
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS
(ZOOLOGIA)

Species composition, ecological functions and ecosystem services
by birds across forest-matrix interfaces in tropical disturbed
landscapes

FÁBIO MONTEIRO DE BARROS

Tese apresentada ao Instituto de
Biociências do Câmpus de Rio
Claro, Universidade Estadual
Paulista, como parte dos requisitos
para obtenção do título de Doutor
em Ciências Biológicas (Zoologia)

Outubro 2017

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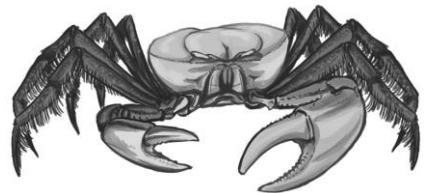
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“...caranguejo em praia não faz bondade,

Pisou macio com leveza gravitacional

Pisou macio.. com esperteza

(Djeiki Sandino / Jackson Bandeira)



RESUMO

A perda e fragmentação dos habitats tem levado a crescentes perdas de biodiversidade e serviços ecossistêmicos em todo mundo. Em paisagens antropogênicas, diversos fatores são conhecidos por moldarem essa biodiversidade e serviços ecológicos, entre elas a quantidade de cobertura florestal e o tipo e composição da matriz antrópicas. Usando aves como objeto de estudo, nesta tese nós basicamente buscamos quantificar a composição, função e serviços ecossistêmicos de espécies de aves que ocorrem em dois tipos de interfaces de habitat mais comum ao longo da Mata Atlântica brasileira (floresta-pasto e floresta-eucalipto), e tentamos entender melhor como as características da paisagem ajudam a moldar os padrões encontrados. No capítulo 1, nossos dados sugeriram que pastagens são capazes de prover maior potencial de prover serviços de dispersão de sementes, controle de pragas e polinização por aves do que plantações de eucalipto, no entanto algumas particularidade e limitações de interpretação desses resultados são apontadas e discutidas. No mesmo capítulo também elucidamos a importância das espécies generalistas na provisão de serviços de dispersão de sementes, assim como a presença das áreas habitadas por pessoas dentro de propriedades rurais como potencial facilitador desse serviço pelas aves em paisagens alteradas. No segundo capítulo, verificamos que o tipo de matriz adjacente (pasto ou eucalipto) interfere na composição taxonômica e funcional das comunidades de aves que habitam bordas de floresta e também que o aumento da cobertura florestal é capaz de aproximar funcionalmente as comunidades de aves adjacente dentro de interfaces de floresta-matriz. Por fim, no terceiro e último capítulo, através de modelos que simulam cenários, nós tentamos prever como as características funcionais das aves em borda de floresta tendem a se distribuir em função do tipo de matriz adjacente, cobertura florestal e heterogeneidade da paisagem.

ABSTRACT

Habitat loss and fragmentation have led to increasing biodiversity and ecosystem loss worldwide. In anthropogenic landscapes, several factors are known to modulate biodiversity and ecosystem services, mainly the amount of forest cover and matrix type and composition. Using birds as study object, in this thesis we basically aimed to quantify composition, function and ecosystem services by birds occurring in two types of most common habitat interfaces across Atlantic forest in Brazil (forest-pastures and forest-eucalyptus), and tried to better understand how landscapes attributes help to drive the patterns found. In the chapter 1, we demonstrated that pastures stands are able to provide higher potential provision of seed dispersal, pest control and pollination services by birds, however some limitation and particularities on these results are pointed and discussed. In the same chapter, we also highlighted the importance of habitat generalist birds as potential providers of ecosystem services as well as the presence of rural homesteads as likely seed dispersal facilitator in highly disturbed landscapes. In the second chapter, we verified that type of adjacent matrix alters taxonomic and functional composition of bird communities inhabiting forest edges, and that an increase of forest cover may lead to a decrease in functional dissimilarities between bird communities within the both types of habitat interfaces (forest-pasture and forest-eucalyptus). Lastly, in the final chapter, using simulation scenarios we tried to predict how some bird functional traits at forest edges tend to be distributed according to adjacent matrix type, forest cover and land use heterogeneity.

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APRESENTAÇÃO

Vivemos atualmente uma época de grandes mudanças globais, e o estudo da ecologia não tem ficado de fora. Softwares de análise de dados têm se tornado cada vez mais potentes e eficientes, e o acesso à dados e informações geográficas e ambientais cada vez mais abertos e gratuitos. Até mesmo os softwares têm ficado muito mais acessíveis e desenvolvidos pelos próprios usuários. No entanto, não é apenas essa capacidade instrumental que vem se transformando e ampliando, nossas crenças e motivações vem ganhando novas direções. A Ecologia e a Economia, por exemplo, que até pouco tempo atrás eram duas áreas que se repeliam, hoje em dia vem sendo cada vez mais convidadas a conversarem entre si, e uma ciência cada vez mais especializada, e ao mesmo tempo aberta e integradora vem emergindo. Mas não apenas por questão de conveniência, sobretudo por questões de necessidade.

Os atuais níveis de degradação dos ecossistemas, aliados à crescente ameaça de mudanças climáticas, tem nos atingido de tal forma que as previsões de colapso ambiental hoje têm se tornado realidade, e esta realidade tem estimulado muito mais rápido a nossa mudança de postura e mentalidade do que o oposto. Prever os custos e efeitos ambientais das nossas ações sobre os ambientes hoje não é mais apenas assunto de ambientalistas, mas também de empresários, marqueteiros e economistas. Assim, uma visão mais aprofundada sobre os processos ecológicos que movimentam os ecossistemas torna-se primordial para um diálogo mais seguro, aberto e motivador entre as diferentes áreas de conhecimento. No entanto, aprofundar o conhecimento sobre o funcionamento dos ecossistemas não tem se mostrado uma tarefa simples e rápida.

Assim como os sistemas econômicos e sociais, os sistemas ambientais funcionam por meio de uma complexa rede de mecanismos e forças altamente interdependentes, e isto acaba dificultado ou até impossibilitando uma compreensão mais simplista ou mecanicista (causa e efeito) sobre seu funcionamento. Com isso, uma análise mais processual e relativa torna-se tão necessária quanto desafiadora. Os mecanismos ecológicos que regem, por exemplo, a provisão de serviços ambientais tais como a biodiversidade, provisão de água potável, sequestro de carbono, regulação climática, controle natural de pragas, capacidade de regeneração dos ambientes, entre outros, são gerados através da interação de diversas forças ou processos ecológicos e humanos que se combinam em diferentes escalas temporais e espaciais para produzirem tais efeitos ou serviços.

E foi tentando entender melhor as forças que regem esse complexo funcionamento dos ecossistemas que esta tese foi elaborada. Usando aves como grupo biológico de estudo, este estudo buscou avaliar como dois tipos de uso da terra (pastagens e plantações de eucaliptos), bem como a estrutura e configuração das paisagens alteradas podem interferir nos processos ecológicos que movem a biodiversidade e a provisão de serviços ecossistêmicos. Em suma, este trabalho visou não apenas contribuir para ampliar o conhecimento científico sobre o assunto, mas também gerar subsídios científicos para a tomada de decisão mais consciente em relação ao uso da terra e os recursos naturais que elas provem.

Fabio M. Barros

1. Introdução geral

A perda e fragmentação dos habitats têm levado a crescentes perdas de biodiversidade e serviços ecossistêmicos ao longo do mundo (Haddad *et al.* 2015; Mitchell *et al.* 2015). Nas regiões tropicais, essas mudanças são ainda mais severas, uma vez que são nessas regiões onde se encontram as maiores *hotspots* de biodiversidade do mundo (Myers *et al.* 2000). Na Mata Atlântica, por exemplo, mais de 70% de sua cobertura original foi substituída por agricultura, cidades e ocupações humanas (Ribeiro *et al.* 2009). Assim, uma maior atenção à esse processo de alteração dos habitats naturais é altamente necessário quando visamos um desenvolvimento mais sustentável e que garanta a qualidade de vida para as gerações futuras.

Resultantes do processo de fragmentação, os fragmentos de habitat remanescentes tendem a exibir uma qualidade ecológica inferior aos contínuos de habitat não fragmentados, e as espécies que habitam esses remanescentes acabam sofrendo alterações negativas quanto a abundância e diversidade, tornando-se assim mais susceptíveis à extinção (Fahrig 2003). Mudanças abruptas na estrutura da vegetação, resultante da retirada da floresta, alteram diversas condições microclimáticas nas bordas das florestas (entrada de luz, incidência de ventos, etc.), o que acaba levando também a alterações nas comunidades biológicas que vivem próximos dessas essas bordas, efeito que também se espalha muitas vezes ao interior dos habitats remanescentes (Murcia 1995). Além desse “efeito de borda”, a fragmentação da floresta cria também condições facilitadoras para a entrada humana dentro das matas remanescentes, elevando assim as chances de distúrbios secundários como caça ilegal, defaunação, pisoteamento das plantas regenerantes, e outros fatores que diminuem a qualidade dos habitats remanescentes (Peres 2001; Rocha-Santos *et al.* 2016). Estima-se que esses distúrbios humanos secundários gerados após o processo de supressão e

fragmentação dos habitats (incluindo o efeito de borda), podem até duplicar a perda de biodiversidade do que a perda dos habitats naturais por si só (Barlow *et al.* 2016). Com isso, torna-se nítida a necessidade de um uso mais racional da terra que considere a biodiversidade e a provisão de serviços ecológicos, sobretudo dentro do domínio da Mata Atlântica onde a quase metade da sua área remanescente se encontra atualmente sob esses efeitos deletérios de borda (Ribeiro *et al.* 2009).

De maneira geral, a fragmentação da paisagem e a intensificação do uso da terra tende a levar à homogeneização biótica (Devictor *et al.* 2008; Clavero & Brotons 2010; Duflot *et al.* 2014; Gámez-Virués *et al.* 2015), mudanças nas características ecológicas das espécies (Newbold *et al.* 2013; De Coster, Banks-Leite & Metzger 2015; Morante-Filho *et al.* 2015; Bregman *et al.* 2016) e até mesmo a alterações na história evolutiva (Bregman *et al.* 2015; Morante-filho *et al.* 2017) das comunidades biológicas remanescentes. Características, como por exemplo a habilidade de dispersão das espécies, pode se alterar em direção a homogeneização, no qual as espécies mais sedentárias tendem a aumentar sua capacidade dispersiva, e as espécies mais dispersivas (ou que se movimentam mais) tendem a diminuir sua capacidade dispersiva (Martin & Fahrig 2015). Até mesmo a competição entre as espécies pode promover o empobrecimento da biodiversidade dentro dos remanescentes florestais (principalmente os de menores tamanho) a partir da fragmentação da paisagem (Robertson *et al.* 2013; Bennett *et al.* 2015; Bregman *et al.* 2015).

Um dos principais fatores que levam a esses processos ecológicos citados acima é descontinuidade dos fluxos bióticos dentro das paisagens fragmentadas (Melles *et al.* 2012; Correa Ayram *et al.* 2015). Muitas espécies são especializadas e exigentes a certos tipos de habitat, e quando se deparam com a descontinuidade deles na paisagem, tornam-se mais susceptíveis a processos de endogamia e extinção (Fahrig

2007). Assim, em paisagens alteradas, as maiores taxas de biodiversidade são frequentemente associadas às paisagens mais conectadas, ou seja, paisagens mais permeáveis ao fluxo biótico (Melles *et al.* 2012; Correa Ayram *et al.* 2015).

Diversas características modulam o seu grau de conectividade da paisagem para os fluxos bióticos. O tamanho e configuração espacial dos remanescentes naturais, assim como a identidade, composição e diversidade das matrizes antropogênicas são primordiais para a dinâmica dos fluxos das espécies e populações, e assim ajudar a manter a biodiversidade em paisagens alteradas (Melo *et al.* 2013). A habilidade das espécies cruzarem ou mesmo habitarem matrizes antropogênicas dependem do tipo de matriz e da característica (ou exigência) ecológica das espécies ou grupo de espécies (Lees & Peres 2009; Kennedy *et al.* 2010; Aben *et al.* 2012; Biz, Cornelius & Metzger 2017). Por exemplo, se um tipo de matriz predominante na paisagem é reconhecida por favorecer a movimentação de espécies florestais, e assim aumentar a riqueza (número) ou abundância delas dentro dos remanescentes florestais rodeados por este tipo de matriz, isto não significa necessariamente que essa matriz também assegura o potencial evolutivo (diversidade filogenética) ou mesmo a diversidade e identidade das funções ecológicas desempenhadas pelas outras espécies dentro das mesmas comunidades que vivem nesses fragmentos florestais. Assim, avaliar como as comunidades se alteram em função não apenas da quantidade e qualidade de habitat naturais, mas também em função do tipo de uso antrópico do solo (matriz) na paisagem torna-se imprescindível quando a meta é ampliar o entendimento sobre o funcionamento dos ecossistemas em paisagens alteradas. Neste sentido, as mudanças e interações bióticas que ocorrem entre a borda do habitat remanescente e a matriz antrópica adjacente (*spillover effect*) emerge como um processo que, apesar de crucial para entender melhor

a conectividade e o funcionamento geral das paisagens, ainda é muito pouco estudado na literatura (Blitzer *et al.* 2012; Tschardtke *et al.* 2012).

Alguns poucos estudos têm avaliado este processo de transbordamento (*spillover*) de espécies e funções, sobretudo em insetos (Tschardtke, Rand & Bianchi 2005; Rand, Tylianakis & Tschardtke 2006; Peyras *et al.* 2013; Martello *et al.* 2016) e plantas (Brudvig *et al.* 2009; Dodonov, Harper & Silva-Matos 2013). No entanto, pouco se sabe sobre esse processo em relação às aves e suas funções e serviços ecossistêmicos. E considerando os possíveis efeitos da paisagem ao redor modulando tais relações dentro das interfaces de habitat, menos informação ainda se encontra disponível na literatura. Em relação, por exemplo, aos grandes vertebrados, ou seja, espécies que geralmente ocupam grandes áreas de vida, se movimentam mais, e são relativamente menos exigentes quanto à qualidade do habitat local, este tipo de processo ocorrendo dentro de interfaces de habitat torna-se menos importante, uma vez que este grupo de animais tendem a responderem às mudanças ambientais em escala espaciais maiores. No entanto, para as aves e outros vertebrados de menor porte que são bastante exigentes e restritos ao habitat local, uma avaliação mais minuciosa com relação a esse processo de *spillover* nesses organismos, torna-se não apenas possível, mas altamente necessário para o melhor entendimento do funcionamento de paisagens alteradas.

1.1. Aves como modelo de estudo

As aves (CLASSE AVES) participam de diversas funções ecológicas que ajudam a manter inúmeros ecossistemas ao longo do mundo (Sekercioglu 2006). Tanto nos habitats naturais como naquelas alterados pelo homem, as aves são capazes de

proverem diversos benefícios diretos e indiretos ao ser humano (i.e. serviços ecossistêmicos) (Sekercioglu 2006). Através de importantes funções ecológicas, como a dispersão de sementes, predação, polinização, remoção de carcaças, etc., as aves acabam ajudando na saúde e equilíbrio dos ecossistemas (Sekercioglu, Daily & Ehrlich 2004; Sekercioglu 2006). Em áreas agrícolas, aves insetívoras atuam no controle de pragas, ajudando a reduzir perdas em produtividade sem necessidade de pesticidas químicos (Maas *et al.* 2016; Boesing, Nichols & Metzger 2017), principalmente quando estas áreas agrícolas estão perto de florestas naturais (Karp *et al.* 2013) ou mesmo dentro de paisagem com maior cobertura florestal (Boesing, Nichols & Metzger 2017). Em pastagens abandonadas, aves frugívoras e dispersoras de sementes contribuem com a chuva de sementes, ajudando a promover a regeneração natural dos habitats (García *et al.* 2012; Carlo & Morales 2016) e processos de resiliência dos habitats (Bregman *et al.* 2016). Nos trópicos, uma grande variedade de espécies de plantas é polinizada por aves (especialmente os beija-flores), e apesar de proporcionalmente menos importantes que os insetos, elas também podem atuar como importantes agentes polinizadores em cultivos agrícolas (Sekercioglu 2011).

Apesar de bastante importantes para o equilíbrio dos ecossistemas, com o avanço da ocupação humana, as aves se tornaram altamente ameaçadas, e a diminuição de suas populações ou mesmo a perda de espécies pode comprometer o próprio desenvolvimento humano futuro através de perdas irreparáveis nas funções ecossistêmicas que as aves provem (Sekercioglu, Daily & Ehrlich 2004). Assim, avaliar essas funções e serviços ecológicos prestados pelas aves torna-se altamente necessário quando buscamos conservar não apenas elas próprias, mas também a saúde e funcionalidade dos ecossistemas que elas habitam (Whelan, Wenny & Marquis 2008). Até agora, poucos estudos tentaram quantificar as funções e serviços prestados

pelas aves (Luck *et al.* 2009, 2012), assim o desafio atual é obter estimativas significativas do potencial de provisão de serviços ecossistêmicos que possam serem incorporados em políticas de uso da terra (Sekercioglu 2006; Wenny *et al.* 2011; Whelan, Şekercioglu & Wenny 2015).

Por serem abundantes e relativamente mais fáceis de observar e estudar, as aves são, entre os vertebrados, o grupo mais conhecido quanto à diversidade de espécies e ecologia. Assim, inúmeros estudos ecológicos enfocando aves têm sido realizados ao longo do mundo, e grande parte do se conhece atualmente em ecologia de paisagem vem de estudos realizados com aves.

Além dos efeitos da borda antropogênica (Ewers, Thorpe & Didham 2007), da área (Banks-Leite, Ewers & Metzger 2010; Barbaro *et al.* 2012) e formato (Prevedello *et al.* 2013) da fragmento, e da cobertura florestal na paisagem (Martensen *et al.* 2012; Banks-Leite *et al.* 2014), estudos mais recentes vem reconhecendo o tipo de matriz (Kennedy *et al.* 2010; Kennedy, Zipkin & Marra 2016; Biz, Cornelius & Metzger 2017) e também a composição e heterogeneidade da paisagem (Deconchat, Brockerhoff & Barbaro 2009; Carrara *et al.* 2015; Lee & Martin 2017) como importantes fatores regulando a persistência das aves em paisagem antrópicas. Neste sentido, os processos ecológicos ocorrendo dentro das interfaces de floresta-matriz geradas pela fragmentação torna-se crucialmente importantes (Rand, Tylianakis & Tschardtke 2006; Blitzer *et al.* 2012; Tschardtke *et al.* 2012), uma vez que a habilidade das aves (e outros organismos também) em usar e cruzar diferentes tipos de interfaces ajudam a entender como as espécies, funções e serviços ecológicos que elas provem são capazes de fluir dentro das paisagens, ampliando assim o conhecimento sobre o funcionamento ecossistêmico em regiões bastante alteradas pelo homem (Rand, Tylianakis & Tschardtke 2006; Blitzer *et al.* 2012; Tschardtke *et al.* 2012).

Pastagens e plantações de eucalipto, além de serem ambientes contrastantes quanto a abertura da vegetação (pasto aberto e eucalipto fechado), e, portanto, funcionalmente diferente para diversos taxa, são uns dos maiores e mais frequentes tipos de matriz encontrados em paisagens alteradas no Sudeste do Brasil. No estado de São Paulo, mais precisamente ao norte da grande mancha urbana ocupada pela região da grande São Paulo, a maior parte das áreas agrícolas são ocupadas por pastagens e plantações de eucalipto. Assim, o contato de destes dois tipos de matriz com as bordas dos remanescente florestais é bastante comum e frequente na região, e apesar de alguns estudos terem avaliado a influência desses dois tipos de matriz na ocorrência de aves (Barbosa *et al.* 2017), os diferentes processos ecológicos ocorrendo dentro destas interfaces de habitat são ainda bastante desconhecidas da literatura científica, principalmente em relação às aves.

2. Objetivos gerais

Esta tese teve como objetivo básico investigar como algumas características dos habitats locais e de paisagem podem influenciar nos padrões de ocorrência de espécies de aves (principalmente em relação à composição e função das assembleias) em bordas de floresta e interfaces de floresta-matriz (pasto e eucalipto), além de quantificar o transbordamento (*spillover*) das espécies entre as interfaces de habitats. Para isso, a tese foi dividida em três capítulos – aqui apresentados em idioma inglês para facilitar o processo de publicação em periódicos científicos internacionais.

No primeiro capítulo usamos novas e eficientes ferramentas estatísticas para entender melhor os efeitos da paisagem e dos traços funcionais na ocorrência (e co-ocorrência) de espécies de aves dentro de bordas de floresta. No segundo,

quantificamos o potencial de provisão de serviços ecossistêmicos (dispersão de sementes, controle de praga e polinização) pelas comunidades de aves em interfaces de floresta-pasto e floresta-eucalipto, descrevendo o efeito de transbordamento (*spillover effect*) de espécies e funções dentro dessas das interfaces de habitat, e também avaliando a importância relativa do habitat local e da paisagem circundante no potencial de provisão desses serviços ecológicos nos três ambientes amostrados (bordas de mata, pasto e plantação de eucalipto). No terceiro e último capítulo, quantificamos a diversidade funcional dos três ambientes amostrados e analisamos a taxa de substituição (beta diversidade) de espécies e funções dentro dos dois tipos de interfaces de habitat, além de examinarmos como a paisagem circundante pode influenciar nas taxas de substituições encontradas.

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Chapter 1 - Research article

Markedly divergent values of bird-mediated ecosystem services across forest-matrix interfaces in human-altered landscapes

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Abstract

(1) Almost half area of the Atlantic forest remnants is under edge effects and in continuous biotic and abiotic changes with the adjacent matrices (*spillover effect*). Improving knowledge on the ecological processes related to ecosystem services (ES) provision within forest-matrix interfaces is essential and urgent to promote more efficient land use management in the face of rapid global changes. **(2)** In this study, we sampled bird communities by paired point counts in forest-pasture (FP) and forest-eucalyptus plantation (FE) interfaces in Brazilian fragmented landscapes to access differences in species richness and the provision of three key ecosystem services mediated by birds: pest control, seed dispersal and pollination. In addition, the relative importance of local and landscape features predicting the ES provision by birds at forests, pastures and eucalyptus was accessed by random forest algorithms. **(3)** The overall loss of ES provision by birds was almost twice higher from forest to eucalyptus than from forest to pastures. In general, habitat generalist species had higher ES in matrices (mainly pastures) while forest-specialists had higher provision in forests edges. FP interfaces had proportionally more sharing habitat species (mainly species providing seed dispersal and pollination services) than FE interfaces. Random forest algorithms showed large variation on the importance of landscape and local variables predicting ES provision. At forest edges, forest cover best predicted species richness and pest control services (and all ES provided by forest species), while the number of rural homesteads patches best predicted seed dispersal and pollination services. Landscape attributes were, in general, less important for predicting all ES provision in the both matrix types, and local features were particularly important to predict all ES by birds in pastures lands. **(4)** Our findings suggest that, at local level, FE interfaces can support smaller provision of ES by birds than FP, which highlight the importance of adjacent matrix type in the ES provision by birds at forest-matrix interfaces. Moreover, forest cover and number of patches of rural homesteads may be key elements to multifunctional landscapes that consider not only integrity of forest remnants but the higher provision of ES by birds at forest-matrix interfaces as well.

Introduction

Birds are involved in many ecological functions which are essential for the maintenance of several ecosystems on Earth (Sekercioglu 2006). In both natural and managed habitats, birds provide direct and indirect ecosystem benefits to humans. In natural ecosystems, birds are well-known to interfere directly on the ecosystem functioning (via seed dispersal, predation, pollination, etc.), contributing to ecosystem balance and health (Sekercioglu, Daily & Ehrlich 2004; Sekercioglu 2006). In croplands, insectivorous birds are known to reduce pest abundance and improve productivity (Maas *et al.* 2016; Boesing, Nichols & Metzger 2017), mainly when croplands are close to forests (Karp *et al.* 2013) or embedded in more forested landscapes (Boesing, Nichols & Metzger 2017). In abandoned lands, seed disperser birds may contribute with seed rain, helping the habitat regeneration (García *et al.* 2012; Carlo & Morales 2016) and resilience processes (Bregman *et al.* 2016). In the tropics, many plant species are pollinated by hummingbirds, and although proportionally less important than insects, they may act as important pollinator agents in croplands (Sekercioglu 2011).

Although birds are essential for the maintenance of important ecological functions and services, they are seriously threatened by human occupation. In tropical regions, habitat loss and fragmentation have been widely considered as the most drivers of bird decline in tropical regions (Lees & Peres 2006; Barlow *et al.* 2016). In South America, for instance, more than 70 % of the original Atlantic forest cover was replaced by croplands and human settlements, and almost half of its remnant area is highly fragmented, under edge effect and in direct contact to matrix lands (Ribeiro *et al.* 2009). Thus, to obtain meaningful estimates of ecosystem service provision to be incorporated in land use policies is urgent (Sekercioglu 2006; Wenny *et al.* 2011; Whelan, Şekercioglu & Wenny 2015).

In addition to effects of anthropogenic edges (Ewers, Thorpe & Didham 2007; Banks-Leite, Ewers & Metzger 2010) and forest amount (Martensen *et al.* 2012; Banks-Leite *et al.* 2014), the type of matrix (Kennedy *et al.* 2010, 2011; Biz, Cornelius & Metzger 2017) as well as the landscape composition and heterogeneity (Carrara *et al.* 2015; Barbaro *et al.* 2016; Lee & Martin 2017) have been increasingly recognized as an important factor regulating bird persistence in modified landscapes. As consequence, the interaction of both edge and matrix effect occurring at forest-matrix interfaces becomes crucially important (Rand, Tylanakis & Tschardtke 2006; Blitzer *et al.* 2012; Tschardtke *et al.* 2012). This may occur because the ability of birds (and other organism) to use and cross different types of habitat interfaces as well as how they interact with these between-habitat difference allow to understand the how the species are able to flow across human-altered landscapes, which can lead to severe consequences for the ecosystem functioning and provision of ecosystem services (Blitzer *et al.* 2012; Tschardtke *et al.* 2012).

Several recent studies have examined the effects and consequences of land use intensification on guilds, functions and ecological groups of bird communities. Particularly within tropical regions, insectivores, frugivores and nectarivores bird species has been pointed to be more sensitive to land use changes than other ecological groups (Sekercioglu 2012; Newbold *et al.* 2013, 2014a; Bregman, Sekercioglu & Tobias 2014; Bregman *et al.* 2016). In turn, large and forest specialist species have been replaced by small and generalist species (Newbold *et al.* 2013, 2014b; De Coster, Banks-Leite & Metzger 2015; Morante-Filho *et al.* 2015). Nevertheless, despite many information on functional changes within bird communities due to human disturbance have been emerged recently, few attention has been given to a further understanding on the relative importance of local and landscape factors modulating the strength of particular functions

straightly linked to ecosystem services provision by birds (Luck *et al.* 2009, 2012), In addition, concerning to bird spillover process across forest-matrix interfaces, even less information are available in the current literature (Blitzer *et al.* 2012; Tschardtke *et al.* 2012).

In southeastern Brazil, particularly in the east portion of State of São Paulo, pastures and eucalyptus plantations have become the most common matrices types and the relative importance of them in providing ES by birds in human-disturbed landscapes is not settled yet. In this study, we used diet-related traits to access the potential provision of three ecosystem services by birds across forest-pasture and forest-eucalyptus plantation interfaces: a) pest control (PC), b) seed dispersal (SD) and c) pollination (PO). We asked if there are differences in ES provision within and between those haibitat interface. In addition, we evaluated the relative importance of local and landscape features modulating these ES within edges of forest, pastures and eucalyptus plantation across highly fragmented and heterogeneous landscapes in the southeastern Brazil.

Methods

Study region

The study was conducted in a region composed by highly disturbed modified landscapes in the São Paulo State, close to the largest Brazilian urban patch (São Paulo city) in the southeastern Brazil (W 23° 04' 09 " , S 46° 32' 87"; Figure 1). The region was originally covered by Atlantic Forest, but was target of intense human exploration throughout many decades ago and the natural vegetation was successively replaced by crops, pastures and urban lands (Morellato and Haddad 2000, Ribeiro *et al.* 2009).

Most of rural lands in the region is currently composed by pasture and eucalyptus plantations, with smaller proportions of lands used as sugar cane and other agricultural fields such as corn, citrus, peach, grape, etc. (MapBiomass 2017). When compared to vast monocultures regions usually found in the northeaster of the São Paulo State or even in the central Brazil, in general the landscapes in the study region have more rugged reliefs, smaller rural lands (including local small farmers) and higher density of urban lands and land use diversity (Mazzei 2007, Camara and Caldarelli 2016, MapBiomass 2017).

The natural vegetation in the region is mainly composed by fragments of secondary forest growth (most of them highly disturbed, with different ages, shapes and sizes), wetlands and regeneration areas. Part of the study region includes two large continuous Atlantic Forest remnants (Serra da Cantareira and Serra da Mantiqueira) and between them one of the major ecological corridor in the Atlantic forest of southeastern Brazil, the Corredor Cantareira-Mantiqueira (SEMA/SP, 2009). The Köpper's climate classification for the study region is Cwa (Alvares *et al.* 2013) and elevation vary between 700-1700 m (Oliveira and Fontes 2000).

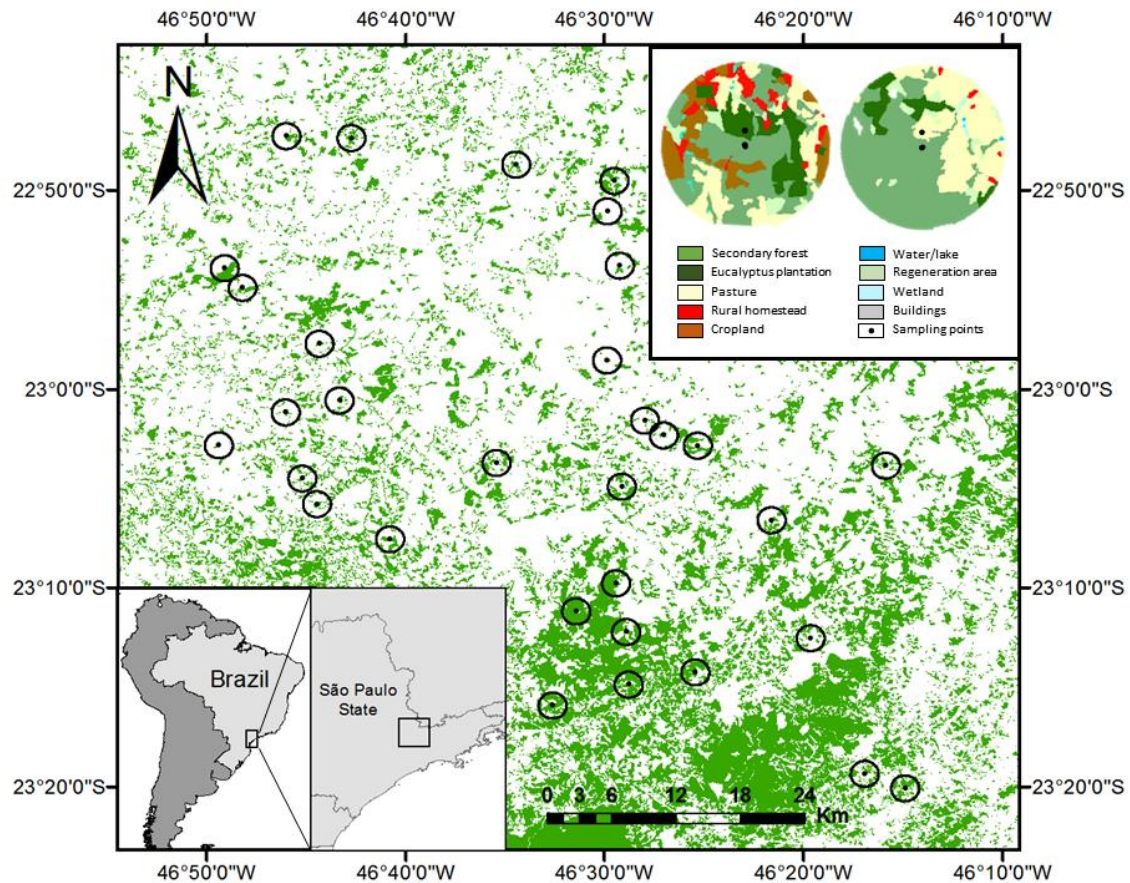


Figure 1. Study region containing 32 bird sampling sites (black dots) surrounded by circular landscapes in southeastern Brazil (data collect from 2014-2015). The green colour represents the native forest cover while the white background represents the non-forest matrix. The extended picture on the right illustrates two examples of paired point counts in (a) forest-pasture and (b) forest-eucalyptus interfaces, within 1.2 km radius circular landscapes classified according to land use types with low (a) and high (b) land use heterogeneity.

Sampling design

Bird communities were recorded at forest-matrix interfaces by 50 m fixed-radius point counts (Bibby *et al.* 2002, Sutherland *et al.* 2004). We sampled 16 forest-eucalyptus plantations and 16 forest-pasture interfaces, totalling 32 sampling sites across the study region. Each sampling site included two pairwise sampling points, one in forest edges and the other in the adjacent matrix (eucalyptus or pasture), both located around 70 - 100 m far from the edge (Figure 1).

The point-counts were conducted between the sunrise and the three first sunlight hours, for three times on different days (totalling 32 sites x 2 points x 3 day = 192 point-counts). All the surveys occurred over two breeding seasons (Sep 2014 to Jan 2015 and Oct to Dec 2015). With the aid of a Nikon Monarch 10x40 binocular, we registered all the birds seen or heard during 10 min on each point count. The bird vocalizations not promptly recognized in the field was recorded by a portable audio recorder (Zoom NH4) and identified later in lab. To maximize species detections, we also considered every species or individual registered during 30 min of irregular transects along 70-100 m trails from the edge to the sampling point. In this case, a special care was taken in order to avoid individual double counting between transects and point counts. The species abundance was measured as the highest value obtained among transects and point counts over the three sampling days.

In order to minimize spatial autocorrelation, the sampling sites were located at least 2 km far from each other, and to avoid spatial-temporal effect bias, we sampled points the most spatially random and non-aggregated as possible across the study region along the both sampling years. The sampling sites were selected in order to include gradients of forest cover (from 12 to 92%) and land use heterogeneity (Shannon diversity varying from 0.6 to 1.8).

Quantifying bird ecosystem services

For this study, we developed and used three new community metrics related to the ability of bird communities to provide ecosystem services such as pest control, seed dispersal and pollination across their habitats. To this, we used data on the percentage of invertebrates, fruits and nectar on the bird species diet (extracted from the database compiled by Wilman *et al.* 2014) as indicative of potential consumption of these food

items (strength of insectivory, frugivory and nectarivory by the communities). Then we used them as proxies of the provision of pest control, seed dispersal and pollination services, respectively. For each species sampled, the value of ES provision was measured from the species absolute abundance multiplied by its percentage of invertebrates, fruits and nectar for the communities, and for each community sampled in the point counts, the ES metrics were calculated from the sum of ES values for all species sampled. For comparisons and even to interpret it as proxy for indirect ES provision (see Mace, Norris & Fitter 2012; Mori, Lertzman & Gustafsson 2016; Ricketts *et al.* 2016), we considered the bird species richness (SR) in the analysis as well. Once these metrics might provide meaningful estimates of the strength of the ecological function and/or ecosystem service provided by birds (Luck *et al.* 2009), and as they seem to be easy-communicating, we believe that they should be very useful to the land use management.

All the ES metrics (PC, SD, PO and also SR) were also calculated from the perspective of forest specialist and habitat generalist species, and classified according to the experts' guess (Whitfield, Ruddock & Bullman 2008). To this, three experienced field ornithologists provided scores [from low (0) to high (10)] to each bird species sampled, considering the probability of the species be found within forest environment in relation to all the times they have ever observed the species in the field. We averaged the values gave by the experts, those species with mean ranging from 0 to 70 % of probability to be found in forests were considered habitat-generalists, while those species with mean 71 % or more were considered forest-specialists.

Local and landscape predictors

Two local variables were considered as predictors of ES potential provision by birds: *type of adjacent matrix* (ADJ), a categorical variable (pasture or eucalyptus) considered only at forest sampling sites and *local habitat* (LOC), a simplified measurement of vegetation structure and other local environmental features which was differently measured according to each habitat type. In forests, we recorded the mean number of trees with small, medium and large caliber (i.e. diameter at height breast – DBH - between 3-10cm, 10-30cm and > 30cm, respectively) within four equidistant 5 m radius circular plots, all 15m distant from the point-counts. To each variable, we considered the average value among the four plots. In the pastures stands we considered mean number of small and large trees (DHB < 2m and > 2m, respectively) within a 50m radius circular plots from the point count, as well as three other visually measured ordinal variables (low, medium and high): intensity of thickets, cattle and presence of streams/lakes within a 150m from the point count. For the eucalyptus plantations, we used mean tree height (m) and three other visually measured ordinal variables: intensity of ground and understory vegetation cover, intensity of native species and density of eucalyptus trees. Thus, we did a principal component analysis (PCA) with these local variables for each habitat type. The resulted scores from the first axis that best explained the total variation on the data (forest = 55.2 %; pasture = 51.3 % and eucalyptus = 59.9 %) was assumed as the local habitat (LOC) values.

As landscape predictors, we considered seven landscape variables: percentage of forest cover (FC), edge density (ED), Shannon diversity index for matrix lands (SHM), percentage of silvicultural area (i.e. *Eucalyptus* plantation; SILV), percentage of pasture area (PAS), rural homestead patch density (RUR) and water patch density (WAT). ED and SHM are metrics commonly used as proxy for landscape heterogeneity, the first

reflecting the amount of edges or habitat contacts within the landscapes (m/ha) regardless the type of land uses, while the second consider the diversity of land uses only within the matrix lands (disregarding forest fragments). As rural homesteads (RUR), we considered small patches with presence of warehouses, farm houses, scattered trees and woodlots (including mainly fruiting trees), small lakes, cultivars and livestock within rural lands. We included this metrics because we guess that they may gather several important resources for birds (perches, nest sites, food, etc.) in small areas, which can work as stepping stones or even suitable habitats for many bird species (mainly the habitat generalists ones), and then enhance the landscape connectivity for those species (Bennett, Radford & Haslem 2006; Uezu, Beyer & Metzger 2008; Derner *et al.* 2009; Manning, Gibbons & Lindenmayer 2009) and to ecosystem services provided by them (Mitchell, Bennett & Gonzalez 2013). Similar to RUR, water bodies (WAT) usually are surrounded by wetlands or riparian habitats which tend to host large amount of invertebrates (Taft & Haig 2005; Tozer, Nol & Abraham 2010) and when it have presence of scattered trees (as in our study area) (Prevedello, Almeida-Gomes & Lindenmayer 2017), it might act as stepping stones and foraging habitat not only to wetland specialist birds but to other species, mainly insectivorous and habitat generalists as well. Thus, we assume that the presence of these structures in the landscape can favour the movement of plenty species across disturbed landscapes, particularly the habitat-generalist and invertebrate-eating species that can play important pest control services across agricultural fields. We considered percentage of silvicultural and pastures areas in the analyses because these structures may regulate the landscape connectivity to forest and generalist birds (Barbosa *et al.* 2017), respectively, and thus regulate ES provision by birds in such habitat interfaces.

To compute the landscape metrics, we first elaborated land use maps within 1.2 km radius circular buffers from the forest sampling site by using the program ArcGIS 10.1 (ESRI 2011). To this, we considered 14 land use cover classes: forest, pasture, eucalyptus plantation, regeneration areas, wetland, cropland (diversified types, but mainly corn), sugar cane, water (lakes and reservoirs), urban areas, rural homesteads, urban homesteads (suburban areas), paved roads, buildings and bare soils. As background image for interpreting and classifying the land use maps, we used satellite images from the program Google Earth Pro (accessed from 25th March to 25th June 2016). The areas where we had doubts on the image interpretation were all checked and validated in the field. Once classified the buffers, we used Fragstats v.4 program (McGarigal *et al.* 2012) to compute all the landscape metrics.

As landscape level of effect, we considered 1.2 km radius circular buffers from the forest sampling site. We believe that the area inside this buffer should be large enough to include daily movements of the most bird species sampled (Odum & Kuenzler 1955; Schoener 1968), and also because it was the scale with the highest importance (among 300, 600, 900 and 1200 m spatial scales) to both species richness and abundance according to Random Forest analysis (Cutler *et al.* 2007; Bradter *et al.* 2013; see Appendix 2)

Data analysis

To test differences on the potential provision of ES by bird communities between paired habitats (forest-pasture and forest-eucalyptus) we used pairwise t-tests, and to access differences between the non-paired habitats (forest-forest or pasture-eucalyptus) we used Mann-Whitney tests (McDonald 2009). The spillover effect between forest-matrix, considered here as the extent to which the species in the communities are able to

share these habitats, was measured by the total values of ES provided by the species recorded only in forest, only in matrix (pasture or eucalyptus), and in the both (shared) habitats. To calculate total ES values, we considered the occurrence frequency of species as quantitative measurement in each habitat type, and for the shared habitats, we used the lowest value of occurrence frequency among forests and matrices.

To identify environmental characteristic that best explain ES by birds, we accessed the relative importance of nine predictors variables (two local-related plus seven landscape-related) in the four bird response variables (SR, PC, SD and PO) separated in forest-specialist, habitat-generalist and all bird species, across three habitat (treatment) types as forest, pasture and eucalyptus), we ran 36 regression tree models using Random Forest (RF) algorithms (Cutler *et al.* 2007; Drew, Wiersma & Huettmann 2011; Triviño *et al.* 2011; Crisci, Ghattas & Perera 2012). This step was done in the program R (R Development Core Team 2011, package “randomForest”). Each tested model had seven predictors variables, so that six of them (LOC, FC, ED, SHM, WAT and RUR) were included in all models and ADJ, PAS and SILV was included only to forest, pasture and eucalyptus treatments, respectively. We used machine learning algorithms such as RF to compute variable relative importance because it has been increasingly used by ecologists and its can be considered the most powerful, accurate and simple estimator of variable importance available (Cutler *et al.* 2007; Crisci *et al.* 2012, Evans *et al.* 2012, Mi *et al.* 2017). Using regression trees, this tool can calculate the variable relative importance among a large number of predictors and model complex non-linear relationships typical from tropical ecological systems (Cutler *et al.* 2007; Triviño *et al.* 2011; Crisci, Ghattas & Perera 2012, Evans *et al.* 2012). Furthermore, with simple and intuitive interface, this tool can provide better (or at least similar) predicting power than generalised linear models (GLMs) and other conventional statistical modelling, even in

small sampling size (Cutler *et al.* 2007; Grömping 2009). RF is particularly efficient when prediction is more relevant than a formal explanation of hypotheses (Evans *et al.* 2012), which may be particularly useful in cases which rapid and precise source of information should be generated to support human interventions into complex ecological systems in the face of the current global change scenario.

Results

In total, we recorded 200 bird species across all sampling sites, in which 83.5% were found in forest edges, 52.2% in pastures and only 24.5% in eucalyptus plantations. From the total number of species sampled, 54% were considered forest-specialist and 46% habitat-generalist. Regarding the diet, 89% had invertebrate in diet, 50% fruits, and only 10% had nectar in diet (mainly hummingbirds).

ES by birds across forest-matrix interfaces

Overall, ES by birds was significantly higher in forest edges than in matrix (pasture and eucalyptus), except PO that had no significant difference within forest-pasture interfaces ($z = -1.60$, $p = 0.10$) (Table 1, Figure 2). In general, there were no differences in ES mean between the two types of forest edges (with adjacent pasture and adjacent eucalyptus), except for habitat-generalist birds that had higher SR and PC in forests beside pastures than in forests beside eucalyptus plantations ($z = -2.87$, $p = 0.004$ and $z = -2.11$, $p = 0.03$, respectively, Table 1, Figure 2). The total number of forest specialist species found in the two types of forest edges was similar (84 in forests beside pastures and 91 in forests beside eucalyptus), however the total number of forest-specialist species found only in forests edges (without sharing the adjacent matrix) was

substantially higher in forests with adjacent eucalyptus (92 species) than in forest with adjacent pastures (68 species) (Figure 3).

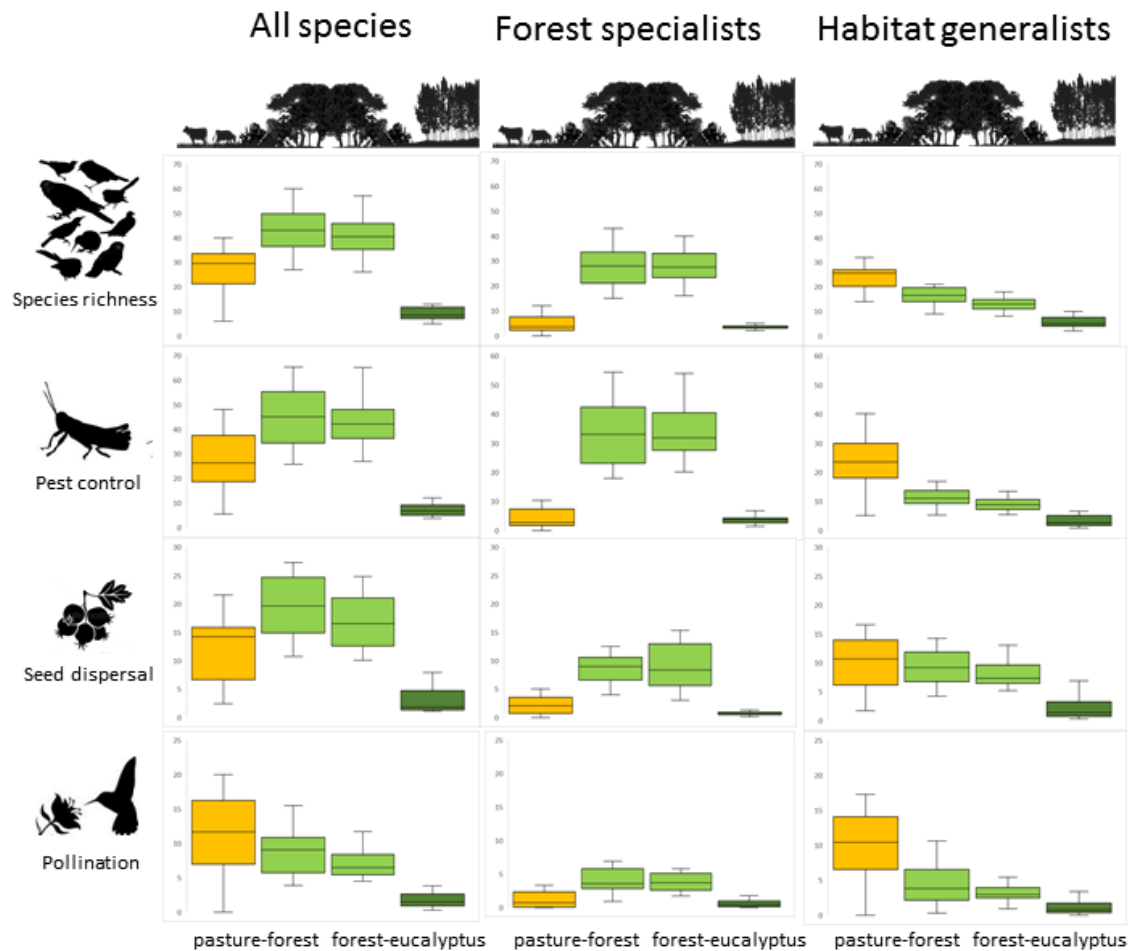


Figure 2. Ecosystem services provision by birds within forest-pastures (N=16) and forest-eucalyptus interfaces (N=16) across a forest loss and fragmentation gradient region in the State of São Paulo, southeastern Brazil (2014-2015). Results presented for all the bird community, and for the forest specialist and habitat generalist species. Values are shown as mean and standard deviation

Table 1. Mann-Whitney and paired t-tests evaluating differences in provision of ecosystem services by bird among habitats sampled. * $p < 0.05$ and ** $p < 0.001$.

<i>All species</i>	ForP Pas	ForE Euc	ForP ForE	Pas Euc
Species richness	+ - (**)	+ - (**)	= (0.17)	+ - (**)
Pest control	+ - (**)	+ - (**)	= (0.67)	+ - (**)
Seed dispersal	+ - (**)	+ - (**)	= (0.15)	+ - (**)
Pollination	= (0.14)	+ - (**)	= (0.14)	+ - (**)
<i>Forest specialists</i>				
Species richness	+ - (**)	+ - (**)	= (0.98)	= (0.52)
Pest control	+ - (**)	+ - (**)	= (0.94)	= (0.59)
Seed dispersal	+ - (**)	+ - (**)	= (0.68)	+ - (**)
Pollination	+ - (**)	+ - (**)	= (0.66)	= (0.48)
<i>Habitat generalists</i>				
Species richness	- + (**)	+ - (**)	+ - (**)	+ - (**)
Pest control	- + (**)	+ - (**)	+ - (*)	+ - (**)
Seed dispersal	= (0.18)	+ - (**)	= (0.33)	+ - (**)
Pollination	- + (**)	+ - (**)	= (0.48)	+ - (**)

Pasture stands had significant higher values than eucalyptus in all ES metrics (Table 1, Figure 2). Moreover, birds shared more total ES within forest-pastures interfaces than within forest-eucalyptus, especially to SR and SD by habitat-generalist birds (Figure 3). Eucalyptus plantations did not host any ES itself – all the values found within eucalyptus plantations were provided by bird species that used the both habitats (forest and eucalyptus) – except two generalist species (*Elaenia flavogaster* and *Cariama cristata*) that were found in few eucalypt stands and not once in forest edges (Figure 3). Pastures had a significant species pool (all habitat-generalists) occurring only in the pastures and not also in the adjacent forests (Figure 3).

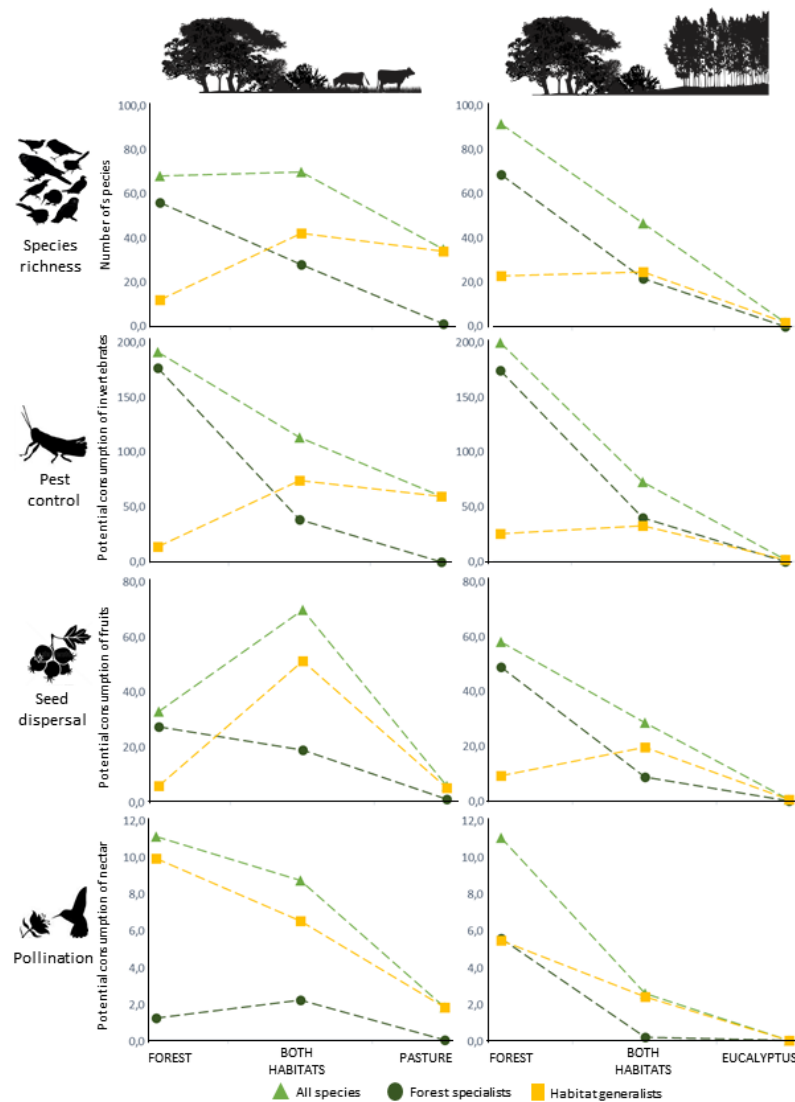


Figure 3. Spillover effect of the provision of ecosystem services by birds in forest-pastures and forest-eucalyptus interfaces. Values shown as total provision of ecosystem services within single and shared habitats.

The mean rates of ES loss from forest to pasture were 38 % for SR, 38 % for PC, 37 % for SD. Concerning to PO, there was a 26% of ES gain in pastures (i.e. higher values in pastures than in the forest besides). From forest to eucalyptus plantation there were ES loss of 78, 84, 82 and 73% for SR, PC, SD and PO, respectively.

Despite the forest-specialist species had higher overall contribution in ES within forests edges and the habitat-generalist species in the matrix, both had equivalent

contribution in SD within forest edges and in SR and PC within eucalyptus plantations (Table 2). At forest edges, habitat-generalist birds had even higher contribution than forest-specialist in providing pollination services (Table 1 and 2).

Local and landscape effect modulating ES by birds

Regression trees performed by Random forest algorithms showed a large range of results regarding the best environmental predictors explaining the ES, and the percentages of variation explained varied widely among the models (Figure 4, Table 2). At forest edges, the forest cover was the best environmental predictor for SR and PC within forest edges, and rural homesteads was the best for SD and PO (Figure 4, Table 2). Forest cover was the best predictor to all ES provided by forest birds at forest edges. At eucalyptus plantations, despite models had very low explained variation (several including negative values, see Table 2), metrics related to landscape heterogeneity – mainly Shannon diversity index - were the best predictors in all ESs (SR, PC, SD and PO) (Figure 4, Table 2). In pastures, local habitat variable was the best predictor to all ES provision. Regarding habitat-generalist birds in all treatments (habitat), the ESs were best explained by rural homesteads, edge density and Shannon diversity for matrix land use, and at forest edges, all ES provided by habitat-generalist birds was best explained by rural homesteads. Details about RF analysis, including all the non-linear relationships between predictors and response variables are found in the Supplementary Materials section (Apêndice II).

Table 2. Local and landscape variables best predicting provision of ecosystem services by birds in edges of forest, pasture and eucalyptus patches in southeastern Brazil. “Prop” means the relative proportion of ES provided by forest-specialist and habitat-generalist in relation to all bird species. “% var expl” refers to the percentage of variation explained by regression tree models performed by random forest algorithms.



	Pasture (N=16)			Forest (N=32)			Eucalyptus (N=16)		
	Prop	Best Predictor	% Var Exp	Prop	Best Predictor	% Var Exp	Prop	Best Predictor	% Var Exp
Species richness									
All species	1.00	LOC	15.9	1.00	FC	14.4	1.00	SHM	-30.9
 forest specialists	0.28	LOC	10.5	0.62	FC	15.0	0.45	ED	1.0
habitat generalists	0.72	RUR	-7.7	0.38	RUR	21.1	0.55	SHM	-7.7
Pest control									
All species	1.00	LOC	8.1	1.00	FC	-10.6	1.00	SHM	-40.6
 forest specialists	0.19	LOC	7.1	0.75	FC	-10.3	0.51	ED	-31.4
habitat generalists	0.81	LOC	-3.5	0.25	RUR	15.3	0.49	SHM	-27.1
Seed dispersal									
All species	1.00	LOC	20.5	1.00	RUR	11.2	1.00	ED	-43.9
 forest specialists	0.24	WAT	40.5	0.56	FC	-1.9	0.30	WAT	-2.4
habitat generalists	0.76	ED	0.5	0.44	RUR	8.4	0.70	ED	-37.6
Pollination									
All species	1.00	LOC	8.7	1.00	RUR	-18.1	1.00	FC	-10.0
 forest specialists	0.18	WAT	31.9	0.31	FC	-2.5	0.08	FC	19.8
habitat generalists	0.82	ED	-2.1	0.69	RUR	-24.5	0.92	ED	-7.1

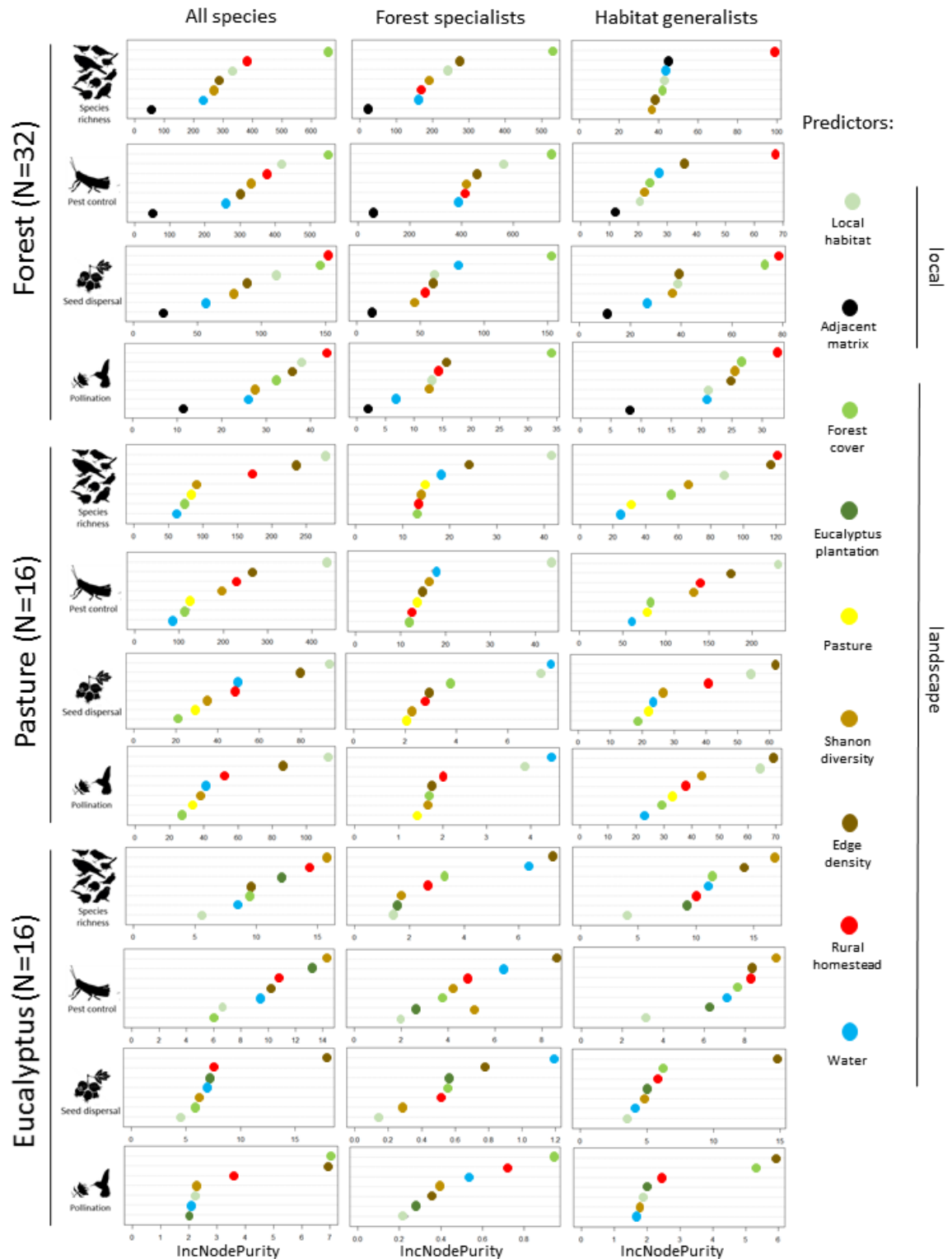


Figure 4. Relative importance of local and landscape predictor variables on the potential provision of ecosystem services by birds in forest pasture and eucalyptus, according to random forest analysis. IncNodePurity values means the total decrease in node impurities, measured by the Gini Index from splitting on the variable, averaged over all regression trees.

Discussion

Forest edges maintained significantly more provision of ES by birds than the adjacent pastures and eucalyptus. This corroborate with the literature once forest environments are well known to provide higher heterogeneity and productivity than simplified and managed habitats such as pastures or tree plantations (Tews *et al.* 2004). However, comparing the two types of matrices, eucalyptus plantation had significant lower provision of ES than pastures, and the overall loss of provision of ES from forest to matrix was almost twice higher in forest-eucalyptus than in forest-pastures interfaces. This difference can be related primarily to the local habitat features and the biotic and abiotic interactions across forest-matrix interfaces.

As local habitat had high relevance to all ES provision by birds in pastures (Table 2, Figure 4), we consider that the structural features and the proximity to water bodies along our sampled pastures are likely associated to resource availability for birds, mainly habitat-generalists (Söderström *et al.* 2001), and this may be triggering the higher ES values in pastures than eucalyptus stands. Although frugivorous birds had been observed as unaffected to spatial structure of tree cover in pastures close to primary forest edges in Amazon (Lasky & Keitt 2012), other studies have demonstrated the importance of vegetation structures in pastures to birds (Söderström *et al.* 2001). Clean pastures (without any scattered trees), for instance, tend to host less bird diversity than abandoned pastures with higher structural complexity and presence of scattered or clustering trees and shrubs (Laiolo *et al.* 2004; Saab, Petit; Victoria A 2017). Cattle in pastures may even act as ecosystem engineers increasing resources availability to grassland birds (Derner *et al.* 2009). Thus, considering that our sampling design in pastures did not considered entirely grazed pastures (with simplified structure, without trees or shrubs), our findings on higher provision of ES by birds in pastures, mainly seed

dispersal and pollination services, are likely limited to pastures with some degree of structural complexity and careful should be taken when interpreting these results.

The higher structural contrast between forest and pastures might be contributing to the higher values of ES found in these habitat interfaces, which included similar values of SD between forest and pastures and even higher values of PO in pastures (Table 1). When in contact with open habitats, forest edges tend to be more exposed to sunlight, favouring higher presence of light-demanding plant species (mainly shrubs and pioneer trees – i.e. *Cecropia sp*) (Watling & Orrock 2010). With this, it is expected that an elevated availability of flesh fruits and flowers (Oosterhoorn & Kappelle 2000; Galetti, Alves-Costa & Cazetta 2003), may attract higher amount of frugivorous and nectarivore species and consequently a higher provision of seed dispersal and pollination services by birds at these habitat interfaces. Furthermore, forest edges in direct contact with open matrix lands are known to provide higher nest predation (Manolis, Andersen & Cuthbert 2002) and higher abundance of nest-predator species (Chalfoun *et al.* 2002). Thus, we believe that the elevated plant-animal and prey-predator interactions (i.e. higher intensity of overall species interactions) that may occur in forest-pastures interfaces may generate higher resource availability not only to frugivorous or nectivorous, but also to insectivorous birds, enabling the higher potential provision of overall ES (including SR and PC) by birds across forest-pasture interfaces.

The importance of tree plantations to bird communities is relatively well studied worldwide. In the tropical regions, tree plantation may improving landscape connectivity to forest birds (Filloy *et al.* 2010; Volpato, Prado & dos Anjos 2010; Zurita & Bellocq 2010), as well as support well diversified bird communities (Volpato, Prado & dos Anjos 2010), mainly when the tree plantations are older, less managed, with presence of native vegetation (Barlow *et al.* 2007; Lopes *et al.* 2015; Millan, Develey & Verdade 2015) and

without pesticides use (Kroll *et al.* 2016). In opposite to some of these authors, our findings show low bird richness using eucalyptus stands close to forest fragments (49 out 200 species in total, 9 in average per sampling area) and the presence of forest-specialist species was below what we expected for this matrix type. This may occur because, despite we have accounted for local habitat variation, the eucalyptus stands sampled were, in general, homogeneous and with low or no presence of native vegetation (and understory), i.e. the worst scenario to bird species richness within eucalyptus plantation (Millan, Develey & Verdade 2015). Moreover, although landscape attributes have ever been demonstrated to little affect bird communities within eucalyptus plantations (Millan, Develey & Verdade 2015), the unexpected high relevance of surrounding landscape in relation to local features to all ES by birds in eucalyptus (Figure 4), may also be explained by worst scenario mostly sampled, despite the low explanatory power by the models (Table 2).

Species composition of bird in eucalyptus plantations was already found to be a subset of those communities inhabiting natural forests (nested pattern) (Wethered & Lawes 2005; Jacoboski, Mendonça-Lima & Hartz 2016). Thus, besides offering less resources to birds, simplified eucalyptus stands may offer the same resources already available in the forests besides, and this may explain, at least partially, the reason why we have found more total forest-specialist species not sharing habitats in forest edges in contact to eucalyptus (92 species) than in forest in contact with pastures (68 species) (Figure 3). Somehow a large number of forest species prefer to stay within forest edges than within eucalyptus, and despite our data cannot not confirm, this may be related to a lower value of eucalyptus as habitat to forest bird, but a higher value as connectors of forest fragments to forest species, when compared to pastures. Thus, more studies are needed to confirm this hypothesis.

Although our results concerning matrices stands be valid only to their edges in contact to forest fragments, we believe that within interior of large and homogeneous stands of pastures and eucalyptus, the ES provision by birds should be similar or even lower to our findings, because the lack of natural vegetation or stepping stones in the middle of large homogeneous matrices tend to difficult the occurrence of more diverse communities or a higher provision of ES.

The loss of ES potential provision by birds from forest to matrix found here should be carefully considered because other ecological processes and/or ecosystem services depending on the type of the surrounding matrix may occur within the forest fragments as well (see Rand, Tylianakis & Tscharnkte 2006; Blitzer *et al.* 2012). A study also conducted in fragmented landscapes in Brazil showed that forest fragments surrounded by eucalyptus plantation had higher proportion of small trees (i.e. higher regeneration or successional processes) than forest fragments surrounded by pastures (de Souza *et al.* 2010), indicating that, in spite of eucalyptus plantation can host few bird species and provide less ES by birds, the presence of such plantations surrounding the fragments may improve the regeneration processes and likely other ES associated to forest environments such as carbon sequestration, climate regulation, etc. in the remnant forest (Mori, Lertzman & Gustafsson 2016). Our results may somehow support this hypothesis as long as the seed dispersal services (or frugivory strength) by birds using only forest edge (and not the adjacent matrix) were indeed higher in forest besides eucalyptus than forest besides pastures (Figure 3), and since fruiting trees are available, seed rain promoted by seed dispersing birds can be higher within fragments surrounded by eucalyptus plantation than within those surrounded by pastures. Thereby, given the high complexity of ecological processes ruling modified landscapes, trade-offs among gain and loss of biodiversity and ecosystem services provision in both natural and managed

habitats should be more studied and carefully considered in land use management practices.

In general, habitat generalist birds were widely represented as ES deliverers in the matrix (both pasture and eucalyptus) and even in forest edges they had equivalent importance to forest-specialists bird when providing seed dispersal and pollination services (Table 2). Indeed, generalist birds are known to be very important seed disperser agents promoting tropical forest regeneration (Carlo & Morales 2016b) as well as good providers of pest control services in agricultural patches close to forest fragments (Boesing, Nichols & Metzger 2017). Due to its ability to use a broad range of habitats types and be more able to move through natural and managed habitats (Table 1, Figure 3), habitat generalist birds may be important ES deliverers across forest-matrix interfaces. In this sense, when the focus is the improvement of the ES provision in highly modified landscapes, more attention should be taken to habitat generalist birds.

At forest edges, landscape forest cover was the best predictor to species richness and pest control services by whole bird communities and to all ES (including species richness) provided by forest species (Table 2, Figure 4), confirming the expected influence of landscape forest cover to bird persistence (Martensen *et al.* 2012; Banks-Leite *et al.* 2014). However, once the available studies focused only in bird communities at forest interior, our results suggest that this pattern can be extended to those communities inhabiting forest edges, when considering the species richness and ecological functions played by the forest species.

Although landscape metrics related to land use heterogeneity (total edge and Shannon diversity index) were the best predictors to all ES and SR at eucalyptus plantation, the explanation power of the models were too low and not much informative (Table 2). In contrast, the number of rural homesteads patches in the surrounding

landscape was the best predictor to the seed dispersal and pollination services by whole communities at forest edges as well as to all ES services (including species richness) by habitat-generalist birds at forest edges. These results suggest that the higher presence of rural homesteads in the landscape (more than landscape heterogeneity *per se*) may enhance the landscape connectivity to avian deliverers of seed dispersal and pollination services. The presence of scattered trees and small woodlots (Prevedello, Almeida-Gomes & Lindenmayer 2017), including fruiting trees (Jacob, Lechowicz & Chapman 2017) may offer sufficient resource to many bird species, mainly thrushes (*Turdus leucomelas* and *Turdus rufiventris*) tanagers (*Tangaras sayaca* and *Tangara cayana*), hummingbirds (*Eupetomena macroura*) and bananaquits (*Coereba flaveola*), species that are very abundant in these areas, but that should be very important seed dispersers and pollinators agents in modified landscapes.

Conclusions

We demonstrated here that the loss of overall potential provision of ES (including species richness) by birds can be almost twice higher from forest to eucalyptus than from forest to pastures in tropical modified landscapes. Furthermore, besides the effect of forest cover to ES provision by bird in forest edges (mainly to forest birds), we also demonstrated the importance of the presence of rural homesteads in the landscape to ES provision by birds (mainly the generalist ones) at forest-pastures interfaces, which can be related to habitat regeneration in pastures close to forest fragments and wider resilience processes across modified landscapes. Thereby, our results highlight not only the importance of matrix type and landscape attributes in maintaining ES provision by birds in forest-matrix interfaces, but also the need to more studies quantifying potential provision of ES in modified landscapes.

Given the high complexity of the ecological processes occurring within our study system, we could not account for important features related to the ES provision such as (1) the quality of particular species interactions promoting the effective ES, (2) the dis-services (i.e. the seed dispersal and pollination of invasive and alien species, or predation on beneficial invertebrates to agriculture) provided by the species, and (3) the direct effect of the spillover patterns on ecosystem process within both forest and matrix lands. However, in spite of such limitations, we believe that this metrics can be very useful to evaluate wider patterns of ES provision by animal communities in large spatial scales, where more precise measurement (field experiments, for instance) is infeasible. Lastly, in the face of rapid global changes, further studies evaluating patterns of the species and functions spillover across habitat interfaces, as well as the environmental drivers of these patterns are particularly needed to better understand flows of functions and ecosystem services linked to resilience processes across disturbed landscapes.

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Chapter 2 - Research article

Matrix type and forest cover modulate avian functional beta diversity across forest-matrix interfaces

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Abstract

Land use intensification continues to promote biodiversity and ecosystem services decline worldwide. In disturbed landscapes, the matrix composition and forest cover are known to induce changes in communities inhabiting natural remnants, nevertheless few studies have evaluated how these changes occur in communities across natural and managed (forest-matrix) habitat interfaces. In this study, we quantified bird taxonomic and functional diversity (alpha and beta) within the two more common types of forest-matrix interfaces along the Atlantic Forest domain in the southeaster Brazil (forest-pastures and forest-eucalyptus plantation). In addition, using stepwise regressions, we tested the effects of landscapes attributes (forest cover, edge density and Shannon diversity) on bird beta diversity. Alpha taxonomic and functional richness (TR and FR, respectively) was higher in forest edges than the both matrix edge types, but between the matrices, pastures had significant higher values than eucalyptus for both TR and FR. Forests adjacent to eucalyptus (ForE) had significant higher species and functions replacements (beta diversity) than forests adjacent to pastures (ForP). For both taxonomic and functional component, bird communities inhabiting forest-eucalyptus interfaces were primarily nested while forest-pastures interfaces were primarily turnover. Landscape attributes related to land use heterogeneity did not explain beta diversity components, however increase in forest cover promoted decrease in functional beta diversity within both ForP and ForE (i.e. as higher the forest cover in the surrounding landscape, higher the bird functional similarity within forest-matrix interfaces). Our results highlight both matrix and landscape-mediated effects on bird communities inhabiting forest-matrix interfaces, which have profound implications to ecosystem functioning across disturbed and fragmented landscapes.

Introduction

Fragmentation and land use intensification have led to species loss and changes in biological communities across the globe (Haddad et al. 2015). In tropical regions, such process become even more threatening because the high biodiversity rates is usually found with the high deforestation and human pressure trends as well (Laurance 1999, Achard et al. 2002). The edge, area and isolation effects leads to decline the habitat quality, and thus to double biodiversity loss from deforestation *per si* (Barlow et al. 2016). In Brazil, for instance, more than 80% of original Atlantic Forest cover was lost and almost half area of the entire biome is currently under edge effects and in direct contact to adjacent matrix (Ribeiro et al. 2009). In this sense, information on the ecological processes occurring within interfaces of natural and managed habitats (forest-matrix) are crucial to better understand ecosystem functioning and patterns of biodiversity and ecosystem services loss across human-altered landscapes (Tscharntke et al. 2012).

In habitat boundaries, the cross-edge spillover of individuals and species is an ecological process particularly important once it is expected to interact with edge effects and consequently influence the overall ecosystem functioning (Blitzer et al. 2012, Tscharntke et al. 2012). Habitat corridor, for instance, are known to promote plant biodiversity to adjacent matrix (non-target habitat) via cross-edge spillover process (Brudvig et al. 2009). The most empirical studies examining these processes relates to plant or insects, mainly in agricultural landscapes (Tscharntke et al. 2005, Rand et al. 2006, Gladbach et al. 2011, Blitzer et al. 2012). Nevertheless, for vertebrates (particularly birds), cross-edge spillover process is still under studied and the available studies focus only on nest predation or parasitism (Paton 1994, Chalfoun et al 2002). Once bird communities inhabiting adjacent habitats are expected to interact between them, such community changes can be considered as cross-edge spillover processes as well. Thus

evaluating boundaries-mediated community changes may help to provide valuable insights on species flow and matrix permeability across in fragmented landscapes (Tscharntke et al. 2012).

Forest cover has been widely accepted as one of the most important factor for the maintenance of biodiversity and ecosystem function in fragmented landscapes (Banks-Leite et al. 2014). Nevertheless, in deforested landscapes, reforestation is often unfeasible due to economic and social costs. Thus, an alternative to minimize biodiversity loss can be manage matrix type and composition (Goulart et al. 2015, Ruffell et al. 2016).

For birds inhabiting agricultural landscapes, the diversity of land use types (landscape heterogeneity) has been pointed as an important factor for diversity maintenance (Haslem and Bennett 2008, Leyequién et al. 2010, Fahrig et al. 2011). The same occurs for the ecosystem services provision (Barbaro et al. 2016, Maas et al. 2016), and small-sized crop fields tend to host higher within-field diversity than the larger ones (Fahrig et al. 2015). However, landscape heterogeneity *per se* is not always clearly related to community process, and it tend to be very dependent on the matrix type and composition across landscapes as well as the species traits (Dufplot et al. 2014). In the USA, landscape heterogeneity was an important factor influencing taxonomic but not functional diversity of birds (Lee and Martin 2017) and more studies are needed to better understand these relationships. Furthermore, despite the most studies have tried to examine those landscape processes by sampling birds at forest patches, to date little is known on how the landscape attributes can affect both taxonomic and functional changes between communities inhabiting adjacent habitats such as forest-matrix interfaces.

Within the Atlantic Forest domain, pastures and eucalyptus are one of the most common matrix types surrounding forest remnants. Thus, considering that open (pastures) and closed (eucalyptus) matrix surrounding forest patches are known to

induce differential effects on birds communities within forest patches (Wethered and Lawes 2003, Barbosa et al. 2017), and that the landscapes attributes (mainly forest cover) are widely known to drive structure and functions of bird communities, in this study we aimed go further in this issue examining: (1) how bird communities behave in terms of alpha and beta diversity across forest-pastures and forest eucalyptus habitat interfaces and (2) how the surrounding landscape can alter patterns of species and functions loss or replacements across these two types of habitat interfaces.

Methods

Study area

Our study was conducted within the Cantareira-Mantiqueira Corridor, where highly fragmented and heterogeneous landscapes predominate in the south-eastern Brazil (W 23° 04' 09 " , S 46° 32' 87"). The region is part of Atlantic Forest biome, which has suffered with human interventions along the last centuries resulting in high levels of habitat loss, patch size reduction, increased forest isolation, with many of remnants disturbed (Ribeiro et al. 2009). In the Cantareira-Mantiqueira Corridor, the anthropogenic matrix lands are basically composed by pastures, eucalyptus plantation and urban zones, with small proportions of other land use type such as sugar cane plantation and other agricultural fields such as corn, citrus, peach, grape, etc. (MapBiomas 2017). The forest remnants are mainly composed by secondary forest fragments, including two large patches of continuous forest in the south-eastern of the region, and between them an extended ecological corridor, where are found landscapes with higher forest cover in the region. In addition to forest environments, the natural vegetation is composed by wetland

and regeneration areas (abandoned lands, primary succession). More details about the study region are found in Barros *et al.* (in prep).

Bird sampling

In the studied region, we selected 32 sampling sites apart at least 2 km from each other (Figure 1), wherein we sampled bird assemblages by 10 min pairwise point counts (Bibby *et al.* 2002, Sutherland *et al.* 2004). Each sampling site included one point-count within forest edges and the other within the adjacent matrix (pasture or eucalyptus plantation), so that from the 32 sites sampled, 16 were at interface of forest-pastures and 16 at interfaces of forest-eucalyptus plantations interfaces. The point counts were located at 70 – 100 m far from the edge in both forest fragment and matrices (pasture and eucalyptus), and consequently at least 140m apart. Each sampling point was sampled for 3 times, during two bird breeding seasons (from Set 2014 to Jan 2015 and then from Oct to Dec 2015). All birds seen or heard within 50 m fixed-radius were recorded by one trained observer (FB) during 10 min between sunrise and the three first hours. We also recorded and considered bird during 30 min of irregular transects along the trails from the edge and the exact sampling point. We included transects to maximize species detection and improve sampling representability, and in this case a special care was taken in order to avoid individual double counting between transects and point counts.

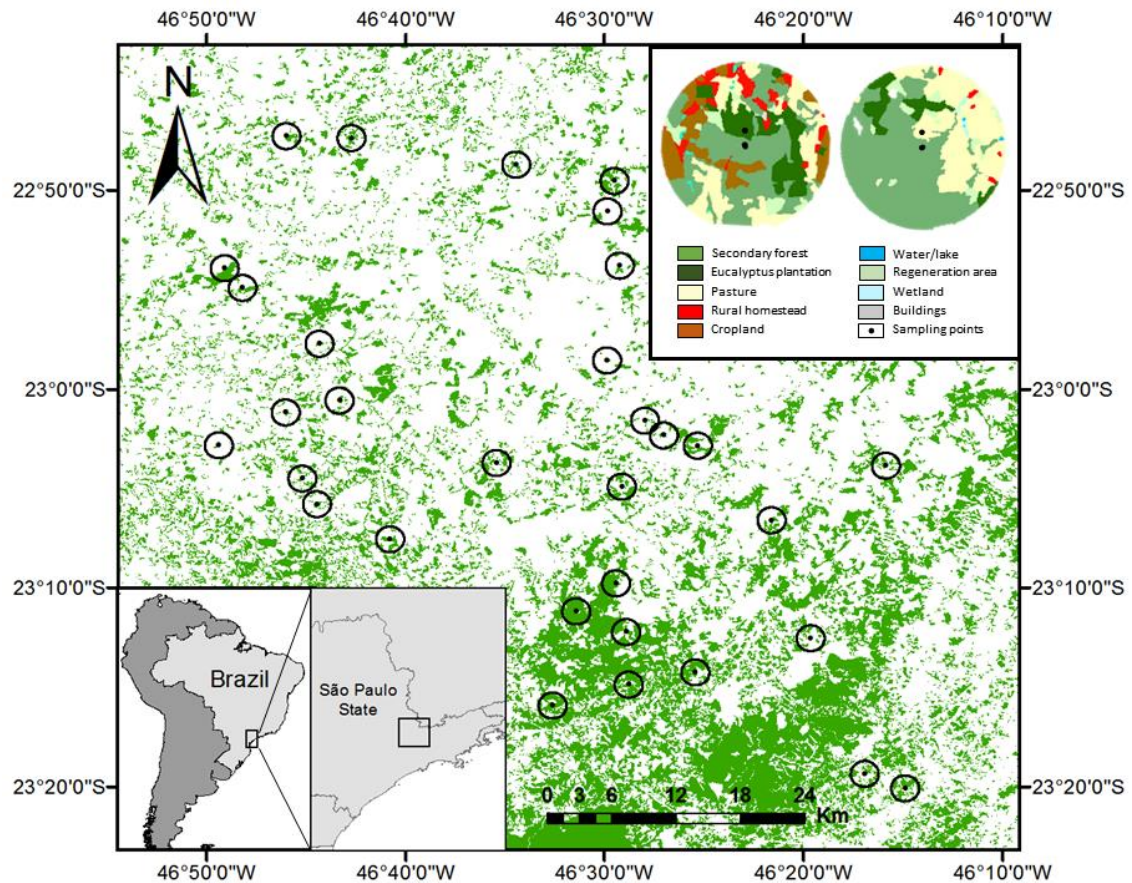


Figure 1. Study region with 32 bird sampling sites surrounded by 1.2 km circular landscapes in southeastern Brazil (data collect from 2014-2015). The green colour represents the native forest cover while the white background represents the non-forest matrix. The extended picture on the upper right corner illustrates the spatial design of paired point-counts sampled in forest-pasture (right) and forest-eucalyptus interfaces (left) in different landscape contexts.

The sampling sites were located at least 2 km apart from each other to minimize spatial autocorrelation. To avoid spatial-temporal effect bias, the points were sampled as most spatially random as possible across the study region along the both sampling years. The sampling sites were selected in order to include gradients of forest cover and land use heterogeneity within the surrounding landscapes.

Landscape variables

To quantify the landscapes predictors for each sampling site, we first mapped land use map in a 1.2 km radius circular buffer around the forest sampling point counts, using the program ArcGis (ESRI 2011). We considered 14 land cover types: forest, pasture, eucalyptus plantation, regeneration areas, wetland, cropland (diversified types, but mainly corn), sugar cane, water bodies (lakes and reservoirs), urban areas, rural homesteads, urban homesteads (suburban areas), paved roads, buildings and exposed soils. We used satellite images from the program Google Earth Pro (accessed from 25th March to 25th June 2016) as background image to support the land use maps elaboration. The image spatial resolution was around 1m and the images were classified at the fixed scale of 1:4000. The areas where we had difficulty for interpreting the images in the lab, field extensive checks were done. Afterwards we computed three landscape metrics using the program Fragstats v.4 (McGarigal et al. 2012): forest cover (%), edge density (m/ha) and Shannon diversity index for matrix lands. Edge density and Shannon diversity were chosen because they represent two distinct proxies for landscape heterogeneity. Given that birds are known to respond to land use heterogeneity, we included this metrics to evaluate if the same pattern occur with bird beta diversity across forest-matrix interfaces as well.

We considered 1.2 km radius size because it should be large enough to include the home range of the most bird populations sampled (Odum and Kuenzler 1955, Schoener 1968). Also because it was the scale with the highest importance (among 300, 600, 900 and 1.200 m spatial scales) according to Random Forest analysis (Cutler et al. 2007, Bradter et al. 2013, see Supporting information - Apendice II).

Functional traits and community indexes

We computed the number of species sampled as the species richness for each sampling site. To compute alpha and beta functional diversity, we considered six functional traits: (a) *body weight*, (b) *forest affinity*, (c) *clutch size*, (d) *diet*, (e) *foraging strata* and (f) *social behaviour*. Information on bird diet (invertebrates, vertebrates, seed, fruit, nectar, plant and waste) and foraging strata (ground, understory and canopy) were extracted in the data-paper published by Wilman et al. (2014). Data on clutch size and social system were extracted and interpreted from the information available at the Handbook of Birds of the World Alive (del Hoyo et al. 2016, online). We included *social system* (i.e. paired, alone, mixed-flocks or mono-flocks) as functional trait because it should influence interspecific interactions and consequently the bird community composition (Maldonado-Coelho and Marini 2004, Goodale et al. 2010) as well as the capacity of birds to cross and use adjacent matrices (Rodríguez et al. 2001). *Forest affinity* represents a quantitative measurement of the extent to which the species tend to use forest environments, and its values was generated by *expert guess* (Whitfield et al. 2008). To this, three highly experienced field ornithologists were invited to give values (scores) on the proportion of times they have observed each bird species in forest environments in relation to the total number of times they have already observed them in the field. Descriptions and data source of functional traits are shown in the Table 1.

As the main goal of our study was to examine how abrupt changes in habitat type (forest-matrix interfaces) can induce changes in species and functions composition (beta diversity) between adjacent communities, the traits chosen were predominantly response-traits, allow to understanding the response of birds to environmental change (Luck et al. 2009, 2012).

Table 1. Descriptions and data source of bird functional traits used to compute alpha and beta functional diversity metrics.

Functional trait	Subdivision	Description	Reference
Body mass		mean body mass	Wilman <i>et al.</i> (2014)
Forest affinity		probability of the species being found within forest environment	Expert guess
Clutch size		maximum clutch size	del Hoyo <i>et al.</i> (2016)
Diet	Invertebrates	proportion of invertebrates in diet	Wilman <i>et al.</i> (2014) <i>*adapted</i>
	Vertebrates	proportion of vertebrates in diet	
	Fruits	proportion of fruits in diet	
	Néctar	proportion of nectar in diet	
	Seed	proportion of seed in diet	
	Plant	proportion of leaf in diet	
	Waste	proportion of carrion or waste in diet	
Foraging strata	Ground	proportion of ground use	Wilman <i>et al.</i> (2014) <i>*adapted</i>
	Understory	proportion of understory use	
	Canopy	proportion of canopy use	
Social behaviour	Alone	probability of the species being observed alone in the field	del Hoyo <i>et al.</i> (2016)
	Pair	probability of the species being observed in pairs in the field	
	Mixed-flocks	probability of the species being observed within mixed species flocks in the field	
	Mono-flocks	probability of the species being observed within mono specific flocks in the field	

The body mass, forest affinity and clutch size traits were log-transformed to avoid that species with extreme values biased the analysis (de Bello *et al.* 2010). Diet, foraging strata and social behaviour functional traits are categorical and it were transformed in fuzzy variable (Pavoine *et al.* 2009). Functional richness (FR) represents the amount of functional trait space that each community occupy and here was considered as a proxy of the overall functional diversity (de Bello *et al.* 2010, Vandewalle *et al.* 2010). To calculate functional richness, a matrix of distance with all predictors were constructed and associated to the community site-species matrix to run with the FD package in R (Laliberté *et al.* 2014).

We decomposed taxonomic and functional beta diversity into turnover and nested components (Taxonomic turnover - TT, Taxonomic nestedness - TN, Functional turnover - FT and Functional nestedness – FN, Table 2). While the turnover component provides a notion about the differences in composition caused by species replacements, the nested component provides a notion about differences in composition caused by species losses (Baselga 2012). TT component was estimated by the Simpson diversity index, while TN was the difference between Sorensen diversity index (total beta diversity) and TT (Baselga 2012). Similar to the taxonomic ones, the functional beta-diversity across the two adjacent communities in forest-matrix interfaces was computed by the functional space not shared divided by the total functional space filled (Villéger et al. 2011). Both taxonomical and functional beta diversity components were calculated using the “Betapart” package in R (Baselga and Orme 2012).

Table 2. Types of bird functional diversity metrics examined in this study, and which treatment they were used by. ForP and ForE represents forest edges adjacent to pasture and eucalyptus, respectively; Pas=pasture, Euc=eucalyptus

Type of diversity	Components of bird diversity		Treatments
Alpha	Taxonomic richness (TR)	Functional Richness (FR)	Local habitats (ForP, ForE, Pas and Euc)
Beta	Taxonomic nested (TN)	Functional nested (FN)	Habitat interfaces (i.e. forest-pasture and forest-eucalyptus) or across the same local habitat type (i.e. ForP, ForE, Pas and Euc)
	Taxonomic turnover (TT)	Functional turnover (FT)	

Data analysis

Alpha and beta diversity by birds in forest-matrix interfaces: to examine differences on both TR and FR among the four types of habitat edges (i.e. forest edge in interface of pasture, forest edge in interface with eucalyptus, pasture edge in interface with forest and eucalyptus edge in interface with forest), first accessed normal distribution on data. To this, we performed a Shapiro-Wilk test in the residuals of a linear regression between each diversity indexes and type of matrix. Once we did not find normal distribution in any diversity indexes, we performed ANOVA test to access for differences in diversity indexes among habitats, followed by a post-hoc test (based on the Studentized range statistic Turkey “Honest Significant Difference” method. TR (taxonomic richness) was measured by species richness (i.e. number of species).

To examine differences in bird beta diversity (TN, TT, FN and FT) between forest-pasture and forest-eucalyptus interfaces, we performed Man Whitney tests.

Adjacent matrix effects on bird communities inhabiting forest edges: to access differences in between bird forest communities adjacent to different matrix we calculated and decomposed the taxonomical and functional beta diversity in turnover and nested components between forest communities adjacent to the same matrix. Afterwards we performed a Kruskal-Wallis tests to access similarities between forest in contact to pasture and eucalyptus.

Landscape effects on birds inhabiting forest-matrix interfaces: in order to investigate how the landscape variables affects taxonomical and functional similarities between bird communities located in pairwise point counts (forest and matrix), for each beta diversity component we fitted a linear model with all landscape predictors using

stepwise regression (Whittingham et al. 2006). This procedure fitted the model with best subset of predictors by AIC values. We also analysed the estimated parameters of the selected models to access what predictors were the main drivers, considering as “drivers” only predictors with slopes higher than 0.1 and significance lower than 0.005 (Benjamin et al. 2017). All statistical analyses were performed in R environment (R Development Core Team 2008).

Results

Alpha and beta diversity by birds in forest-matrix interfaces: taxonomic richness (TR) of bird communities differed among habitat types ($F=63.44$ and $p < 0.001$ ANOVA). Bird communities at forest edges had the highest TR, with no significant differences between forest adjacent to pasture and to eucalyptus ($44.18, \pm 9.77$; $40.6, \pm 8.46$). Pasture edges had intermediate values ($27.5, \pm 9.01$) while eucalypt edges had the lowest values of TR ($9.06, \pm 2.54$) (Figure 2). Functional richness (FR) also differed among habitats (Kruskal Wallis chi-squared= 37.62 and $p<0.001$). However, bird communities located in pasture edges had values as high as communities in both forest adjacent to pasture and eucalyptus ($10.21, \pm 2.54$; $9.15, \pm 1.34$ and $8.68, \pm 1.23$, respectively), while communities in eucalypt edges had the lowest values ($3.18, \pm 1.29$) (Figure 2).

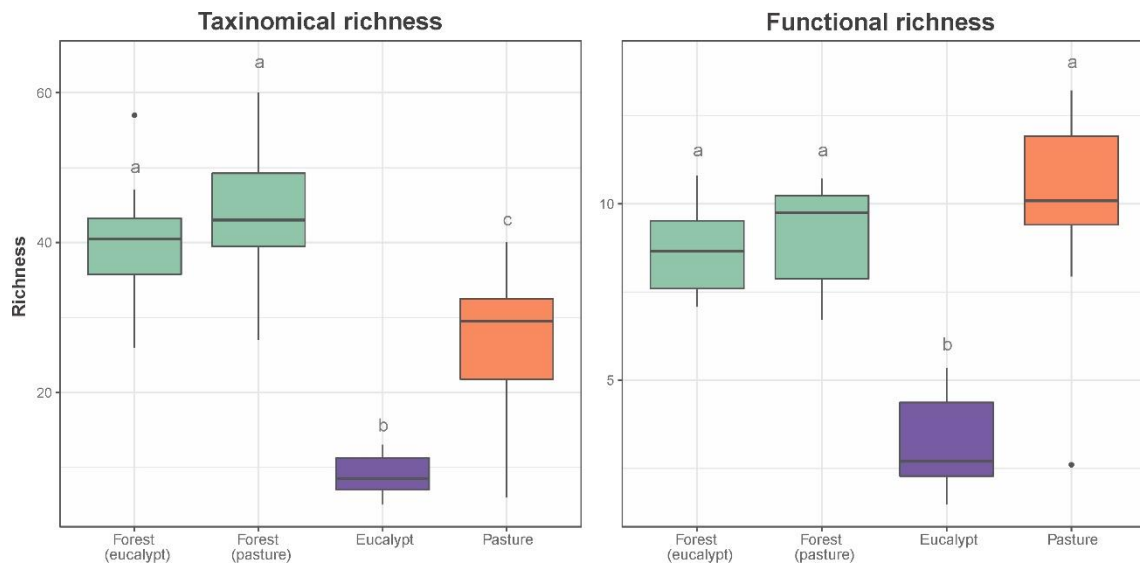


Figure 2. Means and standard deviation of taxonomical and functional richness by birds inhabiting forest edges adjacent to pasture and eucalyptus, and pasture and eucalyptus environments adjacent to forests environments.

Regarding bird similarity within habitat interfaces, for both nested components (TN and FN) forest-eucalyptus had significant higher values than forest-pasture interfaces (Figure 4). In contrast, for turnover component (TT and FT), forest-pastures had significant higher values than forest-eucalyptus interfaces (Figure 4).

Adjacent matrix effects on bird communities inhabiting forest edges: comparing the similarities among bird communities located in forest adjacent to pasture and similarities among communities located in forest adjacent to eucalyptus plantations, we found no significative differences in nested component for both taxonomic (TN) and functional (FN) beta diversity (Kruskall-Wallis chi squared = 6.12, $p=0.013$ respectively). However, the turnover component differed significantly between the two treatments (Kruskall-Wallis chi squared = 36.06, $p<0.001$ and Kruskal-Wallis chi squared = 45.08, $p<0.001$, respectively, Figure 3).

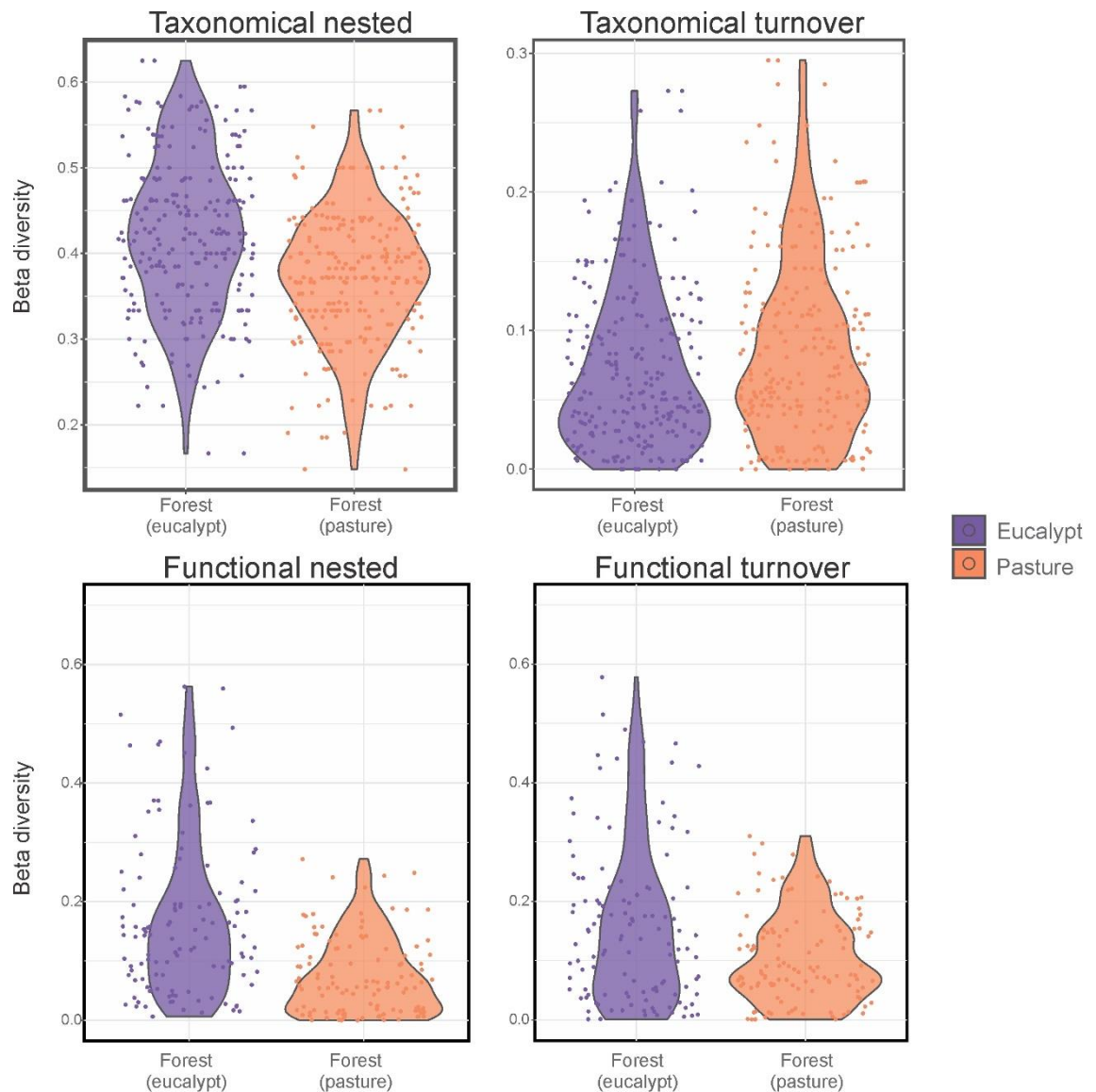


Figure 3. Bird taxonomic and functional beta diversity separated in two components (nested and turnover) within forest edges adjacent to pastures (orange) and forest edges adjacent to eucalyptus plantations (purple). Dots represents distribution values from all possible combinations among bird communities in each treatment type.

Landscape effects on birds inhabiting forest-matrix interfaces: comparing bird communities in forest edge and its adjacent matrix edge, we found that the type of matrix was the main driver of beta diversity components, for both taxonomical and functional beta diversity - once it was the only predictor present in selected models for all components of beta diversity with high and significant slope (Table 3). For taxonomical

nested component, the selected model included all predictors, however only percentage of forest, edge density and type of matrix had significant slope, and just the type of matrix have high slope value. These models also fitted functional nested component, wherein only percentage of forest and only type of matrix had significant slopes and just the latter with p value higher than 0.1. The fitted model for taxonomic turnover component had percentage of forest and type of matrix as predictors, but only type of matrix slope was higher than 0.1. Functional turnover was the only component of diversity wherein the fitted model was two predictors with significant slopes and strong effect: percentage of forest and type of matrix (Table 3, Figure 4).

Table 3. Selected models and slopes for nested and turnover components of taxonomic and functional beta diversity. Empty cells indicate that the correspondent predictor was excluded from the best model. In bold are shown the selected models wherein *, ** and *** means $p < 0.05$, 0.01 and 0.001 , respectively.

Beta diversity	Component	Forest cover	Shannon diversity	Edge density	Matrix type
Taxonomic	Nested	0.077*	-0.156	0.005**	-0.438***
	Turnover	-0.052*	--	--	0.381***
Functional	Nested	-0.095	-0.265	-0.007*	-0.639***
	Turnover	-0.177***	--	--	0.420***

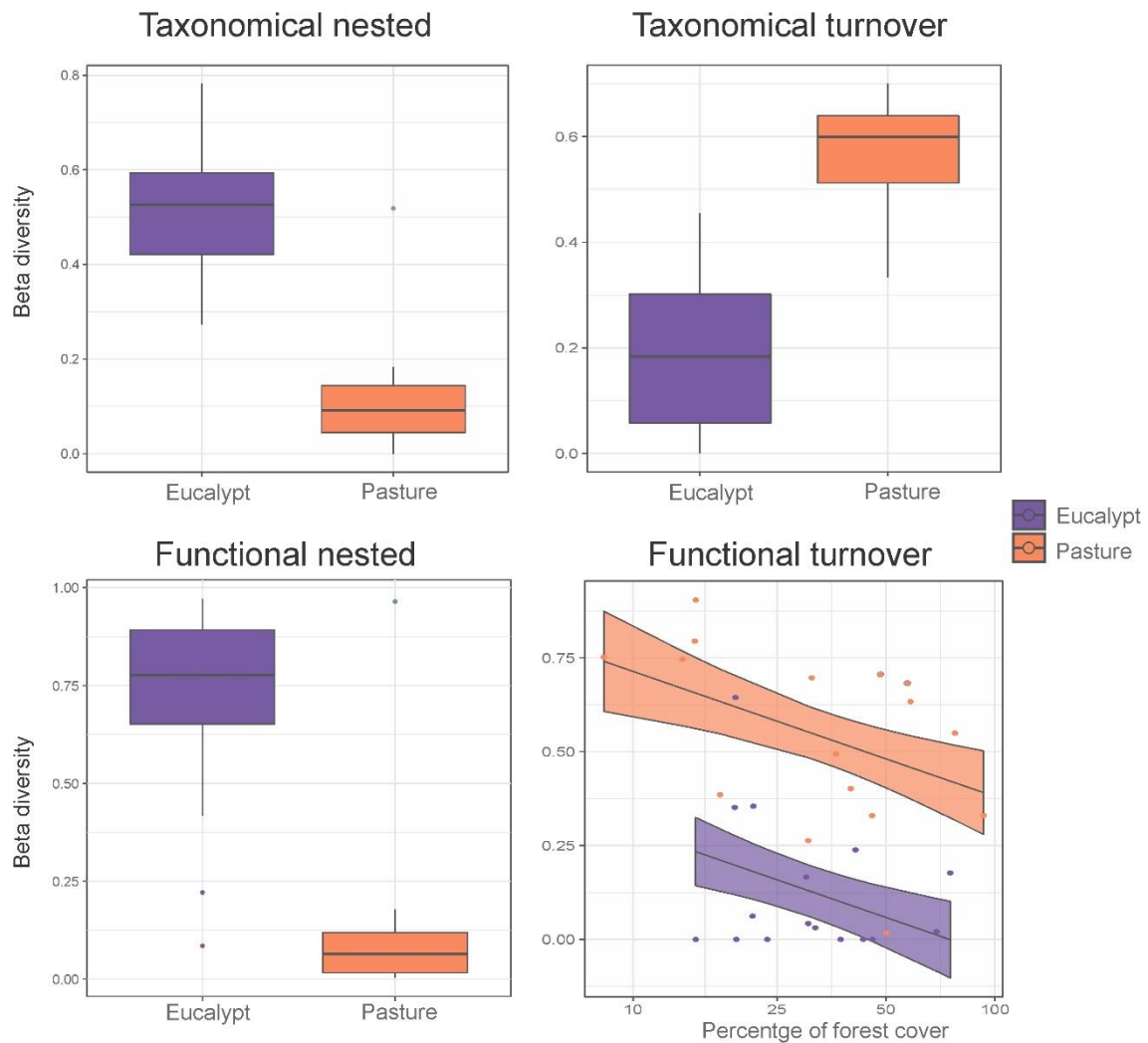


Figure 4. Matrix effect on bird inhabiting forest-matrix interfaces in tropical fragmented landscapes. The plots (mean and standard deviation) represent the differences on beta diversity components (nested and turnover) between forest-pasture and forest-eucalyptus interfaces. The lower right plot represents the effect of forest cover on the functional turnover between forest-pasture and forest-eucalyptus interfaces. Only models with p value equal or smaller than 0.01 and slope higher than 0.1 are represented in this figure.

Discussion

Improve knowledge on the cross-edge spillover process within habitat interfaces are essential to better understand ecosystem functioning (Blitzer et al. 2012, Tscharrntke et al. 2012). To our knowledge, this study is the first to quantify species and functions spillover (or even permeability) by birds across natural and managed anthropogenic edges, despite other studies have evaluated similar patterns to invertebrates (Martello et

al. 2016) and plants (Dodonov et al. 2013). This study should be the first bringing information on the landscape effect on spillover patterns within habitat interfaces.

The higher values of alpha taxonomic diversity found in forest edge compared to both matrix types confirmed what we expected. This pattern found is probably linked to the higher structural complexity and heterogeneity which provide wider niche breadth within natural habitats than in anthropogenic matrices such as pastures and eucalyptus plantation (Tews et al. 2004). However, unlike we expected, closed matrix types (eucalyptus plantation) had lower alpha diversity (taxonomic and functional) than open matrix (pastures). This suggest that, at least where it is close to forest edges, eucalyptus plantations may provide lower number of niches to birds than pastures. Some studies point that landscapes predominantly composed by tree plantations are able to minimize bird diversity loss (mainly forest species) within forest remnants (Wethered and Lawes 2003, Filloy et al. 2010, Zurita and Bellocq 2010, Ruffell et al. 2016, Barbosa et al. 2017). Thus, we expected that eucalyptus stands could sustain higher TR (taxonomic richness) than open habitats such as pastures, mainly when located right next to forest edges, however our results show the opposite pattern.

In our study, the local habitat quality may be a co-factor allowing the difference found in TR between pasture and eucalyptus. The suitability of eucalyptus stand to birds tend to be higher with the presence of native regenerating plants (Lopes et al. 2015, Millan et al. 2015). In our study, the most eucalyptus sampling sites were primarily composed with no or very few native trees within it. Moreover, pastures edges with no presence of scattered trees or water bodies tend to be host only ground and open-specialized bird species (Laiolo *et al.* 2004; Saab & Petit 1992), and our study did not consider clean pastures edges. Thus, the inclusion of worst scenario to eucalyptus sampling sites and better scenario to pastures sampling sites may bolster the differences

between the two types of matrices. Thus, when interpreting these findings, careful is needed.

Surprisingly, bird functional richness in edges of pastures were similar to those found in forest edges, which may reflect an equivalent niche breadth (or functional space) in both pastures and forests. Again, this can be related to the high structure complexity of pastures sampled, that should increase number of bird niches (Söderström et al. 2001). However, there was significant functional turnover from forest to pastures (Figure 3 and 4), so that despite similar functional richness, the taxonomic and functional composition was very different between edges of forests and pastures. This probably is linked to the identity of functional traits selected for the analyses (Trisos et al. 2014, Gagic et al. 2015). The presence of some structural characteristics within the pastures sampled (*i.e.* water bodies, small wetlands, cattle, bushes, scattered trees, etc.) may favour a high variety of feeding guilds as well as reproductive and social traits. For instance, small-bodied passerines such as thrushes (*Turdus* sp) and tanagers (*Tangara* sp) are common to occur in sympatry with large-bodied species (such as *Vanellus chilensis*, *Egretta thula*, *Cariama cristata*, *Mesembrinidis cayennensis*, etc.) within pastures but not in forest edges (persona communication). On the other hand, in pastures close to forest edges some forest species (intermediate to high forest affinity) can co-occur with open habitat species (low forest affinity), mainly when pastures are structurally diversified, but within forests edges, only species with high forest affinity are expected to occur. Thus, this functional compensation mechanism can explain the similar functional richness and high functional turnover by bird communities in pasture and forest edges.

In tropical landscapes, land use intensification may induce different but not fewer functions played by bird communities within forest patches (Newbold et al. 2013, De Coster et al. 2015). Our results on similar functional richness between forest and

pastures suggests that a similar pattern may also occur in small scale land use change such as transitions from forest edges to pastures stands. Thus, to better understand ecosystem processes and ecosystem functioning via functional (alpha or beta) diversity, more attention on the identity of traits used are needed, and comparisons of studies using functional diversity metrics should necessarily consider the identity and ecology characteristic of traits selected (Mokany et al. 2008, Luck et al. 2013, Trisos et al. 2014, Gagic et al. 2015).

The high values on nested component of beta diversity (for both taxonomic and functional) of birds across forest-eucalyptus interfaces agree to other similar studies comparing bird communities in forest patches and tree plantations (Wethered and Lawes 2005, Jacoboski et al. 2016). Nested communities often occur by selective loss of species and functions, so that in our study only species with less ecological requirements are able to cross and use planted forest (Feeley et al. 2007). Other neutral processes such as dispersal or migration can be resulted by the nested pattern found as well (Ulrich et al. 2009). To data, the The high bird functional and taxonomic turnover between adjacent forests and pastures was unknown in the literature until then according to our knowledge, and this suggest that pasture may represent a much more distinct matrix type in terms of types of niches available to overall bird communities than eucalyptus plantation.

Several factors are known to change the magnitude of the edge effects, mainly patch area (Banks-Leite et al. 2010), shape (Prevedello et al. 2013) and edge contrast (Watling and Orrock 2010). In this study, we provided clear evidence of differential effect of matrix type in taxonomic and functional beta diversity across bird communities in forest edges. Despite only detected by observing changes in species and functions composition (beta diversity, Figure 3), and not by alpha diversity indexes (Figure 2), matrix effect

probably contributes to the strength of edge effect in birds. In addition, the fact of forest edge allow more bird species and functions replacements among them when they are adjacent to eucalyptus than when they are adjacent to pastures may suggest a higher capacity of eucalyptus stands in connecting forest patches than open matrix such as pastures (Barbosa et al. 2017). Although our findings do not allow to identify which functional groups or guilds were more affected by this effect mediated by adjacent matrix, we suppose that the forest specialist should be main ecological group responsible for those difference. When compared to forests adjacent to pastures, forests adjacent to eucalyptus were found host higher number of forest specialist species that are restricted to forest edges (i.e. do not share the adjacent matrix) (Barros et al. in prep), which may improve the evidence that eucalyptus stands adjacent to forest edges may facilitate cross-edge spillover of forest species in forest-matrix interfaces. Thus, we suggest that further studies identify which guild, traits or functional groups in forest edges are more sensible to matrix type effects.

To our knowledge, the effect of landscape attributes on the rate of species or functions replacement within habitat interfaces was little or nothing investigated so far. As expected, our results found that, given the functional traits selected, the functions played by the adjacent bird communities (in both forest-pasture and forest-eucalyptus interfaces) tend to become more similar between with increase on surrounding forest cover. In other words, when surrounded by high levels of forest cover, the species inhabiting forest-matrix interfaces tend to converge functionally, increasing the functional spillover and permeability across both sides of edges. This may have important implications to landscape functioning. In highly deforested landscapes, the lower bird functional spillover or permeability across habitat interfaces tend to reduce the connectivity of functionally important species across the landscapes. For bird-mediated seed dispersal, for instance,

the lower permeability of such habitat interfaces in highly deforested landscapes may compromise habitat regeneration leading to a collapse on resilience-related processes at landscape level (Bregman et al. 2016).

Despite the models selected had included landscape edge density as a variable with certain significance as well, the slopes were too slight and this is enough to assume a weak relationship. Indeed, the extent to which the surrounding landscape are “fragmented” by edges is linked to the amount of habitat interfaces, and despite a supposed relationship between beta diversity across forest-matrix and edge density could help understand spillover and movement of birds across the landscapes, it would be still difficult to have a clear notion on how this occur. As our study shows, the type of habitat interface should affect differently landscape connectivity to birds and likely is trait-related, thus, despite the weak relationship found and the complex interpretation, we still argue that the amount of edges in landscapes should be an important covariate modulating bird persistence in disturbed landscapes, and therefore need to be more precisely investigated in further studies.

Future studies recommendations: to a more complete understanding on ecological processes operating at landscape level, we suggest that future studies need go further on the understanding on (1) how do the cross-edge spillover process occur in other types of forest-matrix and even matrix-matrix interfaces, and (2) which function (or trait) are more or less affected in cross-edge spillover processes according to changes in landscape attributes or land use intensification.

Lastly, we argue that information on beta diversity (turnover or nested) within habitat interfaces could be reflect the degree of percolation or permeability of habitat interface, and then used as reference (or training data) for elaborating models and maps

that help to predict species and functions flows across broader spatial scales and then improve knowledge on the functioning of disturbed landscapes.

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Chapter 3 - Research article

Surrounding landscape and matrix type as ecological filters in functional traits and community processes by birds in fragmented forests: a simulation approach

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Abstract

The relative effects of traits, environmental attributes and spatial random processes driving metacommunity dynamics are not well settled yet. Recently, many efforts have been made to better understand those processes in global scales. However, approaches in regional spatial extents is need for generate valuable insights concerning to community and several key ecosystem processes maintenance. Using joint species distribution models, we used data on bird communities inhabiting forest environments in tropical fragmented landscapes to examine how habitat type and landscape processes can influence species richness, community similarity and trait distribution within fragmented landscapes. In addition, using a scenario simulation approach and considering continuous forest as baseline, we predicted distributions of seven functional trait for bird at different habitat and landscape conditions. Fixed effect such as landscape features structure explained 67% of the variance for species richness, mainly forest cover (30%) and edge density (27%) Spatial random effects has little influence (12%) in the bird occurrence models. Altogether, functional traits explained only 12% of the species response to environmental change. In addition, we observed that phylogenetic related species responded similarly to environment change. Bird traits – forest affinity, body mass, clutch size and insectivoy – were negatively related to forest loss and edge density. All traits were lower at forest edges compared to continuous forest. Forest edges in interface with pastures had considerably higher values of frugivory degree than forest edges in interface with eucalyptus plantation., which This should be linked to structural contrast in the habitat across these different forest-matrix interfaces. We highlighted that not only the community structure are influenced by human-induced habitat disturbance, but bird functional traits are particularly affected by gradients of fragmentation and human disturbance, some in which may also affect ecosystem functioning and ecosystem services provision.

Introduction

The anthropogenic edges created from habitat fragmentation usually trigger several synergetic effects throughout human-altered landscapes (Brook et al. 2008). Ecological processes such as species invasions (Cadenasso and Pickett 2001, Honnay et al. 2002), species interactions (Fagan et al. 1999, Harper et al. 2005), nutrient cycling (Weathers et al. 2001, Vasconcelos and Luizão 2004), pollination (Aizen and Feinsinger 1994), herbivory (Cadenasso et al. 2003), seed dispersal (Saavedra et al. 2014, Vespa et al. 2014), hunting pressure (Peres 2001) and local climate change (Ewers and Banks-Leite 2013, Latimer and Zuckerberg 2016, Arroyo-Rodríguez et al. 2017) are known to be severely altered by such human disturbances, which often leads to biodiversity and ecosystem services decline (Melo et al. 2013, Haddad et al. 2015).

For many taxa, particularly birds, land use intensification usually acts as environmental filter, favouring some ecological traits and restricting others. For instance, insectivores, frugivores and nectarivores birds are predicted to suffer disproportional losses than other species from land use intensification (Newbold et al. 2014), and in fragmented forests, forest-specialist species tend to be replaced by habitat generalist ones (Carrara et al. 2015, Morante-Filho et al. 2015). Yet, such human disturbance usually leads to homogenize traits distribution. Variation in dispersal ability in birds, for instance, is expected to moving toward homogenization, with lower dispersal abilities to dispersive species and higher dispersal abilities to sedentary ones (Martin et al. 2017). A recent study also demonstrated that the smallest and largest-bodied animals, including birds, are at higher extinction risk due to human interventions than animal with intermediary body sizes (Ripple et al. 2017).

Characterizing ecological traits is essential for determining the individual and species responses to biotic and abiotic variation as well as their ability to adapt to

particular environmental condition (response trait; Vandewalle et al. 2010, Gallagher et al. 2013). In contrast, some ecological traits may be also related to the ability of species in affecting the ecosystem functioning or even providing ecosystem services (effect traits; Luck et al. 2009, 2012, Vandewalle et al. 2010). Thus, the identification of both types of ecological traits (response and effect) can provide a wider perspective on processes shaping functional dynamics of biological communities and its relation to ecosystem functioning. Therefore, analysing community processes in terms of functional traits can be much more informative than analysing community processes in terms of species identities (McGill et al. 2006, Cadotte et al. 2015).

The diversity of functions played by the communities (functional diversity) are often used to characterize the responses of communities due to environmental change and human disturbance (Mouillot et al. 2011, Carmona et al. 2016). However, it usually fails on estimate a direct effects of the communities on ecosystem functioning (Mokany et al. 2008, Gagic et al. 2015). Thus, the ecological identity of certain functional traits may provide better predictions of ecosystem function than other community indexes, even those related to functional diversity (Mokany et al. 2008, Gagic et al. 2015).

Although several efforts have been made to better understand the role and the relative importance of habitat, landscape and species traits in patterns of bird occurrence, many questions are not well settled yet. The evaluation of the response of species traits to human disturbance, and mainly the impact of their losses on the ecosystem functioning and provision of ecosystem services is still little known. Some studies have focused on the global patterns on human disturbance, such as habitat fragmentation, on community processes (Buckley and Jetz 2008, Devictor et al. 2008, Belmaker et al. 2012, Bregman et al. 2014, Newbold et al. 2016) and traits distribution (Jetz et al. 2008, Olson et al. 2009) by birds. However, to improve prediction accuracy on both loss and

replacements on species and traits, studies testing these global predictions in regional scales are particularly needed.

In this study, we model bird species occurrence at forest environments (edges and continuous forests) using joint species distribution models (JSDM), to examine the relative importance of habitat, matrix type, landscapes attributes and spatial processes in bird community processes. In addition, we used simulation Scenarios to predict bird functional trait distribution in controlled habitat and landscape conditions. In particular, we asked: (1) how much variation in bird species occurrence in a gradient of forest loss and human disturbance is due to environmental filtering (habitat and landscape) and random processes? How do functional traits influence the bird species responses to environmental change? (2) how is bird functional trait and community structure predicted to change under various scenarios of human degradation in habitat and landscape levels?

Methods

Study area

Our study was conducted throughout a vast region composed by highly fragmented and heterogeneous landscapes in the south-eastern Brazil (W 23° 04' 09 ", S 46° 32' 87"). The region suffered human interventions along several years ago and the original cover of Atlantic forest is currently highly fragmented and disturbed. The matrix lands in the region are basically composed by pastures, eucalyptus plantation and urban zones, with small proportions of other land use type such as sugar cane plantation and other agricultural fields such as corn, citrus, peach, grape, etc. (MapBiomass 2017). The forest remnants are composed by secondary forest fragments, including two large

patches of continuous forest in the south-eastern of the region, and between them an extended ecological corridor, where are found landscapes with higher forest cover in the region. In addition to forest environments, the natural vegetation in our study region is composed by wetland and regeneration areas (abandoned lands, primary succession).

Bird community sampling

Bird communities were sampled by 10 min point counts (Bibby et al. 2002, Sutherland et al. 2004) in forest edge adjacent to pastures (N=16), forest edges adjacent to eucalyptus plantation (N=16) and interior of continuous forest (control, N=2) totalling 34 point-counts sampled. The control sampling sites were located within the interior of large patches of continuous forest at least 1 km from the edge, while the other sampling sites were located at 70-100 m far from the edge. All sampling sites were sampled for 3 times each one, during two bird breeding seasons (from Set 2014 to Jan 2015 and then from Oct to Dec 2015). All birds seen or heard within 50 m fixed-radius were recorded by one trained observer (FB) during 10 min between sunrise and the three first hours. We also recorded and considered all birds seen or heard during 30 min of irregular transects along the trails between the edge and the exact sampling point. We included transects to maximize species detection and improve sampling representability, and in this case a special care was taken in order to avoid individual double counting among transects and point counts.

The sampling sites were located at least 2 km far from each other to minimize spatial autocorrelation, and to avoid spatial-temporal effect bias, the points were sampled as most spatially random as possible across the study region along the both sampling years. The sampling sites were selected in order to include gradients of forest amount and Shannon diversity index to matrix lands within the surrounding landscapes.

Functional traits

To this study we included seven bird functional traits: (a) *forest affinity*, (b) *body mass*, (c) *clutch size*, (d) *insectivory*, (e) *frugivory*, (f) *ground use* and (g) *understory use*. Data on *clutch size* was extracted and interpreted from the information available at the Handbook of Birds of the World Alive (del Hoyo et al. 2016), while information on *insectivory* and *frugivory*, *body mass*, *ground* and *understory use* were extracted from Wilman et al. (2014). The *forest affinity* variable was estimated from a quantitative measurement (%) on how much the species tend to use forest environments from data provided by the expert guess (Whitfield et al. 2008). To this, three highly experienced field ornithologists were invited to give values (scores) on the proportion of times they have observed each bird species in forest environments in relation to the total number of times they have already observed them in the field. Except body mass as numeric variable, all the other variables/traits were expressed by percentage values

The selected functional traits were a mix of response and effect traits. We included both trait types to in order to allow a more complete approach to understand the response of birds to environmental change and their impact on the ecosystem functioning and forest dynamics (Luck et al. 2009, 2012). Further, *insectivory* and *frugivory* are variables particularly linked to ecosystem services provision (pest control and seed dispersal, respectively) (Bregman et al. 2016).

In order to examine phylogenetic dependencies in the statistical analysis, we provided a phylogenetic correlation matrix containing phylogenetic correlation between all possible pair of species sampled. Such matrix was derived from phylogenetic trees assuming the diffusion model and thus deriving the fraction of shared branch length with the "ape" package (Paradis et al. 2004) in R software. The information on phylogenetic distances was extracted from the webpage *birdtree.org* (Jetz et al. 2012).

Environmental covariates

We considered one habitat-related and three landscape-related variables as environmental covariates. The habitat-related covariate was categorical (control forest - *ForCont*, forest edge adjacent to pastures *ForPast* and forest edges adjacent to eucalyptus plantation - *ForEuc*). We included different types (treatments) of forest edges because the type of adjacent matrix was already found to affect community processes by birds inhabiting forest edges (Barros et al. in prep). As landscapes covariates we included *forest cover* (FC), *patch density of rural homesteads* (PDRH) and *edge density* (ED). To compute this, we first elaborated land use maps within 1.2 km circular buffers (landscapes) surrounding sampling sites by the program ArcGis (ESRI 2011), considering 14 land cover types: forest, pasture, eucalyptus plantation, regeneration areas, wetland, cropland (many types, but mainly corn), sugar cane, water bodies (lakes and reservoirs), urban areas, rural homesteads, urban homesteads (suburban areas), paved roads, buildings and exposed soils. Then we used satellite images from the program Google Earth Pro (accessed from 25th March to 25th June 2016) as background image to support the land use maps elaboration. The three landscape covariates were computed by the program Fragstats v.4 (McGarigal et al. 2012).

We included *forest cover* as landscape covariate because it is well known to be one of most important driver of community processes within fragmented landscapes (Banks-Leite et al. 2014). *Edge density* represents the extent to which the landscapes are cut by habitat boundaries without considering the identity of land uses. In addition to also provide information on the extent to which landscapes are fragmented, this metric may allow a notion on how landscapes are heterogeneous as well. Thus, we included ED because, together with forest cover, it should provide a complementary understanding on

how the bird communities and species traits are affected by human occupation (Medeiros et al. 2016). We also considered PDRH as an important landscape predictor for birds because in agricultural landscapes (i.e. landscapes dominated by monocultures, with low land use heterogeneity and low forest cover), these structures can favour the fluxes and movements of many bird species across landscapes, mainly those habitat generalist, insectivores and frugivores (Barros et al. in prep, Bennett et al. 2006). Therefore, as forest edges are expected to host several habitat-generalist species (Barros et al. in prep), we considered PDRH as an important metric to include in the analyses.

We considered landscape with 1.2 km radius size because it should be large enough to include the home range of the most bird populations sampled (Odum and Kuenzler 1955, Schoener 1968), and also because it was the scale with the highest importance (among 300, 600, 900 and 1200 m spatial scales) to both abundance and richness of birds according to Random Forest analysis (Cutler et al. 2007, Bradter et al. 2013, see Supporting information - Apêndice II).

Statistical Analyses

We analysed the data with Hierarchical Modelling of Species Communities (HMSC, Ovaskainen et al. 2017), which approach belongs to the class of joint species distribution modelling (JSDM, Warton et al. 2015). HMSC provides simultaneously species and community-level inference based on data on species occurrence, environmental covariates, species traits and phylogenies, and the spatio-temporal context of the study design (Ovaskainen et al. 2017).

Spatial, phylogenetic and trait influences on the response of birds to environmental covariates

To evaluate spatial correlation on species and community similarity, we elaborated a map with areas of common profile, i.e. into areas that have similar bird communities in terms of species richness and composition. To generate this map, we used the fitted model to predict the posterior mean occupancy probability for each species and site. To access for spatial (or geographic) signal on the data, we decomposed the distance decay in community similarity into components that can and cannot be explained by similarity in environmental covariates. To generate this plot, we computed posterior mean occupancy probabilities for each species and site in two ways: using the full model that contained both variation in environmental covariates as well as the spatially structured latent factors, and a model where we had normalized all environmental covariates to their mean values and thus all predicted variation in community structure was based solely on the spatially structured latent factors.

Ignoring the influence of community phylogeny on relationships between functional traits and environments usually leads a decrease estimation accuracy and even false conclusions (Li and Ives 2017). To overcome this, we accounted for the phylogenetic component in the species responses to the environmental covariates by including a phylogenetic correlation matrix in the model's covariance structure (Ives and Helmus 2011). A parameter q that estimate the strength of phylogenetic signal in the data was included in the model so that $q = 1$ indicate that, the residual (after accounting for the effects of the measured traits) environmental responses of the species are fully explained by their phylogenetic correlations, whereas $q = 0$ indicates that the residual environmental responses of the species are randomly distributed according to the phylogeny. We fitted the model to the data with Bayesian inference, using the posterior sampling (Ovaskainen et al. 2016), which was extended here to account for traits and phylogenetic constraints.

In order to quantify how much of the variation in species' responses to environmental variation could be attributed to species traits, we used the parameterized models. The same procedure was taken to construct predictions on the relationship between environmental conditions and the distribution of traits in the bird communities inhabiting forest environments.

Partitioning variation in bird occurrence into different environmental components

To assess how the functional traits of the birds inhabiting forest environments influenced their responses to the habitat and landscapes covariates, we considered a set of traits hypothesized to be important to the response of bird to environmental change as well as their effect on forest dynamics and functioning (see Table 2). To compute variation partitioning of environmental covariates, we modelled presence-absence of the birds with a probit-model (presence-absence). As fixed effect, included the follow explanatory variables: (1) Habitat type (*ForCont*, *ForPast* and *ForEuc*, categoric), (2) FC (forest cover, %), (3) PDRH (patch density of rural homesteads, continuous) and (4) ED (edge density, m/ha). We assumed a spatially explicit structure for the community-level random effects (Ovaskainen et al. 2016).

Bird functional trait distribution under different human disturbance scenarios

To quantified the influence of functional traits, species richness and community similarity on the responses of bird species to their environments, we created Scenarios with different habitats and landscapes conditions (Table 1). The hypothesized relationships between bird functional traits and environmental covariates are shown in the Table 2. The *ForCont* scenario consisted of a sample located in the interior of continuous forest so that the remaining scenarios are deviations from this baseline

scenario. To *ForPast* and *ForEuc* scenarios, we assumed that the sample site is within forest edges in interface with pastures and eucalyptus plantation, respectively.

Concerning to *Forest loss* scenarios, we considered 20%, for instance, when the percentage of forest cover in landscape was 80% (i.e. the amount of forest cover as the opposite of forest loss). To low and high density of rural homesteads (ranging from zero to 9) we arbitrarily considered 2 and 8 respectively, while to edge density (ranging from zero to 148 m/ha) we also arbitrarily considered 42 m/ha and 134 m/ha as low and high values respectively.

Each scenario was defined by describing the environmental covariates of that scenario. As default, the scenarios were set to correspond to the environmental, so that e.g. scenario 2 examined what happens when the environmental covariate 2 changes from its minimal value to the maximal value, with 10 intermediate values to form a continuous gradient. As environmental covariates 1 is usually the intercept of the model (always with value 1), as default it is not included and thus the scenario numbering starts from 2. To compute community similarity, we also considered what happens when the environmental covariate changes from its maximal value to the minimal.

Table 2. Scenarios used to examine how community structure and trait distribution by birds are influenced by human disturbance. The Scenario “Control forest” was considered as the baseline, whereas the other scenarios are modifications of the baseline scenario

Scenario	Description
ForCont (baseline)	Sampling sites in the interior of continuous forests, with 100 % forest cover and zero values to rural homesteads and edge density
ForPast	Sampling sites within forest edges in interface with pastures
ForEuc	Sampling sites within forest edges in interface with eucalyptus plantations
Forest loss 20%	Landscapes with 80% of forest cover
Forest loss 60%	Landscapes with 40% of forest cover
Forest loss 80%	Landscapes with 20% of forest cover
Low rural homesteads	Landscapes with average 2 patches of rural homesteads
High rural homesteads	Landscapes with mean 8 patches of rural homesteads
Low edge density	Landscapes with mean 50 m of edges per hectare
High edge density	Landscapes with mean 130 m of edges per hectare

To characterize the distribution of traits in the simulated communities, we counted the number of occurrences for each species. We then computed the mean values of each trait over the species occurrences and the proportion of occurrences belonging to each habitat type. We averaged the results over 100 replicates of the simulated communities, each generated with resampled parameters from the posterior distribution. All the statistical analysis was made in program MatLab 8.0 (Matlab 2012)

Table 1. The bird functional traits used in the analyses, and their hypothesized relationship with habitat and landscapes conditions to access the Scenario simulations.

Functional trait	Hypothesized relationship
Forest affinity (%)	Forest birds are widely known to be sensitive to forest loss and forest edges (Martensen et al. 2012), so we expect that the average forest affinity by bird communities tend to decrease with forest loss and proximity to edges. Considering that forest-eucalyptus interfaces have less structural contrast than forest-pasture interfaces, we expect that bird inhabiting the first have higher forest affinity than the second. Moreover, we also hypothesize that other landscape disturbance such as rural homesteads and edge density should decrease forest affinity.
Body mass (g, log-transformed)	Considering that the smallest birds are more susceptible to extinction (Ripple et al. 2017) and small birds tend to have restricted visibility and smaller home-range area so that when they need to explore open and/or disturbed sites, they may face higher predation risk and marked microhabitat change, we expect that both forest loss, edge effect and lands use intensification (edge density and homesteads) may induce higher occupancy of large-bodied birds.
Clutch size (1-7)	We expect that bird species with small clutch sizes (e.g. low reproductive rates, infrequent breeding and low annual productivity) have reduced ability to recover from human disturbance (i.e. less resilient to environmental change) (Jetz et al. 2008, Luck et al. 2012). Thus, we expect that forest loss and other human intensification, induces larger mean clutch sizes.
Insectivory (%)	Both insects and insectivorous birds are known to have decreased abundance with forest loss (Didham et al. 1996, Powell et al. 2015, Dodonov et al. 2016), so we expect that insectivory degree should be lower with forest loss and other human disturbance (Sekercioglu et al. 2002). When in contact to open habitat as pastures, abundance of insects at forest edges are also known to be higher compared to closed adjacent habitat, so we expect higher insectivory degree by birds in forest besides pastures than forest besides eucalyptus.
Frugivory (%)	Forest loss lead to decrease fruit consumption by birds in the forest interiors, but not on the forest edges (Menezes et al. 2016). Thus we expect a decrease in frugivory degree by birds with forest loss, but in forest edge we expect higher values, mainly in forest edges besides pastures, where usually are found higher amount of fruiting trees (Oosterhoorn and Kappelle 2000, Galetti et al. 2003). Concerning rural homesteads and edge density, we expect a smooth increase, once this type of habitat or landscape pattern should promote abundance or survival of generalist bird, including many fruit-eater birds.
Ground use (%)	Fragmentation often induce higher ground nest predation, mainly in forest edges (Keyser et al. 1998, Manolis et al. 2002). Considering that ground-nesting birds are strictly linked to ground-using birds, we expect that forest loss and human interventions such as rural homesteads and edge density should decrease ground use by birds
Understory use (%)	Understory birds are one of the most affected guild by the fragmentation processes (Powell et al. 2015), so we expect that understory use by birds should be lower with increasing fragmentation and human alteration as well as in forest edges (Kennedy et al. 2010).

Results

Partitioning variation in bird occurrence into different environmental components:

landscape covariates had dominating effect of the bird communities, explaining on average 67% of the variation (Figure 1). Within this, FC and ED had 30% and 27% of variation explained, respectively, while PDRH only 12 %. Habitat type had 19% of variation explained and the spatial random effect was little explained - on average 13% (despite be relevant effect to one single species, Figure 1).

Altogether, the functional traits considered explained 12% of the variation among species' environmental niches. However, we found clear support for the hypothesis of niche conservatism, with the posterior mean (with 95% credible interval) of the correlation parameter ρ being 0.62 (0.37-0.79). These results suggest that the niches of birds may be structured by traits correlated with their phylogeny so that the related species respond similarly to environment (see Supporting information - Apêndice IV).

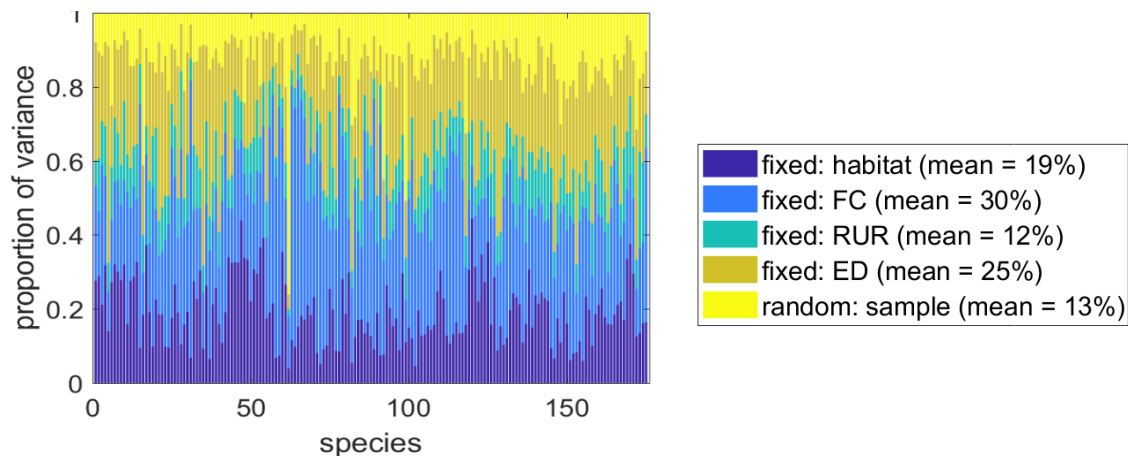


Figure 1. Variation in species occurrence partitioned into responses to the fixed (environmental) and random (spatial) covariates measured to examine how environmental characteristics can modulate bird occurrence within forest environments in fragmented landscapes. The bar-plot shows species-specific results containing proportion of covariates explanation.

Bird functional trait distribution under different human disturbance scenarios: The communities of birds inhabiting continuous forests in fragmented landscapes were dominated by species with higher *forest affinity*, *insectivory* and *understory use*, and lower *body mass*, *clutch size* and *ground use* (Figure 2). *Frugivory* was a particular case and had intermediate values and forest cover changes little changed its trait distribution (Figure 2). In general, forest loss has clear effect in all other traits while rural homesteads and edge density had different patterns according to trait analysed.

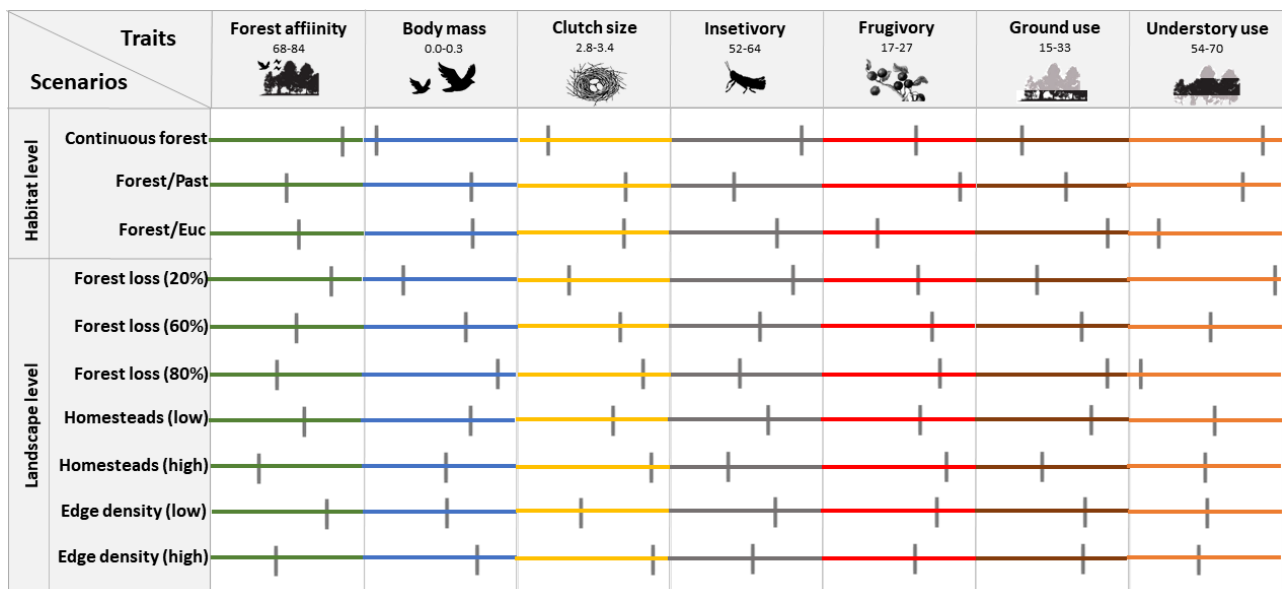


Figure 2. Distributions of bird functional traits in communities inhabiting different kinds of forest environments. The figure is based on the average of 100 communities simulated under the scenarios. The numbers below trait name corresponds to range values (from lowest to highest). For more details on the meaning of scenarios predicted, see Table 2.

Compared to the baseline scenario (control forest, i.e. 100% forest cover and similarity=1), the bird richness was lower in more deforested landscapes, but slightly higher in landscapes with higher edge density, while community similarity decreased according to both forest loss and edge density (Figure 3). Rural homesteads slightly increased species richness and had almost no effect on community similarity (Figure 3).

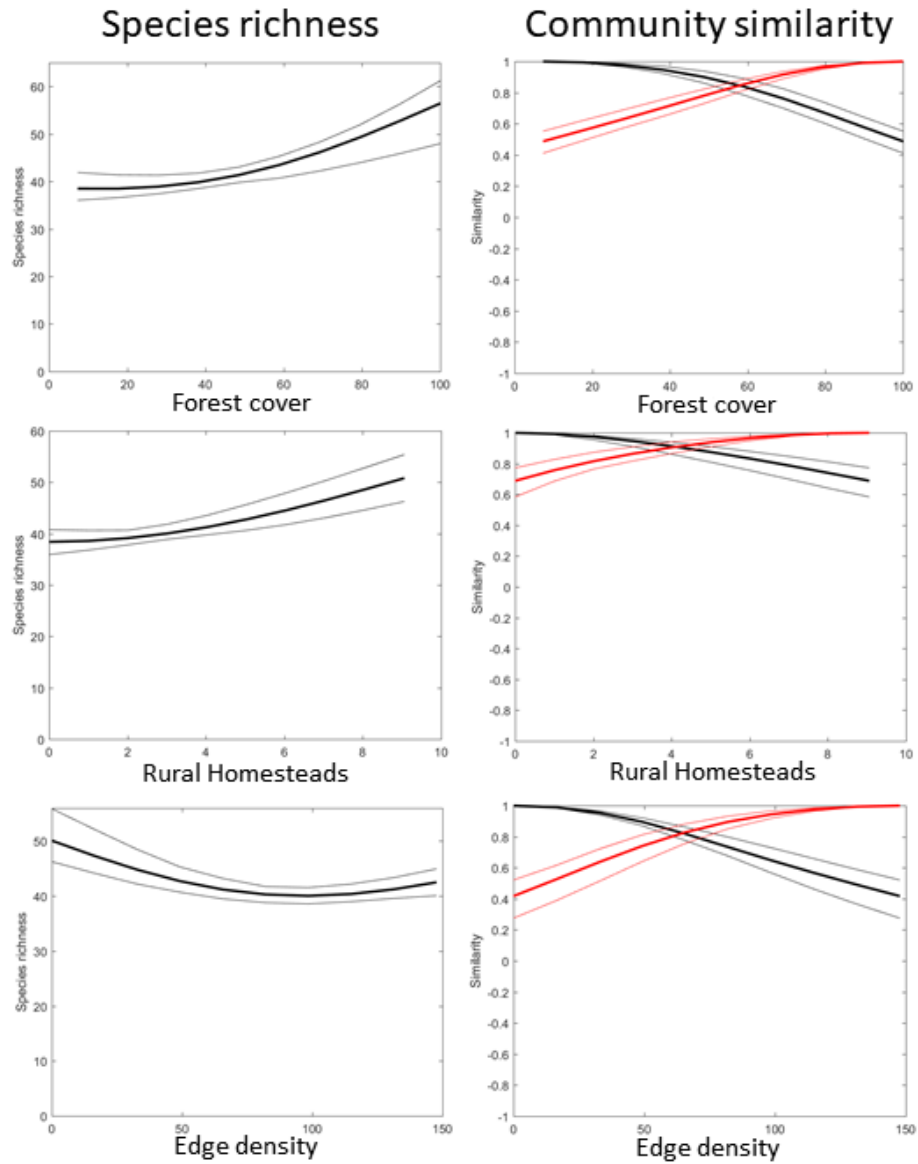


Figure 3. Scenario simulations to species richness and community similarity in three landscapes continuous (*forest cover*, *rural homesteads* and *edge density*). The solid (dashed) lines show the mean (interquartile range) prediction to a reference community, which we defined as the community predicted to occur in continuous forest, i.e 100% of forest cover and zero values for rural homesteads and edge density. For community similarity, we considered two scenarios: community similarity between the focal scenario and the smallest scenario (black lines) and between the focal scenario and the largest scenario (red lines). In each plot, the thick line shows posterior mean and the thin lines 95% credibility interval. The columns are the value of the scenario variable, posterior mean, and 0.025 and 0.975 posterior quantiles.

Discussion

As we expected, forest cover had the higher variation explained among overall landscape covariates (30%) (Figure 1) and affected positively both species richness and community dissimilarity (Figure 3). Overall, these results agree with most studies involving bird communities in the fragmented forests (Martensen et al. 2012, Banks-Leite et al. 2014). However, some studies point the overall bird species richness is much less sensitive to forest loss than bird species composition (Banks-leite et al. 2012) or species richness within certain ecological groups (Morante-Filho et al. 2015). In contrast, our results on scenario simulations showed similar effect of forest cover in both species richness and community similarity (Figure 3). One possible reason for this controversy is that these other studies sampled birds within the interior of forest fragments (avoiding direct edge effects), while our study intentionally sampled birds in forest edges (i.e. forest environments under direct edge effects) - despite two sampling points in continuous forest as reference. Probably, bird communities inhabiting close to edges should be more sensible to changes in the surrounding forest cover than those inhabiting forest interiors. This may occur because birds sampled apart from edges are expected to be more “protected” by surrounding forest habitat (i.e. less affected by edge effects) than those close to edges. On the other hand, it is also reasonable suppose that birds sampled in forest edges were already selected or filtered by the edge effects, so that, unlike, species richness should be more insensitive to changes in the amount of surrounding forest. In other study also conducted in Brazilian Atlantic forests, movements of forest birds in forest fragments were significantly affected by proximity to edges (Hansbauer et al. 2008). Thus, we believe that the movement of birds across interior and edges help to understand these differential species losses between edge and interior. Due to the bird movement, we believe that forest edges may be more sensitive to variation on the

surrounding landscape that forest interior. Thus, we suggest that the magnitude of edge effect on birds tend to be highly dependent on the surrounding landscape context. This can be also bolstered by our other results. Altogether, landscapes attributes had much more variation explained on models than habitat type. This results probably is linked to the high influence of landscape than habitat in bird occurring in disturbed and fragmented forests. The relationship between habitat and landscape effect on bird communities varies widely and usually is complex and entangled (Banks-Leite et al. 2012), and more studies evaluating this issue are needed.

Despite the variation explained by forest cover have been the highest (30%), it was similar to the variation explained by edge density (25%). This suggest an entangled relationship between forest cover and edge density (i.e. the extent to which landscapes are “fragmented”, measured by the extension of edges). A recent study shows that fragmentation *per si* may not necessarily provide negative effect on biological communities in a wide range of situations (Fahrig 2017). In our case, we believe that amount of edges in the surrounding landscape may interact with forest cover to provide these effects found. Scenario simulations predicted a very similar effect of ED on both species richness and community similarity. In addition, ED and Forest loss were predicted to affect similarly some functional traits as *forest affinity*, *body mass*, *clutch size* and *insectivory* - despite ED provided the lower effect magnitude. Although influence bird traits and communities, is difficult to infer particular direct ED effect, disregarding forest cover, land use identity and matrix diversity. Thus, more studies investigating these intricate relationship among landscapes factors are essential to better understand landscape effect on bird and other biological groups.

Rural homesteads (PDRH) had the lowest importance to overall model. To some traits it showed similar effect than edge effects, but not to other traits. The presence of

rural homesteads is expected to influence positively some species in agricultural landscapes (Bennett et al. 2006), mainly those habitat-generalist and/or promoting seed dispersal services such as the frugivores ones (Barros et al. in prep). Our scenario simulation confirmed this assumption. Despite little effect, as more rural homesteads in the landscape, bird communities become with higher frugivory level. This can be particularly important to habitat regenerations and resilience processes (Bregman et al. 2016).

Overall, the Scenario simulations yielded predictions very similar to our expected hypothesis (Table 2). To body mass, higher overall human disturbance (i.e. forest loss, forest edge, PDRH and ED), smaller birds were predicted to occur in forest environments. In a study evaluating global data, body size in birds was negatively correlated to specie richness and environmental productivity (Olson et al. 2009). In other study, the structural complexity of habitats was found to be negatively related to body size in Palearctic birds (Polo and Carrascal 1999). In our study, decreases in body mass values to birds with decreases in forest loss (i.e. high forest cover) may occur by the same factor found by those authors. When compared to intact forests, deforested landscapes are expected to have lower productivity and lower structural complexity within it. In addition, simulation scenarios also predicted average smaller birds in control forests, which host higher species diversity, with agree to Olson et al. (2009). With this, human disturbance is expected to affect mainly the smaller birds, with lower home range and high requirement to microhabitat features (Ripley et al. 2017).

As body mass, bird clutch size was predicted by scenario simulation to follow the same pattern found to body mass: lower broods in higher quality habitat and landscape conditions. In a study using global data, bird species with higher clutch sizes was related to cavity nesters, and was supposed to be linked to higher protection (Jetz et al. 2008).

Frugivory level of communities were predicted to be substantially higher in forest edges adjacent to pastures than forest edges adjacent to eucalyptus plantation. Other similar study found higher abundance of frugivores in forest edge, compared to forest interior. In addition, seed dispersal services by bird in forests in interface with pasture was also found to be higher than seed dispersal by birds in forest edges in interface with eucalyptus (Barros et al. in prep).

Our study provided important predictions of bird trait distribution in regional scale, confirming some patters already found to bird in global scales.

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Conclusões finais

Esta tese gerou e aprimorou conhecimento sobre diversos processos e questões ecológicas importantes, segundo o conhecimento científico ecológico atual. No primeiro capítulo propomos novas métricas de comunidades relacionadas à provisão de serviços ecossistêmicos por aves, além de ressaltar importância das aves generalista de habitat em promover serviços ecossistêmicos relacionados à dispersão de sementes e consequentemente à capacidade de regeneração e resiliência das paisagens onde elas habitam. Além disso, ressaltamos também a importância da presença de propriedades rurais como facilitadoras do fluxo de espécies generalistas, que muitas vezes acabam sendo importantes provedoras de serviços ecossistêmicos como dispersão de sementes, controle de pragas e polinização, em paisagens fragmentadas, sobretudo naquelas dominadas por extensas monoculturas.

No capítulo dois, observamos que o tipo de matriz adjacente à bordas de floresta pode alterar a estrutura de comunidades de aves nas bordas de floresta. Além disso, vimos que em interfaces de floresta-pasto as espécies de aves são prioritariamente substituídas de floresta para matriz, ao passo que em interfaces de floresta-eucalipto, tanto as espécies com suas funções que vivem em plantações de eucalipto podem se apresentar como um subconjunto daquelas espécies encontradas nas florestas ao lado. O resultado mais original, no entanto, foi que o aumento de cobertura florestal nas paisagens ao redor dessas interfaces de habitat pode promover uma “aproximação funcional” entre as comunidades vizinhas, ou seja, quanto mais aumentamos a cobertura florestal na paisagem, mais as funcionalmente parecidas são espécies de aves que habitam os habitats vizinhos, tanto para interfaces de floresta-pasto quanto para interfaces de floresta-eucalipto.

Já no terceiro e último capítulo, através de simulações de possíveis cenários ambientais, observamos que as características das paisagens, principalmente cobertura florestal e densidade de bordas, melhor descrevem a ocorrência de aves em ambientes florestais em paisagens fragmentadas, enquanto que processos espaciais e aleatórios pouco explicaram os dados. Além disso, traços funcionais das aves como afinidade florestal, massa corporal e insetivoria diminuíram em função da perda de floresta e aumento da densidade de borda dentro das paisagens. Todos os traços tiveram menores valores em bordas de mata comparados à floresta contínua, e em relação ao grau de frugivoria, florestas ao lado de pasto tiveram valores ainda maiores aos valores de referência em floresta contínua e bem maiores valores do que bordas de mata ao lado de plantação de eucalipto.

Usando análises modernas, eficientes e até mesmo ousadas, ou seja, ainda relativamente pouco usadas em ecologia (p.e. *Random forests* e *Joint Species Distribution Models*), este estudo foi inovador em diversos outros aspectos de conteúdo ecológico, e serve principalmente de estímulo para novos e outros estudos que aprofundem as fronteiras de conhecimento abordadas neste trabalho. Preenchendo algumas lacunas de conhecimento e gerando diversas outras novas, este estudo, sobretudo contribuiu para o avanço do conhecimento científico sobre funcionamento dos processos ecológicos que operam em nível de comunidades, paisagens e ecossistemas.

Apêndice I: Lista de espécies de aves registradas em campo.

Tabela 1. Lista das espécies de aves amostradas em pastagem (N=16), borda de floresta ao lado de pastagem (N=16), floresta contínua ou controle (N=2), borda de floresta ao lado de plantação de eucalipto (N=16) e plantação de eucalipto (N=16) ao longo da região de estudo (2014-2015). Nomenclatura de acordo com o CBRO 2014. Detalhes da amostragem estão na seção de métodos.



Ordem/Familia	Gênero/Espécie		Pasto	Floresta	Controle	Floresta	Eucalipto
Tinamiformes							
Tinamidae	<i>Crypturellus</i>	<i>obsoletus</i>		X	X	X	
	<i>Crypturellus</i>	<i>parvirostris</i>		X			
	<i>Crypturellus</i>	<i>tataupa</i>		X	X	X	X
Galliformes							
Cracidae	<i>Penelope</i>	<i>obscura</i>	X	X	X	X	
Odontophoridae	<i>Odontophorus</i>	<i>capueira</i>			X		
Pelecaniformes							
Ardeidae	<i>Bubulcus</i>	<i>ibis</i>	X				
	<i>Syrigma</i>	<i>sibilatrix</i>	X				
	<i>Egretta</i>	<i>thula</i>	X				
Pelecaniformes							
Threskiornithidae	<i>Mesembrinibis</i>	<i>cayennensis</i>	X				
Cathartiformes							
Cathartidae	<i>Coragyps</i>	<i>atratus</i>	X				
Accipitriformes							
Accipitridae	<i>Leptodon</i>	<i>cayanensis</i>				X	
	<i>Chondrohierax</i>	<i>uncinatus</i>				X	
	<i>Ictinia</i>	<i>plumbea</i>				X	
	<i>Rupornis</i>	<i>magnirostris</i>	X	X		X	X
	<i>Geranoaetus</i>	<i>albicaudatus</i>	X				
	<i>Buteo</i>	<i>brachyurus</i>	X				
Gruiformes							
Rallidae	<i>Aramides</i>	<i>saracura</i>	X	X		X	
Charadriiformes							
Charadriidae	<i>Vanellus</i>	<i>chilensis</i>	X			X	
Columbiformes							
Columbidae	<i>Columbina</i>	<i>squammata</i>				X	
	<i>Columbina</i>	<i>talpacoti</i>	X	X		X	X
	<i>Patagioenas</i>	<i>cayenensis</i>	X	X		X	
	<i>Patagioenas</i>	<i>plumbea</i>		X	X	X	
	<i>Patagioenas</i>	<i>picauro</i>	X	X	X	X	X
	<i>Zenaida</i>	<i>auriculata</i>	X			X	X
	<i>Leptotila</i>	<i>verreauxi</i>	X	X		X	X
	<i>Leptotila</i>	<i>ruffaxila</i>		X	X	X	X
	<i>Geotrygon</i>	<i>montana</i>			X	X	

Cuculiformes							
Ordem/Familia	Gênero/Espécie		Pasto	Floresta	Controle	Floresta	Eucalipto
Cuculidae	Piaya	cayana		X		X	
	Crotophaga	ani	X				
	Guira	guira	X				
	Tapera	naevia	X	X		X	X
Strigiformes							
Strigidae	Athene	cunicularia	X				
Apodiformes							
Apodidae	Chaetura	meridionalis	X				
Trochilidae	Phaethornis	eurynome	X	X		X	
	Phaethornis	petrei		X		X	
	Eupetomena	macroura	X				
	Aphantochroa	cirrochloris		X			
	Florisuga	fusca		X			
	Colibri	serrirostris	X				
	Chlorostilbon	lucidus	X	X		X	
	Thalurania	glaucoptis		X	X	X	
	Amazilia	lactea		X	X	X	
	Leucochloris	albicollis				X	
	Trogon	surrucura		X	X	X	
Galbuliformes							
Bucconidae	Malacoptila	striata				X	
Piciformes							
Ramphastidae	Ramphastos	toco	X	X		X	
	Ramphastos	dicolorus				X	
Picidae	Picumnus	cirratu		X	X	X	X
	Melanerpes	candidus	X	X		X	
	Venilliornis	spilogaster	X	X	X	X	
	Colaptes	melanochloros	X	X		X	
	Colaptes	campestris	X	X		X	X
	Celeus	flavescens	X	X		X	X
	Dryocopus	lineatus	X	X	X	X	
	Campephilus	robustus			X	X	
Cariamiformes							
Cariamidae	Cariama	cristata	X				X
Falconiformes							
Falconidae	Caracara	plancus	X	X		X	
	Milvago	chimachima	X	X		X	X
	Herpetotheres	cachinnans				X	
	Micrastur	semitorquatus		X		X	
	Micrastur	ruficollis				X	
	Falco	femoralis	X				
Psittaciformes							
Psittacidae	Psittacara	leucophthalmus	X	X		X	X

	<i>Aratinga</i>	<i>auricapillus</i>		X		X	
Ordem/Familia	Gênero/Espécie		Pasto	Floresta	Controle	Floresta	Eucalipto
	<i>Eupsittula</i>	<i>aurea</i>		X			
	<i>Brotogeris</i>	<i>tirica</i>	X	X		X	X
	<i>Brotogeris</i>	<i>chiriri</i>	X	X			
	<i>Pionus</i>	<i>maximiliani</i>	X	X		X	
	<i>Amazona</i>	<i>aestiva</i>		X			
	<i>Forpus</i>	<i>xanthopterygius</i>		X			
Passeriformes							
Thamnophilidae	<i>Rhopias</i>	<i>gularis</i>		X	X	X	
	<i>Dysithamnus</i>	<i>stictothorax</i>				X	
	<i>Dysithamnus</i>	<i>mentalis</i>		X	X	X	
	<i>Herpsilochmus</i>	<i>rufimarginatus</i>		X	X	X	
	<i>Thamnophilus</i>	<i>doliatus</i>	X			X	
	<i>Thamnophilus</i>	<i>ruficapillus</i>	X	X		X	X
	<i>Thamnophilus</i>	<i>caerulescens</i>	X	X	X	X	
	<i>Hypoedaleus</i>	<i>guttatus</i>		X	X	X	
	<i>Myrmoderus</i>	<i>squamosus</i>		X	X	X	X
	<i>Pyriglena</i>	<i>leucoptera</i>		X	X	X	
	<i>Drymophila</i>	<i>ferruginea</i>		X		X	
	<i>Drymophila</i>	<i>malura</i>		X			
Conopophagidae	<i>Conopophaga</i>	<i>lineata</i>		X	X	X	
Rhinocryptidae	<i>Scytalopus</i>	<i>spelunca</i>			X		
Scleruridae	<i>Sclerurus</i>	<i>scansor</i>			X		
Dendrocolaptidae	<i>Sittasomus</i>	<i>griseicapillus</i>		X	X	X	
	<i>Xiphorhynchus</i>	<i>fuscus</i>		X	X	X	
Xenopidae	<i>Xenops</i>	<i>minutus</i>		X			
	<i>Xenops</i>	<i>rutilans</i>		X	X	X	
Furnariidae	<i>Furnarius</i>	<i>rufus</i>	X	X		X	
	<i>Lochmias</i>	<i>nematura</i>		X		X	
	<i>Automolus</i>	<i>leucophthalmus</i>		X	X	X	
	<i>Philydor</i>	<i>rufum</i>		X	X	X	
	<i>Syndactyla</i>	<i>rufosuperciliata</i>				X	
	<i>Phacellodomus</i>	<i>erythrophthalmus</i>			X	X	
	<i>Certhiaxis</i>	<i>cinnamomeus</i>	X			X	
	<i>Synallaxis</i>	<i>ruficapilla</i>		X	X	X	
	<i>Synallaxis</i>	<i>cinerascens</i>		X	X	X	
	<i>Synallaxis</i>	<i>frontalis</i>		X		X	
	<i>Synallaxis</i>	<i>spixi</i>	X	X		X	X
	<i>Cranioleuca</i>	<i>pallida</i>			X		
Pipridae	<i>Neopelma</i>	<i>chrysolophum</i>		X		X	
	<i>Manacus</i>	<i>manacus</i>		X	X	X	
	<i>Chiroxiphia</i>	<i>caudata</i>		X	X	X	
Tityridae	<i>Tityra</i>	<i>cayana</i>				X	
	<i>Schiffornis</i>	<i>virescens</i>		X	X	X	

	<i>Pachyramphus</i>	<i>castaneus</i>	X	X	X		
Ordem/Familia	Gênero/Espécie		Pasto	Floresta	Controle	Floresta	Eucalipto
	<i>Pachyramphus</i>	<i>validus</i>	X	X		X	
	<i>Pachyramphus</i>	<i>polychopterus</i>		X	X	X	X
Cotingidae	<i>Procnias</i>	<i>nudicollis</i>		X			
	<i>Pyroderus</i>	<i>scutatus</i>	X	X		X	
Platyrinchidae	<i>Platyrinchus</i>	<i>mystaceus</i>		X		X	
Rhynchocyclidae	<i>Mionectes</i>	<i>rufiventris</i>		X			
	<i>Corythopsis</i>	<i>delalandi</i>		X		X	
	<i>Leptopogon</i>	<i>amaurocephalus</i>	X	X	X	X	
	<i>Phylloscartes</i>	<i>ventralis</i>					
	<i>Phylloscartes</i>	<i>eximius</i>		X			
	<i>Tolmomyias</i>	<i>sulphurescens</i>	X	X	X	X	X
	<i>Todirostrum</i>	<i>poliocephalum</i>		X	X	X	
	<i>Poecilatriccus</i>	<i>plumbeiceps</i>		X	X	X	X
	<i>Myiornis</i>	<i>auricularis</i>		X			
	<i>Hemitriccus</i>	<i>orbitatus</i>				X	
	<i>Hemitriccus</i>	<i>nidipendulus</i>				X	
Tyrannidae	<i>Hirundinea</i>	<i>ferruginea</i>	X				
	<i>Tyranniscus</i>	<i>burmeisteri</i>			X		
	<i>Camptostoma</i>	<i>obsoletum</i>	X	X	X	X	X
	<i>Elaenia</i>	<i>flavogaster</i>	X	X			X
	<i>Elaenia</i>	<i>mesoleuca</i>		X		X	
	<i>Elaenia</i>	<i>obscura</i>		X			
	<i>Myiopagis</i>	<i>caniceps</i>		X	X		
	<i>Phyllomyias</i>	<i>virescens</i>			X		
	<i>Phyllomyias</i>	<i>griseocapilla</i>		X			
	<i>Serpophaga</i>	<i>subcristata</i>	X				
	<i>Attila</i>	<i>rufus</i>		X	X	X	
	<i>Legatus</i>	<i>leucophaeus</i>	X	X	X	X	
	<i>Myiarchus</i>	<i>swainsoni</i>	X	X	X	X	X
	<i>Myiarchus</i>	<i>ferox</i>	X	X			
	<i>Pitangus</i>	<i>sulphuratus</i>	X	X		X	X
	<i>Machetornis</i>	<i>rixosa</i>	X				
	<i>Myiodynastes</i>	<i>maculatus</i>	X	X	X	X	X
	<i>Megarynchus</i>	<i>pitangua</i>	X	X	X	X	X
	<i>Myiozetetes</i>	<i>similis</i>	X	X		X	
	<i>Tyrannus</i>	<i>melancholicus</i>	X	X		X	X
	<i>Tyrannus</i>	<i>savanna</i>	X				
	<i>Empidonomus</i>	<i>varius</i>	X	X			
	<i>Colonia</i>	<i>colonus</i>				X	
	<i>Myiophobus</i>	<i>fasciatus</i>	X	X			
	<i>Fluvicola</i>	<i>nengeta</i>	X				
	<i>Lathrotriccus</i>	<i>euleri</i>		X		X	
	<i>Knipolegus</i>	<i>lophotes</i>	X				

	<i>Xolmis velatus</i>	X					
Ordem/Familia	Gênero/Espécie	Pasto	Floresta	Controle	Floresta	Eucalipto	
Vireonidae	<i>Cyclarhis gujanensis</i>	X	X	X	X	X	
	<i>Vireo olivaceus</i>	X	X	X	X	X	
	<i>Hylophilus poicilotis</i>		X	X	X		
Corvidae	<i>Cyanocorax cristatellus</i>	X	X		X	X	
	<i>Cyanocorax chrysops</i>		X		X	X	
Hirundinidae	<i>Stelgidopteryx ruficollis</i>	X	X		X		
	<i>Progne tapera</i>	X					
Troglodytidae	<i>Troglodytes musculus</i>	X	X		X	X	
Turdidae	<i>Turdus flavipes</i>	X	X	X	X		
	<i>Turdus leucomelas</i>	X	X	X	X	X	
	<i>Turdus rufiventris</i>	X	X	X	X	X	
	<i>Turdus amaurochalinus</i>		X	X	X	X	
	<i>Turdus subalaris</i>				X		
	<i>Turdus albicollis</i>		X	X	X		
Mimidae	<i>Mimus saturninus</i>	X			X		
Motacillidae	<i>Anthus lutescens</i>	X					
Passerellidae	<i>Zonotrichia capensis</i>	X	X		X	X	
	<i>Ammodramus humeralis</i>	X					
	<i>Arremon semitorquatus</i>				X		
Parulidae	<i>Setophaga pitiauyumi</i>	X	X	X	X	X	
	<i>Geothlypis aequinoctialis</i>	X					
	<i>Basileuterus culicivorus</i>	X	X	X	X	X	
	<i>Myiothlypis flaveola</i>		X		X		
	<i>Myiothlypis leucoblephara</i>		X	X	X	X	
Icteridae	<i>Psarocolius decumanus</i>	X	X				
	<i>Icterus pyrrhopterus</i>		X				
	<i>Pseudoleistes guirahuro</i>	X					
Thraupidae	<i>Coereba flaveola</i>	X	X	X	X	X	
	<i>Saltator similis</i>	X	X	X	X	X	
	<i>Nemosia pileata</i>		X	X	X		
	<i>Thlypopsis sordida</i>		X		X		
	<i>Tachyphonus coronatus</i>	X	X	X	X	X	
	<i>Lanio cucullatus</i>	X	X				
	<i>Lanio pileatus</i>			X			
	<i>Lanio melanops</i>		X		X	X	
	<i>Tangara seledon</i>			X			
	<i>Tangara cyanoventris</i>				X		
	<i>Tangara sayaca</i>	X	X	X	X	X	
	<i>Tangara palmarum</i>	X	X				
	<i>Tangara ornata</i>	X					
	<i>Tangara cayana</i>	X	X		X	X	
	<i>Tersina viridis</i>	X	X	X	X		
	<i>Dacnis cayana</i>	X	X		X		
	<i>Hemithraupis ruficapilla</i>				X	X	

	<i>Conirostrum</i>	<i>speciosum</i>	X	X		X	X
Ordem/Familia	Gênero/Espécie		Pasto	Floresta	Controle	Floresta	Eucalipto
	<i>Volatinia</i>	<i>jacarina</i>	X			X	X
	<i>Sporophila</i>	<i>lineola</i>	X	X			
	<i>Sporophila</i>	<i>caerulescens</i>	X	X			
	<i>Tiaris</i>	<i>fuliginosus</i>				X	
Cardinalidae	<i>Habia</i>	<i>rubica</i>		X			
Fringillidae	<i>Euphonia</i>	<i>chlorotica</i>	X	X		X	
	<i>Euphonia</i>	<i>violacea</i>		X		X	
	<i>Euphonia</i>	<i>pectoralis</i>	X	X	X	X	
Estrildidae	<i>Estrilda</i>	<i>astrild</i>	X				

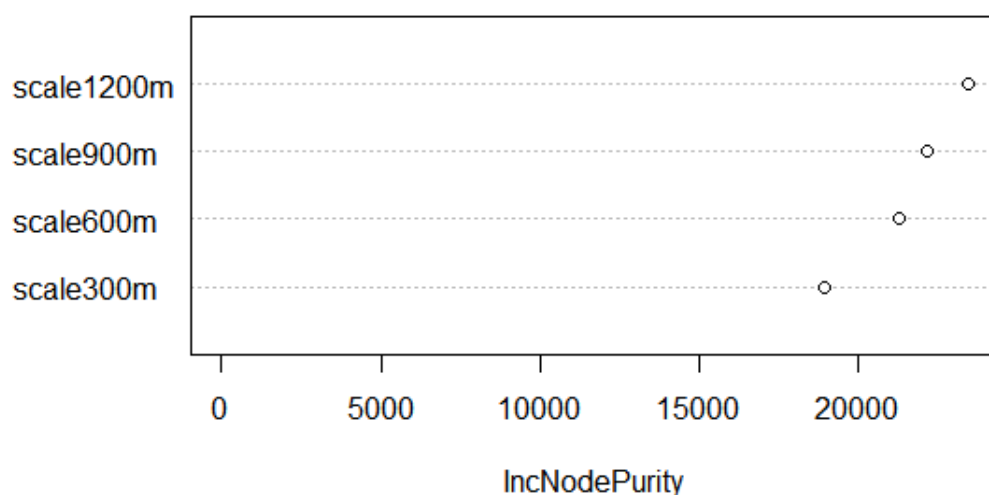
Apêndice II: Resultados detalhados das árvores de regressão computadas pelo algoritmo de aprendizado de máquina (Random Forest): avaliando a escala espacial de efeito na abundância e riqueza de comunidades de aves.

Below are presented all the non-linear relationships regarding the relative importance of four circular landscape scales (300, 600, 900 and 1200m radius from the forest sampling site). Graphs and detailed results are presented in two regression trees based models using random forest algorithms (machine learning). All the outputs were ran by the R studio program, using the function “randomForest” with the packages “mlr”, “randomForest”, “rpart” and “stargazer”.

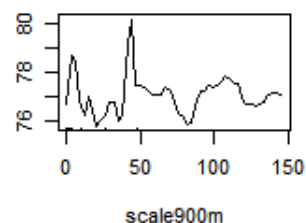
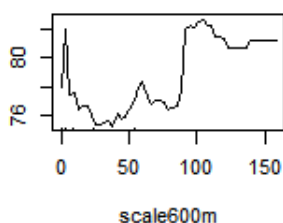
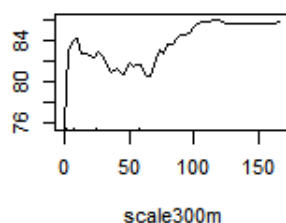
1) Bird abundance

Type of random forest: regression	IncNodePurity
Number of trees: 500	scale300m 18923.86
No. of variables tried at each split: 1	scale600m 21285.81
Mean of squared residuals: 406.19	scale900m 22174.33
% Var explained: -6.76	scale1200m 23482.75

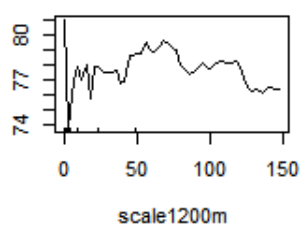
abundance



Partial Dependence on scale300 Partial Dependence on scale600 Partial Dependence on scale900

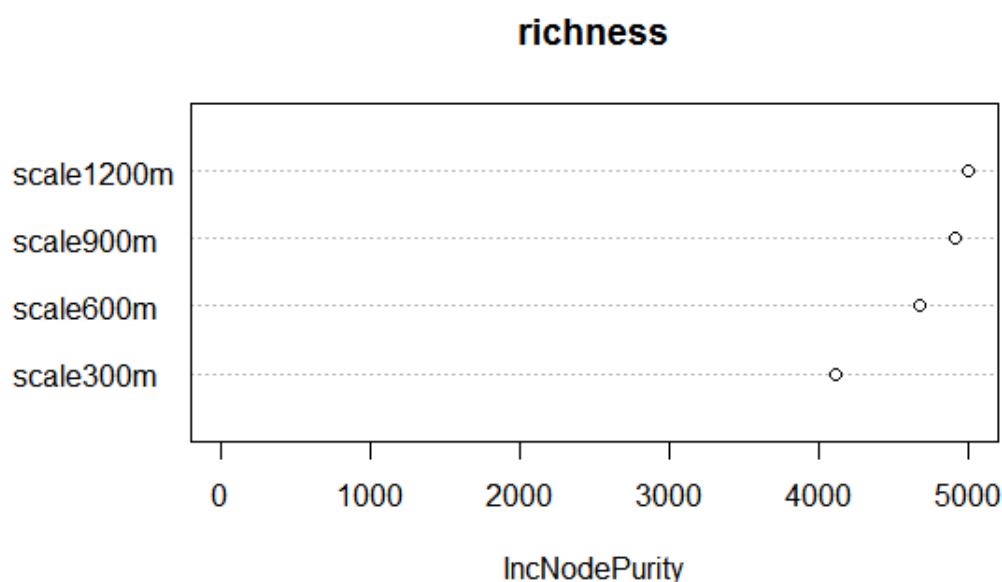


Partial Dependence on scale1200m

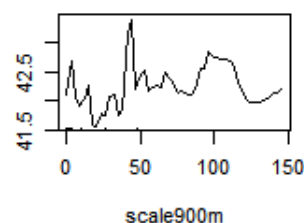
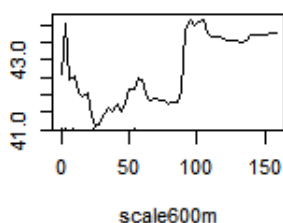
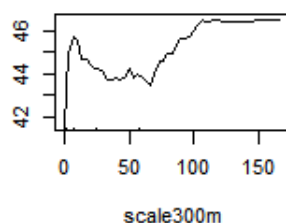


2) Bird richness

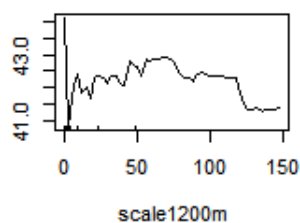
Type of random forest: regression	IncNodePurity
Number of trees: 500	scale300m 4113.062
No. of variables tried at each split: 1	scale600m 4676.920
Mean of squared residuals: 86.30062	scale900m 4906.379
% Var explained: -5.82	scale1200m 5000.711



Partial Dependence on scale300m Partial Dependence on scale600m Partial Dependence on scale900m



Partial Dependence on scale1200m



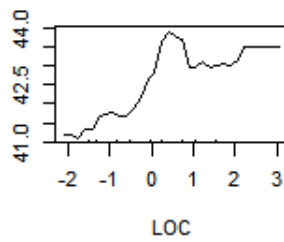
Apêndice III. Resultados detalhados das árvores de regressão computadas pelo algoritmo de aprendizado de máquina (Random Forest): avaliando a importância relativa de preditores ambientais em quatro variáveis respostas das comunidades de aves (riqueza de espécies, controle de peste, dispersão de sementes a polinização). Para mais detalhes, ver texto principal.

Below are represented all the non-linear relationships between the environmental predictors and the response variables concerning the potential ecosystem services provision (species richness, pest control, seed dispersal, pollination) by birds (all species, habitat-generalist and forest specialists) at edges of forest, eucalyptus and pastures stands across a wide fragmented region in southeastern Brazil. Graphs and detailed results are presented by 36 regression trees based models using random forest algorithms (machine learning). All the outputs were ran by the R studio program, using the function “randomForest” with the packages “mlr”, “randomForest”, “rpart” and “stargazer”. Legends: ADJ = type of adjacent matrix, LOC = local habitat features, FC = percentage of forest cover, PAS = percentage of pasture cover, SILV = percentage of tree plantation cover, ED = landscape edge density, SHM = Shannon diversity index for matrix lands, RUR = number of patches of rural homesteads, WAT number of patches of water bodies. The meaning and motivation of all these metrics are found in the Methods section (main text).

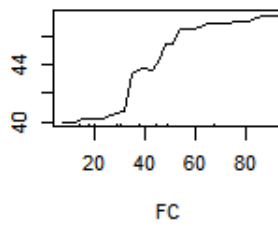
1) Forest->species_richness->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 635.20949
No. of variables tried at each split: 2	ADJ 62.47808
Mean of squared residuals: 73.38366	LOC 327.34314
% Var explained: 10.02	ED 317.67239
	WAT 232.18781
	RUR 411.55168
	SHM 265.72573

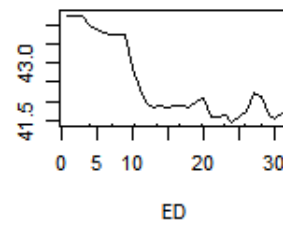
Partial Dependence on LOC



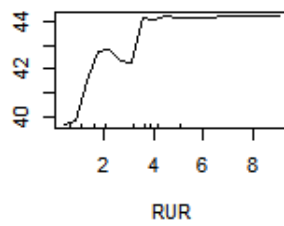
Partial Dependence on FC



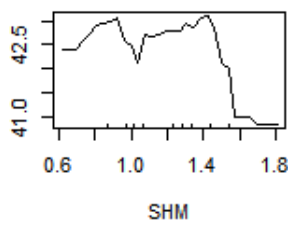
Partial Dependence on ED



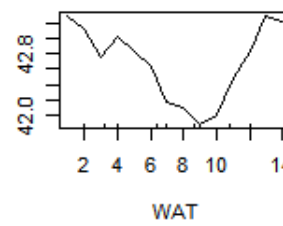
Partial Dependence on RUR



Partial Dependence on SHM



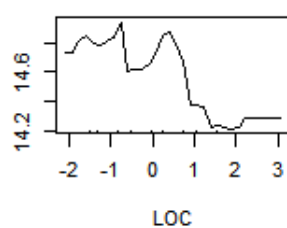
Partial Dependence on WAT



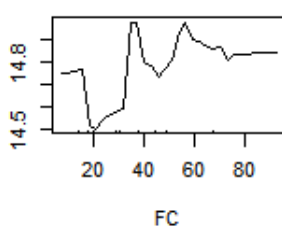
2) Forest->species_richness->habitat-generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 38.20209
No. of variables tried at each split: 2	ADJ 44.17713
	LOC 44.57198
Mean of squared residuals: 9.958041	ED 40.67902
% Var explained: 19.43	WAT 45.27280
	RUR 96.86344
	SHM 40.31972

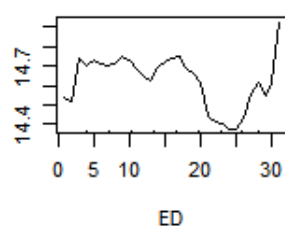
Partial Dependence on LOC



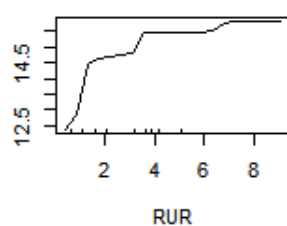
Partial Dependence on FC



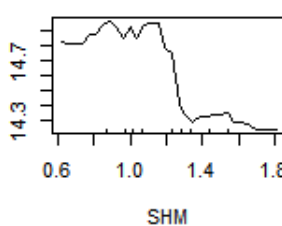
Partial Dependence on ED



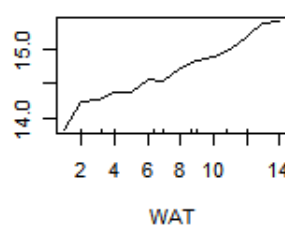
Partial Dependence on RUR



Partial Dependence on SHM



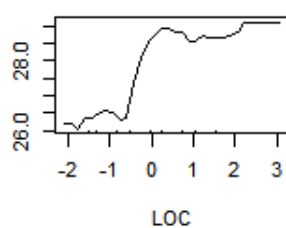
Partial Dependence on WAT



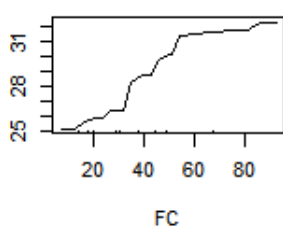
3) Forest->species_richness->forest-specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 513.25327
No. of variables tried at each split: 2	ADJ 29.75355
	LOC 258.32046
Mean of squared residuals: 51.09947	ED 244.59194
% Var explained: 11.87	WAT 179.56523
	RUR 161.83141
	SHM 210.35061

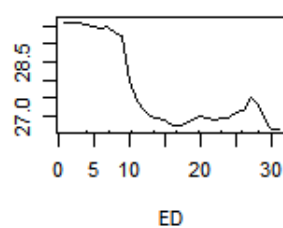
Partial Dependence on LOC



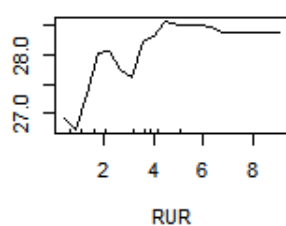
Partial Dependence on FC



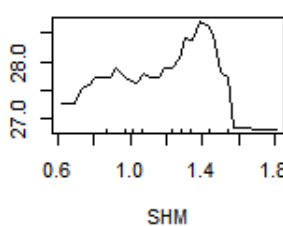
Partial Dependence on ED



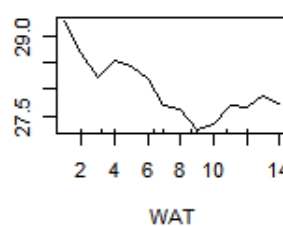
Partial Dependence on RUR



Partial Dependence on SHM



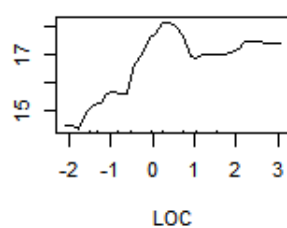
Partial Dependence on WAT



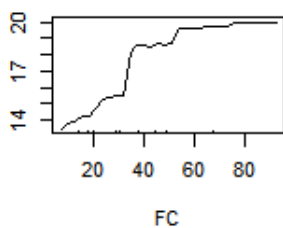
4. Forest->pest_control->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 548.1656
No. of variables tried at each split: 2	ADJ 71.2219
	LOC 382.3618
Mean of squared residuals: 89.69021	ED 293.4093
% Var explained: -5.21	WAT 267.8854
	RUR 350.5990
	SHM 369.6195

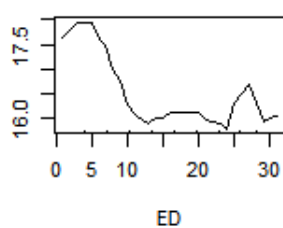
Partial Dependence on LOC



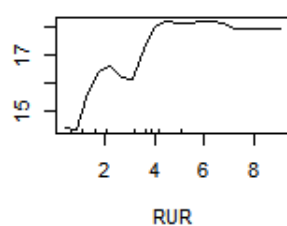
Partial Dependence on FC



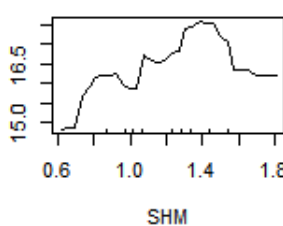
Partial Dependence on ED



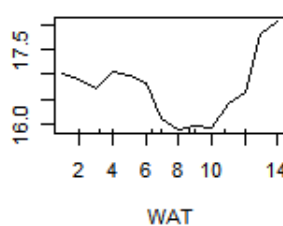
Partial Dependence on RUR



Partial Dependence on SHM



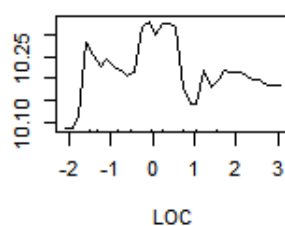
Partial Dependence on WAT



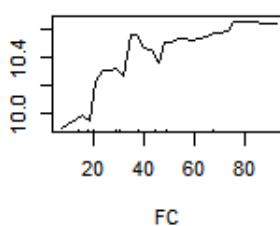
5) Forest->pest_control->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 21.99052
No. of variables tried at each split: 2	ADJ 14.86204
	LOC 20.13552
Mean of squared residuals: 6.291722	ED 34.29580
% Var explained: 14.68	WAT 26.68221
	RUR 66.82373
	SHM 22.54831

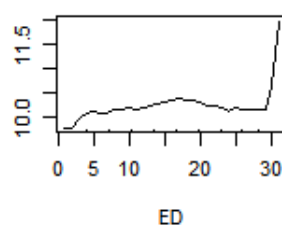
Partial Dependence on LOC



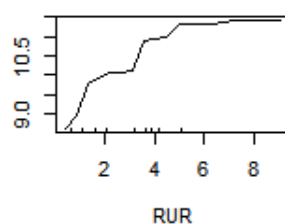
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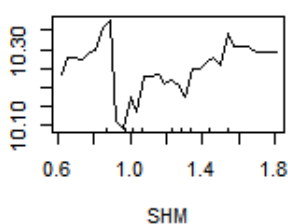
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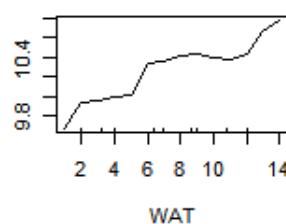
Partial Dependence on RUR



Partial Dependence on SHM



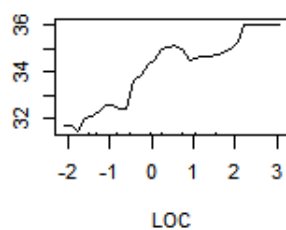
Partial Dependence on WAT



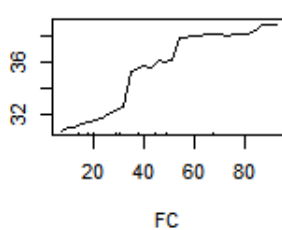
6) Forest->pest_control->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 837.40377
No. of variables tried at each split: 2	ADJ 46.61777
	LOC 536.30199
Mean of squared residuals: 125.3083	ED 471.00332
% Var explained: -11.78	WAT 377.76273
	RUR 361.34047
	SHM 393.76882

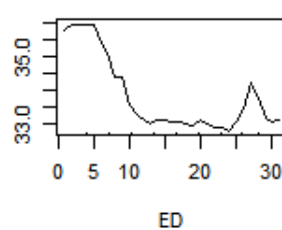
Partial Dependence on LOC



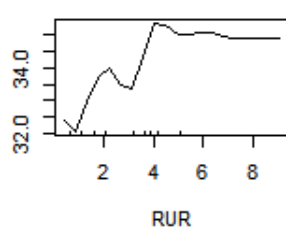
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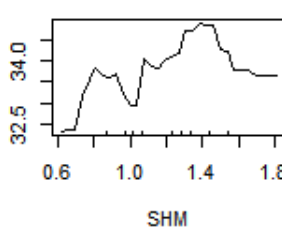
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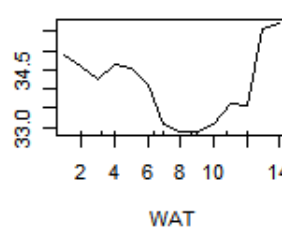
Partial Dependence on RUR



Partial Dependence on SHM



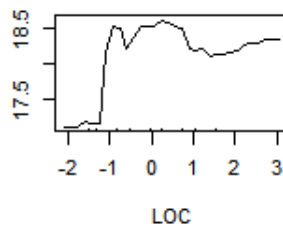
Partial Dependence on WAT



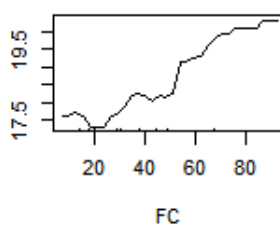
7) Forest->seed_dispersal->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 152.91557
No. of variables tried at each split: 2	ADJ 32.27656
	LOC 102.95237
Mean of squared residuals: 22.05368	ED 81.32287
% Var explained: 9.75	WAT 59.85926
	RUR 139.14976
	SHM 97.53018

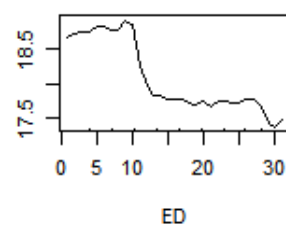
Partial Dependence on LOC



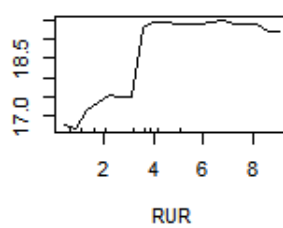
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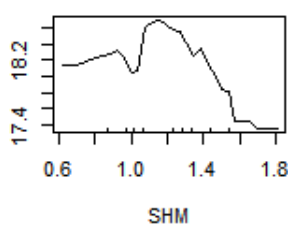
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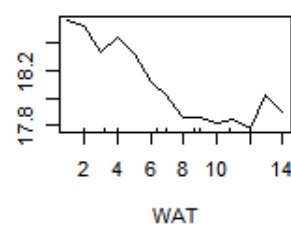
Partial Dependence on RUR



Partial Dependence on SHM



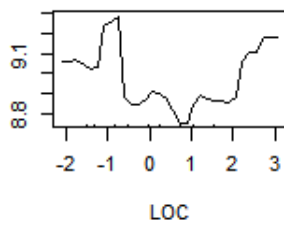
Partial Dependence on WAT



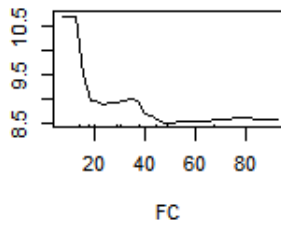
8) Forest->seed_dispersal->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 71.06250
No. of variables tried at each split: 2	ADJ 11.24424
	LOC 37.17551
Mean of squared residuals: 10.76107	ED 45.66733
% Var explained: 8.66	WAT 26.01489
	RUR 79.45478
	SHM 38.50628

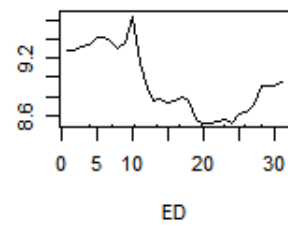
Partial Dependence on LOC



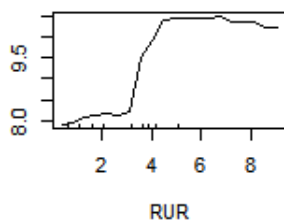
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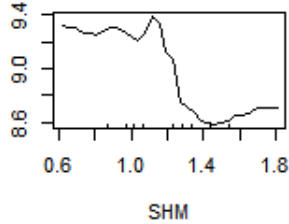
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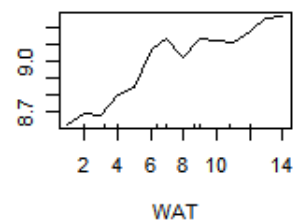
Partial Dependence on RUR



Partial Dependence on SHM



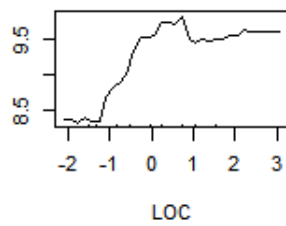
Partial Dependence on WAT



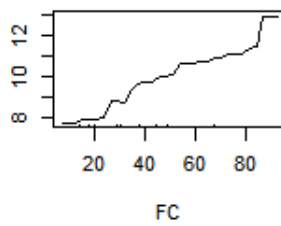
9) Forest->seed_dispersal->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 169.16761
No. of variables tried at each split: 2	ADJ 10.36831
	LOC 63.68095
Mean of squared residuals: 16.87244	ED 60.62763
% Var explained: 1.47	WAT 68.65379
	RUR 48.81731
	SHM 50.80317

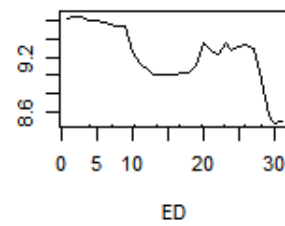
Partial Dependence on LOC



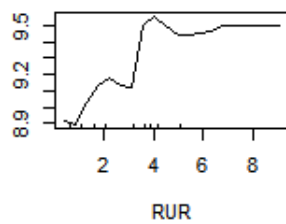
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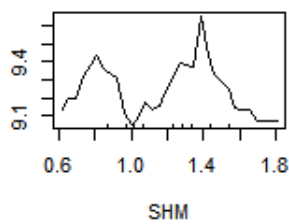
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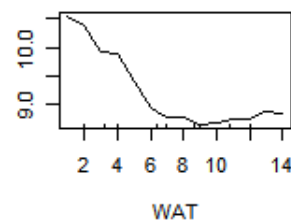
Partial Dependence on RUR



Partial Dependence on SHM



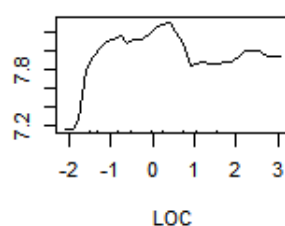
Partial Dependence on WAT



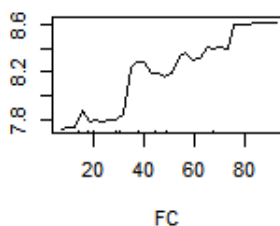
10) Forest->pollination->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 34.42574
No. of variables tried at each split: 2	ADJ 12.16129
	LOC 35.60727
Mean of squared residuals: 9.545451	ED 34.66048
% Var explained: -17.76	WAT 23.71272
	RUR 44.36397
	SHM 29.33477

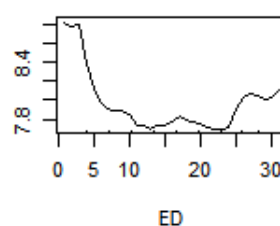
Partial Dependence on LOC



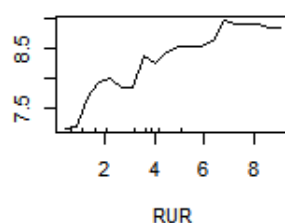
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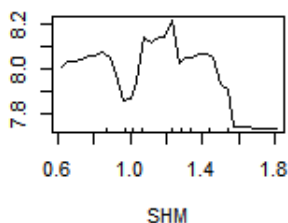
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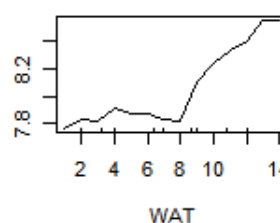
Partial Dependence on RUR



Partial Dependence on SHM



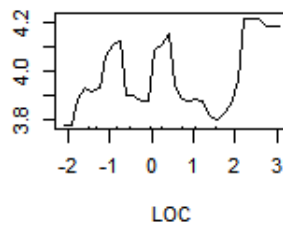
Partial Dependence on WAT



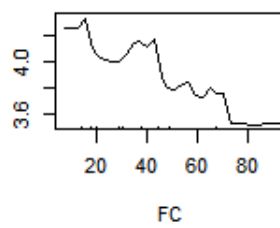
11)Forest->pollination->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 26.328220
No. of variables tried at each split: 2	ADJ 8.239244
	LOC 22.053275
Mean of squared residuals: 7.198164	ED 25.572574
% Var explained: -19.73	WAT 21.309098
	RUR 33.097686
	SHM 25.163394

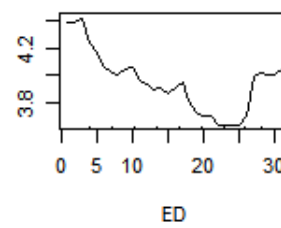
Partial Dependence on LOC



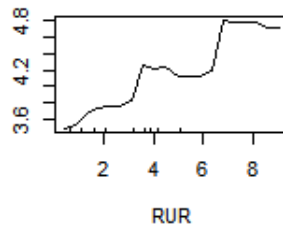
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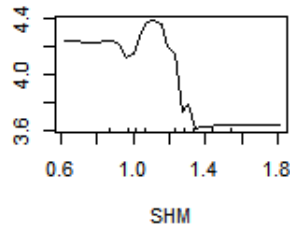
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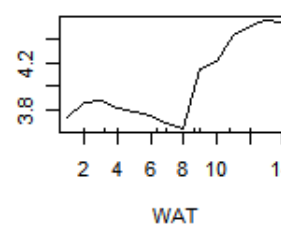
Partial Dependence on RUR



Partial Dependence on SHM



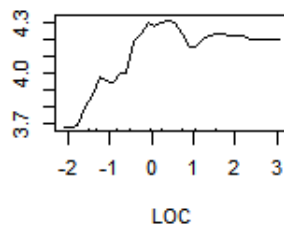
Partial Dependence on WAT



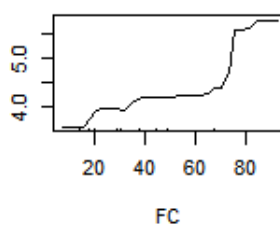
12) Forest->pollination->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 33.893247
No. of variables tried at each split: 2	ADJ 2.469121
	LOC 12.633650
Mean of squared residuals: 4.073829	ED 15.509826
% Var explained: -4.95	WAT 7.598049
	RUR 14.407414
	SHM 14.371990

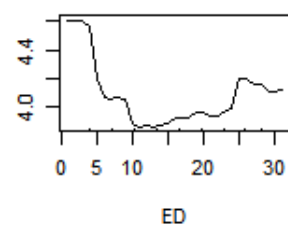
Partial Dependence on LOC



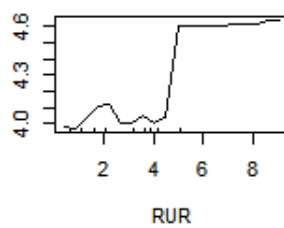
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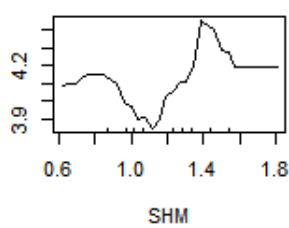
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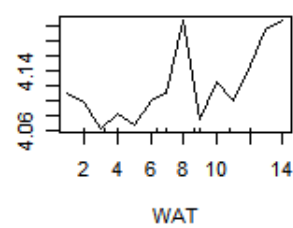
Partial Dependence on RUR



Partial Dependence on SHM



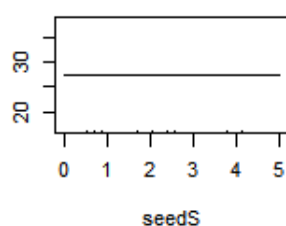
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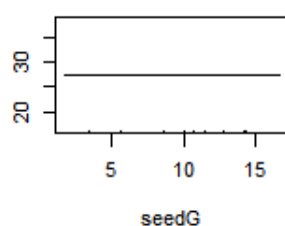
13) Pasture->species_richness->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 79.79024
No. of variables tried at each split: 2	PAS 65.17505
	LOC 268.18792
Mean of squared residuals: 63.78708	ED 239.83793
% Var explained: 16.34	WAT 53.90718
	RUR 197.21652
	SHM 95.98771

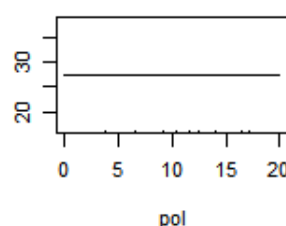
Partial Dependence on seedS



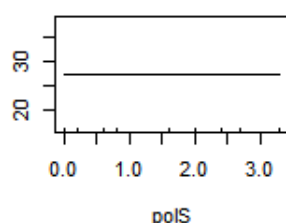
Partial Dependence on seedG



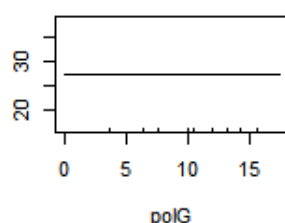
Partial Dependence on pol



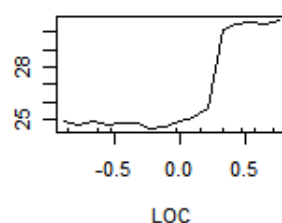
Partial Dependence on polS



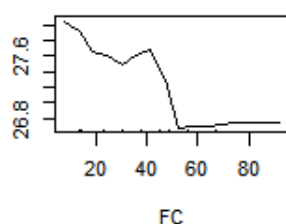
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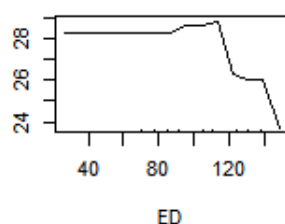
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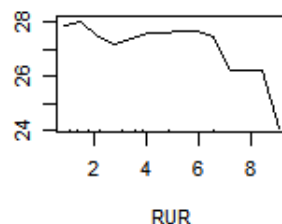
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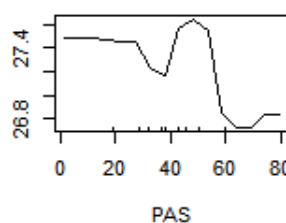
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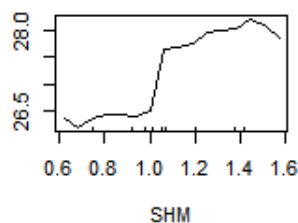
Partial Dependence on RUR



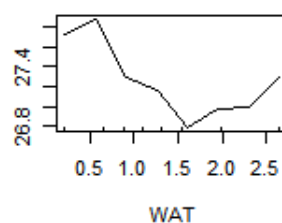
Partial Dependence on PAS



Partial Dependence on SHM



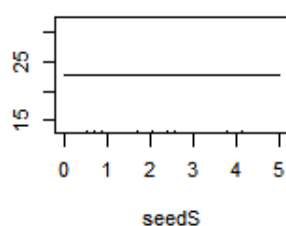
Partial Dependence on WAT



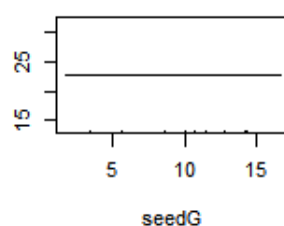
14) Pasture->species_richness->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 51.89927
No. of variables tried at each split: 2	PAS 33.14053
	LOC 95.13634
Mean of squared residuals: 43.44268	ED 134.00339
% Var explained: -9.91	WAT 24.99290
	RUR 123.35707
	SHM 75.21450

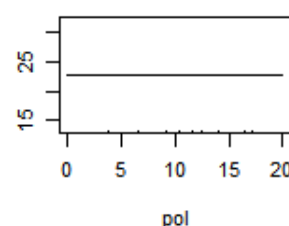
Partial Dependence on seedS



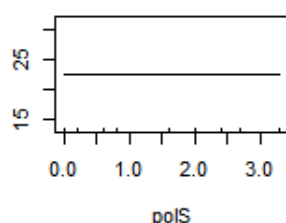
Partial Dependence on seedG



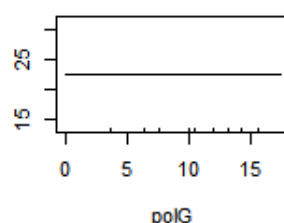
Partial Dependence on pol



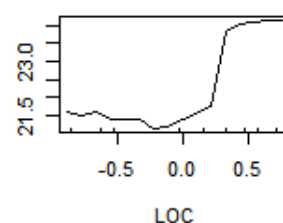
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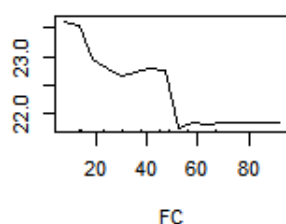
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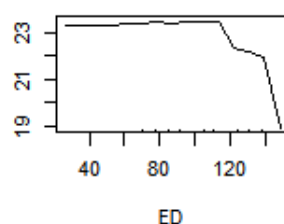
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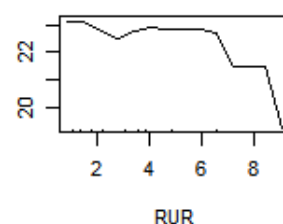
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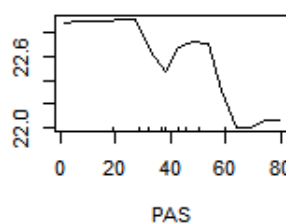
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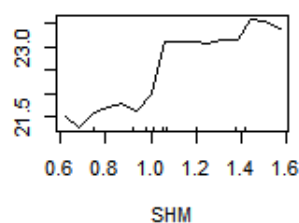
Partial Dependence on RUR



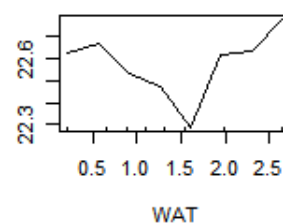
Partial Dependence on PAS



Partial Dependence on SHM



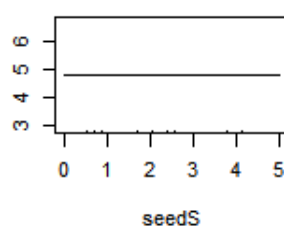
Partial Dependence on WAT



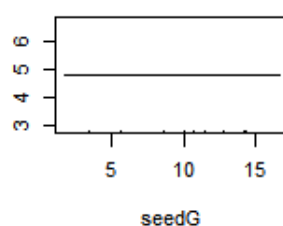
15) Pasture->species_richness->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 13.64694
No. of variables tried at each split: 2	PAS 12.99772
	LOC 43.13221
Mean of squared residuals: 10.09369	ED 25.47702
% Var explained: 6.88	WAT 15.65923
	RUR 13.36832
	SHM 13.00585

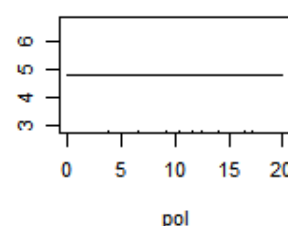
Partial Dependence on seedS



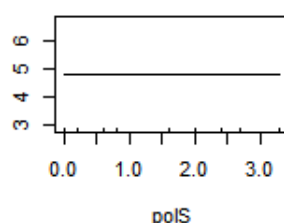
Partial Dependence on seedG



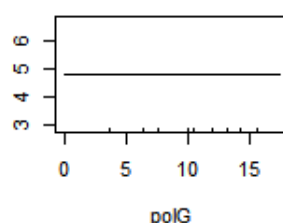
Partial Dependence on pol



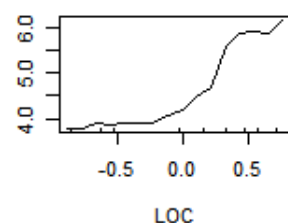
Partial Dependence on polS



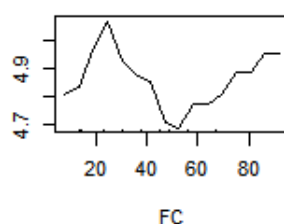
Partial Dependence on polG



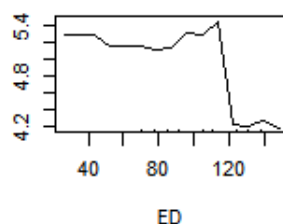
Partial Dependence on LOC



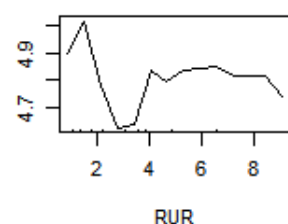
Partial Dependence on FC



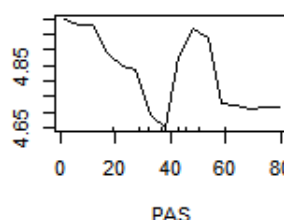
Partial Dependence on ED



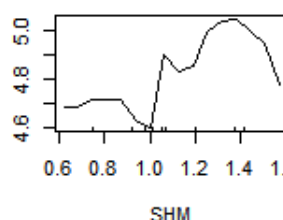
Partial Dependence on RUR



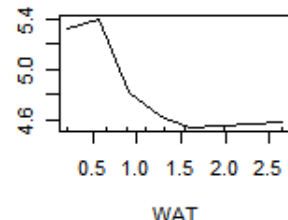
Partial Dependence on PAS



Partial Dependence on SHM



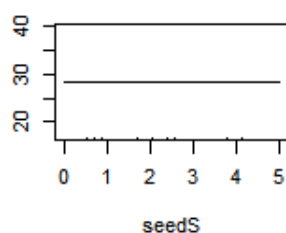
Partial Dependence on WAT



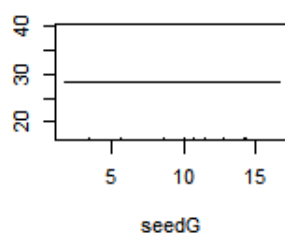
16) Pasture->pest_control->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 149.26389
No. of variables tried at each split: 2	PAS 138.85549
	LOC 487.28465
Mean of squared residuals: 104.2783	ED 282.86203
% Var explained: 9.26	WAT 83.49211
	RUR 221.71215
	SHM 179.17686

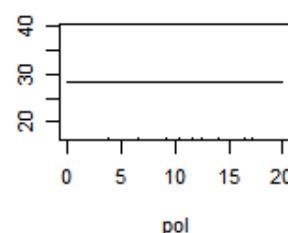
Partial Dependence on seedS



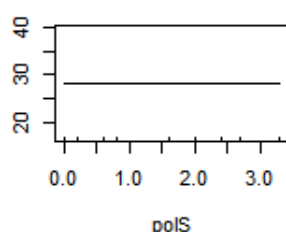
Partial Dependence on seedG



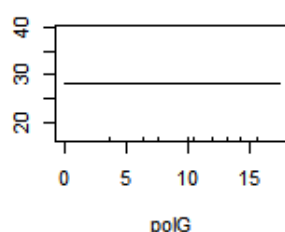
Partial Dependence on pol



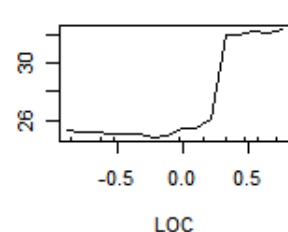
Partial Dependence on polS



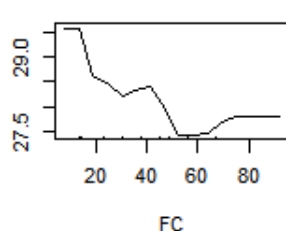
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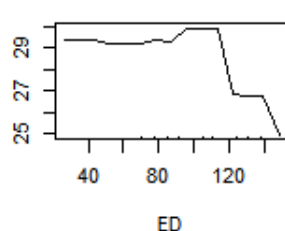
Partial Dependence on LOC



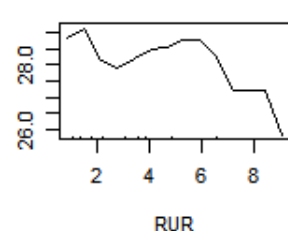
Partial Dependence on FC



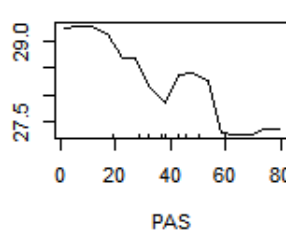
Partial Dependence on ED



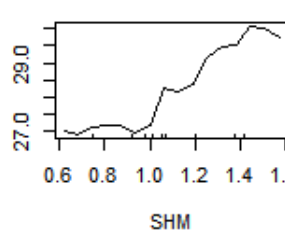
Partial Dependence on RUR



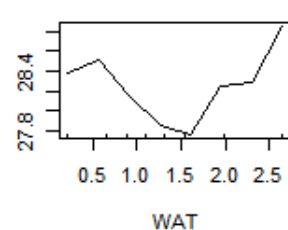
Partial Dependence on PAS



Partial Dependence on SHM



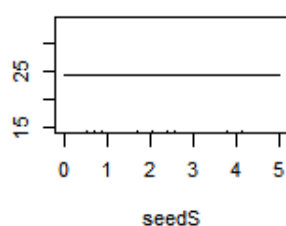
Partial Dependence on WAT



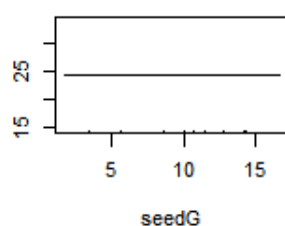
17) Pasture->pest_control->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 88.04395
No. of variables tried at each split: 2	PAS 89.48476
	LOC 199.95680
Mean of squared residuals: 77.18405	ED 181.61833
% Var explained: -11.55	WAT 58.20274
	RUR 154.66009
	SHM 124.00269

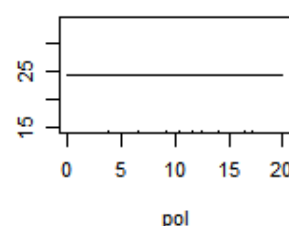
Partial Dependence on seedS



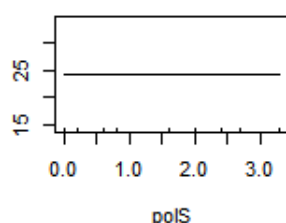
Partial Dependence on seedG



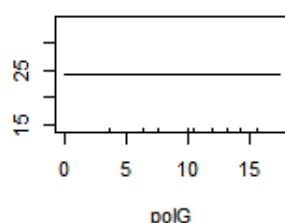
Partial Dependence on pol



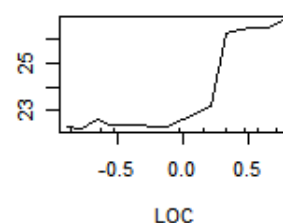
Partial Dependence on polS



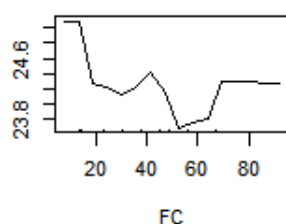
Partial Dependence on polG



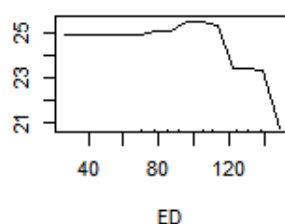
Partial Dependence on LOC



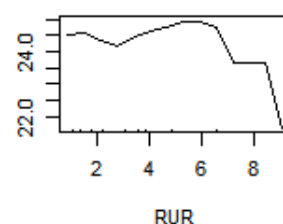
Partial Dependence on FC



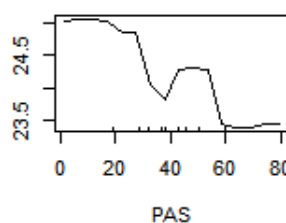
Partial Dependence on ED



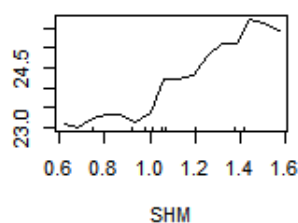
Partial Dependence on RUR



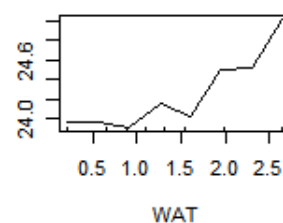
Partial Dependence on PAS



Partial Dependence on SHM



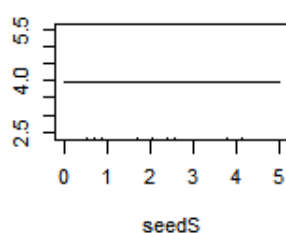
Partial Dependence on WAT



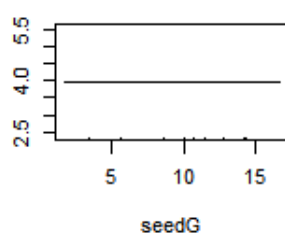
18) Pasture->pest_control->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 11.44701
No. of variables tried at each split: 2	PAS 11.65560
	LOC 43.49165
Mean of squared residuals: 8.926504	ED 15.76313
% Var explained: 10.91	WAT 15.41933
	RUR 12.13996
	SHM 15.93922

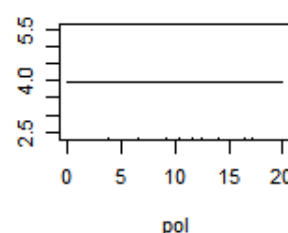
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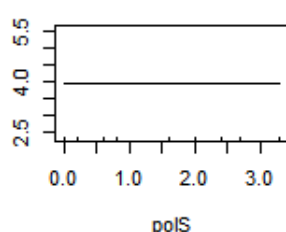
Partial Dependence on seedG



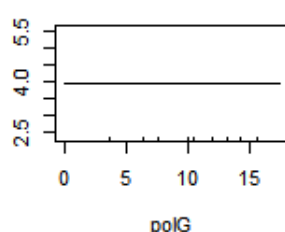
Partial Dependence on pol



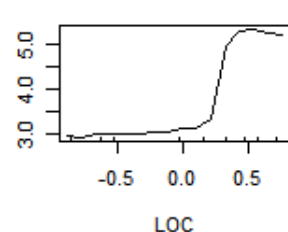
Partial Dependence on polS



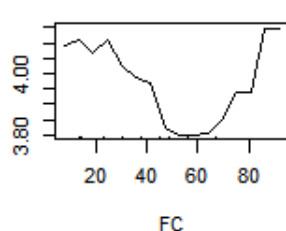
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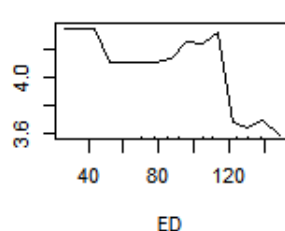
Partial Dependence on LOC



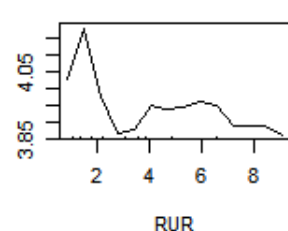
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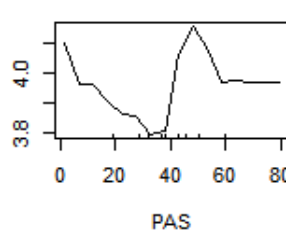
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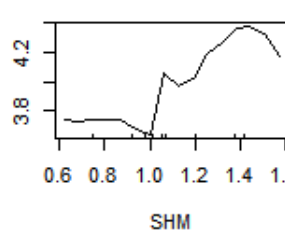
Partial Dependence on RUR



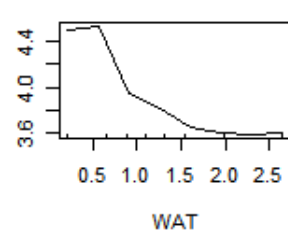
Partial Dependence on PAS



Partial Dependence on SHM



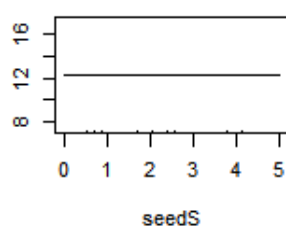
Partial Dependence on WAT



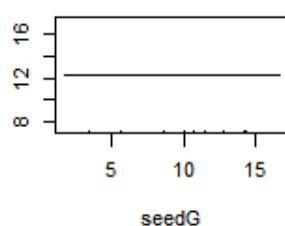
19) Pasture->seed_dispersal->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 19.76421
No. of variables tried at each split: 2	PAS 34.55109
	LOC 84.50984
Mean of squared residuals: 20.2423	ED 79.13731
% Var explained: 23.51	WAT 46.62164
	RUR 50.34510
	SHM 30.36245

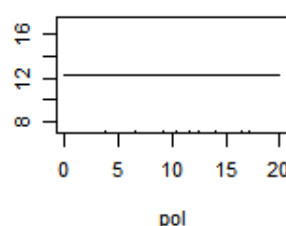
Partial Dependence on seedS



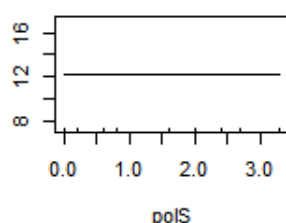
Partial Dependence on seedG



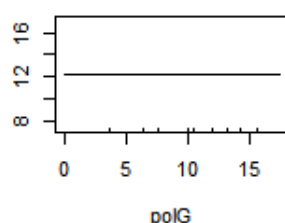
Partial Dependence on pol



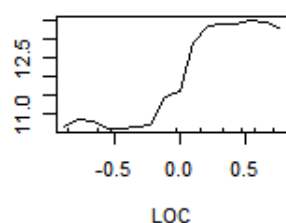
Partial Dependence on polS



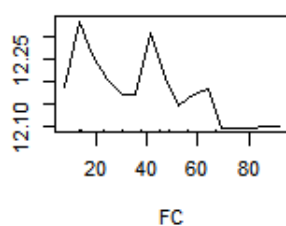
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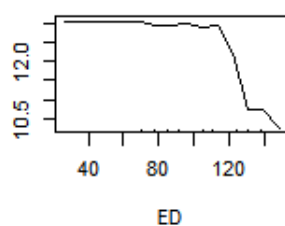
Partial Dependence on LOC



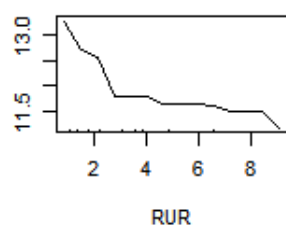
Partial Dependence on FC



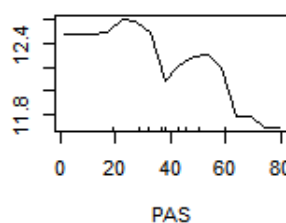
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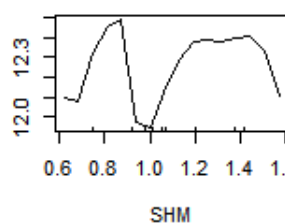
Partial Dependence on RUR



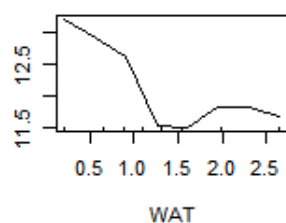
Partial Dependence on PAS



Partial Dependence on SHM



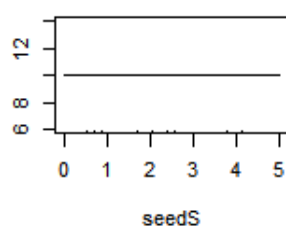
Partial Dependence on WAT



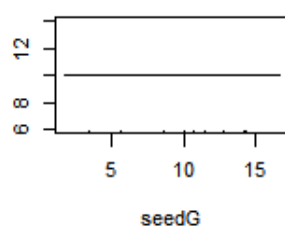
20) Pasture->seed_dispersal->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 14.94001
No. of variables tried at each split: 2	PAS 23.60363
	LOC 46.60207
Mean of squared residuals: 17.67146	ED 61.86322
% Var explained: 4.52	WAT 26.35534
	RUR 40.11252
	SHM 26.43694

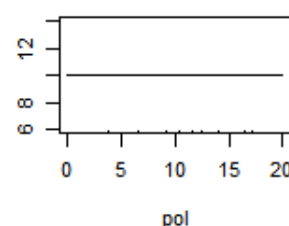
Partial Dependence on seedS



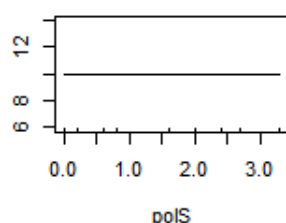
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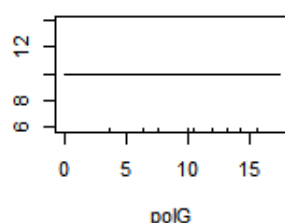
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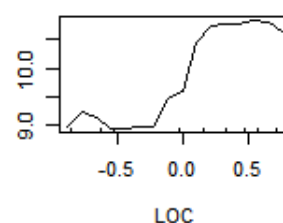
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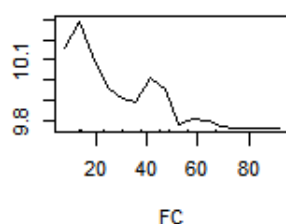
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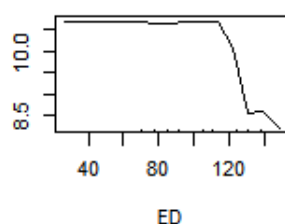
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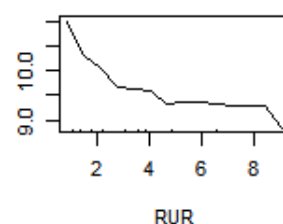
Partial Dependence on FC



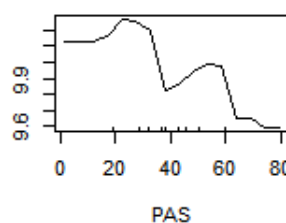
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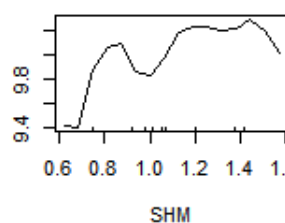
Partial Dependence on RUR



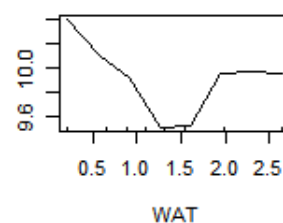
Partial Dependence on PAS



Partial Dependence on SHM



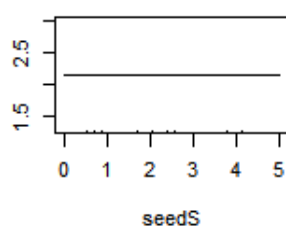
Partial Dependence on WAT



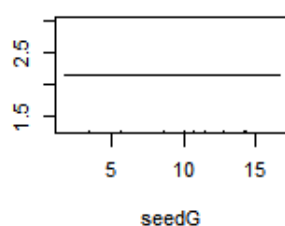
21) Pasture->seed_dispersal->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 3.327215
No. of variables tried at each split: 2	PAS 2.273799
	LOC 7.232875
Mean of squared residuals: 1.30399	ED 3.632924
% Var explained: 40.72	WAT 8.420578
	RUR 2.298249
	SHM 2.164593

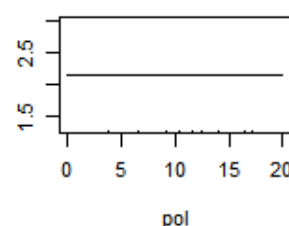
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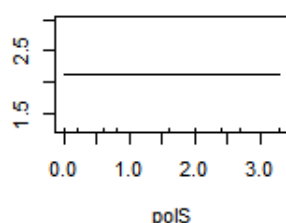
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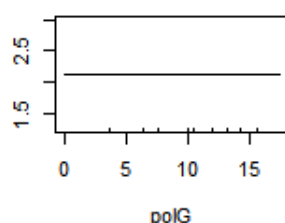
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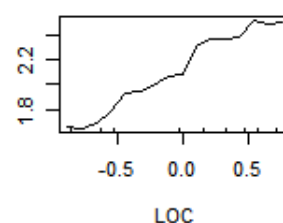
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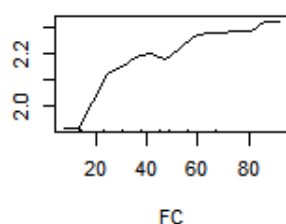
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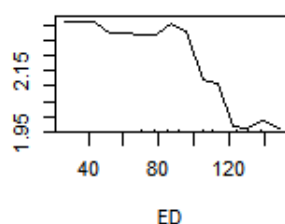
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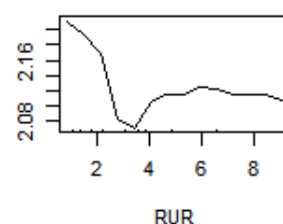
Partial Dependence on FC



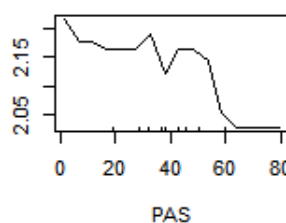
Partial Dependence on ED



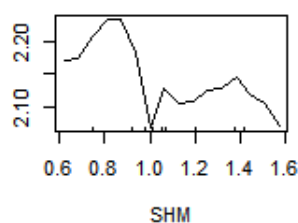
Partial Dependence on RUR



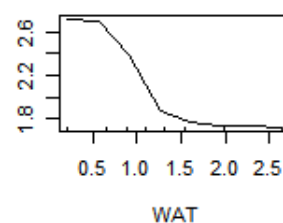
Partial Dependence on PAS



Partial Dependence on SHM



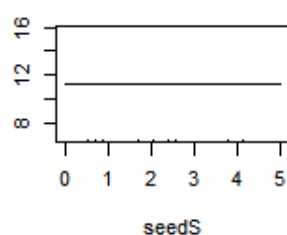
Partial Dependence on WAT



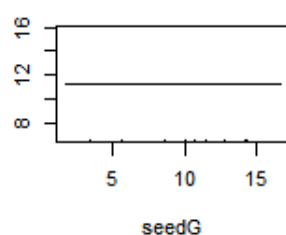
22) Pasture->pollination->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 32.44845
No. of variables tried at each split: 2	PAS 41.23099
	LOC 101.17459
Mean of squared residuals: 26.94782	ED 82.33000
% Var explained: 8.62	WAT 53.10790
	RUR 49.35924
	SHM 33.24533

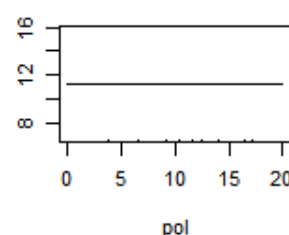
Partial Dependence on seedS



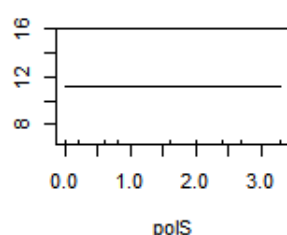
Partial Dependence on seedG



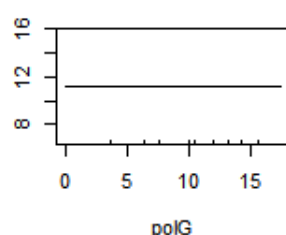
Partial Dependence on pol



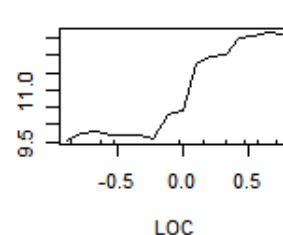
Partial Dependence on polS



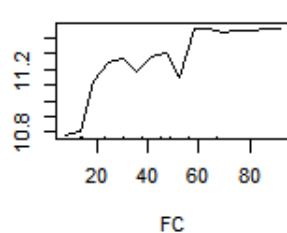
Partial Dependence on polG



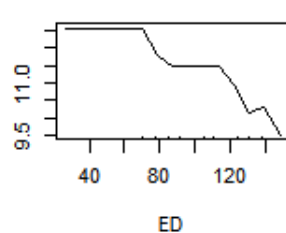
Partial Dependence on LOC



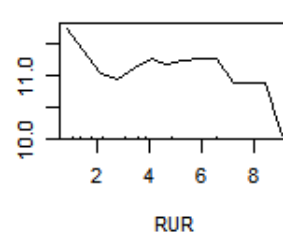
Partial Dependence on FC



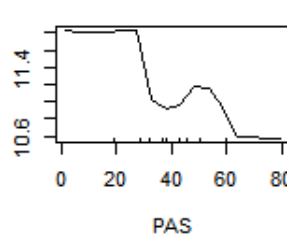
Partial Dependence on ED



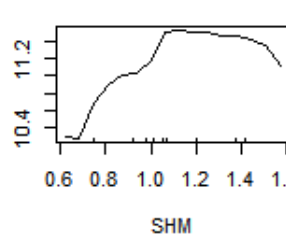
Partial Dependence on RUR



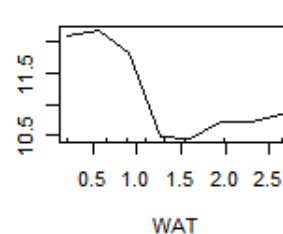
Partial Dependence on PAS



Partial Dependence on SHM



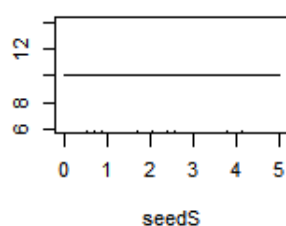
Partial Dependence on WAT



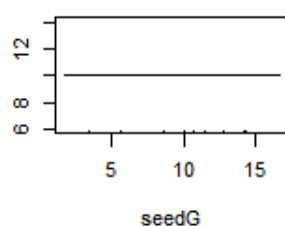
23) Pasture->pollination->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 25.48242
No. of variables tried at each split: 2	PAS 42.49987
	LOC 65.07467
Mean of squared residuals: 22.39042	ED 62.76659
% Var explained: 1.96	WAT 24.08522
	RUR 41.16238
	SHM 42.76593

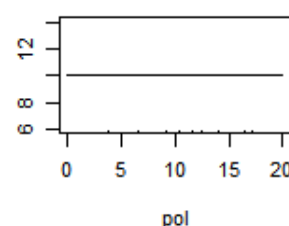
Partial Dependence on seedS



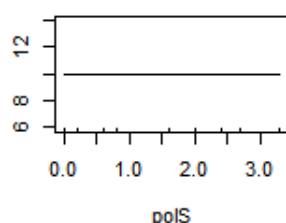
Partial Dependence on seedG



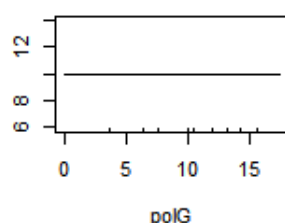
Partial Dependence on pol



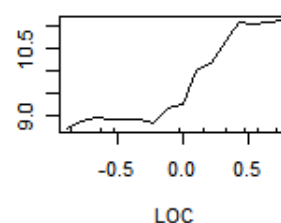
Partial Dependence on polS



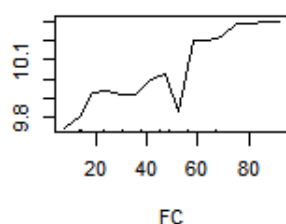
Partial Dependence on polG



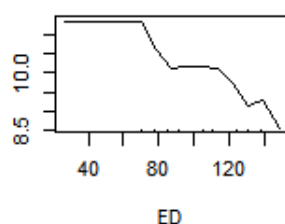
Partial Dependence on LOC



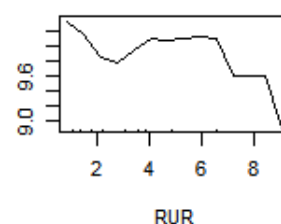
Partial Dependence on FC



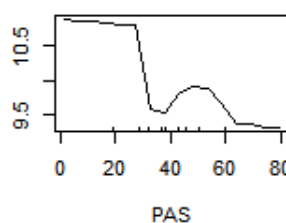
Partial Dependence on ED



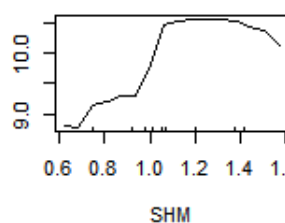
Partial Dependence on RUR



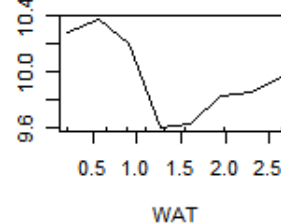
Partial Dependence on PAS



Partial Dependence on SHM



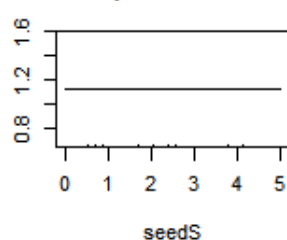
Partial Dependence on WAT



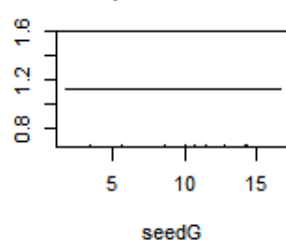
24) Pasture->pollination->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 1.238112
No. of variables tried at each split: 2	PAS 1.204035
	LOC 3.753982
Mean of squared residuals: 0.7856165	ED 1.717193
% Var explained: 35.64	WAT 4.937095
	RUR 1.799232
	SHM 1.878682

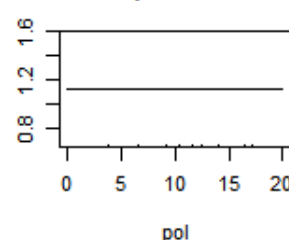
Partial Dependence on seedS



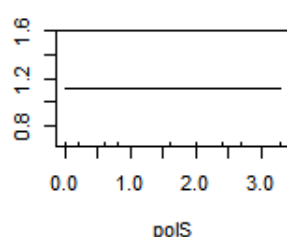
Partial Dependence on seedG



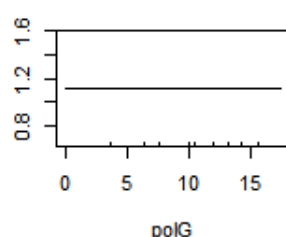
Partial Dependence on pol



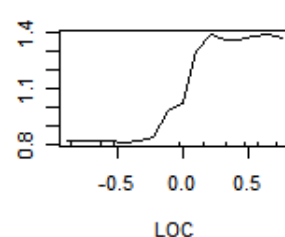
Partial Dependence on polS



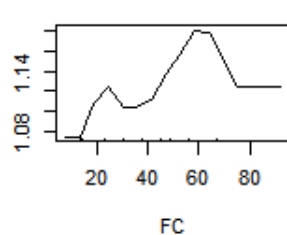
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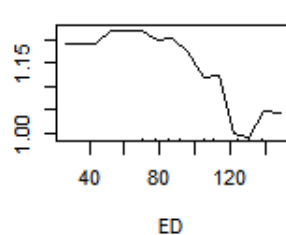
Partial Dependence on LOC



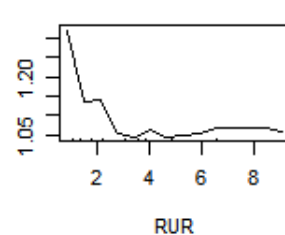
Partial Dependence on FC



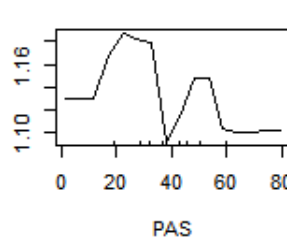
Partial Dependence on ED



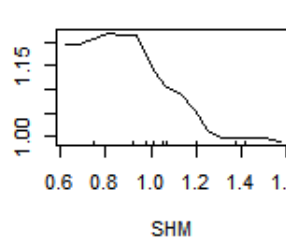
Partial Dependence on RUR



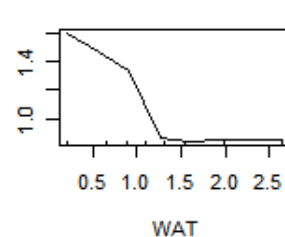
Partial Dependence on PAS



Partial Dependence on SHM



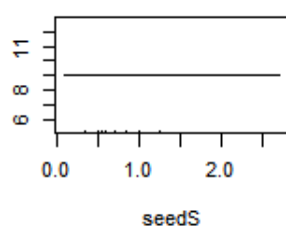
Partial Dependence on WAT



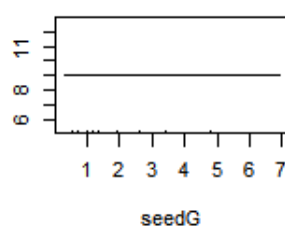
25) Eucalyptus->species_richness->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 9.089156
No. of variables tried at each split: 2	SILV 9.666655
	LOC 4.428823
Mean of squared residuals: 7.978671	ED 11.390244
% Var explained: -31.69	WAT 9.438951
	RUR 13.260779
	SHM 19.348417

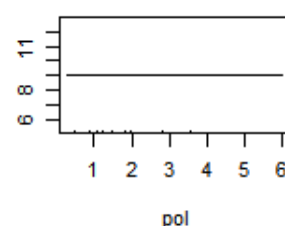
Partial Dependence on seedS



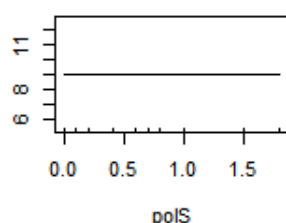
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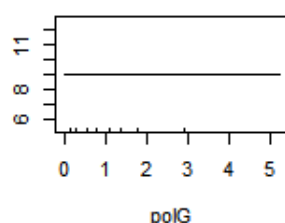
Partial Dependence on pol



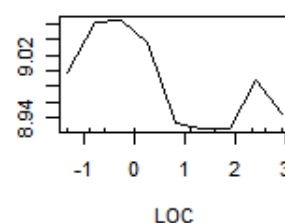
Partial Dependence on polS



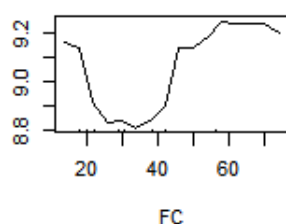
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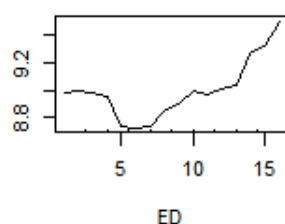
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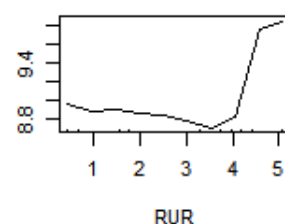
Partial Dependence on FC



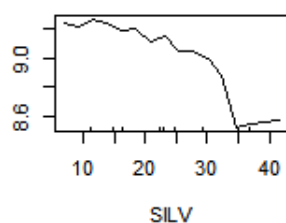
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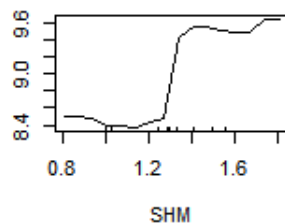
Partial Dependence on RUR



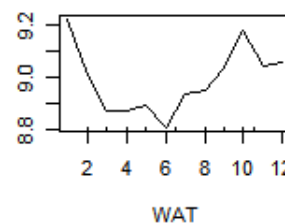
Partial Dependence on SILV



Partial Dependence on SHM



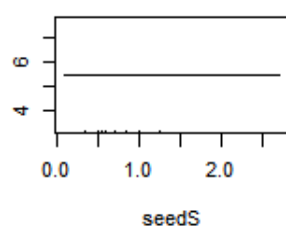
Partial Dependence on WAT



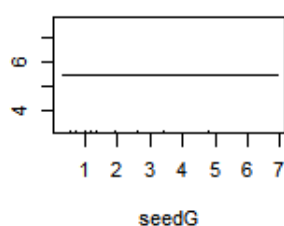
26) Eucalyptus -> species_richness -> habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 11.401257
No. of variables tried at each split: 2	SILV 7.455665
	LOC 3.443199
Mean of squared residuals: 6.752844	ED 14.024746
% Var explained: -14.94	WAT 12.373503
	RUR 9.755028
	SHM 16.561127

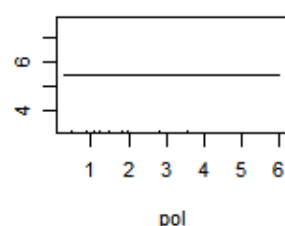
Partial Dependence on seedS



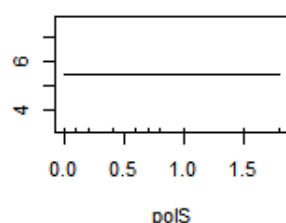
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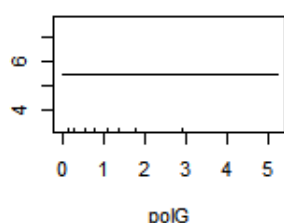
Partial Dependence on pol



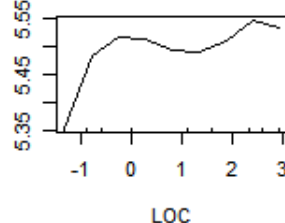
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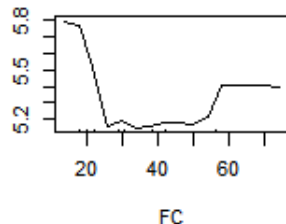
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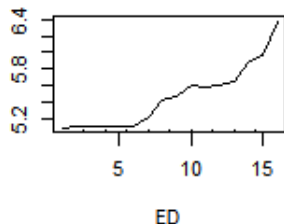
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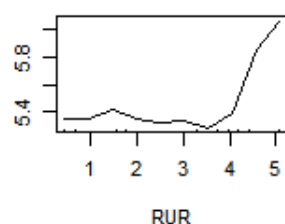
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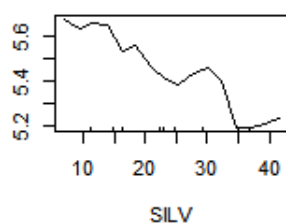
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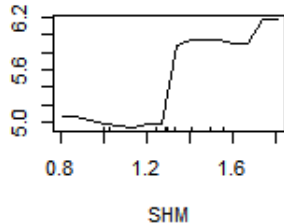
Partial Dependence on RUR



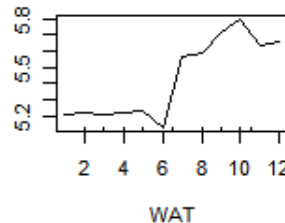
Partial Dependence on SILV



Partial Dependence on SHM



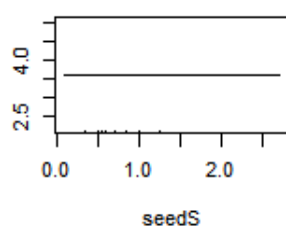
Partial Dependence on WAT



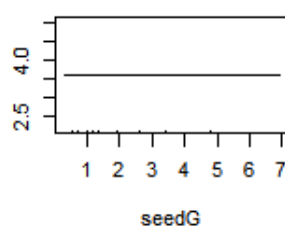
27) Eucalyptus -> Species_richness -> forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 3.219054
No. of variables tried at each split: 2	SILV 1.131191
	LOC 1.330398
Mean of squared residuals: 1.921153	ED 6.444796
% Var explained: -2.68	WAT 6.118690
	RUR 2.991527
	SHM 1.387744

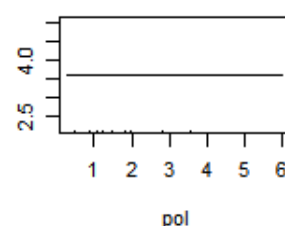
Partial Dependence on seedS



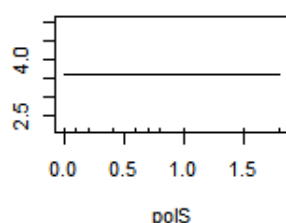
Partial Dependence on seedG



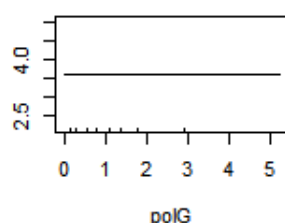
Partial Dependence on pol



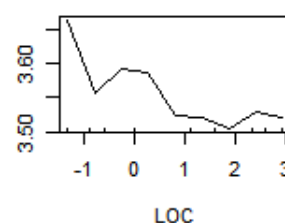
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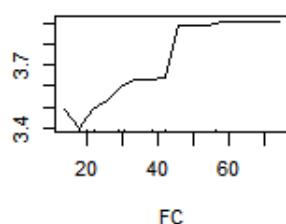
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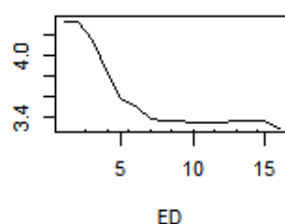
Partial Dependence on LOC



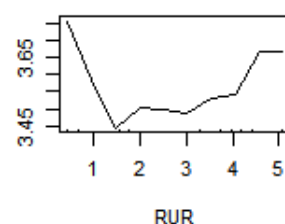
Partial Dependence on FC



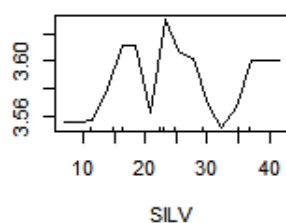
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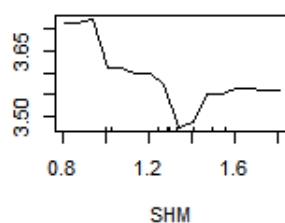
Partial Dependence on RUR



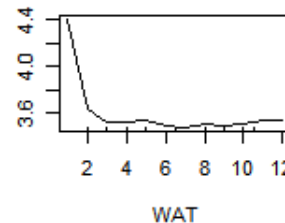
Partial Dependence on SILV



Partial Dependence on SHM



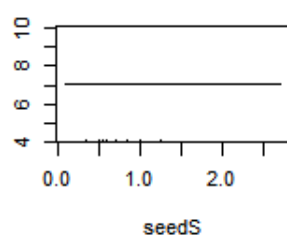
Partial Dependence on WAT



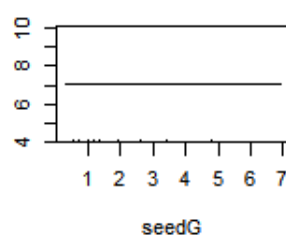
28) Eucalyptus -> pest_control -> all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 4.969253
No. of variables tried at each split: 2	SILV 13.233867
	LOC 5.536934
Mean of squared residuals: 8.148972	ED 11.449552
% Var explained: -43.44	WAT 10.115484
	RUR 11.926786
	SHM 14.562742

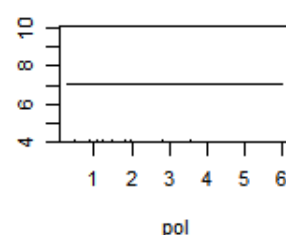
Partial Dependence on seedS



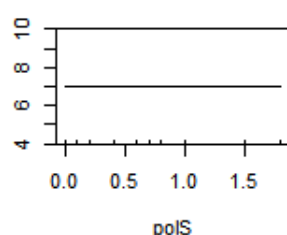
Partial Dependence on seedG



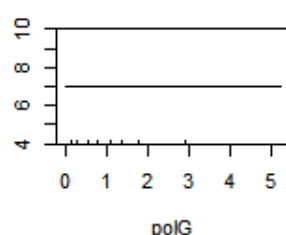
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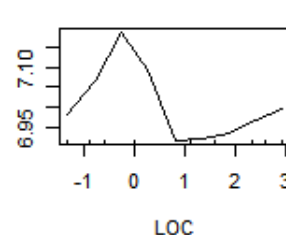
Partial Dependence on polS



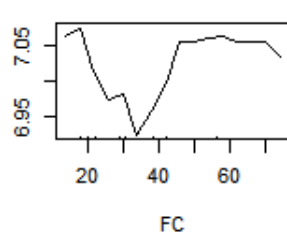
Partial Dependence on polG



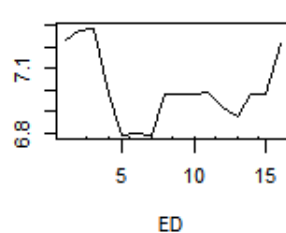
Partial Dependence on LOC



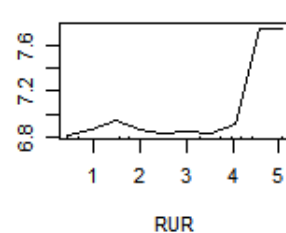
Partial Dependence on FC



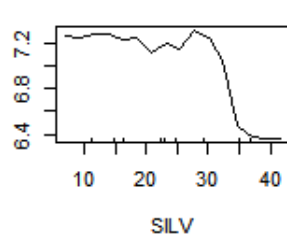
Partial Dependence on ED



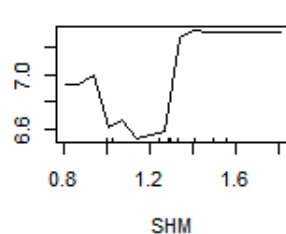
Partial Dependence on RUR



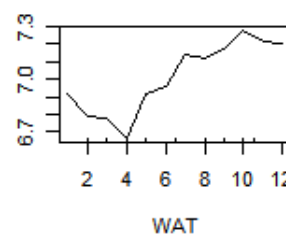
Partial Dependence on SILV



Partial Dependence on SHM



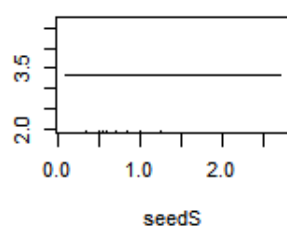
Partial Dependence on WAT



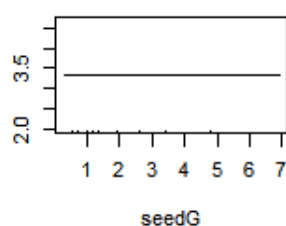
29) Eucalyptus -> pest_control -> habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 6.189248
No. of variables tried at each split: 2	SILV 6.439553
	LOC 2.820909
Mean of squared residuals: 4.774063	ED 9.231273
% Var explained: -22.32	WAT 7.994048
	RUR 8.157686
	SHM 8.980089

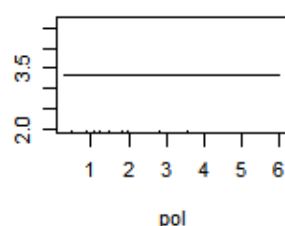
Partial Dependence on seedS



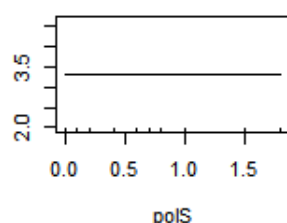
Partial Dependence on seedG



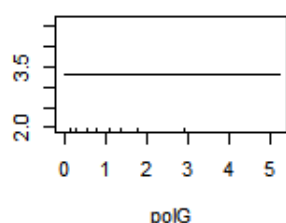
Partial Dependence on pol



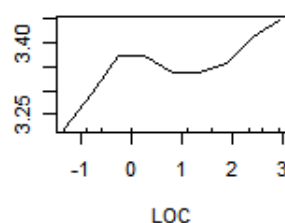
Partial Dependence on polS



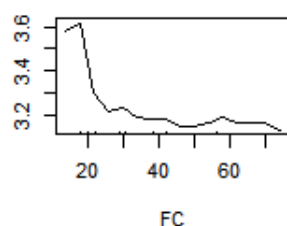
Partial Dependence on polG



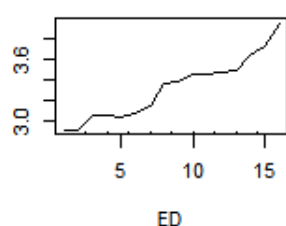
Partial Dependence on LOC



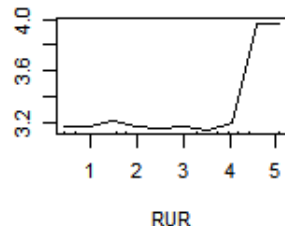
Partial Dependence on FC



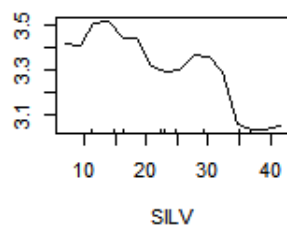
Partial Dependence on ED



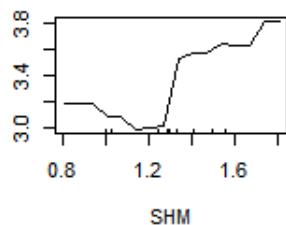
Partial Dependence on RUR



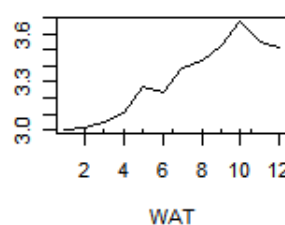
Partial Dependence on SILV



Partial Dependence on SHM



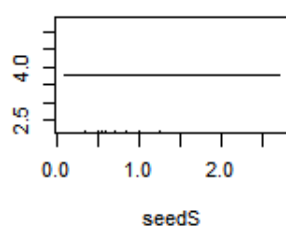
Partial Dependence on WAT



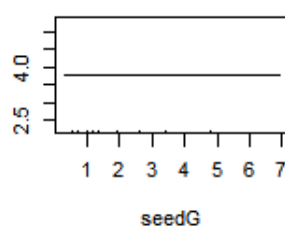
30) Eucalyptus -> pest_control -> forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 3.461196
No. of variables tried at each split: 2	SILV 2.661580
	LOC 2.375107
Mean of squared residuals: 3.3362	ED 7.843229
% Var explained: -30.79	WAT 6.382577
	RUR 5.029590
	SHM 4.452821

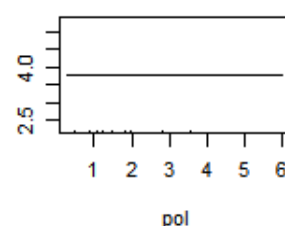
Partial Dependence on seedS



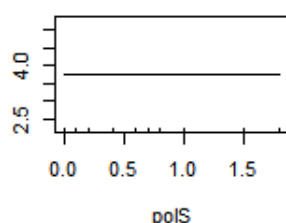
Partial Dependence on seedG



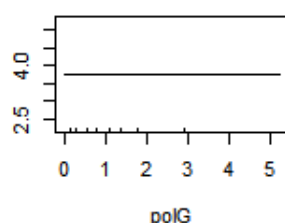
Partial Dependence on pol



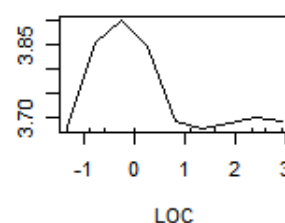
Partial Dependence on polS



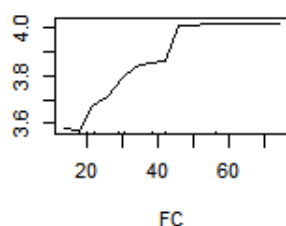
Partial Dependence on polG



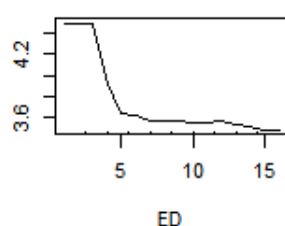
Partial Dependence on LOC



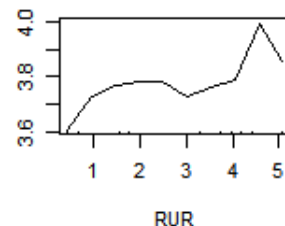
Partial Dependence on FC



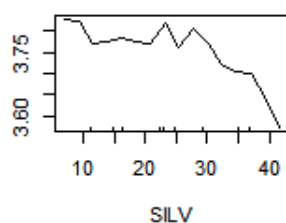
Partial Dependence on ED



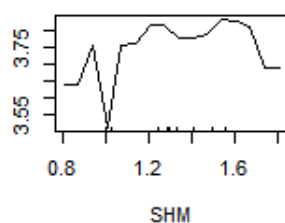
Partial Dependence on RUR



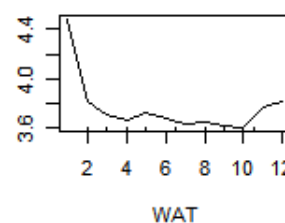
Partial Dependence on SILV



Partial Dependence on SHM



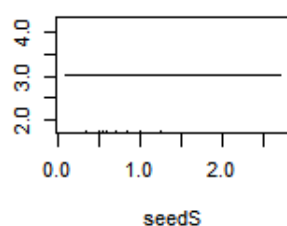
Partial Dependence on WAT



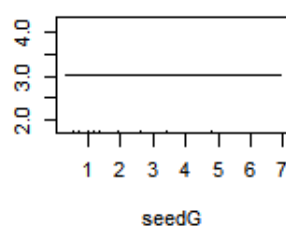
31) Eucalyptus -> seed_dispersal -> all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 6.596968
No. of variables tried at each split: 2	SILV 7.146440
	LOC 4.342582
Mean of squared residuals: 5.973268	ED 16.720589
% Var explained: -35.61	WAT 6.394077
	RUR 7.274476
	SHM 6.924311

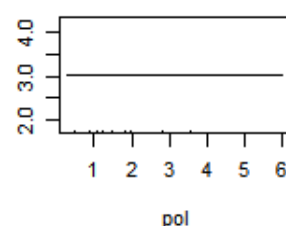
Partial Dependence on seedS



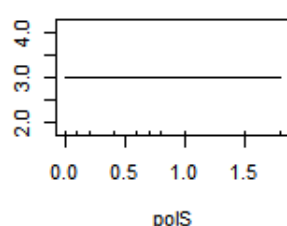
Partial Dependence on seedG



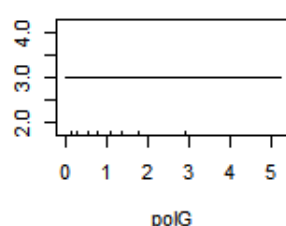
Partial Dependence on pol



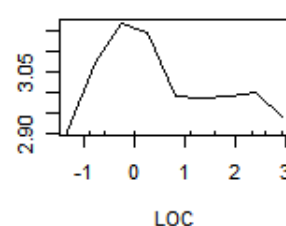
Partial Dependence on polS



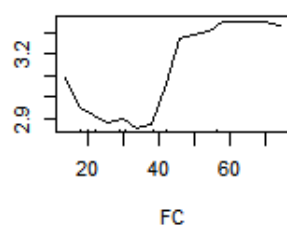
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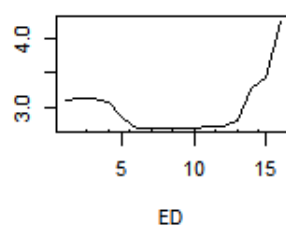
Partial Dependence on LOC



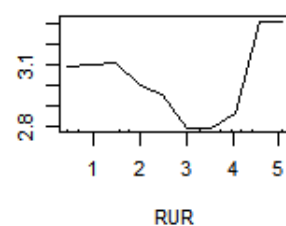
Partial Dependence on FC



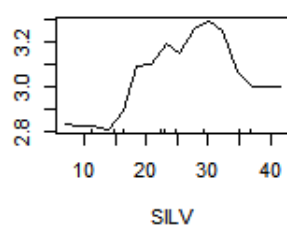
Partial Dependence on ED



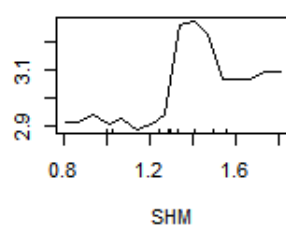
Partial Dependence on RUR



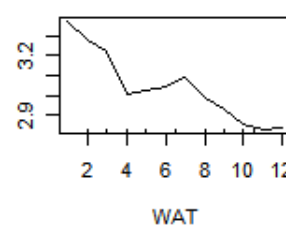
Partial Dependence on SILV



Partial Dependence on SHM



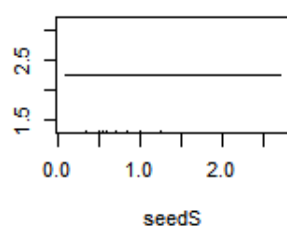
Partial Dependence on WAT



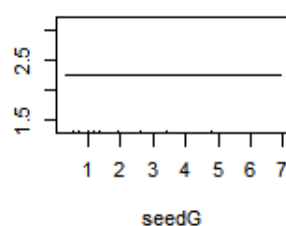
32) Eucalyptus -> seed_dispersal -> habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 5.752625
No. of variables tried at each split: 2	SILV 4.586969
	LOC 3.818616
Mean of squared residuals: 5.03282	ED 15.266774
% Var explained: -43.44	WAT 4.785437
	RUR 6.081539
	SHM 4.797104

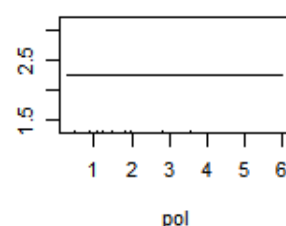
Partial Dependence on seedS



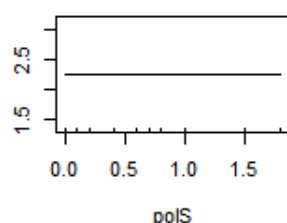
Partial Dependence on seedG



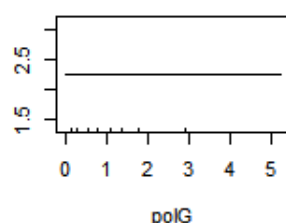
Partial Dependence on pol



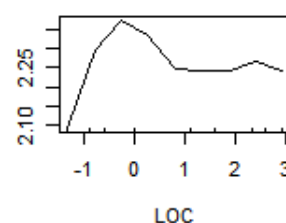
Partial Dependence on polS



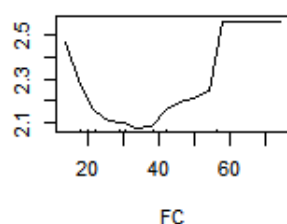
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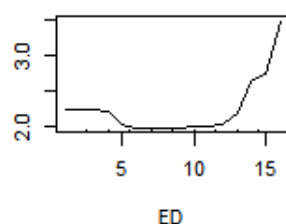
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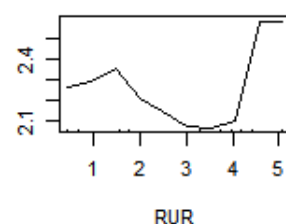
Partial Dependence on FC



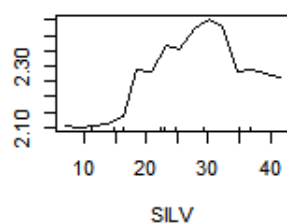
Partial Dependence on ED



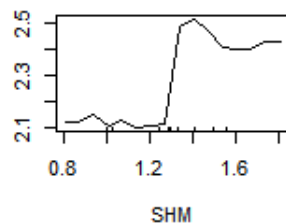
Partial Dependence on RUR



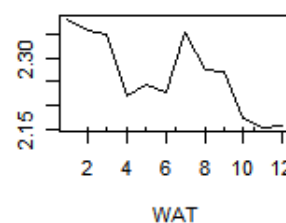
Partial Dependence on SILV



Partial Dependence on SHM



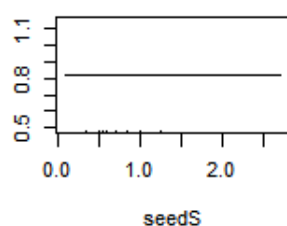
Partial Dependence on WAT



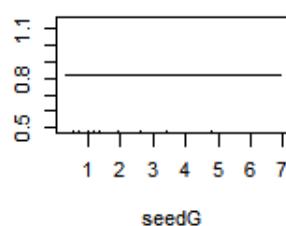
33) Eucalyptus -> seed_dispersal -> forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 0.4542543
No. of variables tried at each split: 2	SILV 0.6677398
	LOC 0.2000999
Mean of squared residuals: 0.3370892	ED 0.8191240
% Var explained: -1.38	WAT 1.2858769
	RUR 0.4947739
	SHM 0.3448393

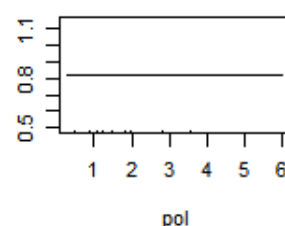
Partial Dependence on seedS



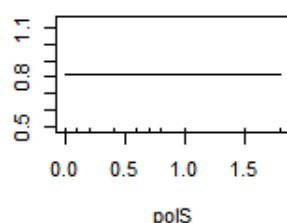
Partial Dependence on seedG



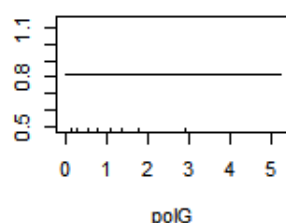
Partial Dependence on pol



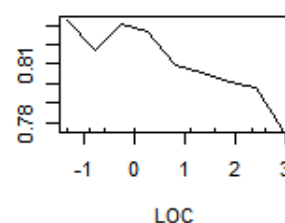
Partial Dependence on polS



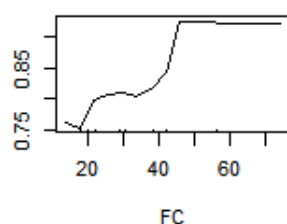
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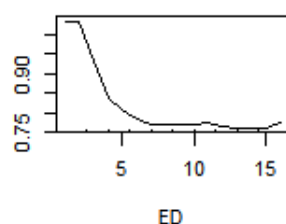
Partial Dependence on LOC



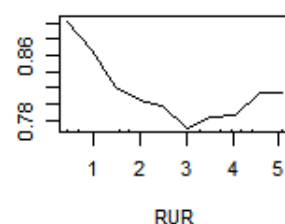
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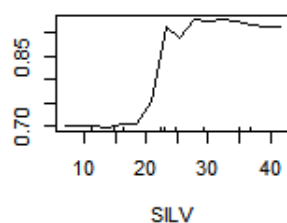
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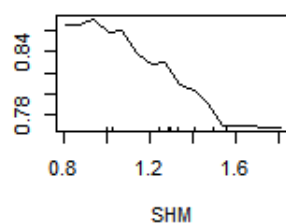
Partial Dependence on RUR



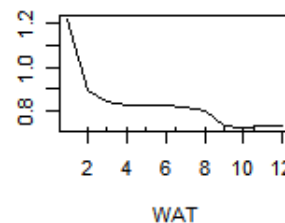
Partial Dependence on SILV



Partial Dependence on SHM



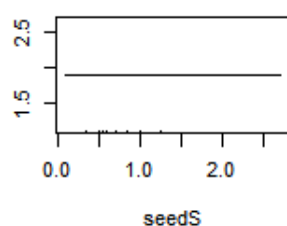
Partial Dependence on WAT



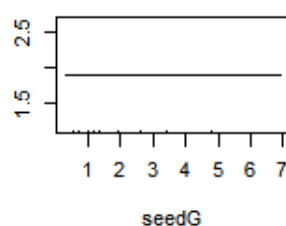
34) Eucalyptus ->pollination->all_species

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 6.791625
No. of variables tried at each split: 2	SILV 2.094308
	LOC 2.029008
Mean of squared residuals: 2.229473	ED 7.658345
% Var explained: -7.8	WAT 2.057191
	RUR 3.163868
	SHM 2.153979

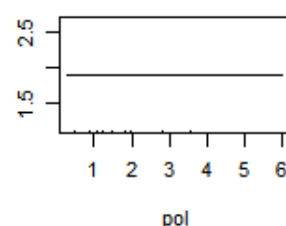
Partial Dependence on seedS



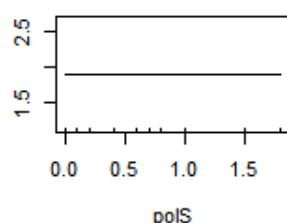
Partial Dependence on seedG



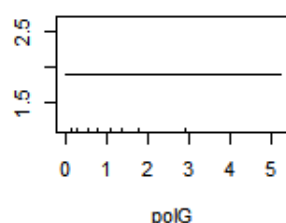
Partial Dependence on pol



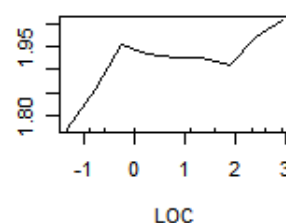
Partial Dependence on polS



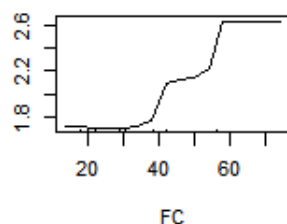
Partial Dependence on polG



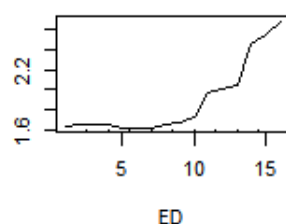
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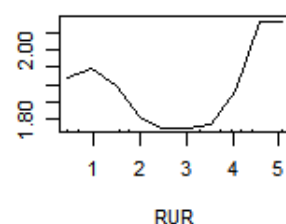
Partial Dependence on FC



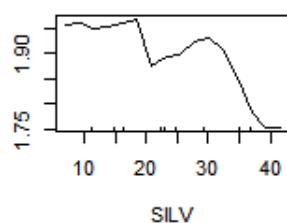
Partial Dependence on ED



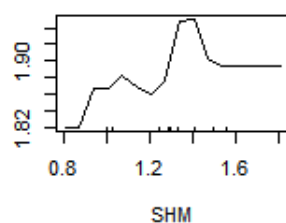
Partial Dependence on RUR



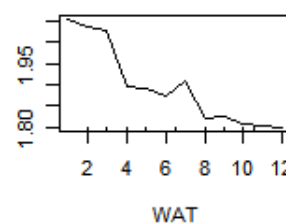
Partial Dependence on SILV



Partial Dependence on SHM



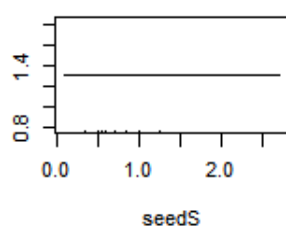
Partial Dependence on WAT



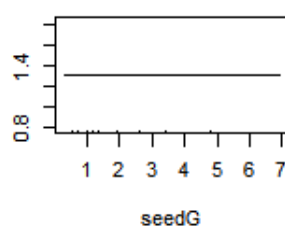
35) Eucalyptus ->pollination->habitat_generalist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 5.726522
No. of variables tried at each split: 2	SILV 1.938490
	LOC 2.071979
Mean of squared residuals: 1.829076	ED 6.928833
% Var explained: -2.94	WAT 1.268841
	RUR 2.337896
	SHM 1.504494

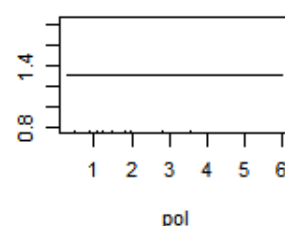
Partial Dependence on seedS



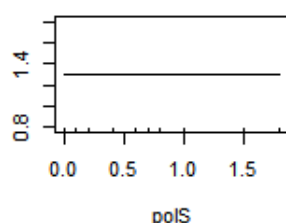
Partial Dependence on seedG



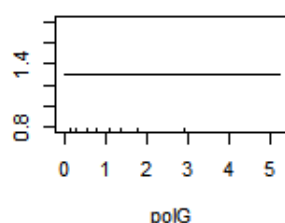
Partial Dependence on pol



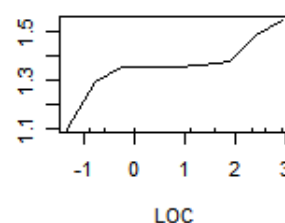
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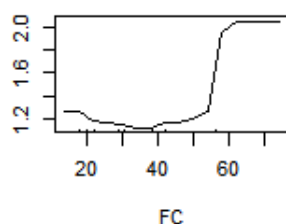
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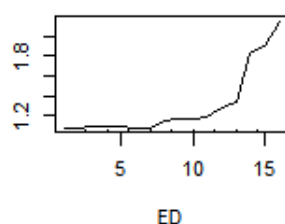
Partial Dependence on LOC



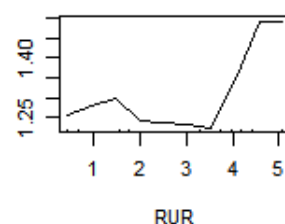
Partial Dependence on FC



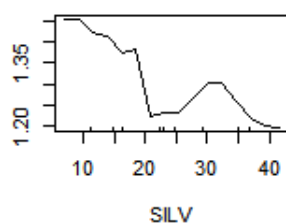
Partial Dependence on ED



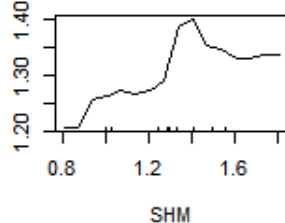
Partial Dependence on RUR



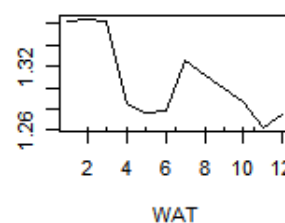
Partial Dependence on SILV



Partial Dependence on SHM



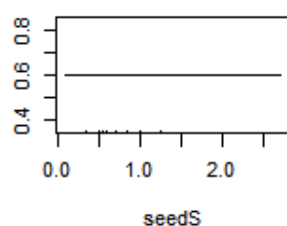
Partial Dependence on WAT



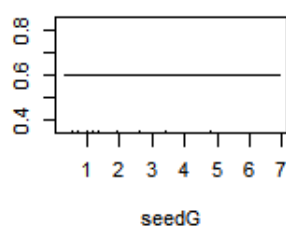
36) Eucalyptus ->pollination->forest_specialist

Type of random forest: regression	IncNodePurity
Number of trees: 500	FC 0.9608776
No. of variables tried at each split: 2	SILV 0.2763763
	LOC 0.2349805
Mean of squared residuals: 0.1997217	ED 0.2546523
% Var explained: 25.06	WAT 0.5838624
	RUR 0.6921449
	SHM 0.4275528

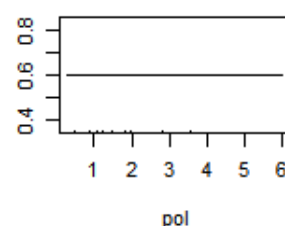
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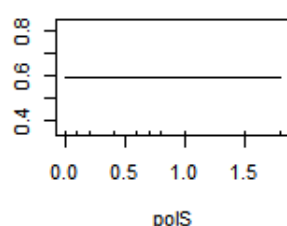
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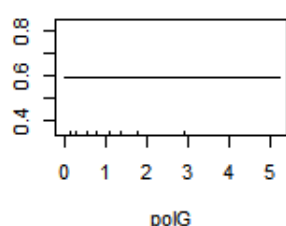
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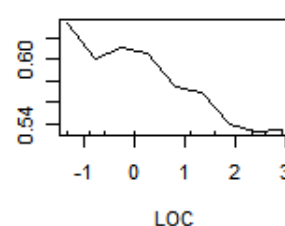
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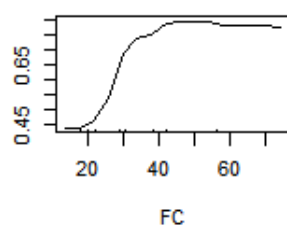
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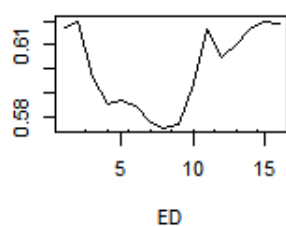
Partial Dependence on LOC



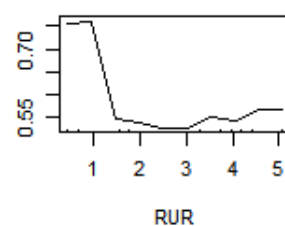
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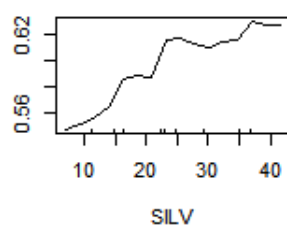
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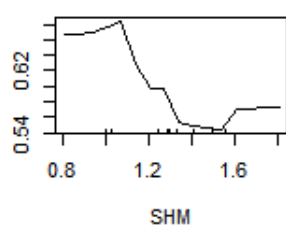
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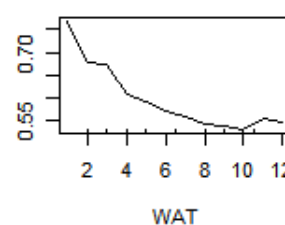
Partial Dependence on SILV



Partial Dependence on SHM



Partial Dependence on WAT



Apêndice IV. Supporting information for the chapter 3 “*Surrounding landscape and matrix lands as ecological drivers to community process and trait distribution by birds in fragmented forests*”

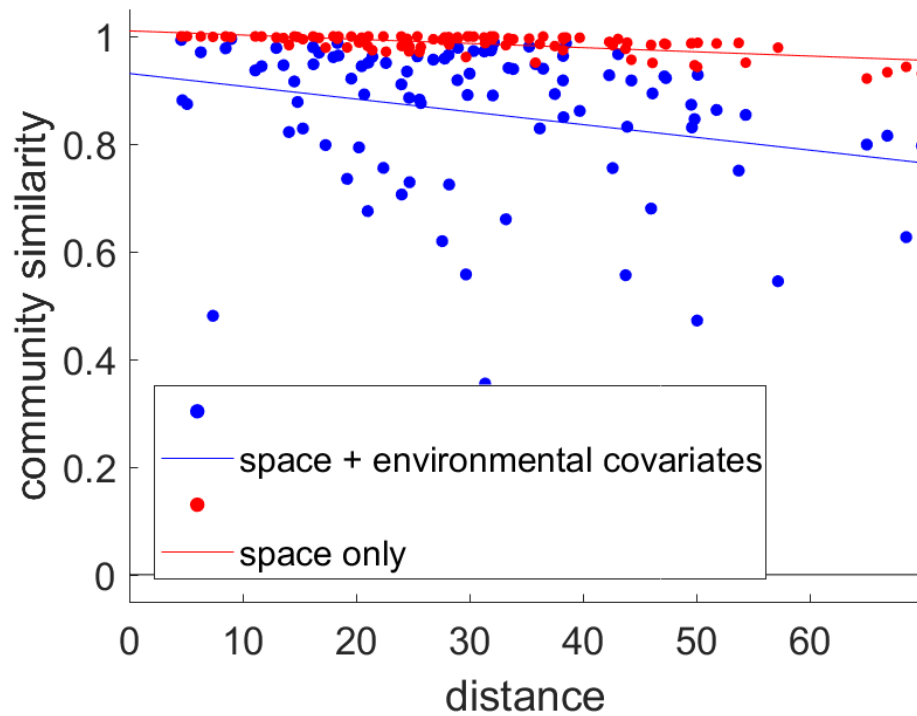


Figure 1. Community taxonomical similarity decay according to space (geographic) effect (red) and according to both space and environmental covariates effect (blue). The circles represent the community similarity values between community pairs.

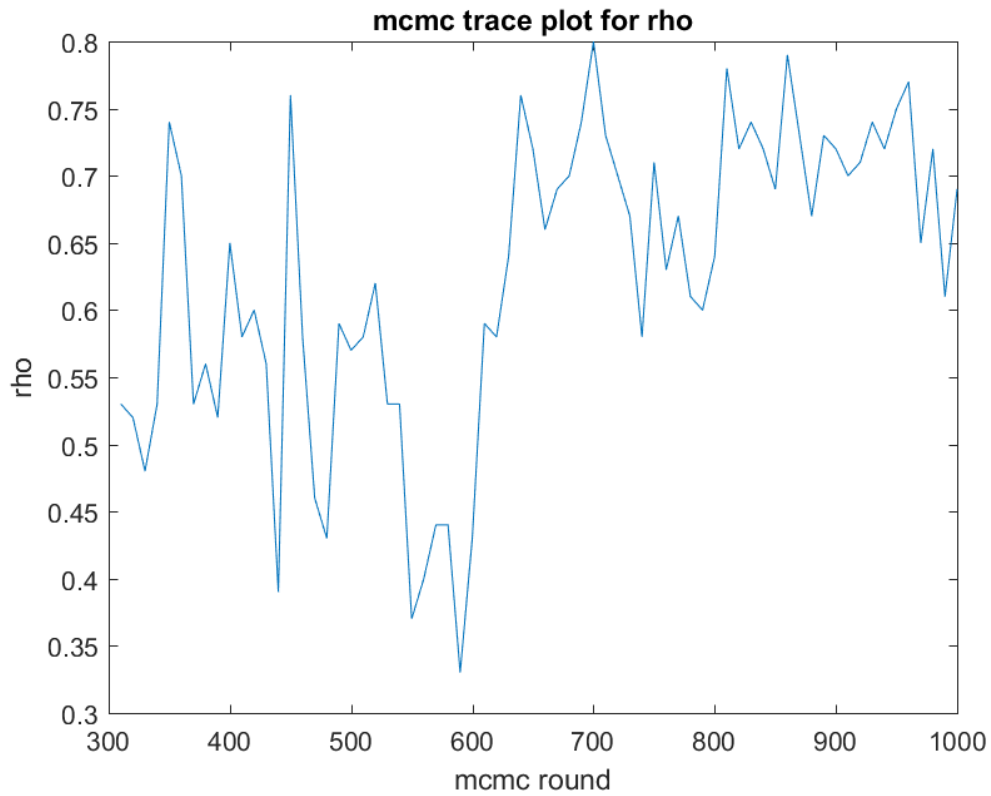


Figure 2. Markov Chain Monte Carlo (MCMC) trace plot illustrating the mixing chains of the Spearman rho parameters for traits and phylogenetic matrices. The x-axis shows the MCMC iterations (100), and the y-axis the rho parameter values at each iteration.

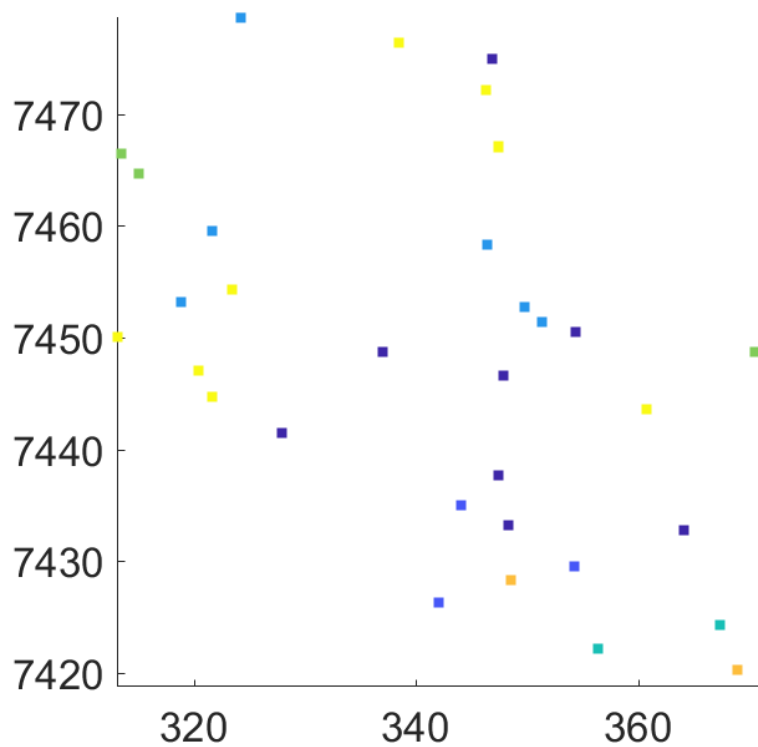


Figure 3. Taxonomic similarities among bird communities across its geographic distribution. Axis x and y represents geographic coordinates (UTM, Datum WGS1984). Dots (squares) with the same colours represent taxonomically similar communities.