor

We evaluated the correlation between each environmental predictor using the Spearman's correlation coefficient (r), which the values of the coefficient can vary between -1 (inverse relations) and +1. In this study, we adopted a cut-off point for predictor variables that presented values of r ≥ 0.70, indicating a strong correlation between them.

Table C.1 Correlation between different predictor variables (abundance of trees, basal area, abundance of cocoa tree, canopy opening, cocoa agroforestry, forest cover, cattle pasture) used in this study.

Richness of complete bird community	Abundance of trees	Basal area	Abundance of cocoa trees	Canopy closure	Cocoa agroforestry (300m scale)	Forest cover (300m scale)	Cattle pasture (200m scale)
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.36
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.08
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.19
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.16
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		-0.62
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.16	-0.62	
Abundance of complete bird community	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (300m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.36
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.08
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.19
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.16
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		-0.62
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.16	-0.62	
Composition of complete bird community	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (200m scale)**	**Forest cover 300m scale)**	**Cattle pasture (900m scale)**
Abundance of trees		0.02	0.04	0.14	0.18	-0.38	0.38
Basal area	0.02		0.19	0.22	0.28	-0.02	-0.08
Abundance of cocoa trees	0.04	0.19		-0.05	-0.02	0.01	-0.22
Canopy closure	0.14	0.22	-0.05		0.08	-0.08	0.35
Cocoa agroforestry (200m scale)	0.18	0.28	-0.02	0.08		**-0.75**	0.4
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.75**		-0.66
Cattle pasture (900m scale)	0.38	-0.08	-0.22	0.35	0.4	-0.66	

Richness of forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (300m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.36
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.08
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.19
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.16
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		-0.62
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.16	-0.62	

Abundance of forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (300m scale)**	**Cattle pasture (300m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.42
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.14
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.12
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.29
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.25
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		**-0.74**
Cattle pasture (300m scale)	0.42	-0.14	-0.12	0.29	0.25	**-0.74**	

Composition of forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (1000m scale)**	**Forest cover (300m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	-0.14	-0.38	0.36
Basal area	0.02		0.19	0.22	0.21	-0.02	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.37	0.01	-0.08
Canopy closure	0.14	0.22	-0.05		-0.12	-0.08	0.19
Cocoa agroforestry (1000m scale)	-0.14	0.21	0.37	-0.12		-0.1	-0.01
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	-0.1		-0.62
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	-0.01	-0.62	

Richness of non-forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (1000m scale)**	**Forest cover (200m scale)**	**Cattle pasture (1000m scale)**
Abundance of trees		0.02	0.04	0.14	-0.14	-0.33	0.38
Basal area	0.02		0.19	0.22	0.21	-0.17	-0.08
Abundance of cocoa trees	0.04	0.19		-0.05	0.37	0.04	-0.24
Canopy closure	0.14	0.22	-0.05		-0.12	-0.09	0.36
Cocoa agroforestry (1000m scale)	-0.14	0.21	0.37	-0.12		-0.08	-0.39
Forest cover (200m scale)	-0.33	-0.17	0.04	-0.09	-0.08		-0.61
Cattle pasture (1000m scale)	0.38	-0.08	-0.24	0.36	-0.39	-0.61	

Abundance of non-forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry**	**Forest cover (1000m**	**Cattle pasture**

					(600m scale)	scale)	(1000m scale)
Abundance of trees		0.02	0.04	0.14	-0.07	-0.32	0.38
Basal area	0.02		0.19	0.22	0.21	0	-0.08
Abundance of cocoa trees	0.04	0.19		-0.05	0.31	-0.17	-0.24
Canopy closure	0.14	0.22	-0.05		0.004	-0.15	0.36
Cocoa agroforestry (600m scale)	-0.07	0.21	0.31	0.004		-0.44	-0.17
Forest cover (1000m scale)	-0.32	0	-0.17	-0.15	-0.44		-0.66
Cattle pasture (1000m scale)	0.38	-0.08	-0.24	0.36	-0.17	-0.66	
Composition of non-forest-dependent birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (200m scale)**	**Cattle pasture (300m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.33	0.42
Basal area	0.02		0.19	0.22	0.22	-0.17	-0.14
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.04	-0.12
Canopy closure	0.14	0.22	-0.05		0.07	-0.09	0.29
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.8**	0.25
Forest cover (200m scale)	-0.33	-0.17	0.04	-0.09	**-0.8**		**-0.71**
Cattle pasture (300m scale)	0.42	-0.14	-0.12	0.29	0.25	**-0.71**	
Richness of frugivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (500m scale)**	**Forest cover (600m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	-0.01	-0.35	0.36
Basal area	0.02		0.19	0.22	0.23	0.004’’’’’’’	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.29	-0.14	-0.08
Canopy closure	0.14	0.22	-0.05		0.01	-0.17	0.19
Cocoa agroforestry (500m scale)	-0.01	0.23	0.29	0.01		-0.58	0.11
Forest cover (600m scale)	-0.35	0.004	-0.14	-0.17	-0.58		-0.58
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.11	-0.58	
Abundance of frugivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (300m scale)**	**Cattle pasture (300m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.42
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.14
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.12
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.29
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.25
Forest cover (300m scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		**-0.74**
Cattle pasture (300m scale)	0.42	-0.14	-0.12	0.29	0.25	**-0.74**	
Composition of frugivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (400m scale)**	**Forest cover (600m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	0.11	-0.35	0.36
Basal area	0.02		0.19	0.22	0.23	0	-0.07

Abundance of cocoa trees	0.04	0.19		-0.05	0.24	-0.14	-0.08
Canopy closure	0.14	0.22	-0.05		0.05	-0.17	0.19
Cocoa agroforestry (400m scale)	0.11	0.23	0.24	0.05		-0.67	0.12
Forest cover (600m scale)	-0.35	0	-0.14	-0.17	-0.67		-0.58
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.12	-0.58	

Richness of insectivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (300m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.38	0.36
Basal area	0.02		0.19	0.22	0.22	-0.02	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.01	-0.08
Canopy closure	0.14	0.22	-0.05		0.07	-0.08	0.19
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.79**	0.16
Forest cover (300 scale)	-0.38	-0.02	0.01	-0.08	**-0.79**		-0.62
Cattle pasture (200 scale)	0.36	-0.07	-0.08	0.19	0.16	-0.62	

Abundance of insectivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (300m scale)**	**Forest cover (200m scale)**	**Cattle pasture (200m scale)**
Abundance of trees		0.02	0.04	0.14	0.19	-0.33	0.36
Basal area	0.02		0.19	0.22	0.22	-0.17	-0.07
Abundance of cocoa trees	0.04	0.19		-0.05	0.1	0.04	-0.08
Canopy closure	0.14	0.22	-0.05		0.07	-0.09	0.19
Cocoa agroforestry (300m scale)	0.19	0.22	0.1	0.07		**-0.8**	0.16
Forest cover (200m scale)	-0.33	-0.17	0.04	-0.09	**-0.8**		-0.6
Cattle pasture (200m scale)	0.36	-0.07	-0.08	0.19	0.16	-0.6	

Composition of insectivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (200m scale)**	**Forest cover (200m scale)**	**Cattle pasture (500m scale)**
Abundance of trees		0.02	0.04	0.14	0.18	-0.33	0.38
Basal area	0.02		0.19	0.22	0.28	-0.17	-0.15
Abundance of cocoa trees	0.04	0.19		-0.05	-0.02	0.04	-0.13
Canopy closure	0.14	0.22	-0.05		0.08	-0.09	0.34
Cocoa agroforestry (200 scale)	0.18	0.28	-0.02	0.08		**-0.83**	0.42
Forest cover (200 scale)	-0.33	-0.17	0.04	-0.09	**-0.83**		**-0.71**
Cattle pasture (500 scale)	0.38	-0.15	-0.13	0.34	0.42	**-0.71**	

Richness of omnivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (200 scale)**	**Forest cover (1000m scale)**	**Cattle pasture (1000m scale)**
Abundance of trees		0.02	0.04	0.14	0.18	-0.32	0.38
Basal area	0.02		0.19	0.22	0.28	0	-0.08
Abundance of cocoa trees	0.04	0.19		-0.05	-0.02	-0.17	-0.24
Canopy closure	0.14	0.22	-0.05		0.08	-0.15	0.36
Cocoa agroforestry (200m scale)	0.18	0.28	-0.02	0.08		-0.37	0.38

Forest cover (1000m scale)	-0.32	0	-0.17	-0.15	-0.37		-0.66
Cattle pasture (1000m scale)	0.38	-0.08	-0.24	0.36	0.38	-0.66	
Abundance of omnivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (700m scale)**	**Forest cover (1000m scale)**	**Cattle pasture (1000m scale)**
Abundance of trees		0.02	0.04	0.14	-0.1	-0.32	0.38
Basal area	0.02		0.19	0.22	0.21	0	-0.08
Abundance of cocoa trees	0.04	0.19		-0.05	0.32	-0.17	-0.24
Canopy closure	0.14	0.22	-0.05		-0.02	-0.15	0.36
Cocoa agroforestry (700m scale)	-0.1	0.21	0.32	-0.02		-0.41	-0.24
Forest cover (1000m scale)	-0.32	0	-0.17	-0.15	-0.41		-0.66
Cattle pasture (1000m scale)	0.38	-0.08	-0.24	0.36	-0.24	-0.66	
Composition of omnivorous birds	**Abundance of trees**	**Basal area**	**Abundance of cocoa trees**	**Canopy closure**	**Cocoa agroforestry (200m scale)**	**Forest cover (200m scale)**	**Cattle pasture (500m scale)**
Abundance of trees		0.02	0.04	0.14	0.18	-0.33	0.38
Basal area	0.02		0.19	0.22	0.28	-0.17	-0.15
Abundance of cocoa trees	0.04	0.19		-0.05	-0.02	0.04	-0.13
Canopy closure	0.14	0.22	-0.05		0.08	-0.09	0.34
Cocoa agroforestry (200m scale)	0.18	0.28	-0.02	0.08		**-0.83**	0.42
Forest cover (200m scale)	-0.33	-0.17	0.04	-0.09	**-0.83**		**-0.71**
Cattle pasture (500m scale)	0.38	-0.15	-0.13	0.34	0.42	**-0.71**	

Appendix D. Significant predictor variables of best models for each response variable

Table D.1 Parameters of the best models (ΔAIC ≤ 2) used for explains the richness, abundance and composition of birds in cocoa agroforestry. The significative predictors (P ≤ 0.05) are highlighted in bold.

Richness of bird complete community				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	2.33	0.38	6.20	<0.001
Abundance of cocoa trees	0.003	0.002	1.41	0.18
Cattle pasture	**-0.02**	**0.01**	**-2.81**	**0.01**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	2.82	0.13	21.75	<0.001
Cattle pasture	**-0.02**	**0.01**	**-2.89**	**0.01**
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	1.99	0.39	5.09	<0.001
Abundance of trees	0.01	0.01	1.59	0.14
Cattle pasture	-0.02	0.01	-1.84	0.09
Region (Ilhéus)	**0.65**	**0.30**	**2.15**	**0.05**
Region (Una)	0.55	0.28	2.00	0.07
Model 4				
	Estimate	Std. Error	t value	P-value
Intercept	2.42	0.28	8.80	<0.001
Cattle pasture	-0.02	0.01	-1.64	0.12
Region (Ilhéus)	0.45	0.28	1.62	0.13
Region (Una)	0.36	0.25	1.45	0.17
Abundance of bird complete community				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	2.94	0.53	5.52	<0.001
Abundance of cocoa trees	0.004	0.003	1.39	0.19
Cattle pasture	**-0.04**	**0.02**	**-2.29**	**0.04**
Region (Ilhéus)	0.44	0.39	1.13	0.28
Region (Una)	0.60	0.34	1.75	0.10
Composition of bird complete community				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.37	0.24	1.54	0.14

	Estimate	Std. Error	t value	P-value
Cocoa agroforestry	-0.01	0.004	-1.64	0.12
Model 2				
Null model	Estimate	Std. Error	t value	P-value
Intercept	0.00	0.09	0.00	1.00
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	-0.10	0.12	-0.86	0.40
Forest cover	0.004	0.003	1.20	0.25
Model 4				
	Estimate	Std. Error	t value	P-value
Intercept	0.11	0.12	0.85	0.41
Cattle pasture	-0.004	0.003	-1.15	0.27
Richness of forest-dependent birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	2.31	0.15	15.70	<0.001
Cattle pasture	**-0.03**	**0.01**	**-3.36**	**0.004**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	1.95	0.42	4.65	<0.001
Abundance of cocoa trees	0.002	0.002	0.94	0.36
Cattle pasture	**-0.03**	**0.01**	**-3.31**	**0.005**
Abundance of forest-dependent birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	1.10	0.84	1.32	0.21
Canopy closure	0.01	0.01	1.21	0.25
Forest cover	**0.02**	**0.01**	**2.30**	**0.04**
Region (Ilhéus)	0.73	0.56	1.30	0.22
Region (Una)	0.69	0.49	1.41	0.18
Composition of forest-dependent birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	-0.09	0.22	-0.40	0.70
Abundance of cocoa trees	0.002	0.001	1.78	0.10
Cattle pasture	**-0.02**	**0.004**	**-4.93**	**<0.001**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	0.28	0.08	3.45	0.003
Cattle pasture	**-0.02**	**0.004**	**-4.79**	**<0.001**
Richness of non-forest-dependent birds				

	Estimate	Std. Error	t value	P-value
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	1.99	0.15	13.52	<0.001
Cattle pasture	-0.01	0.00	-2.07	0.06
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	2.58	0.44	5.85	<0.001
Canopy closure	-0.01	0.01	-1.39	0.18
Cattle pasture	-0.01	0.01	-1.52	0.15
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	2.62	0.45	5.80	<0.001
Canopy closure	-0.02	0.01	-1.93	0.07
Model 4				
	Estimate	Std. Error	t value	P-value
Intercept	1.46	0.49	2.99	0.01
Abundance of cocoa trees	0.003	0.002	1.15	0.27
Cattle pasture	-0.01	0.005	-1.71	0.11
Model 5				
	Estimate	Std. Error	t value	P-value
Intercept	1.34	0.23	5.78	<0.001
Region (Ilhéus)	**0.65**	**0.29**	**2.26**	**0.04**
Region (Una)	0.48	0.30	1.61	0.13
Model 6				
	Estimate	Std. Error	t value	P-value
Intercept	2.22	0.26	8.46	<0.001
Basal area	-0.01	0.01	-1.03	0.32
Cattle pasture	-0.01	0.005	-2.05	0.06
Model 7				
	Estimate	Std. Error	t value	P-value
Intercept	1.84	0.22	8.22	<0.001
Abundance of trees	0.01	0.01	0.93	0.37
Cattle pasture	**-0.01**	**0.01**	**-2.18**	**0.05**
Model 8				
	Estimate	Std. Error	t value	P-value
Intercept	2.23	0.68	3.31	0.01
Canopy closure	-0.01	0.01	-1.39	0.19
Region (Ilhéus)	0.53	0.31	1.73	0.11
Region (Una)	0.21	0.36	0.59	0.56
Abundance of non-forest-dependent birds				
Model 1				

	Estimate	Std. Error	t value	P-value
Intercept	1.09	0.59	1.87	0.08
Abundance of cocoa trees	**0.01**	**0.003**	**2.83**	**0.01**
Cocoa agroforestry	**-0.01**	**0.01**	**-2.12**	**0.05**
Region (Ilhéus)	0.48	0.36	1.33	0.21
Region (Una)	**0.94**	**0.34**	**2.78**	**0.02**
Composition of non-forest-dependent birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	-0.56	0.18	-3.16	0.01
Basal area	**0.01**	**0.01**	**2.25**	**0.04**
Cattle pasture	**0.01**	**0.004**	**3.17**	**0.01**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	0.08	0.16	0.52	0.61
Basal area	0.01	0.01	2.01	0.06
Region (Ilhéus)	**-0.54**	**0.15**	**-3.52**	**0.003**
Region (Una)	**-0.45**	**0.15**	**-2.90**	**0.01**
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	0.33	0.12	2.72	0.02
Region (Ilhéus)	**-0.54**	**0.17**	**-3.22**	**0.01**
Region (Una)	**-0.43**	**0.17**	**-2.55**	**0.02**
Richness of frugivorous birds				
Model 1				
	Estimate	Std. Error	z value	P-value
Intercept	1.62	0.18	8.97	<0.001
Cattle pasture	**-0.03**	**0.01**	**-2.20**	**0.03**
Model 2				
	Estimate	Std. Error	z value	P-value
Intercept	0.93	0.22	4.28	<0.001
Forest cover	**0.01**	**0.00**	**2.22**	**0.03**
Model 3				
	Estimate	Std. Error	z value	P-value
Intercept	1.84	0.28	6.68	<0.001
Cocoa agroforestry	**-0.01**	**0.01**	**-2.11**	**0.03**
Abundance of frugivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.79	0.94	0.84	0.41
Abundance of cocoa trees	0.01	0.005	1.11	0.29

Forest cover	**0.02**	**0.01**	**2.31**	**0.04**
Region (Ilhéus)	-0.11	0.80	-0.14	0.89
Region (Una)	0.38	0.54	0.71	0.49
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	1.25	0.72	1.74	0.10
Abundance of cocoa trees	0.004	0.004	1.07	0.30
Forest cover	**0.02**	**0.005**	**3.74**	**0.002**
Composition of frugivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.20	0.11	1.90	0.08
Cattle pasture	**-0.01**	**0.005**	**-2.64**	**0.02**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	-0.23	0.29	-0.80	0.44
Abundance of cocoa trees	0.002	0.001	1.58	0.14
Cattle pasture	**-0.01**	**0.005**	**-2.62**	**0.02**
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	0.59	0.30	1.97	0.07
Canopy closure	-0.01	0.005	-1.38	0.19
Cattle pasture	**-0.01**	**0.005**	**-2.40**	**0.03**
Richness of insectivorous birds				
Model 1				
	Estimate	Std. Error	z value	P-value
Intercept	1.16	0.28	4.18	<0.001
Abundance of trees	0.02	0.01	1.88	0.06
Cattle pasture	**-0.03**	**0.01**	**-2.54**	**0.01**
Model 2				
	Estimate	Std. Error	z value	P-value
Intercept	0.54	0.61	0.89	0.37
Canopy closure	0.02	0.01	1.73	0.08
Cattle pasture	**-0.03**	**0.01**	**-2.50**	**0.01**
Model 3				
	Estimate	Std. Error	z value	P-value
Intercept	1.51	0.20	7.75	<0.001
Cattle pasture	**-0.03**	**0.01**	**-2.24**	**0.03**
Model 4				
	Estimate	Std. Error	z value	P-value
Intercept	0.92	0.56	1.63	0.10

Abundance of cocoa trees	0.003	0.003	1.15	0.25
Cattle pasture	**-0.03**	**0.01**	**-2.19**	**0.03**
Abundance of insectivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.17	0.60	0.28	0.78
Canopy closure	**0.03**	**0.01**	**3.16**	**0.01**
Cattle pasture	**-0.03**	**0.01**	**-2.78**	**0.01**
Composition of insectivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.34	0.12	2.86	0.01
Cattle pasture	**-0.01**	**0.004**	**-3.72**	**0.002**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	-0.03	0.32	-0.10	0.92
Abundance of cocoa trees	0.002	0.002	1.24	0.24
Cattle pasture	**-0.01**	**0.004**	**-3.58**	**0.003**
Richness of omnivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.51	0.28	1.84	0.09
Region (Ilhéus)	**0.96**	**0.33**	**2.92**	**0.01**
Region (Una)	**0.92**	**0.33**	**2.79**	**0.01**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	1.54	0.16	9.77	<0.001
Cattle pasture	**-0.01**	**0.01**	**-2.53**	**0.02**
Model 3				
	Estimate	Std. Error	t value	P-value
Intercept	1.87	0.27	6.93	<0.001
Basal area	-0.01	0.01	-1.45	0.17
Cattle pasture	**-0.01**	**0.01**	**-2.59**	**0.02**
Model 4				
	Estimate	Std. Error	t value	P-value
Intercept	-0.18	0.55	-0.32	0.75
Abundance of trees	0.02	0.01	1.61	0.13
Region (Ilhéus)	**1.29**	**0.41**	**3.14**	**0.01**
Region (Una)	**1.23**	**0.40**	**3.05**	**0.01**
Model 5				
	Estimate	Std. Error	t value	P-value

	Estimate	Std. Error	t value	P-value
Intercept	0.81	0.35	2.31	0.04
Basal area	-0.01	0.01	-1.37	0.19
Region (Ilhéus)	**0.96**	**0.33**	**2.91**	**0.01**
Region (Una)	**0.92**	**0.33**	**2.79**	**0.01**
Model 6				
	Estimate	Std. Error	t value	P-value
Intercept	2.12	0.48	4.40	0.001
Canopy closure	-0.01	0.01	-1.25	0.23
Cattle pasture	-0.01	0.01	-2.06	0.06
Model 7				
	Estimate	Std. Error	t value	P-value
Intercept	-0.76	1.12	-0.68	0.51
Cattle pasture	0.02	0.02	1.19	0.25
Region (Ilhéus)	2.12	1.05	2.02	0.06
Region (Una)	**1.84**	**0.85**	**2.15**	**0.05**
Abundance of omnivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	-0.55	1.72	-0.32	0.76
Basal area	-0.03	0.01	-2.01	0.07
Cattle pasture	0.04	0.03	1.59	0.14
Region (Ilhéus)	3.36	1.59	2.11	0.06
Region (Una)	**3.11**	**1.28**	**2.44**	**0.03**
Composition of omnivorous birds				
Model 1				
	Estimate	Std. Error	t value	P-value
Intercept	0.34	0.12	2.86	0.01
Cattle pasture	**-0.01**	**0.004**	**-3.72**	**0.002**
Model 2				
	Estimate	Std. Error	t value	P-value
Intercept	-0.03	0.32	-0.10	0.92
Abundance of cocoa trees	0.002	0.002	1.24	0.24
Cattle pasture	**-0.01**	**0.004**	**-3.58**	**0.003**

Appendix E. Spatial autocorrelation test

We tested spatial autocorrelation on residues of best models using the Moran's I test (Legendre, 1993). From the derivation of a geographic distance matrix among forest sites, we tested the effect of the distance on the residuals of the models. Here, we use the x and y coordinates of the sample sites where the data were collected. From this point, we generated an inverse distance matrix with the diagonals set to 0 for the Moran's I test in the GLM model residuals (for more details see Guisan et al., 2017, p 114). This method considers that the values of $P \leq 0.05$ indicate spatial correlation between the model variables (Gittleman and Kot, 1990).

Table E.1 Spatial autocorrelation test estimated by best models used to explain the effect of several environmental predictors on richness, abundance and composition of birds.

Richness of complete bird community		
Models	P-value	Std. Moran's I
Abundance of cocoa trees + Cattle pasture	0.62	0.11
Cattle pasture	0.31	0.1
Abundance of trees + Cattle pasture + Region	0.7	0.11
Cattle pasture + Region	0.86	0.11
Abundance of complete bird community		
Model	P-value	Std. Moran's I
Abundance of cocoa trees + Cattle pasture + Region	0.42	0.11
Composition of complete bird community		
Models	P-value	Std. Moran's I
Cocoa agroforestry	0.33	0.11
Null model	0.43	0.11
Forest cover	0.39	0.11
Cattle pasture	0.51	0.11
Richness of forest-dependent birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.83	0.11
Abundance of cocoa trees + Cattle pasture	0.87	0.11
Abundance of forest-dependent birds		
Model	P-value	Std. Moran's I
Canopy closure + Forest cover + Region	0.39	0.11
Composition of forest-dependent birds		
Models	P-value	Std. Moran's I
Abundance of cocoa trees + Cattle pasture	0.95	0.11

Cattle pasture	0.4	0.11
Richness of non-forest-dependent birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.81	0.11
Canopy closure + Cattle pasture	0.49	0.11
Canopy closure	0.09	0.11
Abundance of cocoa trees + Cattle pasture	0.87	0.11
Region	0.98	0.11
Basal area + Cattle pasture	0.95	0.11
Abundance of trees + Cattle pasture	0.94	0.11
Canopy closure + Region	0.87	0.11
Abundance of non-forest-dependent birds		
Model	P-value	Std. Moran's I
Abundance of cocoa trees + Cocoa agroforestry + Region	0.89	0.11
Composition of non-forest-dependent birds		
Models	P-value	Std. Moran's I
Basal area + Cattle pasture	0.49	0.11
Basal area + Region	0.17	0.11
Region	0.62	0.11
Richness of frugivorous birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.79	0.10
Forest cover	0.36	0.11
Cocoa agroforestry	0.34	0.11
Abundance of frugivorous birds		
Models	P-value	Std. Moran's I
Abundance of cocoa trees + Forest cover + Region	0.43	0.11
Abundance of cocoa trees + Forest cover	0.91	0.11
Composition of frugivorous birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.35	0.11
Abundance of cocoa trees + Cattle pasture	0.56	0.11
Canopy closure + Cattle pasture	0.41	0.11
Richness of insectivorous birds		
Models	P-value	Std. Moran's I
Abundance of trees + Cattle pasture	0.62	0.1
Canopy closure + Cattle pasture	0.99	0.1
Cattle pasture	0.88	0.11
Abundance of cocoa trees + Cattle pasture	0.85	0.11
Abundance of insectivorous birds		
Model	P-value	Std. Moran's I

Canopy closure + Cattle pasture	0.95	0.1
Composition of insectivorous birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.65	0.11
Abundance of cocoa trees + Cattle pasture	0.95	0.11
Richness of omnivorous birds		
Models	P-value	Std. Moran's I
Region	0.42	0.11
Cattle pasture	0.31	0.11
Basal area + Cattle pasture	0.48	0.11
Abundance of trees + Region	0.51	0.11
Basal area + Region	0.65	0.11
Canopy closure + Cattle pasture	0.32	0.11
Cattle pasture + Region	0.5	0.11
Abundance of omnivorous birds		
Model	P-value	Std. Moran's I
Basal area + Cattle pasture + Region	0.51	0.11
Composition of omnivorous birds		
Models	P-value	Std. Moran's I
Cattle pasture	0.65	0.11
Abundance of cocoa trees + Cattle pasture	0.95	0.11

References

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