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BRUNA GONÇALVES DA SILVA

EFEITOS DE ESTRADAS E TRILHAS NA VEGETAÇÃO, DISPONIBILIDADE DE  
FRUTOS E AVIFAUNA EM UMA ÁREA PROTEGIDA DE MATA ATLÂNTICA  
DO SUDESTE DO BRASIL

EFFECTS OF ROADS AND TRAILS ON VEGETATION, FRUIT AVAILABILITY  
AND BIRDS IN A PROTECTED AREA OF ATLANTIC FOREST IN  
SOUTHEASTERN BRAZIL

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BIRDS IN A PROTECTED AREA OF ATLANTIC FOREST IN SOUTHEASTERN  
BRAZIL

*Tese apresentada ao Instituto de Biologia da Universidade  
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## Dedicatória

*“À natureza, que nos ensina a arte de ser, em vez de fazer,  
de experimentar, em vez de possuir”*



Ted O'Neal 2002. *Nature Therapy*. Ilustração de R.W. Alley

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## Resumo

A dinâmica de clareiras imposta por trajetos, como estradas e trilhas, em meio a ambientes florestais pode afetar os ecossistemas naturais e os processos ecológicos. Grande parte dos remanescentes de Mata Atlântica são intersectados por inúmeras estradas e trilhas, que cruzam até mesmo Unidades de Conservação. A presença dos trajetos pode afetar a comunidade de plantas e a fauna, como a estrutura do habitat, os processos reprodutivos das plantas e o comportamento da fauna. No entanto, os efeitos da largura dos trajetos e de seu uso na fauna e na flora na Mata Atlântica não são bem conhecidos. Neste estudo nós investigamos se (1) a comunidade de plantas, (2) a disponibilidade de frutos e (3) a comunidade de aves frugívoras são afetadas por esses trajetos, e (4) realizamos um diagnóstico dos impactos e suas implicações, propondo estratégias locais de conservação relacionadas às vias de uso intensivo. Os dados foram coletados entre 2013 e 2015 em três trajetos em meio a floresta, com diferentes larguras e usos: estrada principal (20 m de largura – uso intensivo), estrada secundária (10 m de largura – baixo uso), trilha turística (2 m de largura – uso intensivo) - e em uma área controle sem trajetos, com oito parcelas de 100 m<sup>2</sup> para cada área. Foi analisada, de forma comparativa, a estrutura e composição da vegetação, a disponibilidade espacial e temporal de frutos e a avifauna consumidora de frutos. Este estudo mostrou que a estrutura e a composição da vegetação são alteradas nas bordas de vias largas (10 – 20 m) quando comparadas com vias estreitas (2 m) ou a região controle; que a disponibilidade de frutos zoocóricos é maior em área contínua distante das bordas dos trajetos e que a produção de frutos anemocóricos foi maior nas bordas do trajeto mais largo. Picos de frutificação ocorreram nas bordas dos trajetos, não sendo evidenciados em área contínua (controle). Aves mais especialistas na dieta frugívora foram mais abundantes no controle e na estrada com baixo uso, enquanto onívoros foram mais abundantes no trajeto mais largo. A largura da via, juntamente com a intensidade de uso e a disponibilidade de frutos, foram os componentes mais importantes na determinação da comunidade de aves. Para os frugívoros, o uso intensivo do trajeto foi mais importante que a largura da via. Nossos resultados demonstram como a comunidade de plantas e a avifauna consumidora de frutos respondem à presença e à intensidade de uso de estradas e trilhas em meio a uma floresta ombrófila densa contínua. A alteração do habitat, a limitação de recursos alimentares e a presença de distúrbios podem gerar o desaparecimento de algumas espécies em longo prazo, comprometer processos ecológicos e conseqüentemente, a conservação da Mata Atlântica, já intensivamente fragmentada. A regulamentação da implantação e do uso de vias em meio a Unidades de Conservação, assim como estratégias de monitoramento e educacionais, são essenciais para minimizar os impactos nas comunidades naturais da Mata Atlântica.

**Palavras chave:** clareiras lineares, conservação, impactos, floresta tropical, frugívoros, plantas.



## **Abstract**

The dynamics of gaps imposed by roads and trails can affect natural ecosystems and ecological processes. Great part of the Atlantic Forest remnants is intersected by numerous roads and trails, which cross even protected areas. The presence of pathways may affect the plant and animals communities, such as habitat structure, plant reproductive processes and wildlife behavior. However, the effects of width and usage of the pathways on fauna and flora in the Atlantic Forest are not well known. Here we investigate if (1) the plant community, (2) fruit availability, and (3) fruit-eating bird community are affected by pathways, and (4) make a diagnosis of the pathway's impact and propose local strategies of conservation related to the intensive use of pathways. Data were gathered between 2013 and 2015 in three pathways inside forest, with varying widths and use – main road (20m wide - high usage), secondary road (10m wide - low usage), touristic trail (2m wide - high usage) – and in a control area, with eight 100 m<sup>2</sup> plots within each area. We sampled the structure and composition of vegetation, fruit availability and seasonality and fruit-eating bird community. This study showed that vegetation structure and composition change at the wide pathways edges (10-20 m) when compared to narrow pathways (2 m) or the control area; that the availability of zoocoric fruits is greater in a continuous area far from the pathways edges and the production of anemocoric fruits was larger at the edges of wider pathways. Fruiting peaks occurred at the pathways edges, but not in the control area. Frugivorous birds were more abundant in control and on the pathway with low use, while omnivores were more abundant in the wider pathway. Pathway width coupled with pathway use and fruit availability were the most important components in determining the bird community. For frugivores, the usage is more important than width. Our results demonstrate that pathways presence and use generate responses in plant community, changes in fruit production, and affect the birds. Habitat changing, food resources limitation, and the presence of disturbances that may scare the fauna can lead to the disappearance of some species in the long term, jeopardizing ecological processes and, consequently, the conservation of the severely fragmented Atlantic Forest. Regulating the implementation and use of roads in protected areas, as well as monitoring and educational strategies, are essential to minimize impacts on natural communities in the Atlantic forest.

**Key words:** linear gaps, conservation, impacts, tropical forest, frugivorous, plants.

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## **Introdução geral**

### **Florestas tropicais e suas ameaças**

As florestas tropicais recobrem apenas cerca de 10% da superfície terrestre, mas são de grande importância para os processos atmosféricos e para a manutenção da biodiversidade mundial, formando um dos sistemas mais ricos da Terra (Cramer et al., 2006; Groombridge e Jenkins, 2003), abrigando mais de dois terços das espécies do planeta (Myers et al., 2000; Ribeiro et al., 2011). Um conjunto muito diversificado de formações compõe essas florestas, incluindo florestas úmidas, manguezais, florestas de altitude, florestas secas e savanas arborizadas (Groombridge e Jenkins, 2003). Pequenas mudanças nesses habitats podem gerar consequências importantes para a manutenção da biodiversidade e dos processos ecológicos (Lewis, 2006). Estima-se que as florestas tropicais úmidas ocupavam cerca de 16 milhões de km<sup>2</sup>, mas que hoje sua área tenha sido reduzida para cerca da metade de sua distribuição original (Primack e Rodrigues, 2001) (Figura 1 A). Esse processo de destruição é decorrente de mudanças e pressões que podem ocorrer desde as formas mais extremas, como a conversão do uso da terra para agricultura ou fazendas de gado, até as mais pontuais, como a extração ilegal de recurso vegetal, a caça e a fragmentação (Mayaux et al., 2005).

No conjunto de florestas tropicais, a Mata Atlântica é a segunda maior floresta pluvial tropical no continente americano, estendendo-se de 4° a 32° S e cobrindo uma ampla faixa de zonas climáticas e formações vegetais (Fundação SOS Mata Atlântica e INPE, 2001; Myers et al., 2000; Ribeiro et al., 2011). Inicialmente ocupava mais de 1,5 milhões de km<sup>2</sup>, mas hoje está restrita a fragmentos que, juntos, somam uma área com menos de 100.000 km<sup>2</sup>, o que torna essa formação uma das mais ameaçadas (Fundação SOS Mata Atlântica e INPE, 2001; Myers et al., 2000; Ribeiro et al., 2009) (Figura 1 B). Esse domínio, apesar de amplamente impactado, abriga mais de 8.000 espécies endêmicas de plantas vasculares, anfíbios, répteis, aves e mamíferos (Myers et al., 2000). Uma das regiões mais importantes para a conservação da biodiversidade da Mata Atlântica, que é considerada um hotspot de biodiversidade, está localizada no sudeste do Brasil, no estado de São Paulo (Fundação SOS Mata Atlântica e INPE, 2001). Essa região abriga remanescentes de floresta que se concentram principalmente ao longo das regiões escarpadas e montanhosas do Vale do Ribeira, Litoral e Vale do Paraíba. Grande parte dessas florestas encontra-se sob proteção em Unidades de Conservação, somando 1.730.000 ha de Floresta Atlântica de encosta (Fundação SOS Mata Atlântica e INPE, 2001).

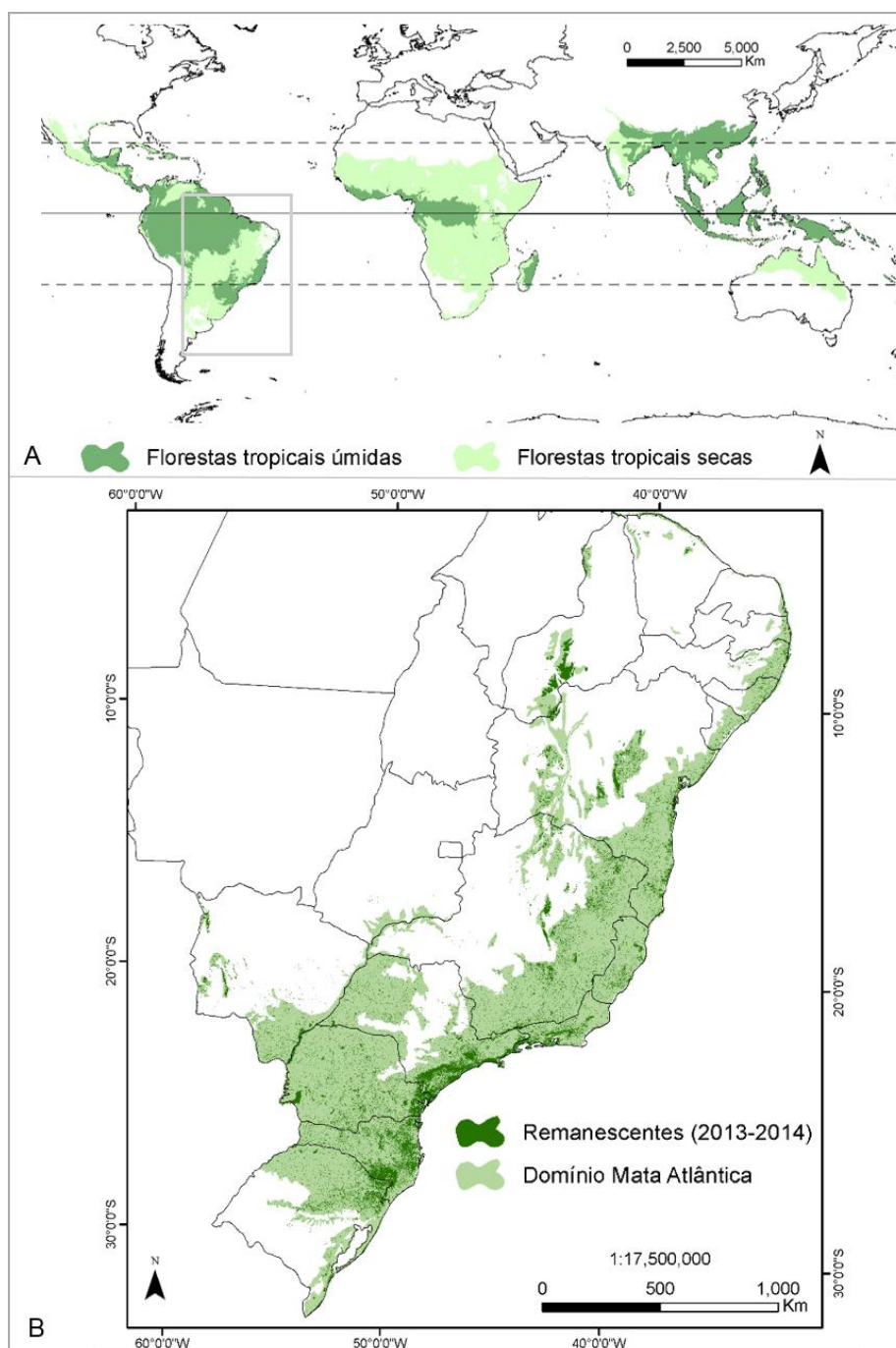


Figura 1 – Distribuição de florestas tropicais. A. Distribuição original das florestas tropicais. Base de dados: Global Forest Monitoring Project (<http://glad.geog.umd.edu/projects/gfm/>). Acesso em: 10 de agosto de 2016. B. Distribuição original da Mata Atlântica e os remanescentes. Base de dados: Cobertura original do domínio Mata Atlântica – IBGE (<http://mapas.ibge.gov.br/en/>); Remanescentes – SOS Mata Atlântica (<http://mapas.sosma.org.br/dados/>). Acesso em: 10 de agosto de 2016.

Apesar de grande parte da Mata Atlântica no sudeste do Brasil estar em unidades de conservação, esta sofre diversas pressões e impactos, pois encontra-se na região mais populosa do país, o que contribui para o processo de fragmentação. A fragmentação de um habitat ocorre mesmo quando a área total não é significativamente reduzida, como quando uma barreira linear é implantada em meio a um ambiente florestal contínuo (Laurance et al., 2014; Schonewald-Cox e Buechner, 1992). A implantação de aceiros, redes de transmissão elétrica, estradas e trilhas são exemplos de infraestruturas lineares que podem gerar esse tipo de fragmentação (Primack e Rodrigues, 2001; Trombulak e Frissell, 2000). A região sudeste do Brasil é atravessada por inúmeras clareiras lineares, como estradas que conectam o interior dos estados de São Paulo e Paraná aos seus litorais, além do intenso uso de trilhas em unidades de conservação (UCs), destinadas aos serviços de deslocamento, vigilância, manutenção e, mais recentemente, ao desenvolvimento do ecoturismo.

### **Clareiras lineares em florestas e seus efeitos**

A perda do habitat gerada pela implantação de uma infraestrutura linear, o aumento do efeito de borda, o uso intensivo, a poluição, a facilitação para invasão de espécies e doenças, a facilitação para ocupação humana, o aumento da mortalidade da fauna por atropelamento e a clareira atuando como barreira para a dispersão de espécies, são indicadas como as principais pressões geradas por clareiras lineares em meio a florestas tropicais (Goosem, 2007; Laurance et al., 2009; Laurance e Goosem, 2008). A presença de vias de transporte, como as estradas e trilhas, gera uma barreira fragmentando o habitat e ocasionando a alteração da paisagem (Goosem, 2007; Laurance et al., 2009), e um aumento na quantidade de borda por área de habitat (Murcia, 1995) (Figura 2). Quando imaginamos um fragmento quadrado hipotético de 100 ha, supondo que o efeito de borda é de 100 m no sentido do interior da floresta, a região de interior com características de uma floresta madura é de 64 ha (Figura 2 A). Com a implantação de duas estradas cortando esse fragmento, embora essas infraestruturas ocupem pouca área, o efeito de borda é gerado a partir dessas estradas, reduzindo a área de interior de floresta para 34,8 ha (Figura 2 B) (Primack e Rodrigues, 2001).

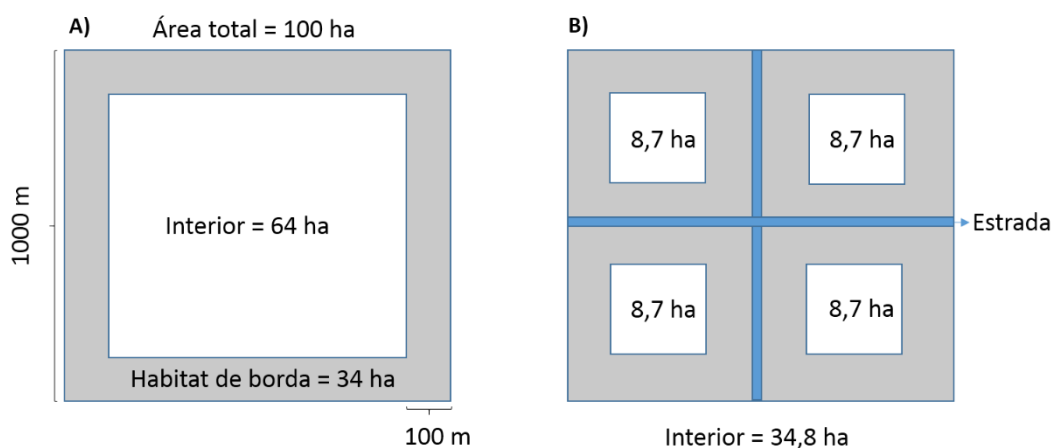


Figura 2 – Área de habitat de uma área protegida hipotética reduzida por fragmentação e efeito de borda (área sombreada). A) Efeito de borda nos limites da área protegida. B) Fragmentação da área protegida por clareiras lineares e aumento do efeito de borda (traços em azul indicam a presença de estradas). Fonte: (Primack e Rodrigues, 2001).

As alterações decorrentes da presença de clareiras lineares, como as vias de transporte, podem penetrar no sentido do interior da floresta e alcançar até 400 metros de distância (Laurance et al., 1997; Rodrigues, 1998), causando alguns efeitos nas comunidades de plantas e animais (Goosem, 1997; Laurance et al., 2009) e afetando processos ecológicos (Couto-Santos et al., 2015; Prieto et al., 2014; Reznik et al., 2012). As florestas tropicais apresentam uma distribuição diferencial de espécies, que está relacionada com as diferentes tolerâncias específicas ao habitat (e.g. seca, sombra, nutrientes) (Baltzer e Thomas, 2010; Engelbrecht et al., 2007; Sterck et al., 2006). As espécies são, ao menos parcialmente, separadas em diferentes nichos de recursos e condições dentro de uma comunidade local e esses fatores moldam sua distribuição e abundância (Kraft e Ackerly, 2010; Sterck et al., 2014). Assim, os efeitos das vias de transporte estão relacionados às respostas das espécies às alterações no habitat (Kraft e Ackerly, 2010).

### **Impacto de vias de transporte na flora e na fauna**

As bordas criadas pela implantação de clareiras lineares antrópicas, como as vias de transporte, em meio a fragmentos florestais estão sujeitas a uma série de alterações microclimáticas (Laurance et al., 2009; Pohlman et al., 2007). Nessas bordas observa-se um aumento da intensidade luminosa juntamente com a temperatura e uma redução da umidade do

solo, bem como uma maior exposição às variações na intensidade do vento (Laurance e Goosem, 2008; Pohlman et al., 2007). Esses efeitos se mostram mais intensos em clareiras antrópicas quando comparados com clareiras naturais (como rios) (Pohlman et al., 2007). Além disso, os efeitos decorrentes do efeito de borda são decorrentes de diferenças nas larguras das clareiras e na sua natureza (antrópicas ou naturais) (Pohlman et al., 2007). Durante o processo de implantação da via ocorrem alterações na topografia, com as atividades de terraplanagem que alteram o relevo (Montgomery, 1994; Webb et al., 1999), o que gera a compactação do solo, que juntamente com o fluxo de veículos e a pavimentação, altera a percolação da água, o escoamento superficial e a disponibilidade de nutrientes (Reid e Dunne, 1984). O aumento do nível de poluentes no ar também pode ocorrer devido à presença de veículos (Black et al., 1985; Forman e Alexander, 1998).

Essas alterações intensas geradas pelas vias de transporte podem afetar as comunidades de plantas e de animais das áreas adjacentes (Ahmed et al., 2014; Couto-Santos et al., 2015; Oliveira et al., 2011; Prieto et al., 2014; Reznik et al., 2012; Wolf et al., 2013). A comunidade de plantas pode ter sua estrutura e composição alterada, com espécies tolerantes a perturbações e espécies exóticas ocorrendo nas bordas (Couto-Santos et al., 2015; Prieto et al., 2014). Contudo, os estudos não apresentam resultados conclusivos para a comunidade arbórea da Floresta Ombrófila Densa em Mata Atlântica, pois foram desenvolvidas observações apenas na comunidade de sub-bosque da floresta (Prieto et al., 2014), ou realizados em floresta estacional, onde muitas espécies de plantas apresentam variação sazonal dos processos fenológicos (ex. perdendo suas folhas na estação seca), podendo responder de maneira distinta à alterações nas condições climáticas quando comparadas com espécies perenifólias típicas de florestas ombrófilas (Couto-Santos et al., 2015). Além disso, esses estudos não compararam clareiras lineares com diferentes larguras em meio a matriz florestal (Couto-Santos et al., 2015; Prieto et al., 2014), o que poderia revelar os diferentes efeitos gerados por clareiras com diferentes características.

As mudanças no microclima e, conseqüentemente, na disponibilidade de recursos para as plantas, juntamente com as alterações na composição da vegetação, podem afetar os processos fenológicos da comunidade e a produção de estruturas reprodutivas (Gressler, 2010; Pohlman et al., 2007; Reznik et al., 2012). Picos na produção de frutos, mudança na quantidade e no tamanho médio de inflorescências foram observados em bordas de clareiras lineares, antrópicas ou naturais (rios) (Gressler, 2010; Pohlman et al., 2007; Reznik et al., 2012). A

produção de frutos nas florestas tropicais é fundamental para a manutenção da fauna frugívora e de processos ecossistêmicos (Jordano et al., 2006). No entanto, o efeito de clareiras lineares antrópicas na disponibilidade espacial e temporal de recursos para fauna frugívora tem sido pouco investigado e apresenta resultados inconclusivos (Ramos e Santos, 2006; Reznik et al., 2012). Apenas um estudo foi conduzido no nível de comunidade e revela alterações na dinâmica temporal da frutificação, mas ausência de efeitos na distribuição das síndromes de dispersão (Reznik et al., 2012). Esse estudo foi conduzido comparando diferentes matrizes florestais, uma com predominância de herbáceas e outra de arbustos e árvores até 4 m de altura. Assim, resultados distintos podem ser encontrados ao se acompanhar a comunidade arbustivo-arbórea das bordas de trajetos com diferentes características em meio a mesma matriz florestal. Outro estudo desenvolvido no nível de espécie não revelou padrões claros, não sendo observadas diferenças na produção de frutos total, mas sim no número de frutos por flor, sendo que os autores enfatizam a necessidade de se considerar outros fatores, como a característica da clareira e tipo da matriz (Ramos e Santos, 2006).

Vias de transporte, como estradas e trilhas, que permeiam extensivamente as formações florestais (Laurance et al., 2014), afetam a fauna em vários aspectos, podendo gerar efeitos na riqueza, abundância ou no comportamento das espécies (Ahmed et al., 2014; Goosem, 2001; Laurance et al., 2004; Oliveira et al., 2011; Wolf et al., 2013). A riqueza em comunidades de aves pode ser alterada nas proximidades de trajetos e pode ocorrer também a redução da ocorrência de espécies exclusivas e/ou mais sensíveis nas proximidades das bordas (Ahmed et al., 2014; Whitworth et al., 2015; Wolf et al., 2013). As vias também geram a inibição do movimento em alguns grupos da fauna, como detectado para aves (Develey e Stouffer, 2001; Laurance et al., 2004; Oliveira et al., 2011) e para pequenos mamíferos que, principalmente durante a época reprodutiva, evitam cruzar as estradas (Goosem, 2001). No entanto, esses estudos foram conduzidos em formações florestais da Austrália e da Amazônia (Ahmed et al., 2014; Develey e Stouffer, 2001; Goosem, 2004, 2001; Laurance et al., 2004; Wolf et al., 2013). Na Mata Atlântica do sudeste do Brasil apenas um estudo foi conduzido, que mostra que algumas espécies de aves de sub-bosque, sensíveis ao efeito de borda, não cruzam as vias de transporte (Oliveira et al., 2011). As características locais da formação florestal e das vias são fatores regionais importantes a serem considerados ao se investigar os efeitos dos trajetos na fauna (Laurance et al., 2014). No entanto, não foram conduzidos estudos que abordem os impactos de diferentes trajetos na comunidade de aves frugívoras e que busquem compreender



quais as principais alterações no habitat causadas pela presença e uso dos trajetos afetam as aves.

### **Importância das características locais e de estratégias de conservação em áreas protegidas permeadas por vias de transporte**

Os impactos das clareiras lineares não são os mesmos para todos os táxons e podem variar geograficamente dependendo das condições climáticas e da formação vegetal considerada (Whitworth et al., 2015). É desejável que esses estudos sejam realizados em diferentes formações florestais englobando uma ampla gama de espécies, pois as condições de microclima são distintas entre as formações vegetais, o que resulta em um conjunto de espécies particular adaptado às condições locais (Engelbrecht et al., 2007; Kraft e Ackerly, 2010; Sterck et al., 2014). Por exemplo, ao se comparar dois biomas tropicais, como a savana brasileira em sentido restrito e a Mata Atlântica, observa-se que no primeiro grande parte das espécies de plantas são adaptadas à exposição ao sol, enquanto que para o segundo muitas espécies são tolerantes a sombra e a um ambiente úmido (Eiten, 1972; Oliveira Filho e Ratter, 2002). Ou mesmo ambientes florestais como uma floresta estacional com espécies caducifólias e uma floresta ombrófila com espécies perenifólias, e que possuem diferentes tolerâncias à presença ou ausência de variação sazonal das condições. Considerando essas diferenças, pode-se inferir que a abertura de uma clareira linear traga diferentes respostas nas comunidades locais.

A grande heterogeneidade de formações da Mata Atlântica, por sua ampla extensão latitudinal e longitudinal, variação altitudinal (0 – 2.900 m) e de gradientes de solo e clima (por exemplo, precipitação 1.000 – 4.200 mm anuais) (Ribeiro et al., 2011), gera a necessidade de uma abordagem regional dos estudos de impactos das estradas e trilhas que interseccionam esse domínio. Adicionalmente, a variação nas características das estradas e trilhas, como a largura e a intensidade de uso antrópico (Whitworth et al., 2015), são importantes aspectos a serem observados, pois podem resultar em diferentes efeitos. Alterações na estrutura do habitat e na disponibilidade de recursos poderiam afetar as comunidades diferentemente entre trajetos largos e estreitos, com uso restrito ou intensivo, e esses aspectos precisam ser investigados. Não se sabe o quanto a largura ou o tipo de uso dos trajetos pode ampliar os efeitos de um trajeto, e esse conhecimento é necessário para a implantação de medidas de proteção e manejo de áreas protegidas intersectadas por vias.

Concomitante com estudos que identifiquem os impactos das clareiras lineares sobre as espécies é necessário realizar estudos que apontem como tais impactos poderiam ser reduzidos e mitigados dentro do contexto local das áreas protegidas afetadas (Taylor e Goldingay, 2010). A principal ação que tem sido proposta para minimizar impactos de estradas e trilhas é a construção de passagens de fauna acopladas a cercas ou barreiras de direcionamento, estando ausentes estratégias como a limitação do uso e a educação ambiental (Taylor e Goldingay, 2010). No entanto, um monitoramento que avalie a eficiência das estratégias implantadas é de extrema importância e tem sido negligenciado. Os estudos disponíveis não têm abordado os efeitos de algumas variáveis na eficácia das ações de proteção, como a interferência da atividade humana e a sensibilidade das espécies aos impactos dos trajetos (Clevenger, 2005). As estratégias e ações de mitigação precisam ser elaboradas de acordo com as características de cada via de transporte, da paisagem em que a via está inserida e da zona de amortecimento. São essenciais estudos que realizem essas descrições e proponham linhas de ação específicas para cada região e/ou unidade de conservação afetada.

Considerando o contexto apresentado, o objetivo geral desse estudo foi investigar se (1) a comunidade de plantas, (2) a disponibilidade de frutos e (3) a comunidade de aves frugívoras são afetadas por trajetos que intersectam a Mata Atlântica no sudeste do Brasil, bem como (4) realizar um diagnóstico dos impactos, propondo estratégias locais de conservação. Essa tese foi dividida em capítulos, cujos objetivos específicos estão listados a seguir, e as expectativas em relação a cada objetivo se encontram nos respectivos capítulos.

O Capítulo 1 investiga o impacto de trajetos de diferentes larguras na estrutura e composição de espécies de plantas, considerando formas de vida, categorias sucessionais, ocorrência de espécies exóticas e ameaçadas, e a predominância de síndromes de dispersão. O Capítulo 2 avalia a influência de trajetos de diferentes larguras na disponibilidade espacial e temporal de frutos, considerando o número de espécies e indivíduos em frutificação, quantidade de frutos produzida, síndromes de dispersão e a sazonalidade. O Capítulo 3 compara a comunidade de aves frugívoras entre as áreas afetadas por trajetos, considerando a largura e a intensidade de uso, estrutura da vegetação e a disponibilidade de frutos. E, finalmente, no Capítulo 4 é apresentado um diagnóstico dos impactos gerados na flora e em alguns grupos da fauna por duas vias de uso intensivo em uma área protegida, com sugestões de estratégias de conservação aplicáveis no contexto local da unidade de conservação.

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## **CAPÍTULO I - Pathways affect vegetation structure and composition in the Atlantic Forest in southeastern Brazil**

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## **Abstract**

Although impacts generated by gaps can affect vegetation, few studies have addressed these impacts in the Atlantic Forest. Our aim was to investigate the effects of pathways of varying widths on vegetation structure and composition, considering dispersal syndromes, diversity, life forms, successional categories and threatened and exotic species occurrence in the Atlantic Forest. We studied three pathways with widths of 2, 10 and 20 m, intersecting a protected area in southeastern Brazil. To assess edge effects, plots were established adjacent to paths (edge) and 35 m from the edge (neighborhood), and in a control area without pathways. Wider pathways (10 and 20 m) exhibited reduced tree height and diameter, high liana density, exotic species, and a high proportion of pioneer and anemochorous species. In conclusion, our results indicate that the vegetation structure of narrow pathways (2 m) is similar to the control area, and that wide linear gaps cause negative effects on vegetation and extend to a distance of at least 35 m into the forest interior. Considering that linear gaps generate permanent effects to vegetation and may affect other organisms, we suggest that these effects must be considered for successful management of protected areas, including planning and impact mitigation.

**Keywords:** Carlos Botelho State Park, conservation, linear gaps, plants, roads, trails

## **Introduction**

Pathway construction amidst forests creates gaps that increase habitat fragmentation, one of the main threats to tropical forests (Gascon et al. 2000). Unlike natural forest gaps, anthropic linear gaps are practically immutable due to maintenance activities, imposing persistent effects on the conditions and resources of the forest nearby (Laurance et al. 2009). The effects of pathways relate to topography (e.g. earthmoving), soil conditions, microclimatic conditions, light exposure, which create distinct environments compared to the forest interior (Tabarelli et al. 1999; Webb et al. 1999; Laurance et al. 2009), affecting habitat structure and species composition (Mantovani 2001; Enoki et al. 2012).

Tall trees and shade tolerant species usually inhabit old-growth tropical forest interiors (Liebsch et al. 2008). Environments with increased light availability create conditions for the colonization of early-successional species, normally wind-dispersed (Tabarelli et al. 1999;

Laurance et al. 2009). The maintenance of these conditions over time and space allows the permanence of species associated with disturbed environments (Murcia 1995). Consequently, a permanent shift in plant community structure and composition might occur (Mantovani 2001).

Several studies addressed the changes in vegetation structure and composition at the edges of linear forest gaps (Demir 2007; Enoki et al. 2012; Otto et al. 2013; Li et al. 2014) and just a few conducted in tropical forests focused on linear gaps caused by roads, gas pipelines and power lines (Reznik et al. 2012; Prieto et al. 2014; Couto-Santos et al. 2015), or pastures (Ribeiro et al. 2009a). In those studies, linear gaps affected the phenodynamics of animal dispersed plants (Reznik et al. 2012), tree species structure and richness (Ribeiro et al. 2009a; Couto-Santos et al. 2015), and proportion of pioneer species (Prieto et al. 2014). However, the extent to which the pathway width affects those forest attributes has never been properly assessed and understood.

The largest remaining portion of the Atlantic Forest, one of the biodiversity hotspots, lies in the Southeastern Brazil (Myers et al. 2000; Ribeiro et al. 2009b; Ribeiro et al. 2011a). Ecosystems within the Atlantic forest are being continuously degraded by illegal (e.g. poaching, selective logging), and legal (e.g. infrastructure installations such as roads, power lines, natural gas pipelines) impact vectors (Terborgh & Schaik 2002; Ribeiro et al. 2011a). On the other hand, roads and pathways are part of the necessary infrastructures that allow the management and surveillance of any park, which are also sometimes used for educational, ecotourism and research purposes. Therefore, research on the impacts of gaps generated by pathways and their associated influence on vegetation integrity is a promising approach to guide a more critical discussion on the two sides of the conservation issue (effective management x effective protection), contributing for decisions on the landscape changes and management strategies along the Atlantic forest continuum.

In this study we investigate the impacts of pathways of varying widths on the vegetation structure and species composition in an Atlantic forest protected area in southeastern Brazil, through the assessment of different life forms, successional categories, threatened and exotic species and the predominance of dispersal syndromes. We hypothesize that impacts in the wider pathway are more pronounced than in areas where pathways are narrow or absent. These impacts differentially affect the vegetation structure and composition among pathways, with

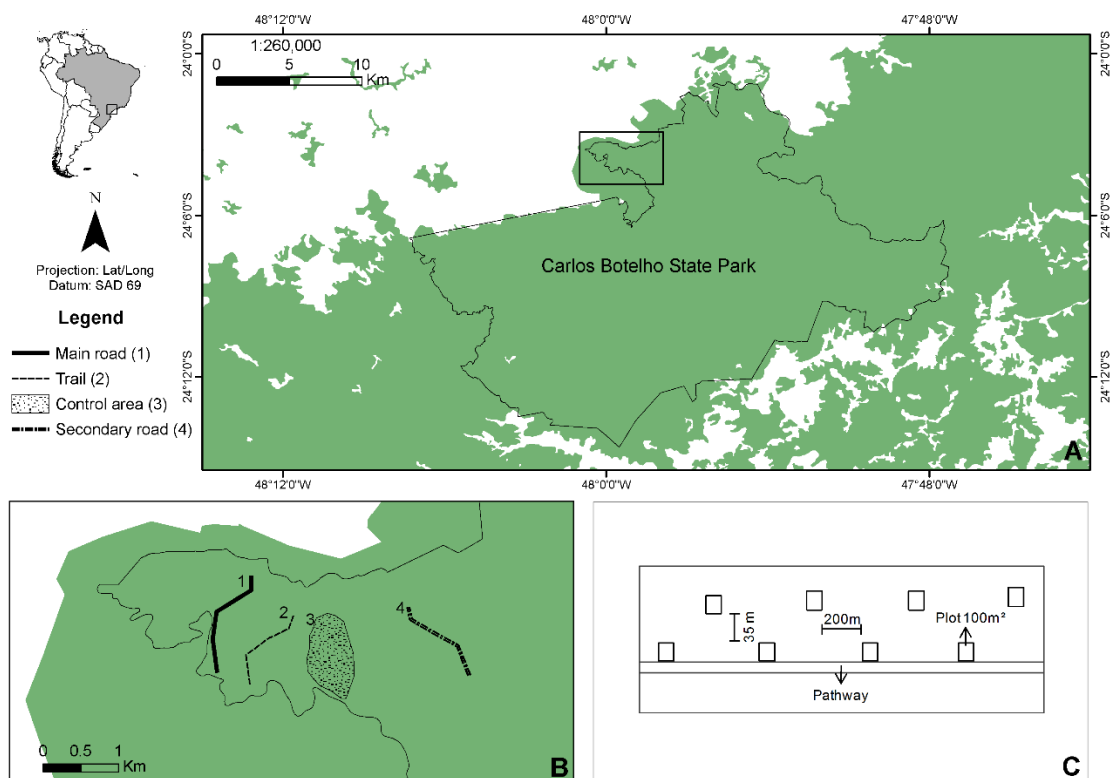
wider ones characterized by plants with low height and small diameter, a high proportion of pioneer and wind dispersed species, and the occurrence of exotic species.

## **Materials and methods**

### *Study site*

We conducted this study at Carlos Botelho State Park (CBSP), a 37,644.36 ha protected area, part of the Atlantic Forest continuum, located between 24°06'55" - 24°14'41"S and 47°47'18" - 48°07'17"W, in the São Paulo state, southeastern Brazil (Fig. 1A). Altitudinal amplitude within the CBSP ranges from 20 to 1000 m. The climate is tropical, with mean annual temperature of 18 °C, and annual precipitation between 1500 - 2200 mm (Ferraz & Varjabedian 1999). The predominant vegetation type is Dense Ombrophilous Forest, which is divided into the following categories along the altitudinal gradient (Kronka et al. 2005): Lowland Dense Ombrophilous Forest (0 - 50 m), Submontane Dense Ombrophilous Forest (51 - 500 m) and Montane Dense Ombrophilous Forest (501 - 1500 m).

Pathways selected for sampling are located at an average altitude of 800 m, in the Montane Dense Ombrophilous Forest (Fig. 1B). Several ecological aspects for plant communities (e.g. density, richness, diversity and species composition) are more affected in the first 35 m from forest edges (Rodrigues 1998). Thus, to include edge effects, we sampled at the pathways edge and 35 m from the edge (neighborhood) (Fig. 1C). We selected a single path per pathway type because in the same forest continuum and elevation there are no replicas for the pathway types. We collected data on the following pathway types: main road, secondary road and trail (Fig. 1B). In addition, we established a control area, reputedly close to a reference state of conservation (Fig. 1B) (SMA 2008). All sampled plots are distributed within the same forest matrix, climate, altitude, and are spatially close (minimum distance between plots within the same pathway = 200 m and between pathways = 600 m). The control area is at least 1000 m away from the forest edge. Given the small spatial scale of the study, it is possible to assume that differences between plots are more related to direct effects of the pathways instead of purely spatial effects. The topography distribution of the plots encompassed mostly slopes, with some at hilltops and stream valleys, a similar pattern across all survey pathways.



**Figure 1.** A. Location of Carlos Botelho State Park, SE Brazil. B. Situation of the pathways and control area sampled – 1: main road, 2: trail, 3: control area, 4: secondary road. C. Distribution of plots along the pathway (four adjacent to the pathway - edge - and four 35 m towards the forest interior - neighborhood).

### *Types of pathway*

The main road within the CBSP is a dirt road of 112 km long (named SP-139) and about 20 m wide that intersects a total of 33 km of the state park area, with a completely open canopy (Fig. 2A). The secondary road is a dirt road approximately 12 km long and mostly 10 m wide, with the canopy covered at some points (Fig. 2B). The trail is approximately 4.5 km, 2.0 m wide, with the canopy covered along its total extension (Fig. 2C). The control area is representative of the mature forest occurring in most of the park (Fig. 2D), without apparent anthropic influence (SMA 2008).



**Figure 2.** Sampling areas at Carlos Botelho State Park, São Paulo state, SE Brazil. Different pathways used as treatments – A: main road (20 m of width), B: secondary road (10 m of width), C: trail (2 m of width), D: control area.

### *Sampling Design*

In each pathway we a priori selected a stretch of 1400 m along its total extension that was parallel to the pathway. We disregarded the first 500 m of each pathway in order to minimize forest edge effects, and only achieve pathway edge effects. Along each selected stretch eight 10 x 10 m sampling plots were alternately set: four adjacent to the path (edge) and four 35 m from the edge (neighborhood) (Fig. 1B). Plots were separated at least by 200 m of each other along the path to secure the independence of sampling units (Dias & Couto 2005; Lenza *et al.* 2011) (Fig. 1B). At the control area we set the eight plots in the same manner, except that there was no pathway. We used the pathways width (2, 10 and 20 m), named here

as “type of pathway”, as a proxy of edge effects. In this design, the “type of pathway” (including control area) and “distance to edge” (0 and 35 m) are considered as treatments.

### *Vegetation survey*

Vegetation structure and abundance - We recorded the following variables from individuals with diameter at breast height (DBH)  $\geq 3.18$  cm: total height, DBH and tree crown diameter (Durigan 2003). Total height (measured from ground) and tree crown diameter (by estimating the canopy radius) were visually estimated using a 3 m stick as a parameter. The same person made all measurements. Based on total height, individuals were classified into three strata: high understory (1.5 - 5 m), intermediate level (5.1 - 11 m) and canopy (above 11 m). We also measured the low understory density of each plot by counting the number of individuals with 10 - 100 cm in height (DBH was always lower than 3.18 cm), in four sub-plots of 1 x 1 m at sampling points randomly assigned within each 10 x 10 m plot. Subplots were only installed for measuring the understory density, where individuals were counted but not identified. We excluded bamboo species (*Merostachys* sp.) from low understory density surveys, because they were considered as a separate variable (see below).

Abundance of epiphytes, vines (considering the herbaceous or woody) and bamboos (*Merostachys* sp.) in each plot was also recorded and classified in categories according to the percentage of the plot area cover. For epiphytes and vines we considered the categories low (< 20%), medium (20 - 50%) and high (> 50%), and for bamboos we established lower abundance thresholds (10% - low, 10-30% - medium and > 30% - high). We recorded the presence of exotic species inside plots and along the pathways. This methodology was adapted from the Brazilian Ministry of Environment Resolution No. 01/94 (CONAMA 2015).

Canopy openness in each plot was measured using hemispherical photographs (Frazer et al. 2001), taken with a Nikon Coolpix 4500 camera with a fish-eye FC-E8 lens. We positioned the camera, with the aid of a tripod, at an approximate 60 cm height, at the centre of each plot. Photographs were taken in cloudy days to avoid over exposure to direct sunlight, which may influence image analysis (Frazer et al. 2001). We converted the resulting images in black and white colours in ImageJ software (2015). The canopy openness was estimated based on white pixels, which correspond to the percentage of gaps.

Vegetation composition - We considered the following variables to assess vegetation composition in each plot: life forms, diversity, successional categories, threatened and exotic species occurrence and predominance of dispersal syndromes. We identified and tagged all individuals with  $DBH \geq 3.18$  cm. Plant species were identified by collecting individual reproductive branches under SISBIO (#23627-1) and IBAMA (#4968681) collection permission. Identification was based on the literature and consultation to botanists. Vouchers were deposited at the Universidade Estadual de Campinas herbarium (UEC).

We grouped species according to two general successional categories: pioneer, including pioneer and early secondary, and non-pioneer, including late secondary and climax species (São Paulo 2008; Ronquim & Torresan 2011; Lingner et al. 2013). Dispersal syndromes were identified as zoochorous, anemochorous and autochorous following Pijl (1970). In addition, we considered the species' level of threat, according to the list of threatened flora of São Paulo state (São Paulo 2008), the red book of Brazilian flora (Martinelli & Moraes 2013) and IUCN's list of threatened flora (IUCN 2015). The species list was organized according to the taxonomical arrangement adopted by the Angiosperm Phylogeny Group IV (APG 2016). Species names were cross-checked with the List of Species of the Brazilian Flora (2015).

#### *Data analyses*

Vegetation structure and abundance - Plots were considered as independent sampling units. We applied a two-way ANOVAs for tree crown diameter, *DBH* and total height (considering mean values for plots), canopy openness for plot and percentage of individuals per stratum (high understory, intermediate level and canopy) and low understory density as response variables and “type of pathway” and “distance to edge” as predictors. The assumptions of normality and homogeneity of variance were verified using the Shapiro-Wilk test and confirmed visually in graphic analyses. When a significant ANOVA was obtained ( $P < 0.01$ ), a post hoc HSD Tukey test was used to investigate differences between treatments, where  $P < 0.05$  was considered significant.

Vegetation composition - We tested the difference in species composition for “type of pathway” and “distance to edge”, considering abundance and richness, using the permutational multivariate analysis of variance (Permanova; Anderson 2001) ( $P < 0.01$  was considered significant). We used the “adonis” function of the R vegan package with Bray-Curtis distances and 10,000 permutations. In order to verify general tendencies of variation in vegetation

composition, we performed an ordination analysis with non-metric multidimensional scaling (NMDS; Minchin 1987). We adopted this approach to better identify and interpret similarities between treatments. All analyses were performed in the R environment (R Core Team 2015).

We performed a diversity profile analysis, because it enables comparisons, as opposed to description of diversity indices only. With  $\alpha = 1$ , it is equivalent to Shannon's diversity index ( $H'$ ), and  $\alpha = 2$ , it is equivalent to Simpson's diversity index ( $D$ );  $\alpha = 0$  corresponds to richness values in different pathways. Therefore, we were able to compare treatments according to evenness and richness. These analyses were conducted using PAST (Hammer *et al.* 2001).

To evaluate differences in the proportion of zoochorous and pioneers species between the "type of pathway" and "distance to edge" we used generalized linear models with a binomial distribution. Significance of the factors was assessed by means of a Chi-squared Analysis of Deviance ( $P < 0.01$  was considered significant). The analyses were carried out in the R statistical software (R Core Team 2015).

## Results

### *Vegetation structure and abundance*

We sampled 1019 individual trees ( $DBH \geq 3.18$  cm) and 2302 individuals in the low understory (10 - 100 cm,  $DBH < 3.18$  cm). Mean crown diameter, mean  $DBH$ , mean total height, canopy openness, tree percentage per stratum (except intermediate stratum) and low understory density were affected by type of pathway (Tab. 1). For those variables, trail and control areas were similar, but they significantly differed from main and secondary roads, which were also similar to each other (Tab. 2). The trail and control area had higher values for  $DBH$ , tree crown diameter, tree height and number of individuals in the canopy stratum, whereas main and secondary roads had higher values for canopy openness and number of individuals in the high and low understory (Tab. 2).



**Table 1.** ANOVA results. Variables of vegetation structure considering type of pathway, distance to edge (35 m) and interaction, at Carlos Botelho State Park - SP, Brazil. *DBH* - diameter at breast height.  $P < 0.01$  was considered significant.

		<i>Df</i>	<i>F</i>	<i>p</i>
Tree crown diameter*	Type of pathway (TP)	3	18.64	<0.0001
	Distance to edge (DE)	1	0.007	0.934
	TP x DE	2	0.714	0.499
	Residuals	25		
<i>DBH</i> (cm)*	Type of pathway	3	13.09	<0.0001
	Distance to edge	1	0.57	0.457
	TP x DE	2	0.72	0.493
	Residuals	25		
Total height (m)*	Type of pathway	3	29.94	<0.0001
	Distance to edge	1	0.91	0.349
	TP x DE	2	0.57	0.571
	Residuals	25		
Canopy openness	Type of pathway	3	13.34	<0.0001
	Distance to edge	1	1.53	0.227
	TP x DE	2	0.91	0.415
	Residuals	25		
Percentage of trees surveyed on the high-understory (1.5 – 5 m)	Type of pathway	3	23.02	<0.0001
	Distance to edge	1	0.163	0.69
	TP x DE	2	0.527	0.597
	Residuals	25		
Percentage of trees surveyed on the intermediate level (5.1 – 11 m)	Type of pathway	3	2.3	0.101
	Distance to edge	1	0.04	0.835
	TP x DE	2	0.34	0.714
	Residuals	25		
Percentage of trees surveyed on the canopy level (above 11 m)	Type of pathway	3	10.49	0.0001
	Distance to edge	1	0.03	0.859
	TP x DE	2	0.02	0.974
	Residuals	25		
Low-understory (10 cm – 100 cm height)*	Type of pathway	3	6.41	0.002
	Distance to edge	1	0.28	0.596
	TP x DE	2	0.08	0.923
	Residuals	25		

\* = Mean values for plot

**Table 2.** HSD Tukey's test. Variables of vegetation structure among type of pathway at Carlos Botelho State Park - SP, Brazil. *DBH* - diameter at breast height.  $P < 0.05$  was considered significant.

	Main road	Secondary road	Trail	Control area
Tree crown diameter*	1.77 ± 0.62 <sup>a</sup>	1.55 ± 0.13 <sup>a</sup>	2.98 ± 0.43 <sup>b</sup>	2.77 ± 0.48 <sup>b</sup>
<i>DBH</i> (cm)*	8.34 ± 0.96 <sup>a</sup>	9.35 ± 1.30 <sup>a</sup>	12.37 ± 1.51 <sup>b</sup>	12.62 ± 2.44 <sup>b</sup>
Total height (m)*	6.04 ± 1.18 <sup>a</sup>	6.61 ± 1.33 <sup>a</sup>	10.69 ± 1.23 <sup>b</sup>	10.58 ± 1.33 <sup>b</sup>
Canopy openness	12.87 ± 1.41 <sup>a</sup>	11.67 ± 1.49 <sup>a</sup>	9.31 ± 1.23 <sup>b</sup>	9.15 ± 1.53 <sup>b</sup>
Percentage of trees surveyed on the high-understory (1.5 – 5 m)	50.96 <sup>a</sup>	43.88 <sup>a</sup>	10.47 <sup>b</sup>	10.33 <sup>b</sup>
Percentage of trees surveyed on the intermediate level (5.1 – 11 m)	40.32 <sup>a</sup>	42.61 <sup>a</sup>	32.19 <sup>a</sup>	53.99 <sup>a</sup>
Percentage of trees surveyed on the canopy level (above 11 m)	8.7 <sup>a</sup>	13.5 <sup>a</sup>	25.13 <sup>b</sup>	36.15 <sup>b</sup>
Low-understory (10 cm – 100 cm height)*	24.43 ± 9.42 <sup>a</sup>	21.17 ± 9.35 <sup>a</sup>	11.37 ± 2.48 <sup>b</sup>	12.25 ± 3.00 <sup>b</sup>
Total number of trees with <i>DBH</i> ≥ 3.18 cm	310	237	259	213

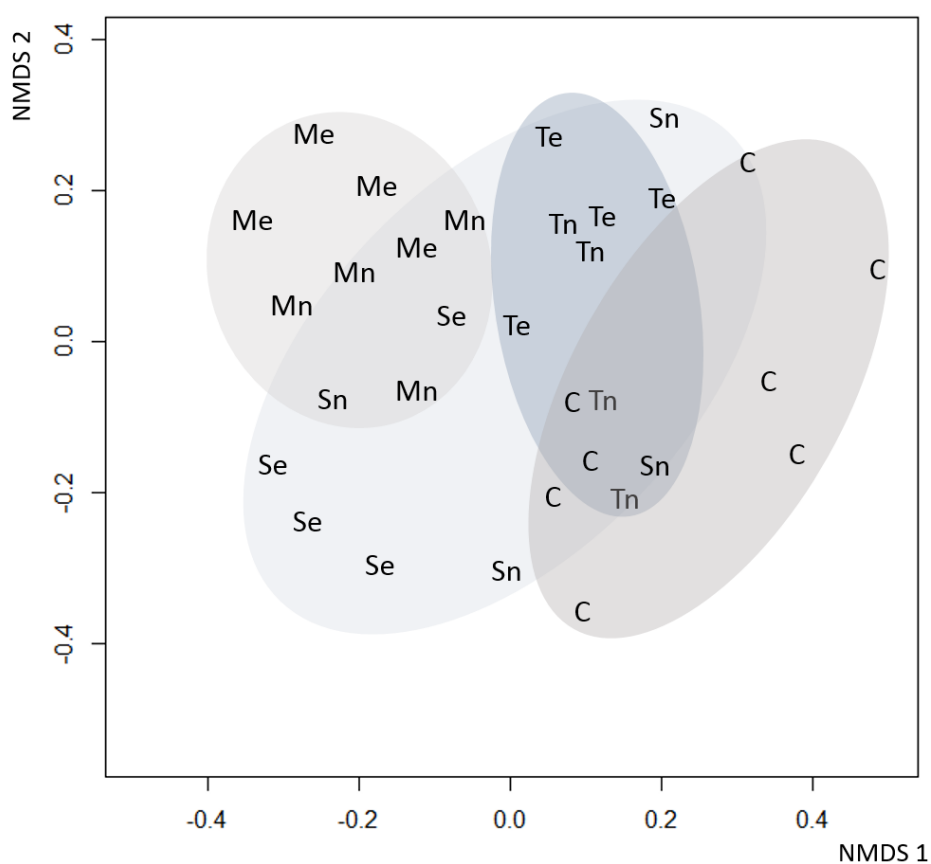
<sup>a, b</sup> = Variables significantly different according to HSD Tukey test  $p < 0.05$   
\* = Mean values for plot

We found low epiphytes abundance, and low/medium herbaceous vines abundance for main road. In main and secondary roads, abundance of both epiphytes and herbaceous vines ranged from low to high. For trail and control area, epiphytes abundance was medium to high, and abundance of herbaceous vines was low, with predominance of woody vines (i.e. lianas). Bamboo (*Merostachys* sp.) clumps predominated in some points of the main and secondary roads (low, medium and high abundance), while in the control and trail areas bamboo abundance was low. In the main and secondary roads we recorded *Urochloa* sp. (= *Brachiaria* sp.), an exotic species, and the invasive *Pteridium* sp.. Additionally, we observed *Citrus x limon* and *Eucalyptus* sp. present along the main and secondary roads outside the sampled plots.

#### *Vegetation composition*

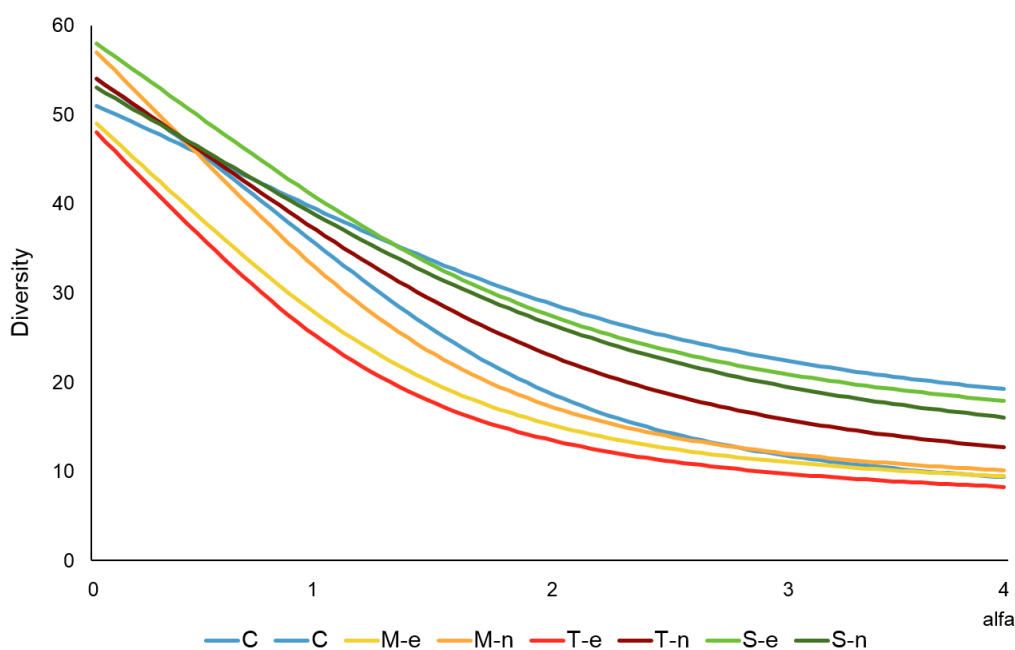
Only the type of pathway influenced plant composition (PERMANOVA; type of pathway:  $F_{3,25} = 1.78$ ,  $p < 0.001$ ), while distance to the edge ( $F_{1,25} = 1.12$ ,  $p = 0.283$ ) and their

interaction ( $F_{2,25} = 1.08, p = 0.995$ ) were not significant. The ordination analysis (NMDS), final stress: 0.22, was consistent with results generated by PERMANOVA, and plots surveyed in the main road were grouped and separated from plots in the control area and trail, highlighting a marked difference between these areas. There was a distribution of points along axis 1 going from the wider pathways to the control area. However, no pattern was observed along axis 2. Data of the secondary road plots data formed an undefined grouping pattern (Fig. 3).



**Figure 3.** Scaling analysis (nMDS) of plant community among surveyed plots of treatments type of pathway and distance to edge in Carlos Botelho State Park, SP, Brazil. M: main road, S: secondary road, T: trail (e - edge, n - neighborhood), C: control area (nMDS, Final stress: 0.22).

The control area and secondary road presented equal number of species (84 spp.), followed by trail (80 spp.) and main road (76 spp.). The control area and main road had the highest number of exclusive species (27 spp.), followed by secondary road (24 spp.) and trail (17 spp.). Secondary road and trail shared a high number of species (43 spp.). In contrast, control area and main road had the lowest number of shared species. Only 17 species were sampled in all areas (Tab. S1 in supplementary material). Of the total species (178 spp.), 15 are listed in threatened flora lists (São Paulo 2008; Martinelli & Moraes 2013; IUCN 2015). Six species are listed as vulnerable and five as endangered; four are listed in more than one list of threatened flora (Tab. S1 in supplementary material). Main road was the pathway with the lowest number of threatened species. The diversity profile analysis demonstrated that the diversity index is similar among the areas (Fig. 4). However, when assigned more weight to evenness ( $\alpha = 2$ ) main road plots and trail edge plots had the lowest values, and when assigned more weight to richness secondary road had high values (Fig. 4).



**Figure 4.** Diversity profile of plant community among pathways at Carlos Botelho State Park, SP, Brazil. M: main road, S: secondary road, T: trail, (e – edge, n – neighborhood), C: control area.  $\alpha = 1$ , it is equivalent to Shannon’s diversity index ( $H'$ ), and  $\alpha = 2$ , it is equivalent to Simpson’s diversity index ( $D$ );  $\alpha = 0$  corresponds to richness values. Please see the PDF version for color reference.

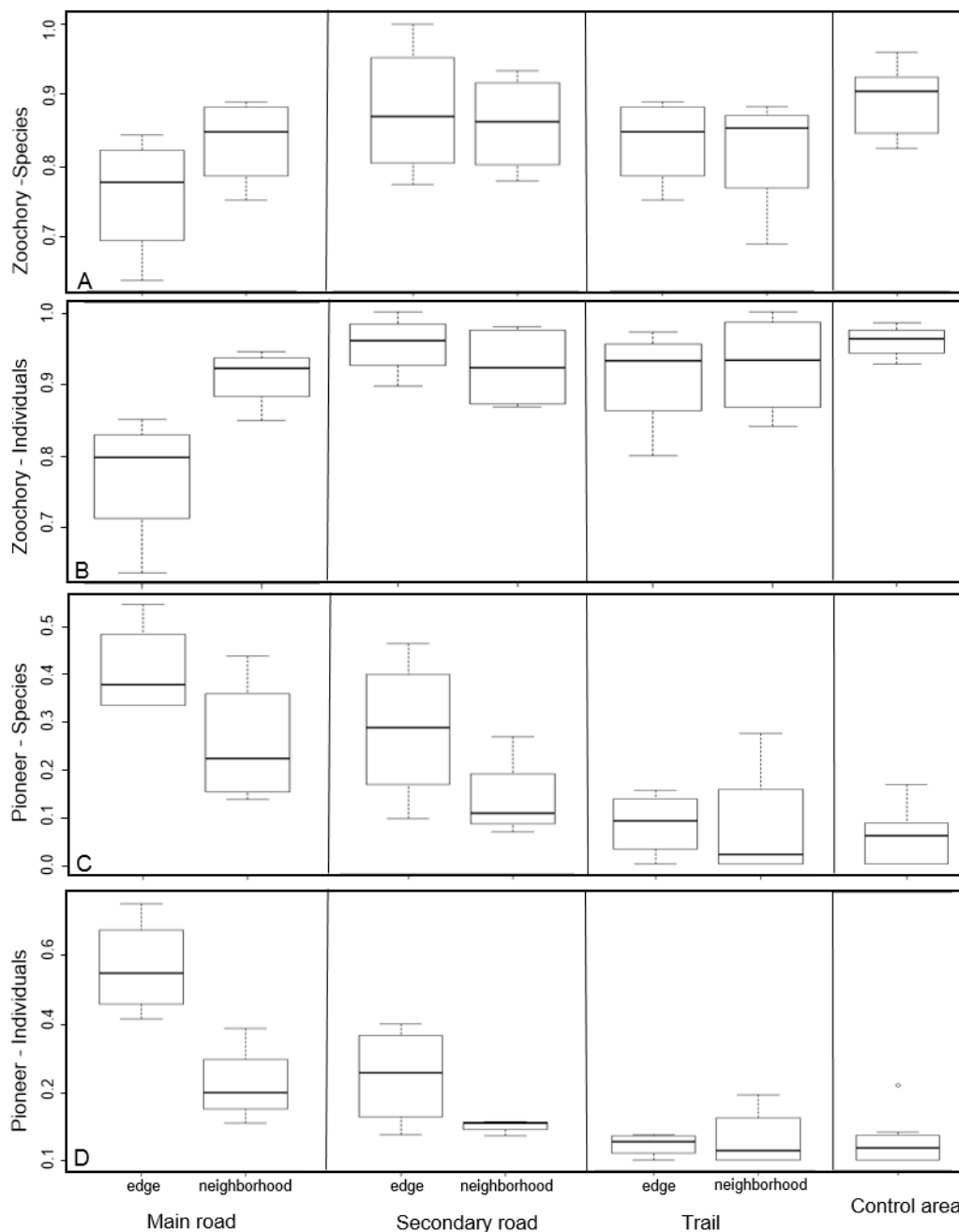
Zoochorous species predominated in all areas, representing more than 70% of the total species number (Fig. 5A). There was no difference in zoochorous species predominance among types of pathway and distance to edge (Tab. 3, Fig. 5A). The number of individuals, on the other hand, was smaller in the main road edge compared to neighborhood and other pathways and control area (Tab. 3, Fig. 5B).

The proportion of pioneer species and individuals was different for type of pathway and distance to edge (Tab. 3, Fig. 5C, D). Wider pathways presented higher values when compared to the trail and control area (Tab. 3, Fig. 5C, D). The edge plots of wider pathways had the highest values when compared to their own neighborhood plots (Fig. 5C, D).

**Table 3.** Results for generalized linear model for proportion of dispersal syndromes: zoochorous vs. non-zoochorous (anemochorous plus autochorous) species and individuals; and proportion of successional categories: pioneer vs. non-pioneer species and individuals, considering “type of pathway”, “distance to edge” and interaction, at Carlos Botelho State Park - SP, Brazil.  $P < 0.01$  was considered significant.

Dispersal syndromes			
Species	<i>Df</i>	Deviance	<i>p</i>
Type of pathway	3	2.855	0.414
Distance to edge	1	2.785	0.095
Type of pathway x Distance to edge	2	0.684	0.71
NULL	31	32.722	
Individuals			
Species	<i>Df</i>	Deviance	<i>p</i>
Type of pathway	3	28.505	<0.0001
Distance to edge	1	16.663	<0.0001
Type of pathway x Distance to edge	2	11.532	0.003
NULL	31	111.828	
Successional categories			
Species	<i>Df</i>	Deviance	<i>p</i>
Type of pathway	3	31.158	<0.0001
Distance to edge	1	15.117	0.0001
Type of pathway x Distance to edge	2	0,085	0.958
NULL	31	79.437	
Individuals			
Species	<i>Df</i>	Deviance	<i>p</i>

Type of pathway	3	92.778	<0.0001
Distance to edge	1	45.155	<0.0001
Type of pathway x Distance to edge	2	5.500	0.063
NULL	31	192.702	



**Figure 5.** Proportion of dispersal syndromes - zoochorous vs. non-zoochorous (anemochorous plus autochorous) species and individuals; and proportion of successional categories: pioneer vs. non-pioneer species and individuals among “type of pathway” and “distance to edge” at Carlos Botelho State Park, SP, Brazil. The box-plots are displaying the median, the first and

third quartile, and the maximum and minimum values of the data sets. A: Zoochorous species, B: Zoochorous individuals, C: Pioneer species, D: Pioneer individuals.

## Discussion

Changes in vegetation were detectable beyond the edges in wider (10 and 20 m) pathways, at least 35 m towards the forest interior. Different widths can determine the degree of microclimatic changes in the edge zone of a pathway (Pohlman *et al.* 2007). Light availability, high temperatures, low relative humidity, variation in soil nutrient availability and sediment runoff are variables that change according to the characteristics of linear gaps (Reid & Dunne 1984; Denslow 1987). Edges of wide pathways are more exposed to those factors when compared to narrow pathways, and can modify both the vegetation structure and the successional process in their vicinities (Goosem 1997). The distribution of plant species in tropical forests reflects different specific tolerances to drought, shade, and nutrient stress (Sterck *et al.* 2006; Engelbrecht *et al.* 2007; Baltzer & Thomas 2010), implying that species are at least partially separated for different resource niches within a local community (Kraft & Ackerly 2010; Sterck *et al.* 2014).

Species composition differed in pathways with different widths. The control area and the narrow pathway (trail) exhibited similar species composition, but differed from the wider pathway (main road). Plots along the 10 m-width secondary road varied widely in species composition. The secondary road had half the width of the main road and canopy connection occurs in some points along its extension. This characteristic can promote high habitat heterogeneity and contribute to mixed species composition. Shade-tolerant species occurring in secondary road plots (e.g. *Micropholis crassipedicellata*, *Ocotea odorifera* and *Myrcia eugeniopsoides*) were also found in trail and control plots, but pioneer species (e.g. *Tibouchina pulchra* and *Miconia cabucu*) occurred mostly in main road plots. Thus, the high species diversity in the secondary road may be explained by a combination of species with different ecological requirements (Allouche *et al.* 2012), corroborating the intermediate disturbance hypothesis (Connel 1978; Molino & Sabatier 2001). The low diversity in trail can be probably related to the selective logging that occurred during the extractive period (near the 40's) of

charcoal production (SMA 2008), as indicated by the presence of some charcoal ovens along the trail (SMA 2008).

A wide linear gap such as the main road (20 m) may disturb microclimate conditions and resource availability for plants, affecting the species distribution and eventually causing differences in the vegetation structure and composition between the edges and their inner adjacent areas (Hartshorn 1980; Sterck *et al.* 2014). Recruitment of generalist species can be facilitated by a wide pathway gap, which would benefit from highly variable ecological conditions found at the edge of the main road (Forman & Alexander 1998), resulting in species dominance (Denslow 1980), as demonstrated by the low evenness found in the main road. An increase in 10 m between the secondary and main road widths can be sufficient to determine differences in species composition, which emphasizes the importance of the gap size in the structuring of local plant communities (Denslow 1980; Zhu *et al.* 2014).

The predominance of species of different successional groups also depends on the gap size and the environmental conditions prevailing at the pathway edges (Denslow 1980), as verified for pioneer species, which have a positive relationship with gap size (Denslow 1980; Laurance *et al.* 2009). Shade intolerant pioneer species usually establish from the seed bank that existed prior to clearing or from subsequent recruitment (Tabarelli & Peres 2002). When a linear gap is established in a forested area, microclimatic conditions are inevitably altered, which allows pioneer species germination and/or seed dispersal (Webb *et al.* 1999). On the other hand, non-pioneer species are much less abundant and are prone to death at edges (Tabarelli & Peres 2002).

Wider pathways benefit anemochorous species because the aerodynamic design of their propagules enable them to be easily wind-transported for long distances in open environments (Howe & Smallwood 1982; Jara-Guerrero *et al.* 2011). Changes in the frequency of dispersal strategies are a result of favorable habitat conditions and disperser activity (wind vs. vertebrate dispersal) coupled with specific life forms (shrubs vs. trees) and the species frequency in these groups through successional stages (Tabarelli & Peres 2002). Accordingly, the wider pathway was characterized by a low frequency of zoochorous and a high density of anemochorous species. Gap size also determines the abundance of shrubs and small trees, since these life forms have greater densities in large rather than in small gaps (Zhu *et al.* 2014), as demonstrated by the higher densities of individuals smaller than 1m height in the wider pathways.



Atlantic Forest threatened species with restricted distributions were also affected by pathway width, with lower numbers occurring in the wider pathway. The exception was *Euterpe edulis*, a dominant palm species in undisturbed areas of the Atlantic forest (Guilherme *et al.* 2004), which, contrary to our expectations, was among the most abundant species in all pathways. Possibly, the high survival rates of juvenile in gaps, compared to areas with dense canopy cover, may explain this unexpected pattern (Nakazono *et al.* 2001; Ribeiro *et al.* 2011b).

Vine abundance is also positively related to increases in linear gaps (Laurance *et al.* 2001; Bataghin *et al.* 2010). High abundance of vines at forest edges results from their demand for intense light exposure and the presence of slender trees that provide support for their fixation (Putz 1984). On the other hand, epiphytes are more sensitive to microclimate variations (Hietz 1998), require tall trees as substrate, and are therefore negatively related to linear gap width (Gonçalves & Waechter 2002; Wolf 2005). Not surprisingly, we found low abundance of epiphytes in areas intersected by wide pathways.

Intense management and traffic favor dispersal of exotic species along pathways (Dar *et al.* 2015), which is the case in our study, mainly at the main road. Despite the low traffic in the secondary road inside CBSP, exotic species were also recorded for this pathway, suggesting that even light traffic can promote the dispersal of exotic species. Moreover, the traffic-mediated dispersal of exotic species overcome competition with native plants, as many exotic species can withstand extreme conditions, like high light exposure, and succeed in colonising and establishing at the edges of pathways (Dar *et al.* 2015).

Plant communities with high number of individuals with small diameter and height were more frequent in the pathway edges but not in the control area, which indicates a typical initial regeneration phase (Guariguata & Ostertag 2001; Couto-Santos *et al.* 2015). This condition was probably set well before the park creation (between 40's and 70's), with the implantation of the pathways, and remained stable over time due to path maintenance.

In tropical forests, areas adjacent to linear gaps are characterized by low species richness, high proportion of pioneers and anemochorous plants and presence of exotic species, as reported in this study and others (Ribeiro *et al.* 2009a; Reznik *et al.* 2012; Prieto *et al.* 2014). We also found that pathway width influences the nearby vegetation as much as its presence.

Therefore, the impacts of pathways on the vegetation and, subsequently, on their associated fauna should be carefully considered for conservation and management purposes (Dewalt *et al.* 2003; Watson *et al.* 2004). Unfortunately, despite under state protection, our study area will probably continue to suffer impacts, because the roads are permanent. Additionally, modifications promoted by linear gaps may change over time according to the adopted management decisions and actions (Pickering *et al.* 2010; Müllerová *et al.* 2011), jeopardizing the status and distribution of several native plant species, as well as the control of the exotic ones, mostly in the wider pathways.

In conclusion, our study highlights that pathways wider than 10 m intersecting native forest areas negatively affect the vegetation structure and species composition, modifying the predominance of life forms and the (distribution/proportion) of dispersal syndromes, with consequences for the successional categories, threatened species, besides increasing the occurrence of exotic species. These changes are permanent, interrupt the process of species turnover in ecological succession, and increase the intensity of effects according to the pathway width. We expect that changes in the vegetation should also influence the resource availability and habitat use by the fauna (Restrepo *et al.* 1999; Dewalt *et al.* 2003; Watson *et al.* 2004). Our study stresses the importance of assessing the trade-offs between the consequences for conservation and the necessities of management of Atlantic Forest protect areas crossed by different kinds of pathways.

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## Supplementary data

Pathways affect vegetation structure and composition in an Atlantic Rainforest in Southeastern Brazil

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Table S1 – Plant species surveyed of different types of pathway and distance to edge (E: edge, N: neighborhood) in Carlos Botelho State Park, SP, Brazil. The values are numbers of individuals with diameter at breast height  $\geq 3.18$  cm. SG: successional groups (P: pioneer, NP: non-pioneer, UN: undetermined), DS: dispersal syndromes (ZOO: zoochorous, ANE: anemochorous, AUT: autochorous, UN: undetermined), LT: level of threat (VU: vulnerable, EN: endangered), SP: list of threatened flora of São Paulo state, BR: red book of Brazilian flora, IUCN: IUCN's list of threatened flora.

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
<b>Ferns</b>												
Cyatheaceae	<i>Alsophila setosa</i> Kaulf.	Samambaiçu	3	26	25	9	1	15	7	UN	UN	
	<i>Cyathea delgadii</i> Sternb.	Xaxim- espinhento	9	3	3	0	4	7	5	UN	UN	
<b>Angiosperms</b>												
Anacardiaceae	<i>Tapirira guianensis</i> Aubl.	Peito-de-pombo	0	0	0	1	0	0	0	P	ZOO	
Annonaceae	<i>Guatteria australis</i> A.St.- Hil.	Pindaúva-preta	3	2	6	2	5	0	3	NP	ZOO	
Apocynaceae	<i>Aspidosperma olivaceum</i> Müll.Arg.	Guatambu	0	0	1	0	0	0	1	NP	ANE	
Aquifoliaceae	<i>Ilex dumosa</i> Reissek	Caúna	0	2	4	1	2	0	0	NP	ZOO	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
	<i>Ilex</i> sp.		0	1	0	0	0	0	0	UN	UN	
Araliaceae	<i>Dendropanax australis</i> Fiaschi & Jung-Mend.	Pau-toa	1	0	0	0	0	0	0	UN	UN	
	<i>Schefflera calva</i> (Cham.) Frodin & Fiaschi	Embirutó	0	0	0	0	0	1	0	NP	ZOO	
Arecaceae	<i>Euterpe edulis</i> Mart.	Palmito-jussara	31	8	20	9	13	27	18	NP	ZOO	VU (SP, BR)
	<i>Geonoma gamiova</i> Barb.Rodr.	Guaricanga-de-folha-larga	2	0	0	0	0	0	0	NP	ZOO	
	<i>Geonoma schottiana</i> Mart.	Guaricanga	2	0	0	0	1	0	1	NP	ZOO	
Asteraceae	<i>Baccharis montana</i> DC.	Vassoura	0	1	0	0	0	0	0	UN	UN	
	<i>Piptocarpha organensis</i> Cabrera	Vassourãozinho	0	2	0	0	0	0	0	P	ANE	
	<i>Piptocarpha oblonga</i> (Gardner) Baker	Braço-do-rei	0	1	0	0	0	0	1	NP	ANE	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
	<i>Verbesina glabrata</i> Hook. & Arn.		0	0	1	0	0	0	0	P	ANE	
Bignoniaceae	<i>Jacaranda montana</i> Morawetz	Caroba	0	0	0	1	0	0	0	UN	UN	
	<i>Jacaranda puberula</i> Cham.	Caroba	0	0	0	3	6	1	1	NP	ANE	
Burseraceae	<i>Protium widgrenii</i> Engl.	Breu	1	0	1	0	0	0	0	NP	ZOO	
Celastraceae	<i>Maytenus robusta</i> Reissek	Coração-de-bugre	1	0	0	0	1	0	0	NP	ZOO	
Chrysobalanaceae	<i>Hirtella hebeclada</i> Moric. ex DC.	Uva-de-facho	1	0	0	0	0	0	1	NP	ZOO	
	<i>Parinari brasiliensis</i> (Schott) Hook.f.	Gonçalo-alves	1	0	0	0	1	0	0	NP	ZOO	EN (BR)
Clethraceae	<i>Clethra scabra</i> Pers.	Carne-de-vaca	0	13	6	1	0	0	0	P	ANE	
Clusiaceae	<i>Clusia criuva</i> Cambess.	Mangue-do-mato	0	2	2	0	0	0	0	P	ZOO	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
Combretaceae	<i>Buchenavia hoehneana</i> N.F.Mattos	Piuna	0	0	0	0	0	1	0	UN	UN	VU (IUCN)
Cunoniaceae	<i>Lamanonia ternata</i> Vell.	Guaraperê	0	0	0	0	0	1	0	NP	ANE	
	<i>Weinmannia paulliniifolia</i> Pohlex Ser.	Gramimunha	1	0	0	0	0	0	0	P	ANE	
Elaeocarpaceae	<i>Sloanea hirsuta</i> (Schott) Planch. exBenth.	Sapopema	0	0	0	0	1	2	0	NP	ZOO	
Euphorbiaceae	<i>Alchornea glandulosa</i> Poepp. &Endl.	Tapiá	7	4	0	2	0	2	1	P	ZOO	
	<i>Sapium glandulosum</i> (L.) Morong	Pau-de-leite	0	0	0	0	1	0	0	P	ZOO	
	<i>Sebastiania brasiliensis</i> Spreng.	Branquilha	0	0	0	0	0	1	0	NP	AUT	
Fabaceae	<i>Abarema langsdorffii</i> (Benth.) Barneby & J.W.Grimes	Raposeira-branca	1	1	0	0	0	0	0	NP	AUT/ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Andira antheimia</i> (Vell.) Benth.	Angelim- amargoso	0	1	2	0	0	1	0	NP	ZOO	
<i>Andira fraxinifolia</i> Benth.	Pau-angelim	0	1	1	1	0	0	1	NP	ZOO	
<i>Copaifera trapezifolia</i> Hayne	Copaiba	0	0	0	0	0	0	1	NP	ZOO	
<i>Dahlstedtia pinnata</i> (Benth.) Malme	Timbó	1	0	1	0	0	0	1	NP	AUT	
<i>Inga laurina</i> (Sw.) Willd.	Ingá-feijão	0	0	0	1	0	0	3	NP	ZOO	
<i>Lonchocarpus nitidus</i> (Vogel) Benth.	Rabo-de-bugio	0	0	0	0	0	0	1	UN	UN	
<i>Machaerium nyctitans</i> (Vell.) Benth.	Bico-de-pato	0	1	0	0	0	0	0	NP	ANE	
<i>Myrocarpus frondosus</i> Allemão	Cabreúva	1	0	0	1	0	1	0	NP	ANE	
<i>Ormosia minor</i> Vogel	Olho-de-cabra	0	0	1	0	0	0	0	NP	ZOO	



Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Pterocarpus rohrii</i> Vahl	Aldrago	4	0	0	0	3	0	1	NP	ZOO	
<i>Senna multijuga</i> (Rich.) H.S.Irwin & Barneby	Pau-cigarra	0	5	1	0	0	0	0	P	ANE	
<i>Tachigali denudata</i> (Vogel) Oliveira-Filho	Passariúva	1	0	0	0	1	0	0	P	ANE	
<i>Centrolobium robustum</i> (Vell.) Mart. exBenth.	Araribá	0	0	1	0	0	0	0	NP	ANE	
Humiriaceae	<i>Vantanea compacta</i> (Schnizl.) Cuatrec.	Guaraparim	1	0	0	0	0	0	NP	ZOO	
Indeterminate	Indet. 1	0	0	0	0	1	0	0	UN	UN	
	Indet. 2	0	0	0	0	0	0	1	UN	UN	
Lamiaceae	<i>Vitex polygama</i> Cham.	Tarumã	1	0	0	0	0	0	NP	ZOO	
Lauraceae	<i>Aiouea acarodomatifera</i> Kosterm.	Canela	1	0	0	1	0	0	NP	ZOO	VU (SP)

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Aniba firmula</i> (Nees & Mart.) Mez	Pau-rosa	2	0	0	1	0	2	1	NP	ZOO	
<i>Aniba viridis</i> Mez	Canela-de-mono	2	0	1	2	0	0	1	NP	ZOO	
<i>Cinnamomum hirsutum</i> Lorea-Hern.	Garuva-da-serra	0	0	1	0	0	0	0	UN	UN	
<i>Cryptocarya mandioccana</i> Meisn.	Cajati	0	0	0	0	1	0	0	NP	ZOO	
<i>Endlicheria paniculata</i> (Spreng.) J.F.Macbr.	Canela-frade	0	0	0	2	1	1	0	NP	ZOO	
Lauraceae sp1		1	1	0	0	0	0	0	UN	UN	
Lauraceae sp2		0	0	0	0	1	0	0	UN	UN	
Lauraceae sp3		0	0	0	1	0	0	0	UN	UN	
Lauraceae sp4		0	0	0	0	0	5	0	UN	UN	
Lauraceae sp5		0	2	0	0	0	0	0	UN	UN	
<i>Licaria armeniaca</i> (Nees) Kosterm.	Canela	0	0	1	0	0	0	0	NP	ZOO	
<i>Nectandra debilis</i> Mez	Canela-fogo	2	0	0	1	0	0	1	NP	ZOO	EN (SP)

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Nectandra leucantha</i> Nees	Canela-amarela	2	0	1	1	1	1	0	NP	ZOO	CR (IUCN)
<i>Nectandra oppositifolia</i> Nees	Canela-amarela	0	2	1	5	1	1	0	P	ZOO	
<i>Ocotea aciphylla</i> (Nees & Mart.) Mez	Canela-amarela-de-cheiro	1	0	0	0	0	0	0	NP	ZOO	
<i>Ocotea catharinensis</i> Mez	Canela-coqueiro	1	0	0	1	0	1	4	NP	ZOO	VU (BR, IUCN)
<i>Ocotea dispersa</i> (Nees & Mart.) Mez	Canela-sabão	1	2	4	0	1	1	2	P	ZOO	
<i>Ocotea elegans</i> Mez	Canela-sassafrás-do-campo	5	0	1	2	0	1	4	NP	ZOO	
<i>Ocotea odorifera</i> (Vell.) Rohwer	Canela-sassafrás	1	0	0	1	2	0	2	NP	ZOO	EN (BR)
<i>Ocotea puberula</i> (Rich.) Nees	Canela-guaicá	0	0	0	0	0	1	0	NP	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT	
			E	N	E	N	E	N				
	<i>Ocotea tabacifolia</i> (Meisn.) Rohwer		0	0	1	1	0	0	NP	ZOO	VU (SP) EN (BR)	
	<i>Ocotea teleiandra</i> (Meisn.) Mez	Canela-fogo	0	0	0	1	0	1	NP	ZOO		
	<i>Ocotea venulosa</i> (Nees) Baitello	Canelão-amarelo	0	0	2	0	0	0	NP	ZOO		
	<i>Persea venosa</i> Nees & Mart.	Pau-andrade	1	0	0	0	0	0	NP	ZOO		
Magnoliaceae	<i>Magnolia ovata</i> (A.St.-Hil.) Spreng.	Pinha-do-brejo	0	0	1	0	0	0	NP	ZOO		
	<i>Leandra variabilis</i> Raddi		0	0	1	3	0	1	UN	ZOO		
Melastomataceae	<i>Miconia cabucu</i> Hoehne	Pixiricão	0	0	10	13	5	1	2	NP	ZOO	
	<i>Miconia cinnamomifolia</i> (DC.) Naudin	Jacatirão	0	0	0	1	0	0	0	P	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Miconia cubatanensis</i> Hoehne	Pixirica	0	0	0	0	2	0	0	P	ZOO	
<i>Miconia paniculata</i> (DC.) Naudin		0	2	1	4	4	0	2	UN	UN	
<i>Miconia petropolitana</i> Cogn	Pixirica	1	0	0	0	0	0	1	NP	ZOO	
<i>Miconia racemifera</i> (DC.) Triana	Pixirica	0	0	3	0	0	0	0	NP	ZOO	
<i>Miconia sellowiana</i> Naudin	Pixirica	0	0	1	0	0	0	0	P	ZOO	
<i>Miconia valtheri</i> Naudin		0	0	0	6	0	0	0	P	ZOO	
<i>Tibouchina fothergillae</i> (Schrank & Mart. ex DC.) Cogn.	Quaresmeira	0	1	0	0	0	0	0	UN	ANE	
<i>Tibouchina pulchra</i> Cogn.	Manacá-da-serra	0	21	6	2	1	1	1	P	ANE	
<i>Cabranea canjerana</i> (Vell.) Mart.	Canjerana	4	3	4	0	2	5	5	NP	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Guarea macrophylla</i> Vahl	Café-bravo	1	0	0	0	0	0	0	NP	ZOO	
<i>Cedrela fissilis</i> Vell.	Cedro	0	0	0	0	1	0	0	NP	ANE	VU (BR), EN (IUCN)
<i>Mollinedia boracensis</i> Peixoto		2	0	0	0	0	0	1	UN	UN	
<i>Mollinedia gilgiana</i> Perkins		1	0	0	0	0	0	0	NP	ZOO	VU (SP), CR (IUCN)
<i>Mollinedia luizae</i> Peixoto		1	0	0	0	0	1	0	NP	ZOO	VU (SP, BR)
Monimiaceae <i>Mollinedia oligantha</i> Perkins	Capixim	0	0	0	1	0	0	0	NP	ZOO	
<i>Mollinedia</i> sp.		0	0	0	0	0	1	0	NP	ZOO	
<i>Mollinedia schottiana</i> (Spreng.) Perkins	Pimenteira	7	0	2	0	1	4	6	NP	ZOO	
<i>Mollinedia widgrenii</i> A.DC.	Capixim	0	0	0	2	0	0	0	NP	ZOO	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
Moraceae	<i>Brosimum glaziovii</i> Taub.	Maminha-cadela	0	2	0	0	0	0	0	NP	ZOO	EN (IUCN)
	<i>Ficus insipida</i> Willdenow		0	0	0	1	0	0	0	P	ZOO	
	<i>Ficus luschnathiana</i> (Miq.) Miq.	Figueira-do-brejo	0	1	0	0	0	0	0	NP	ZOO	
	<i>Sorocea bonplandii</i> (Baill.) W.C.Burger et al.	Cincho	2	1	0	0	0	2	3	NP	ZOO	
Myrtaceae	<i>Calyptranthes lanceolata</i> O.Berg	Guamirim	2	0	0	1	0	0	0	NP	ZOO	
	<i>Calyptranthes obovata</i> Kiaersk.	Guamirim	2	0	0	0	0	0	0	NP	ZOO	
	<i>Campomanesia guaviroba</i> (DC.) Kiaersk.	Guabiroba	0	1	0	1	1	1	2	NP	ZOO	
	<i>Eugenia brevistyla</i> D.Legrand	Guamirim	1	0	0	0	0	0	0	NP	UN	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Eugenia capitulifera</i> O.Berg	Mamoneira	1	0	0	0	0	0	0	NP	ZOO	
<i>Eugenia involucrata</i> cf. DC.	Cereja-do-rio-grande	4	0	1	0	0	0	0	NP	ZOO	
<i>Eugenia copacabanensis</i> Kiaersk.	Bapuana	1	0	0	0	0	0	0	NP	ZOO	
<i>Eugenia florida</i> DC.	Pitanga-preta	3	0	0	0	0	0	0	NP	ZOO	
<i>Eugenia mosenii</i> (Kausel) Sobral	Cuxita	6	0	0	0	0	0	0	NP	ZOO	
<i>Eugenia prasina</i> O.Berg	Araçarana	0	0	0	3	1	0	1	NP	ZOO	VU (IUCN)
<i>Eugenia pruinosa</i> D.Legrand		0	0	0	0	0	0	1	NP	ZOO	EN (BR)
<i>Eugenia</i> sp1		0	0	1	0	0	0	1	UN	UN	
<i>Eugenia</i> sp2		3	0	0	2	0	1	0	UN	UN	
<i>Eugenia</i> sp3		1	0	0	1	0	0	0	UN	UN	
<i>Eugenia</i> sp4		0	0	0	0	0	1	0	UN	UN	
<i>Eugenia subavenia</i> O.Berg	Guamirim	2	0	0	0	0	1	1	NP	ZOO	



Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Eugenia supraaxillaris</i> Spring	Fruta-de-tatu	0	0	0	0	0	0	2	NP	ZOO	
<i>Marlierea eugeniopsoides</i> (D.Legrand & Kausel)	Cambucá	2	0	0	0	0	0	0	NP	ZOO	
D.Legrand <i>Myrceugenia myrcioides</i> (Cambess.)	Araçarana	4	0	0	0	0	0	0	NP	ZOO	
O.Berg <i>Myrceugenia seriatoramosa</i> (Kiaersk.)	Guamirim	1	0	0	0	0	0	0	NP	ZOO	
D.Legrand & Kausel <i>Myrcia anacardiifolia</i> Gardner	Guamirim	1	0	0	0	0	0	0	NP	ZOO	
<i>Myrcia brasiliensis</i> Kiaersk.		0	0	1	0	1	0	1	NP	ZOO	
<i>Myrcia eugeniopsoides</i> (D.Legrand & Kausel) Mazine		1	0	0	0	1	0	2	NP	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT	
			E	N	E	N	E	N				
<i>Myrcia pubipetala</i> Miq.	Guamirim-chorão	2	0	0	1	1	0	0	NP	ZOO		
<i>Myrcia</i> sp1		0	0	0	0	1	0	0	UN	UN		
<i>Myrcia splendens</i> (Sw.) DC.	Guamirim-miúdo	6	5	2	7	3	2	1	NP	ZOO		
<i>Myrciaria floribunda</i> (H.West Willd.) O.Berg ex	Camboinzinho	1	0	0	0	0	0	0	NP	ZOO		
Myrtaceae sp1		0	0	0	0	0	1	0	UN	UN		
Myrtaceae sp2		0	1	0	0	0	0	0	UN	UN		
Myrtaceae sp3		4	0	1	0	1	1	0	UN	UN		
Myrtaceae sp4		2	0	0	0	0	1	1	UN	UN		
<i>Plinia complanata</i> M.L.Kawas. & B.Holst		0	0	0	0	0	1	0	UN	UN	EN (BR)	
<i>Psidium cattleianum</i> Sabine	Araçá-rosa	0	3	0	2	0	0	0	NP	ZOO		
Nyctaginaceae	<i>Guapira opposita</i> (Vell.) Reitz	Moço-mole	6	0	2	0	3	0	3	NP	ZOO	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
Oleaceae	<i>Chionanthus filiformis</i> (Vell.) P.S.Green	Azeitona-silvestre	0	0	0	0	2	0	0	UN	UN	
Phyllanthaceae	<i>Hyeronima alchorneoides</i> Allemão	Aracurana-da-serra	0	1	2	3	0	1	0	NP	ZOO	
Polygonaceae	<i>Coccoloba alnifolia</i> Casar.	Pau-de-estalo	0	0	0	0	1	0	0	UN	UN	
	<i>Cybianthus</i> sp.		0	0	0	1	1	0	0	UN	UN	
	<i>Myrsine coriacea</i> (Sw.) R.Br. ex Roem. &Schult.	Capororoca	0	6	2	1	0	0	0	P	ZOO	
Primulaceae	<i>Myrsine umbellata</i> Mart.	Capororocão	1	4	4	5	3	1	0	NP	ZOO	
	<i>Stylogyne depauperata</i> Mez		3	0	2	0	0	0	0	NP	ZOO	
	<i>Stylogyne lhotzkyana</i> (A.DC.) Mez		3	0	0	0	0	0	0	NP	ZOO	
	<i>Stylogyne pauciflora</i> Mez	Pau-de-charco	1	1	0	0	1	0	0	NP	ZOO	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
Rosaceae	<i>Prunus myrtifolia</i> (L.) Urb.	Pessegueiro-bravo	0	1	1	0	0	0	0	NP	ZOO	
	<i>Alseis floribunda</i> Schott	Quina-de-são-paulo	1	0	0	0	0	0	0	NP	AUT	
	<i>Amaioua intermedia</i> Mart. ex Schult. &Schult.f.	Marmelada	2	0	0	0	0	0	1	NP	ZOO	
	<i>Bathysa australis</i> (A.St.-Hil.) K.Schum.	Fumão	1	2	2	0	0	10	7	NP	AUT	
Rubiaceae	<i>Chomelia brasiliiana</i> A.Rich.		1	0	0	0	0	1	0	NP	ZOO	
	<i>Cordia concolor</i> (Cham.) Kuntze		0	0	0	1	0	0	0	NP	ZOO	
	<i>Faramea montevidensis</i> (Cham. &Schltdl.) DC.	Café-do-mato	0	0	0	1	0	2	0	NP	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Ixora gardneriana</i> Benth.	Ixóra-arbórea	6	0	0	0	0	0	2	NP	ZOO	
<i>Psychotria gracilenta</i> Müll.Arg.		0	0	0	0	0	0	0	P	ZOO	
<i>Psychotria leiocarpa</i> Cham. & Schltdl.	Cafeeiro-do-mato	0	3	2	1	0	0	0	NP	ZOO	
<i>Psychotria mapourioides</i> DC.	Café-do-mato	0	0	1	0	0	0	0	NP	ZOO	
<i>Psychotria nuda</i> (Cham. & Schltdl.) Wawra	Grandiúva-d'anta	0	1	1	0	0	2	0	NP	ZOO	
<i>Psychotria vellosiana</i> Benth.	Quina-mole	0	3	1	0	0	0	0	NP	ZOO	
<i>Rudgea jasminoides</i> (Cham.) Müll.Arg.	Buquê-de-noiva	1	0	0	0	0	0	0	NP	ZOO	
Rutaceae <i>Esenbeckia grandiflora</i> Mart.	Guaxupita	2	0	1	1	1	2	0	NP	AUT	

	Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
				E	N	E	N	E	N			
	<i>Zanthoxylum rhoifolium</i> Lam.	Mamica-de-cadela	1	0	0	2	1	0	0	NP	ZOO	
Salicaceae	<i>Casearia decandra</i> Jacq.	Guaçatonga	1	1	1	2	1	0	0	NP	ZOO	
	<i>Casearia obliqua</i> Spreng.	Cambroé	1	1	1	0	0	11	1	P	ZOO	
	<i>Casearia sylvestris</i> Sw.	Guaçatonga	0	2	1	3	0	0	0	NP	ZOO	
	<i>Xylosma glaberrima</i> Sleumer	Açucará-manso	0	1	1	0	0	0	0	P	ZOO	
Sapindaceae	<i>Allophylus edulis</i> (A.St.-Hil. et al.) Hieron. ex Niederl.	Chal-chal	0	0	0	1	0	0	0	P	ZOO	
	<i>Cupania oblongifolia</i> Mart.	Pau-magro	6	0	3	1	7	5	2	NP	ZOO	
	<i>Cupania vernalis</i> Cambess.	Arco-de-peneira	3	0	1	0	3	0	0	NP	ZOO	
	<i>Cupania zanthoxyloides</i> Radlk.	Cupânia-veludo	0	0	0	0	0	0	2	P	ZOO	

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
<i>Diatenopteryx sorbifolia</i> Radlk.	Correeiro	1	0	0	0	0	0	0	P	ANE	
<i>Matayba elaeagnoides</i> Radlk.	Camboatá-branco	1	0	0	0	0	0	0	NP	ZOO	
<i>Matayba guianensis</i> Aubl.	Camboatá	0	2	3	0	0	0	0	P	ZOO	
<i>Matayba intermedia</i> Radlk.	Camboatá-branco	0	1	2	0	0	0	0	NP	ZOO	
<i>Matayba juglandifolia</i> (Cambess.) Radlk.	Camboatá-branco	3	0	0	0	0	0	1	NP	ZOO	
Sapotaceae	<i>Micropholis crassipedicellata</i> (Mart. & Eichler) Pierre	Bacubixá	2	0	0	1	2	1	1	NP	ZOO
	<i>Pouteria caimito</i> (Ruiz & Pav.) Radlk.	Abiu	1	0	0	0	0	0	0	NP	ZOO
	<i>Pouteria torta</i> (Mart.) Radlk.	Abiu-piloso	3	0	0	0	1	1	4	NP	ZOO
Solanaceae	<i>Cestrum</i> cf. <i>schlechtendalii</i> G. Don	Berinjelinha-da-mata	0	0	0	1	0	0	0	NP	ZOO

Species	Vernacular name	Control area	Main road		Secondary road		Trail		SG	DS	LT
			E	N	E	N	E	N			
Symlocaceae	<i>Solanum argenteum</i> Dunal	Solanum-prata	0	2	0	1	2	0	0	P	ZOO
	<i>Solanum bullatum</i> Vell.	Fumeiro-alho	0	1	0	0	0	0	0	P	ZOO
	<i>Symplocos laxiflora</i> Benth.	Orelha-de-onça	0	0	1	0	0	0	0	NP	ZOO



## **CAPÍTULO II –Fruit availability along roads and footpaths in an Atlantic rain forest area**

Artigo nas normas da revista *Plant Ecology & Diversity*

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## **Abstract**

**Background:** Linear openings - roads and footpaths - are associated with edge effect. The magnitude of these effects depends, largely, on the width of the pathways. Thus, different pathways width result in different effects on forest structure, composition and function.

**Aim:** We investigated the effects of pathways of varying widths on the temporal and spatial fruit production of the forest nearby.

**Methods:** We studied three paths, 2, 10 and 20m wide, in the Atlantic forest in southeast Brazil. A total of 3,762 woody individuals (taller than 50 cm) were surveyed and their fruit production monitored over a 2-year period in eight plots (100 m<sup>2</sup> each) per pathway along edges and neighborhood (35 m toward the forest interior), and in a control area without paths.

**Results:** The number of species and individuals bearing fruit was higher in wider pathways than along footpath and control, and the amount of zoochorous fruits produced was higher in the control than along all pathways. The widest pathway had the highest amount of non-zoochorous fruits. Fruiting peaks occurred only in the forest with pathways, while in the control fruiting was not seasonal.

**Conclusions:** Pathways affect the amount of fruits produced, dispersal syndromes predominance and temporal fruit availability. These effects on fruit availability extend toward the forest interior beyond 35 m in wide pathways. The establishment of permanent paths can affect food resources for frugivores in space and time.

**Key-words** – Dispersal syndromes, food resource for frugivores, fruit production, linear forest gaps, seasonality.

## Introduction

Variations in the fruit available in a habitat may occur, for example, among patches with different regeneration stages or, temporally, with fluctuations in phenological fruiting curves that can occur in tropical forests (Longman & Jenik 1987; Morellato et al. 2000). Although studies reveal a continuous fruit production and a predominance of trees producing fleshy fruits (zoochory) in Atlantic Forest mature areas (Morellato et al. 2000; Almeida-neto et al. 2008), variation in the conditions of disturbed areas with gaps can affect plant phenological processes (Restrepo et al. 1999; Laurance et al. 2003). Phenological changes, as the occurrence of peaks and depressions in fruit production, may affect the abundance, species richness and temporal pattern of fruit-bearing species and fruiting intensity in fragment edges (Restrepo et al. 1999; Laurance et al. 2003; Cara 2006; Felton et al. 2006), altering the level of fruit availability in a given habitat (Longman and Jenik 1987).

Along the edges, higher irradiation changes micro-climatic conditions on the forest floor causing higher temperatures, lower humidity, higher wind speed and air turbulence, and shifts in soil nutrient availability, resulting in an environment that is different from that in the closed forest interior (Goosem 1997; Laurance et al. 1998; Laurance et al. 2016). These changes can cause various degrees of edge effect (Murcia 1995; Laurance et al. 1998; Webb et al. 1999), that can be felt in the forest away from the edges at greater or lesser intensity, depending on the gap characteristics (Pohlman et al. 2007; Broadbent et al. 2008; Laurance et al. 2009), and can affect plant and animal communities (Goosem 1997; Laurance et al. 1998). The changes in plant species composition include increased occurrence of heliophylous pioneer species, which with time may substitute species adapted to shade (Tabarelli et al. 1999; Tabarelli and Peres 2002). Eventually, the seasonal patterns of reproduction by trees and thus fruit availability for consumers may change (Denslow 1987; Heideman 1989; DeWalt et al. 2003).

The responses of plants to different gap characteristics are a subject that still deserves more investigation (Cara 2006; Ramos & Santos 2006). Different patterns can be found in the literature when compared natural and anthropic gaps, presenting inconclusive results (Restrepo et al. 1999; Ramos & Santos 2006; Reznik et al. 2012), as higher fruit production in natural gaps (Restrepo et al. 1999; Ramos & Santos 2006), contrasting with low fruit and flower production in anthropic ones (Ramos & Santos

2006), and changes in the temporal dynamics of fruiting in anthropic linear gaps, but no effect on the distribution of the dispersal syndromes (Reznik et al. 2012), even though it is known that there is a predominance of zoochory in advanced stage of regeneration. Besides that, the gap size is an important variable that can structure the local plant communities (Denslow 1980; Zhu et al. 2014). For example, size of anthropogenic gaps is positively related with density of typical plants of secondary stage of regeneration (Zhu et al. 2014). Thus, the gap size could affect the spatial and temporal reproductive process in plants. However, there are no studies that investigate and compare these reproductive processes among anthropogenic gaps with different sizes.

Concerning anthropogenic gaps, several kinds of highways, roads and footpaths form linear gaps that intersect tropical forests remnants (MMA 2000), potentially affecting the adjacent plant and animal communities (Goosem 1997; Laurance et al. 2009). Such impacts have been studied in tropical areas and focused mainly on the fauna (Whitworth et al. 2015), movement of seed dispersers (Laurance et al. 2004) and composition of seed disperser communities (Ahmed et al. 2014; Astudillo et al. 2014). A few studies have investigated the impacts of pathways on vegetation (Prieto et al. 2014; Couto-Santos et al. 2015; Silva et al. 2017), and identified that roads and footpaths of varying widths within a tropical forest can result in differential effects on its structure and composition (Silva et al. 2017). However, the extent to which these effects can modify the plant reproductive phenology and fruit offer (Reznik et al. 2012) has not yet been investigated. Unlike natural forest gaps, that rapidly close after their formation (Denslow 1987), man-made 'linear gaps' are practically immutable in time and space and can affect fruit offer permanently (Laurance et al. 2009), bringing consequences for the local fauna.

Studies that compare anthropic linear gaps with different widths can help to understand the impact of kinds of road or footpath in the reproductive processes of plants in tropical forests. Additionally, addressing the influence of pathways in fruit offer can provide an important tool for understanding the space-time organization of food resources. Thus, our objective was to assess the impacts of pathways of varying widths on temporal and spatial fruit availability in the surrounding tracts in a protected area in the Atlantic forest. We hypothesize that pathways presence have impacts in fruit offer in the Atlantic forest, and that the effects will be perceived in (1) the number of species and fruit-bearing individuals, (2) the temporal fruit offer, (3) the predominance of dispersal syndromes, and also that (4) the propagation of those impacts toward the forest interior

will be dependent upon the pathway width. We predicted that: (1) the number of species and fruit-bearing individuals will be higher at the forest edges, (2) forest edges will present well defined peaks in fruit production, (3) forest adjacent to narrow pathways and areas without pathways will produce more zoochorous fruits than those adjacent to wider pathways, and (4) the propagation of those impacts toward the forest interior will be more intense in the wider pathways.

## **Material and Methods**

### *Study area*

We conducted this study in a continuous forest in the southeastern Brazil at the Carlos Botelho State Park (CBSP), a 37,644.36 ha area, located between 24° 06' 55" – 24° 14' 41" S and 47° 47' 18" – 48° 07' 17" W (Figure 1 a). The climate is tropical, with mean annual temperature of 18°C, and annual precipitation from 1500 - 2200 mm (Ferraz and Varjabedian 1999). The study areas selected for sampling are located at an average altitude of 800 m, in the Montane Dense Ombrophilous Forest, where we collected data along some park's pathways with different widths, named: main road (20m width), secondary road (10m) and footpath (2m) (Figure 1 b).

As in the Atlantic Forest several ecological aspects of plant communities (e.g. density, richness, diversity and species composition) are more affected in the first 35 m from forest edges (Rodrigues 1998) and in order to ensure edge effects, we sampled at the edge and neighborhood (35 m from the edge toward the forest interior) (Figure 1 c). Considering that local conditions of climate and domain are determinants to plants responses we used a single pathway per pathway type, because there are no other pathways with the same characteristics in the same forest continuum and elevation. In addition, we established a control area, reputedly close to a reference state of conservation (Figure 1 b). All sampled plots were distributed within the same forest matrix, climate, altitude, and are spatially close (distant 200m inside the same pathways and about 600m among pathways). Given the small spatial scale of the study, it is possible to assume that differences between plots are more related to direct effects of the pathways instead of purely spatial effects.

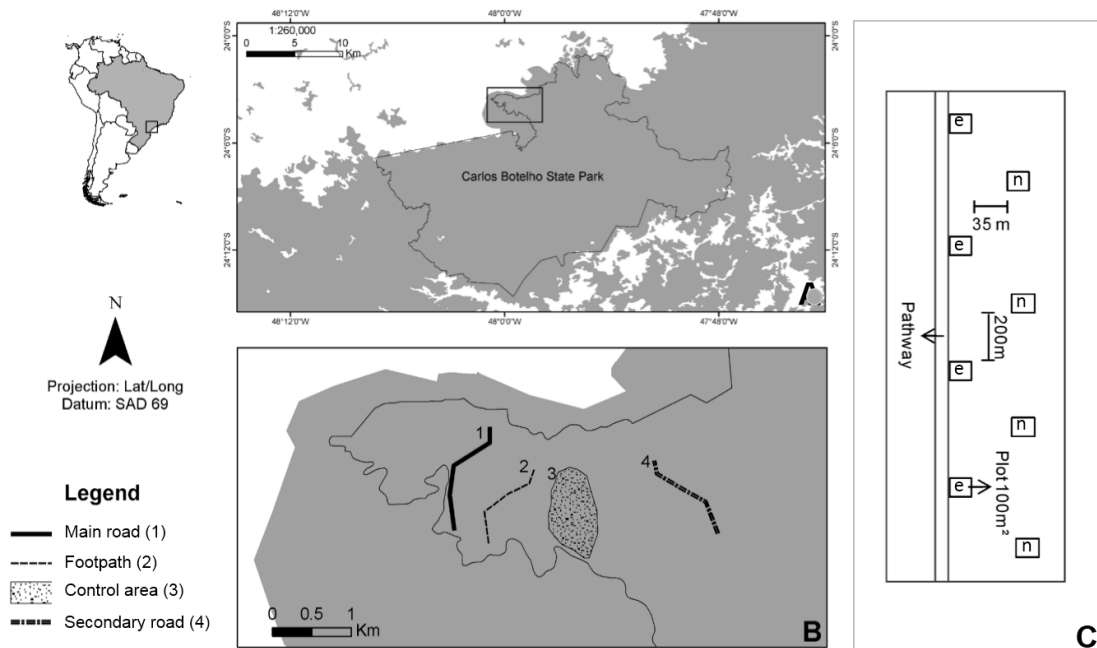


Figure 1. A. Location of Carlos Botelho State Park, São Paulo state, SE Brazil. B. Different pathways: 1) main road (20 m wide), 2) footpath (2 m wide), 3) control area, 4) secondary road (10 m wide). C. Distribution and spacing of plots along the pathway, e: edge, n: neighborhood. In gray the forest remnants - (Fundação SOS Mata Atlântica and INPE 2001).

### *Types of pathway*

The pathways studied were implanted before the park creation (between the 40's and 70's). The main road within the CBSP is mostly 20 m wide, was implanted near the 40's and intersects a total of 33 km of the state park area, with a completely open canopy (Figure 2 a). The secondary road, implanted before the 70's, is approximately 12 km long and mostly 10 m wide, with canopy cover at some points (Figure 2 b). The footpath, opened in the 40's, is approximately 4.5 km long, 2.0 m wide, with canopy cover along its total extension (Figure 2 c). The control area is representative of the species composition and structure of the mature forest occurring in most of the park, without apparent anthropic influence (SMA 2008) (Figure 2 d).



Figure 2. Sampled pathways at Carlos Botelho State Park, São Paulo state, SE Brazil, used as treatments: A: main road (20 m wide), B: secondary road (10 m wide), C: footpath (2 m wide), D: control area.

### *Sampling design*

In each pathway, we selected a stretch of 1400 m at least 500 m from the forest edge, in order to minimize natural edge effects. Along that stretch, eight 10 x 10 m sampling plots were alternately set: four adjacent to the pathway (edge) and four 35 m toward the forest interior (neighborhood) (Figure 1 c). Plots were placed at intervals of 200 m along the pathway to secure the independence of sampling units (Lenza et al. 2011) (Figure 1 c). At the control area we used the same sampling design, except that there was no pathway.

### *Data sampling*

Data collection was carried out during July 2013 to June 2015. We measured fruit availability considering the following variables: (i) the number of species and fruit-bearing individuals; (ii) amount of fruits produced; (iii) dispersal syndromes and (iv) seasonality in fruit production.

We marked and identified each woody individual taller than 50 cm with fruits inside plots. Fruiting and flowering branches were collected for further identification, under SISBIO (collection permit #23627-1) and IBAMA (#4968681), based on reference literature and with the aid of botanical specialists. The vouchers were deposited at the herbarium of the Universidade Estadual de Campinas (*UEC*). The species list (Supplementary Material Table 1) was organized according to the familial classification of the Angiosperm Phylogeny Group III (APG 2016). Species names were checked on the species list of Flora of Brazil (2015). Dispersal syndromes for fruiting individuals were classified according to Van der Pijl (1982) general classification: zoochorous and non-zoochorous (anemochorous plus autochorous), based on field observations and information from the literature.

We recorded fruit presence or absence on a monthly basis with the aid of a 10x36 binocular (between July 2013 and June 2015). Fieldwork was conducted preferentially during the last fortnight of each month, assuring a 30-day interval between each data collection event to make it possible to sample differences in phenological dynamics. For fruit quantification we also used the Fournier's intensity index (*FI*) (Fournier 1974).

$$\%FI = \left[ \frac{\sum_{i=1}^n (xi \times DBH)}{(\sum DBH) \times 4} \right] \times 100$$

According to the index, each phenophase is classified in a scale from 0 to 4, in which: 0 = absence of resource; 1 = presence of fruit in 1 to 25% of branches; 2 = 26 to 50%; 3 = 51 to 75%; 4 = 76 to 100% of branches. To measure total fruit availability per plot, we summed *FIs* of each individual weighted by diameter at breast height (*DBH*) as a surrogate for plant size (Reznik et al. 2012). This was then standardized as a percentage of maximum fruit availability (Equation 1).



Equation 1. Fournier's intensity index ( $FI$ ), where  $n$  is the number of individuals sampled in the plot,  $x_i$  is the value of the semi quantitative scale attributed to the individual, and  $DBH$  is the individual diameter at breast height.

### *Data analysis*

The number of fruiting species and individuals and amount of fruits produced (total, zoochorous, non-zoochorous) were treated as the response variables in linear mixed-effects models (Zuur et al. 2009). As fixed effects, we considered “type of pathway” and “distance to pathway edge”. To account for temporal autocorrelation, we used year and month as random effects. We used a model selection approach to assess which of the fixed effect combinations better fitted the data. Five models with the random effects and all combinations of the predictor variables used as fixed effects were built: a) a full model, including type of pathways, distance to pathway edge and their interaction, b) a model without interaction, c) a model without distance to pathway edge d) a model just with distance to pathway edge and e) null model containing no fixed effects. The assumptions of normality and homogeneity of variance were examined visually and through the Shapiro-Wilk test (Zar 1996). A post hoc HSD Tukey test was used to investigate differences between the types of pathway and distance to pathway edge for number of fruiting species and individuals and amount of fruits produced. We used the R lme4 package in the R statistical environment for these analyses (R Core Team 2016).

To evaluate differences in the proportion of dispersal syndromes (zoochory compared to non-zoochorous species) between the types of pathway and at different distances to the edge we used a generalized linear model with binomial distribution. Significance of the factors was assessed by means of a Chi-squared Analysis of Deviance. A post hoc HSD Tukey test was used to investigate differences between the types of pathway and distance to pathway edge. All analyses were carried out in the R statistical software (R Core Team 2016) and we considered plots as independent sampling units. To model selection analysis, the models were compared using the Akaike Information Criterion –  $AICc$  (Akaike 1974) by which the model with the lowest  $AICc$  is the one with the better fit ( $dAICc = 0$ ) (Zuur et al. 2009).

*Seasonality* – To assess temporal variation in the number of species and fruit-bearing individuals, as well as in amount of fruits produced, we used circular statistics, which

takes the periodicity of the data into account (Mahan 1991). For the analysis of monthly variation in fruit production, months were converted into angles, so that the complete circumference represents a year, with months represented in 30° intervals. Firstly, we verified whether our data followed the Von Mises' distribution (or circular normality) using graphical analyses and Watson's test. Mean vector length ( $r$ ) varies from 0 to 1, in which 0 indicates data homogeneity, thus an absence of a defined peak. High values of Rayleigh's test ( $z$ ) and significant values of  $P$  indicate peak presence. These analyses were performed in the R statistical software (R Core Team 2016). Given species and individuals data followed circular normality, we used the Rayleigh's test to calculate the mean group, which corresponds to the month at which the studied variable peaks (Morellato et al. 2000). Circular analyses were carried out in the ORIANA software (Kovach 2002).

## Results

### *Fruit availability*

A total of 3,762 individuals belonging to 32 families (Supplementary Material Table 1) were monitored within plots, of which 403 representing 101 species produced fruits. The number of species and fruit-bearing individuals differed between the types of pathway and distance to pathway edge, including interaction (Table 1, Figure 3). The main road had the highest values, followed by secondary road and then by footpath. Footpath and control areas had lower values and did not differ from one another. Main and secondary roads edge plots had more species and individuals in fruiting, compared to the neighborhood plots (Figure 3).

As for the amount of fruits produced there was a difference between types of pathway and distance to pathway edge (total amount, zoochorous, non-zoochorous fruits) (Table 1). Footpath and secondary road had the lowest values in total amount of fruits produced (Figure 3). The control area produced more zoochorous fruits than other pathways. However, for both, total and zoochorous fruits, the secondary road presented high values at edge plots, whereas in the main road the higher production occurred at the neighborhood plots (Figure 3). Main road produced more non-zoochorous fruits compared to the other types of pathways and the control area. There was a high fruit

production in the main road for both neighborhood and edge plots. For footpath and secondary road, edge plots produced more non-zoochorous fruits than the neighborhood plots of these same pathways (Figure 3).

Table 1. Selected models by Akaike Information Criterion (AICc) ( $dAICc = 0$ ) to the response variables: number of species and individuals in reproductive phase and fruit production (total amount, zoochorous, non-zoochorous fruits) among the studied types of pathways, considering distance to edge and interaction, at Carlos Botelho State Park – SP, Brazil, (n = 32 plots sampled along 24 months).

Models	Species		Individual	Total	Zoo	Non-
	<i>D</i>		s	<i>dAICc</i>	<i>dAICc</i>	zoo
	<i>f</i>	<i>dAICc</i>	<i>dAICc</i>	<i>c</i>	<i>c</i>	<i>dAICc</i>
	1					
Type of pathway x distance to edge	0	0	0	0	0	0
Type of pathway + distance to edge	8	14.6	31.9	39.8	22.8	15.8
Type of pathway	7	80.5	128.6	41.3	23.7	17.3
Distance to edge	5	106.4	144.4	64.2	70.8	54.2
NULL	4	167.4	214	66.3	73.3	58.8

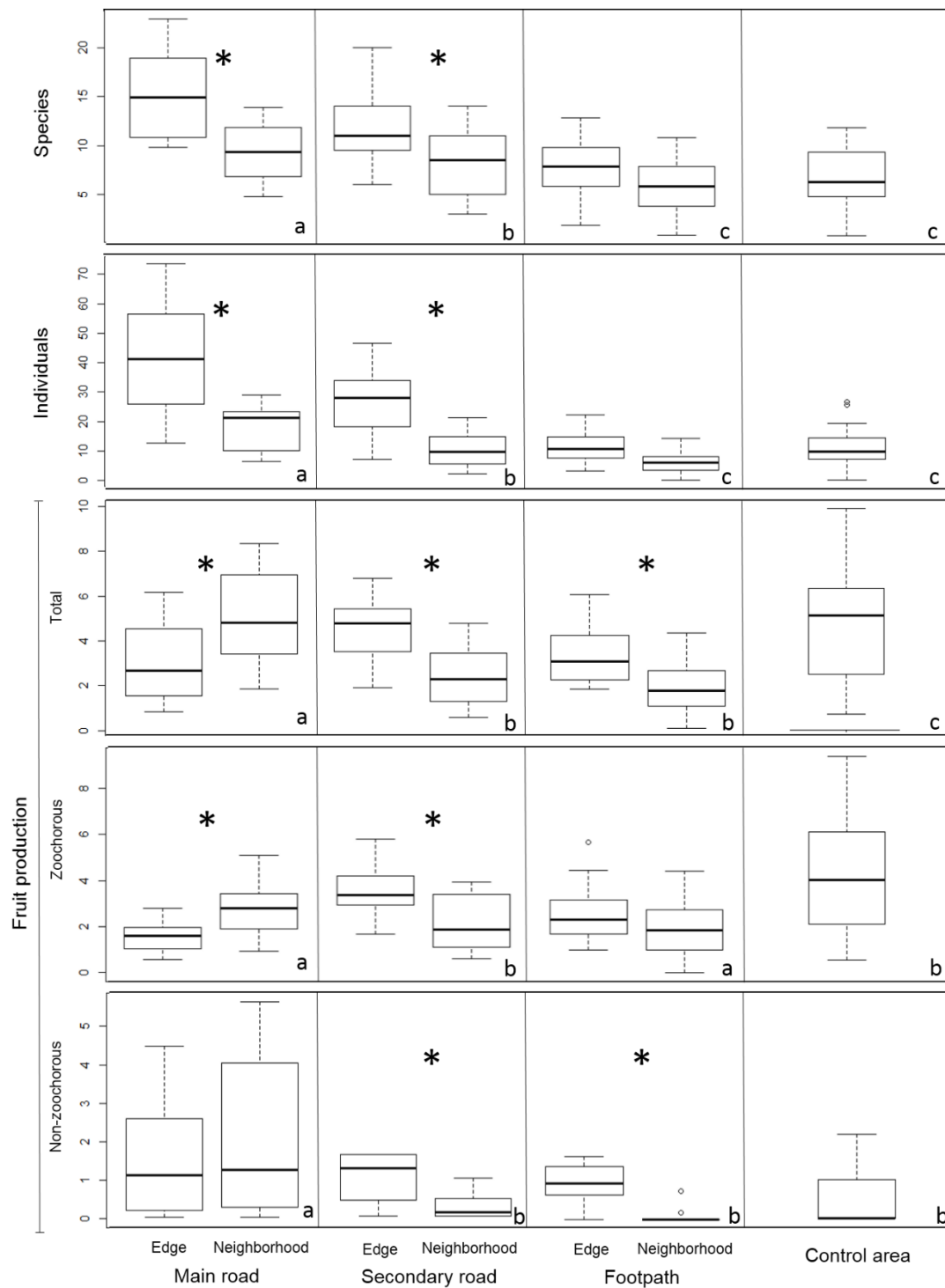


Figure 3. Number of species and individuals in fruiting phase and amount of fruits produced (total, zoochorous, non-zoochorous fruit production) among the studied types of pathways considering distance to pathway edge, at Carlos Botelho State Park – SP, Brazil. Collected data across eight plots 10 x 10 m<sup>2</sup> per type of pathway (n = 32 plots per 24 months). The box-plots are displaying the median, the first and third quartile, and the

maximum and minimum values of the data sets. Significant different variables according to HSD Tukey's test  $p < 0.05$  were indicated with letters for differences between pathways and asterisks for differences between edge and neighborhood.

Zoochory was the predominant dispersal syndrome in all areas and represented more than 70% of the total number of fruiting species and individuals. The proportion of zoochorous species did not vary among types of pathway, but was different between the distances to the edge (Table 2). The proportion of zoochorous individuals was different among types of pathway and between distances to the edge (Table 2). For both species and individuals, the proportion of zoochory was higher in the neighborhood (Figure 4). For individuals the values were smaller for the main road plots compared to the remaining types of pathways, demonstrating that the largest proportion of non-zoochoric fruits was produced in the widest pathway (Figure 4).

Table 2. Results for generalized linear model for proportion of dispersal syndrome: zoochorous vs. non-zoochorous species and fruit-bearing individuals considering "type of pathway", "distance to pathway edge" and their interaction, at Carlos Botelho State Park – SP, Brazil, (n=32 plots).

Dispersal syndromes			
Species	<i>Df</i>	Deviance	<i>P</i>
Type of pathway	3	3.087	0.378
Distance to edge	1	4.454	0.034
Type of pathway x distance to edge	2	3.967	0.137
NULL	31	34.808	
Individuals	<i>Df</i>	Deviance	<i>P</i>
Type of pathway	3	17.053	0.0006
Distance to edge	1	7.701	0.005
Type of pathway x distance to edge	2	2.47	0.29
NULL	31	61.934	

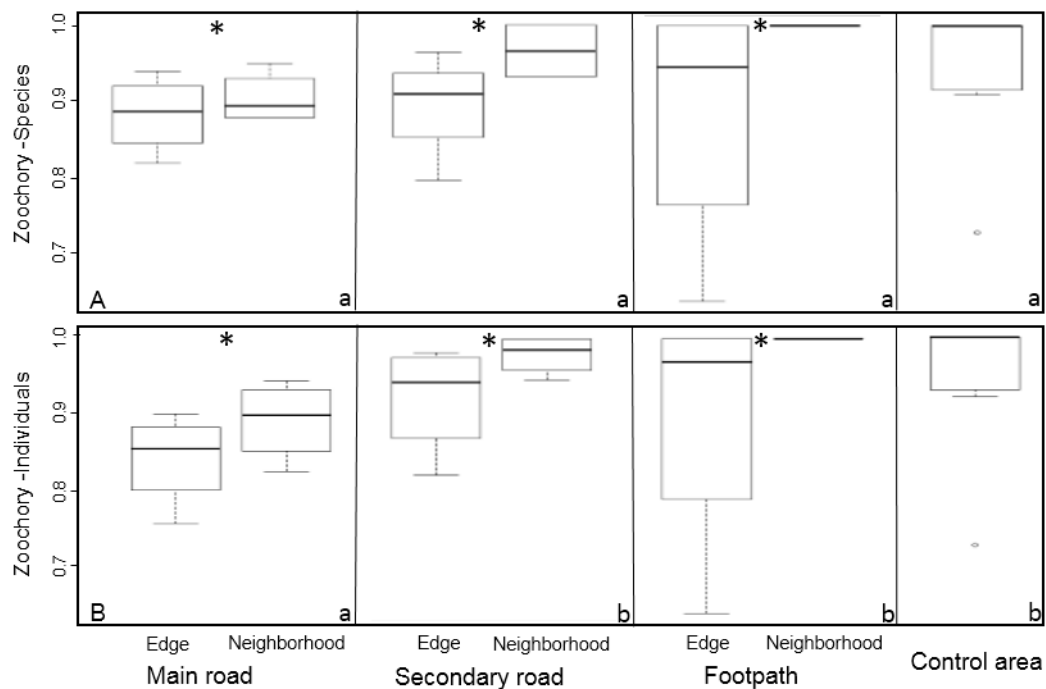


Figure 4. Proportions along 24 months of dispersal syndromes – zoochorous vs. non-zoochorous species and individuals in fruiting phase among “type of pathways” and “distance to pathway edge” at Carlos Botelho State Park, SP, Brazil. A: Zoochorous species, B: Zoochorous individuals. Data collected across eight 10 x 10 m<sup>2</sup> plots per type of pathway. The box-plots are displaying the median, the first and third quartile, and the maximum and minimum values of the data sets. Significantly different variables according to HSD Tukey’s test  $p < 0.05$  were indicated with letters for differences between pathways and asterisks for differences between edge and neighborhood.

### Seasonality

We found seasonality in the number of species and fruit-bearing individuals (Supplementary Material Figure 1). A high seasonality was more apparent for reproductive processes involving individuals (Table 3). For number of species in fruiting, only main road edge plots peaked in April, and secondary road peaked in January (Table 3). The control area and footpath had a less marked seasonality (Table 3). Conversely, high seasonality was observed for the number of individuals in fruiting in all types of pathways, except for the footpath neighborhood plots, whose peaks occurred between January and May (Table 3).

We also detected seasonality in amount of fruits produced (Table 3, Supplementary Material Figure 2). In the main road, fruit availability was seasonal both in neighborhood and edge plots, with total amount fruits and amount of non-zoochorous fruits, peaking in May (Table 3). In this area, zoochorous fruits peaked in April in the edge and in late December in the neighborhood (Table 3). Footpath also showed seasonal fruit production, with differential peaks, between edge and neighborhood. Total fruit production and zoochorous fruits peaked in June and July in edge plots and in October in neighborhood plots, but non-zoochorous fruit peaks varied depending on the distance to pathway edge (peaks in March and January) (Table 3). The control area showed an unseasonal pattern for all fruiting categories (Table 3).

Table 3. Calculated parameters for variation in total amount of fruits produced, zoochorous, non-zoochorous fruits (anemochorous plus autochorous), number of species and fruit-bearing individuals during two years (2013 – 2015) in areas affected by pathways within Carlos Botelho State Park – SP, Brazil, considering two treatments for each area: edge (E) and neighborhood (N). Data collected across eight 10 x 10 m<sup>2</sup> plots per type of pathway (n = 32 plots per 24 months).

Species	Main road		Secondary road		Footpath		Control
	E	N	E	N	E	N	
Mean group	Apr	Mar	Jan	Mar	Apr	Jan	Feb
Mean vector length ( <i>r</i> )	0.15	0.10	0.10	0.07	0.09	0.08	0.09
Standard Error of Mean	13.80°	24.35°	23.23°	38.44°	30.97°	40.70°	24.30°

Rayleigh's test ( $z$ )	8.51	2.75	3.02	1.10	1.70	0.99	2.76
Rayleigh's test ( $P$ )	<b>&lt;0.001</b>	0.064	<b>0.049</b>	0.331	0.182	0.373	0.063
<b>Individuals</b>							
	Main road		Secondary road		Footpath		Control
	E	N	E	N	E	N	
Mean group	Apr	Feb	Jan	Mar	May	Feb	Apr
Mean vector length ( $r$ )	0.25	0.20	0.23	0.15	0.12	0.06	0.11
Standard Error of Mean	5.08°	9.24°	6.88°	16.07°	19.64°	44.38°	15.61°
Rayleigh's test ( $z$ )	61.49	18.8	33.74	6.27	4.22	0.83	6.69
Rayleigh's test ( $P$ )	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>0.002</b>	<b>0.015</b>	0.436	<b>0.001</b>
<b>Total fruit production</b>							
	Main road		Secondary road		Footpath		Control
	E	N	E	N	E	N	
Mean group	May	May	Feb	Jun	Jun	Oct	Feb
Mean vector length ( $r$ )	0.32	0.12	0.07	0.09	0.11	0.23	0.04
Standard Error of Mean	5.85°	13.68°	26.78°	30.87°	12.88°	8.45°	36.04°
Rayleigh's test ( $z$ )	45.33	8.71	2.28	1.71	9.84	22.29	1.26
Rayleigh's test ( $P$ )	<b>&lt;0.001</b>	<b>&lt;0.001</b>	0.102	0.18	<b>&lt;0.001</b>	<b>&lt;0.001</b>	0.283
<b>Zoochorous fruits</b>							
	Main road		Secondary road		Footpath		Control
	E	N	E	N	E	N	
Mean group	Apr	Dec	Dec	Jun	Jul	Oct	Feb
Mean vector length ( $r$ )	0.15	0.17	0.07	0.16	0.15	0.25	0.03
Standard Error of Mean	18.19°	12.46	30.36	18.30°	10.93°	8.27°	58.38°
Rayleigh's test ( $z$ )	4.90	10.42	1.78	4.84	13.58	23.30	0.48
Rayleigh's test ( $P$ )	<b>0.007</b>	<b>&lt;0.001</b>	0.169	<b>0.01</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	0.618
<b>Non-zoochorous fruits</b>							
	Main road		Secondary road		Footpath		Control
	E	N	E	N	E	N	
Mean group	May	May	Mar	Dec	Mar	Jan	Feb
Mean vector length ( $r$ )	0.50	0.47	0.25	0.79	0.21	0.42	0.2
Standard Error of Mean	5.04°	4.85°	15.08°	11.65°	12.05°	20.38°	24.62°
Rayleigh's test ( $z$ )	55.77	61.62	6.97	8.73	11.05	3.58	2.65
Rayleigh's test ( $P$ )	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>&lt;0.001</b>	<b>0.03</b>	0.071

Mean group corresponds to the peak month. Mean vector length ( $r$ ) varies from 0 to 1, in which 0 indicates data homogeneity, thus an absence of a defined peak. High values of Rayleigh's test ( $z$ ) and significant values of  $P$  indicate peak presence.



## Discussion

Our results highlight that the effects of pathways intersecting native vegetation cause changes on fruit production patterns and point that the differences found between pathways can be assigned to changes in the ecological processes generated by linear gaps presence and width, because the areas were very close to each other, minimizing spatial effects. Temporal effects due to time of the pathways implantation also are minimized because the vegetation condition is the same since the period following the pathways implantation and remains stable over time due to pathway maintenance (Silva et al. 2017). Pathways influenced fruit availability patterns and their effects are present even 35 m from the edge. However, these impacts occur in different ways depending on pathway width, which corroborates our general assumption. Number of species and fruit-bearing individuals was higher in wide pathways (10 to 20 m), especially at the edges. Considering that total richness of trees and shrubs, plus sample effort, is similar among the sampled areas (Silva et al. 2017), the difference in the number of fruiting species possibly reflects the effect of pathways. Wider pathways also produced more non-zoochorous fruit and exhibited temporal variation in fruit production, with peaks and troughs through the year. Although being a narrow pathway with a vegetation structure and composition similar to control (Silva et al. 2017), the footpath also affects the temporal fruit availability. In the control area, in turn, most of the produced fruits were zoochorous and there was no evidence of fruit peaks.

It is known that forested areas under pathway influence are more susceptible to environmental oscillation in micro-climatic conditions (Guariguata and Ostertag 2001), which affects the vegetation structure and composition (Laurance et al. 2003; Couto-Santos et al. 2015; Silva et al. 2017). These habitat changes influence plant reproduction (Tabarelli et al. 1999; Enoki et al. 2012). Indeed, edge plots of wide pathways (10 m and 20 m) showed more species and fruit-bearing individuals through time, compared to the respective neighborhood plots and even to the footpath (2 m wide) and control area. The higher number of species and fruit-bearing individuals at edges of wide pathways can be associated to higher plant density and canopy openness, which are related to forest gap effects and are more pronounced at forest edges (Guariguata and Ostertag 2001; Silva et al. 2017).

Fruiting patterns are mainly caused by differences among species in their response to environmental conditions (Laurance et al. 2003). By generating different environments, forest gaps may affect the distribution and composition of plant species, as already observed for the Atlantic forest (Oliveira et al. 2004; Couto-Santos et al. 2015). In our areas (Silva et al. 2017), differences in tree and shrub community composition were observed, where generalist and pioneer species with non-zoochorous fruits were predominant at edges of wider pathways (10 to 20) when compared to control. The same differences in species composition are likely to be the main source of variation in fruit type and predominance of dispersal syndrome in fruiting plants among types of pathways and distances to edge.

Zoochory was the predominant dispersal syndrome for fruiting species in all areas, as also found by Reznik et al. (2012), who investigated the phenological patterns of linear gaps formed by gas pipelines and power lines inside forests. However, in our study, zoochorous species produced more fruit in the control area. On the contrary, non-zoochorous species accounted for the majority of total fruit production in the wider pathway (20m). Possibly, the high number of non-zoochorous species and individuals at the wider pathway indicates that the dry and highly variable environmental conditions that predominate at its edges favor wind dispersal and the establishment of species belonging to this syndromes (Howe and Smallwood 1982; Jara-Guerrero et al. 2011). Reznik et al. (2012) reported the predominance of anemochory in plants that bore fruit at the edges, and Tabarelli and Peres (2002) also found similar results for early successional stages in the Atlantic forest.

Different responses in plant species can be caused by modified environmental conditions at edges that extend toward the forest interior. In our study, production of dry fruits (non-zoochorous) did not differ between the edge and neighborhood of the wider pathway plots (main road), indicating that such environmental changes in wider pathways affect non-zoochorous species at least 35 m toward the forest interior. On the other hand, higher zoochorous fruit production in the neighborhood plots of the wider pathway may indicate that edge effects on this syndrome decrease toward the forest interior, where more suitable conditions may favor the establishment of species with fleshy fruits (Liebsch et al. 2008). This suggests that non-zoochorous and zoochorous species might have different physiological responses to the edge effect, a speculation to be investigated in future studies. This pattern could also be influenced by life form frequencies in the

habitat, since in earlier successional stages there are more shrubs and small trees, usually dispersed by abiotic means (Tabarelli and Peres 2002). Conversely, in more advanced stages tall trees dispersed by vertebrates are dominant (Tabarelli and Peres 2002).

Pathway effects are not limited to static changes in fruit production, but also affect the temporal fruiting pattern, increasing seasonality. In fact, climatic factors (e.g. day length, temperature and precipitation) do not limit fruit production in the humid Atlantic forest (Morellato et al. 2000). Mature forests in which zoochorous plants predominate tend to be less seasonal, with zoochorous fruits being produced throughout the year (Morellato et al. 2000; Almeida-neto et al. 2008). However, despite this low climatic seasonality, in some parts of the Atlantic forest (Morellato et al. 2000) areas intersected by linear gaps are particularly affected, presenting fruiting peaks (Reznik et al. 2012). In our study site, pathways produced fruiting peaks not observed in the control area. This increase in phenological seasonality may be caused by the degree to which plants are exposed to more harsh environmental conditions generated by permanent linear gaps and differences in species composition (Reid and Dunne 1984; Denslow 1987; Heideman 1989; Webb et al. 1999).

Distribution and availability of fruits in the landscape are important for maintenance of the local fauna (Jordano et al. 2006; Díaz Vélez et al. 2015). About 20-50% of bird and mammal species eat fruits at least during part of the year (Fleming 1987). Zoochorous fruit availability may change frugivore movement patterns (Herrera 1984; Hasui et al. 2007; Díaz Vélez et al. 2015). Fruit-eating birds in tropical forests, for example, are capable to migrate between patches and gradients in search for fruits (Jordano et al. 2006). Our results showed that spatial and temporal fruit availability for frugivores is affected by the presence of pathways, which could affect seed dispersers in space and time, compromising structure and conservation of plant-animal interactions and reflecting changes in the vegetation composition (Cardoso da Silva and Tabarelli 2000; Morellato et al. 2016). Absence of seed dispersal services can impair such a pattern, acting as a filter for seedling recruitment and successful colonization (Duncan and Chapman 1999; Cardoso da Silva and Tabarelli 2000).

In conclusion, our study revealed that pathways with different widths might have pervasive spatial and temporal effects on the fruit availability in tropical forests, affecting the food provided for frugivores throughout the year. These effects can extend to at least 35 m toward the forest interior, depending on the pathway width and the way in which

environmental conditions influence species. The presence pathways can reduce the amount of zoochorous fruits at the edges over time. On the other hand, mature forests may provide better resources for frugivorous species, because they are available throughout the year, and in higher quantity when compared to edges of 20 m-wide linear gaps. In addition, there is a difference in the types of fruits produced among the areas affected by pathways, with a predominance of non-zoochory at the edges of the wide pathways and of zoochory in the areas without pathways. Therefore, we expect that the variation in the spatial-temporal fruit availability imposed by pathways to the Atlantic forest may have consequences for frugivorous species and the process of seed dispersal.

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## Supplementary Material

Silva, B.G. et al. **Fruit availability along roads and footpaths in an Atlantic rain forest area**

Supplementary Material Figure 1. Number of species and fruit-bearing individuals.

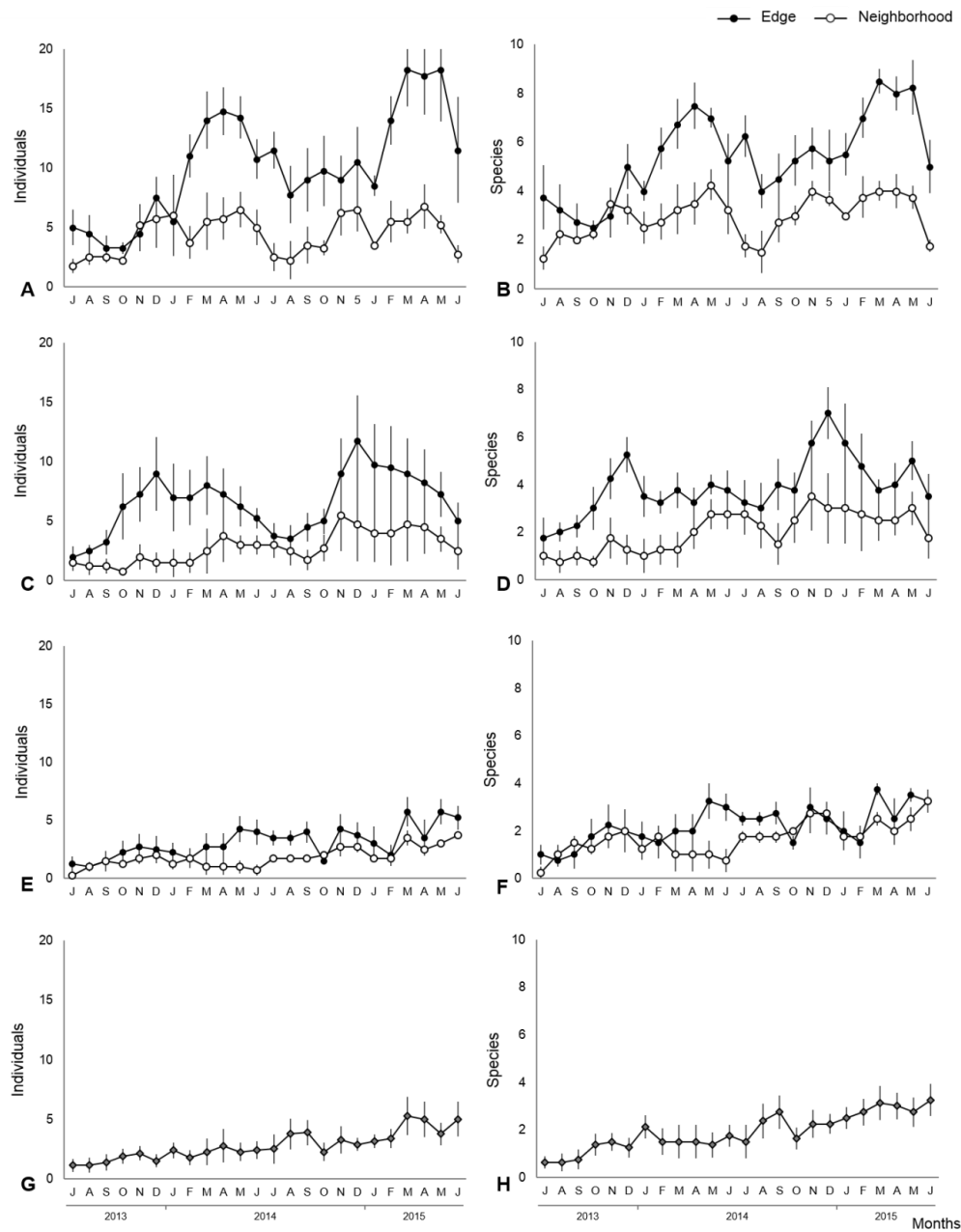


Figure 1. Number of species and fruit-bearing individuals during a two-year survey in four areas (three pathways and a control area) within Carlos Botelho State Park – SP, Brazil. A, B: main road; C, D: secondary road; E, F: footpath; G, H: control area.

Supplementary Material Figure 2. Amount of fruits produced: zoochorous and non-zoochorous fruits.

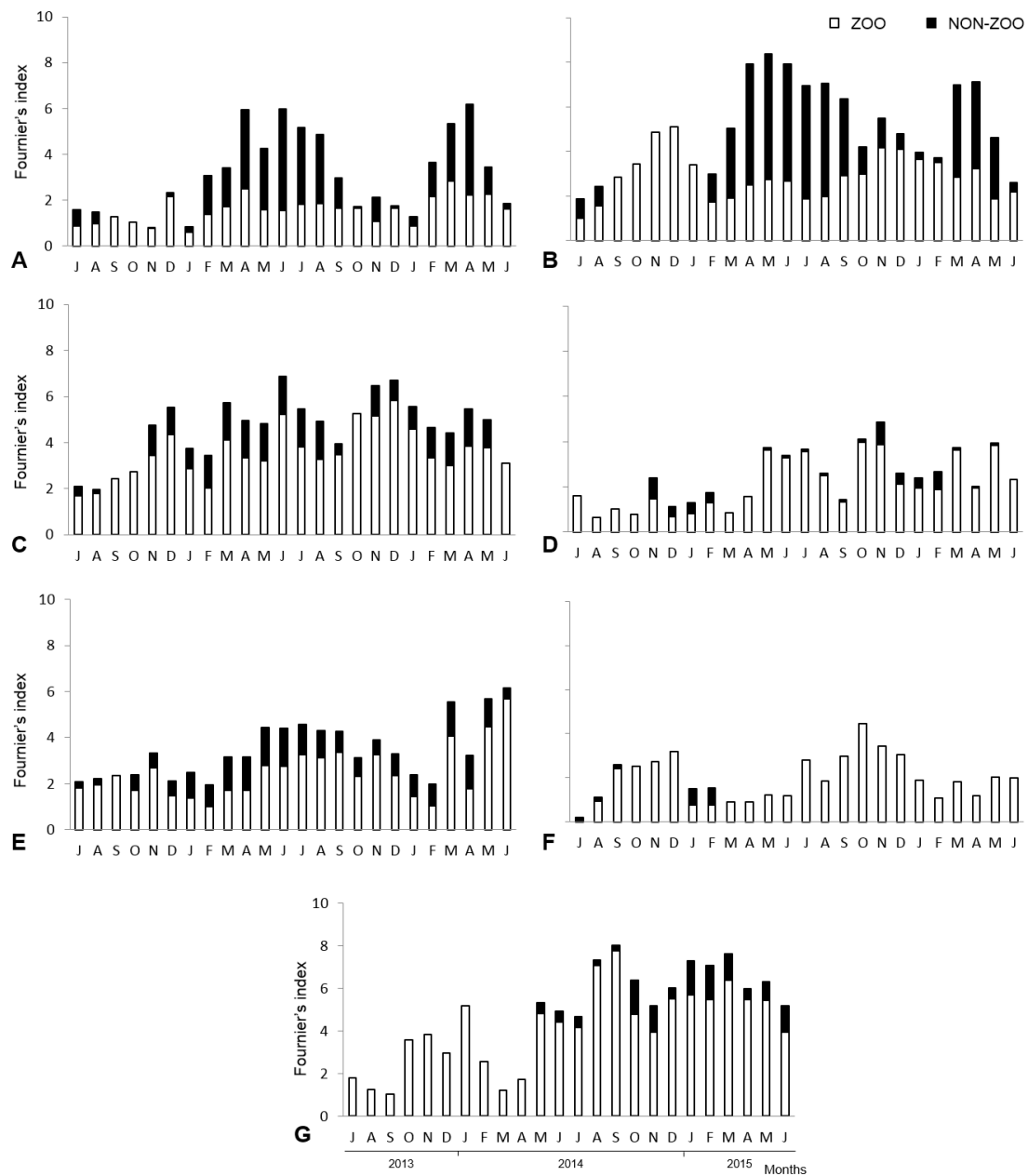


Figure 2. Average number of fruits produced during two years estimated by Fournier's index, considering zoochorous and non-zoochorous fruits (anemochorous plus autochorous) in four areas within Carlos Botelho State Park – SP, Brazil. A: main road edge, B: main road neighborhood, C: secondary road edge, D: secondary road neighborhood, E: footpath edge, F: footpath neighborhood, G: control area, ZOO: zoochorous, NON-ZOO: anemochorous plus autochorous.

Supplementary Material Table 1 - Trees and shrubs recorded in fruiting during two years in four areas within Carlos Botelho State Park – SP, Brazil. The numbers indicate the abundance of species recorded in fruiting. Individuals taller than 50 cm. H: habit, DS: dispersal syndromes, ZOO: zoochorous, ANE: anemochorous, AUT: autochorous.

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area	
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood		
<b>Anacardiaceae</b>										
<i>Tapirira guianensis</i> Aubl.	Tree	ZOO	0	0	1	0	0	0	0	
<b>Annonaceae</b>										
<i>Guatteria australis</i> A.St.-Hil.	Tree	ZOO	0	1	0	0	0	2	0	
<b>Areceaceae</b>										
<i>Euterpe edulis</i> Mart.	Tree	ZOO	2	4	2	3	5	1	3	
<i>Geonoma gamiova</i> Barb.Rodr.	Shrub	ZOO	0	0	0	0	0	0	9	
<i>Geonoma schottiana</i> Mart.	Shrub	ZOO	0	0	0	1	0	1	2	
<b>Asteraceae</b>										
<i>Austroeupatorium inulaefolium</i> (Kunth) R.M.King & H.Rob.	Shrub	ANE	0	0	1	0	0	0	0	
<i>Baccharis anomala</i> DC.	Shrub	ANE	0	0	1	0	0	0	0	
<i>Baccharis dentata</i> (Vell.) G.M.Barroso	Shrub	ANE	1	0	0	0	0	0	0	
<i>Baccharis montana</i> DC.	Shrub	ANE	1	0	0	0	0	0	0	
<i>Piptocarpha organensis</i> Cabrera	Tree	ANE	1	0	0	0	0	0	0	
<i>Verbesina glabrata</i> Hook. & Arn.	Tree	ANE	0	1	0	0	0	0	0	
<b>Bignoniaceae</b>										
<i>Jacaranda montana</i> Morawetz	Tree	ANE	0	0	1	0	0	0	0	
<i>Jacaranda puberula</i> Cham.	Tree	ANE	0	0	2	1	0	0	0	

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood	
<b>Chrysobalanaceae</b>									
<i>Parinari brasiliensis</i> (Schott) Hook.f.	Tree	ZOO	0	0	0	0	0	0	1
<b>Clethraceae</b>									
<i>Clethra scabra</i> Pers.	Tree	ANE	4	2	0	0	0	0	0
<b>Clusiaceae</b>									
<i>Clusia criuva</i> Cambess.	Tree	ZOO	1	1	0	0	0	0	0
<b>Elaeocarpaceae</b>									
<i>Sloanea hirsuta</i> (Schott) Planch. ex Benth.	Tree	ZOO	0	0	0	0	2	0	1
<b>Erythroxylaceae</b>									
<i>Erythroxylum ambiguum</i> Peyr.	Shrub	ZOO	6	7	6	0	0	0	0
<b>Euphorbiaceae</b>									
<i>Alchornea glandulosa</i> Poepp. & Endl.	Tree	ZOO	0	0	0	0	1	0	2
<i>Sebastiania brasiliensis</i> Spreng.	Tree	AUT	0	0	0	0	1	0	0
<b>Fabaceae</b>									
<i>Centrolobium robustum</i> (Vell.) Mart. ex Benth.	Tree	ANE	0	1	0	0	0	0	0
<i>Copaifera trapezifolia</i> Hayne	Tree	ZOO	0	0	0	0	0	1	0
<i>Inga laurina</i> (Sw.) Willd.	Tree	ZOO	0	0	0	0	0	1	0
<i>Myrocarpus frondosus</i> Allemão	Tree	ANE	0	0	0	0	0	0	1
<i>Senna multijuga</i> (Rich.) H.S.Irwin & Barneby	Tree	ANE	0	1	0	0	0	0	0
<b>Humiriaceae</b>									
<i>Vantanea compacta</i> (Schnizl.) Cuatrec.	Tree	ZOO	0	0	0	0	0	0	1

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area	
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood		
<b>Lamiaceae</b>										
<i>Hyptis lacustris</i> A.St.-Hil. ex Benth.	Shrub	ANE	1	0	0	0	0	0	0	0
<b>Lauraceae</b>										
<i>Aiouea acarodomatifera</i> Kosterm.	Tree	ZOO	0	0	1	0	0	0	1	1
<i>Aniba firmula</i> (Nees & Mart.) Mez	Tree	ZOO	0	0	0	0	0	0	1	1
<i>Aniba viridis</i> Mez	Tree	ZOO	0	1	2	0	0	1	0	0
<i>Cryptocarya mandioccana</i> Meisn.	Tree	ZOO	0	0	0	2	0	0	0	0
<i>Endlicheria paniculata</i> (Spreng.) J.F.Macbr.	Tree	ZOO	0	0	2	0	0	0	0	0
<i>Nectandra leucantha</i> Nees	Tree	ZOO	0	0	1	1	0	0	0	0
<i>Nectandra oppositifolia</i> Nees	Tree	ZOO	0	0	2	1	0	0	0	0
<i>Ocotea dispersa</i> (Nees & Mart.) Mez	Tree	ZOO	0	3	0	1	1	0	0	0
<i>Ocotea odorifera</i> (Vell.) Rohwer	Tree	ZOO	0	0	0	0	0	1	0	0
<i>Ocotea tabacifolia</i> (Meisn.) Rohwer	Tree	ZOO	0	0	1	0	0	0	0	0
<i>Ocotea teleiandra</i> (Meisn.) Mez	Tree	ZOO	1	0	2	1	0	2	0	0
<i>Ocotea venulosa</i> (Nees) Baitello	Tree	ZOO	0	0	1	0	0	0	0	0
<i>Persea venosa</i> Nees & Mart.	Tree	ZOO	0	0	0	0	0	0	1	1
<b>Melastomataceae</b>										
<i>Clidemia hirta</i> (L.) D.Don	Shrub	ZOO	1	0	0	0	0	0	0	0
<i>Leandra acutiflora</i> (Naudin) Cogn.	Shrub	ZOO	0	0	2	1	0	0	4	4
<i>Leandra melastomoides</i> Raddi	Shrub	ZOO	1	0	1	0	0	0	0	0
<i>Leandra variabilis</i> Raddi	Shrub	ZOO	0	0	0	1	0	1	0	0
<i>Miconia cabucu</i> Hoehne	Tree	ZOO	0	9	2	2	1	1	0	0
<i>Miconia cubatanensis</i> Hoehne	Tree	ZOO	0	0	0	2	0	0	0	0

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area	
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood		
<i>Miconia latecrenata</i> (DC.) Naudin	Tree	ZOO	1	0	0	0	0	0	0	
<i>Miconia paniculata</i> (DC.) Naudin	Tree	ZOO	2	0	3	0	0	2	0	
<i>Miconia racemifera</i> (DC.) Triana	Tree	ZOO	0	6	0	0	0	0	0	
<i>Miconia sellowiana</i> Naudin	Tree	ZOO	0	1	0	0	0	0	0	
<i>Miconia tristis</i> Spring	Tree	ZOO	2	0	0	0	0	1	0	
<i>Miconia valtheri</i> Naudin	Tree	ZOO	0	0	4	0	0	0	0	
<i>Pleiochiton blepharodes</i> (DC.) Reginato et al.	Shrub	ZOO	1	0	3	0	0	0	0	
<i>Tibouchina fothergillae</i> (Schrank & Mart. ex DC.) Cogn.	Tree	ANE	1	0	0	0	0	0	0	
<i>Tibouchina pulchra</i> Cogn.	Tree	ANE	17	4	2	0	1	0	0	
<b>Meliaceae</b>										
<i>Cabralea canjerana</i> (Vell.) Mart.	Tree	ZOO	0	0	0	0	0	1	0	
<b>Monimiaceae</b>										
<i>Mollinedia boracensis</i> Peixoto	Tree	ZOO	0	0	0	0	0	0	1	
<i>Mollinedia elegans</i> Tul.	Tree	ZOO	0	0	0	1	0	0	0	
<i>Mollinedia gilgiana</i> Perkins	Tree	ZOO	0	0	0	0	0	0	1	
<i>Mollinedia oligantha</i> Perkins	Tree	ZOO	0	0	1	0	0	0	0	
<i>Mollinedia schottiana</i> (Spreng.) Perkins	Tree	ZOO	0	0	0	1	0	0	2	
<b>Moraceae</b>										
<i>Brosimum glaziovii</i> Taub.	Tree	ZOO	2	0	0	0	0	0	0	
<b>Myrtaceae</b>										
<i>Campomanesia guaviroba</i> (DC.) Kiaersk.	Tree	ZOO	1	0	0	0	0	1	0	



Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area	
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood		
<i>Eugenia copacabanensis</i> Kiaersk.	Tree	ZOO	0	0	0	0	0	0	1	
<i>Eugenia mosenii</i> (Kausel) Sobral	Tree	ZOO	0	0	0	0	0	0	1	
<i>Eugenia prasina</i> O.Berg	Tree	ZOO	0	0	0	0	0	1	0	
<i>Marlierea eugeniopsoides</i> (D.Legrand & Kausel) D.Legrand	Tree	ZOO	0	0	0	0	0	0	1	
<i>Myrceugenia myrcioides</i> (Cambess.) O.Berg	Tree	ZOO	0	0	0	0	1	0	1	
<i>Myrcia eugeniopsoides</i> (D.Legrand & Kausel) Mazine	Tree	ZOO	0	0	0	1	0	4	0	
<i>Myrcia pubipetala</i> Miq.	Tree	ZOO	0	0	0	1	0	0	0	
<i>Myrcia splendens</i> (Sw.) DC.	Tree	ZOO	1	0	1	0	0	0	3	
<i>Psidium cattleianum</i> Sabine	Shrub	ZOO	3	0	1	0	0	0	0	
<b>Nyctaginaceae</b>										
<i>Guapira opposita</i> (Vell.) Reitz	Tree	ZOO	0	0	0	1	0	0	0	
<b>Ochnaceae</b>										
<i>Ouratea parviflora</i> (A.DC.) Baill.	Shrub	ZOO	0	0	0	0	0	3	0	
<b>Oleaceae</b>										
<i>Chionanthus filiformis</i> (Vell.) P.S.Green	Tree	ZOO	0	0	0	1	0	0	0	
<b>Phyllanthaceae</b>										
<i>Hyeronima alchorneoides</i> Allemão	Tree	ZOO	1	0	0	0	0	0	0	
<b>Piperaceae</b>										
<i>Piper aduncum</i> L.	Shrub	ZOO	5	3	26	0	3	0	7	
<i>Piper pseudopothifolium</i> C.DC.	Shrub	ZOO	0	0	0	0	0	1	0	
<b>Primulaceae</b>										

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area	
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood		
<i>Cybianthus</i> sp.	Shrub	ZOO	0	0	0	1	0	0	0	
<i>Myrsine coriacea</i> (Sw.) R.Br. ex Roem. & Schult.	Tree	ZOO	2	2	1	0	0	0	0	
<i>Myrsine umbellata</i> Mart.	Tree	ZOO	4	2	4	2	1	0	0	
<i>Stylogyne pauciflora</i> Mez	Shrub	ZOO	0	0	0	0	3	1	7	
<b>Rubiaceae</b>										
<i>Bathysa australis</i> (A.St.-Hil.) K.Schum.	Tree	AUT	0	0	0	0	2	0	1	
<i>Ixora gardneriana</i> Benth.	Tree	ZOO	0	0	0	0	0	1	2	
<i>Psychotria gracilentia</i> Müll.Arg.	Shrub	ZOO	8	2	6	8	0	0	0	
<i>Psychotria leiocarpa</i> Cham. & Schltdl.	Shrub	ZOO	0	1	0	0	0	0	0	
<i>Psychotria nuda</i> (Cham. & Schltdl.) Wawra	Shrub	ZOO	6	2	0	0	2	1	0	
<i>Psychotria vellosiana</i> Benth.	Shrub	ZOO	16	3	0	0	0	0	0	
<b>Rutaceae</b>										
<i>Esenbeckia grandiflora</i> Mart.	Tree	AUT	0	0	0	1	0	0	1	
<b>Salicaceae</b>										
<i>Casearia obliqua</i> Spreng.	Tree	ZOO	1	0	0	0	5	0	0	
<i>Casearia sylvestris</i> Sw.	Tree	ZOO	1	0	1	0	0	0	0	
<b>Sapindaceae</b>										
<i>Allophylus edulis</i> (A.St.-Hil. et al.) Hieron. ex Niederl.	Tree	ZOO	0	0	1	0	0	0	0	
<i>Cupania oblongifolia</i> Mart.	Tree	ZOO	0	1	0	0	0	0	0	
<i>Cupania vernalis</i> Cambess.	Tree	ZOO	0	1	0	1	0	0	1	
<i>Diatenopteryx sorbifolia</i> Radlk.	Tree	ANE	0	0	0	0	0	0	1	

Family/Specie	H	DS	Main road		Secondary road		Footpath		Control area
			Edge	Neighborhood	Edge	Neighborhood	Edge	Neighborhood	
<i>Matayba elaeagnoides</i> Radlk.	Tree	ZOO	0	0	0	0	0	0	1
<b>Sapotaceae</b>									
<i>Micropholis crassipedicellata</i> (Mart. & Eichler) Pierre	Tree	ZOO	0	0	1	1	0	0	1
<i>Pouteria torta</i> (Mart.) Radlk.	Tree	ZOO	0	0	0	0	0	0	1
<b>Solanaceae</b>									
<i>Cestrum cf. schlechtendalii</i> G.Don	Shrub	ZOO	0	0	1	0	0	0	0
<i>Solanum argenteum</i> Dunal	Tree	ZOO	2	0	1	2	0	0	0
<i>Solanum bullatum</i> Vell.	Tree	ZOO	1	0	0	0	0	0	0

### **CAPÍTULO III – Impact of park roads and trails on a community of Atlantic forest fruit-eating birds**

Artigo nas normas da revista *Biodiversity and Conservation*

Title page

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**Abstract**

Roads and trails in forested areas may affect birds, depending on the species sensitivity to habitat disturbance. Our aim was to assess the impact of pathways with different widths and uses on fruit-eating birds. We hypothesized that the abundance, richness, diversity and community composition of birds respond to the effects of pathways. These effects should be modulated by the dependence on fruits in the diet. Data were collected in a main road (20m wide - high usage), secondary road (10m wide - low usage), in a touristic trail (2m wide - high usage) – and in a control area, all areas inside the Atlantic Forest in southeastern Brazil. We established eight sampling plots and point counts at the edge of each pathway. The control area showed the highest diversity, followed by the wider pathway (main road). The main road, however, presented the lowest richness and abundance of large frugivores and the highest abundance of omnivores. Pathway width, fruit availability and pathway use were the most important components structuring the bird communities. Our study revealed that the impacts generated by pathways in forested areas may have negative consequences for the local communities of fruit-eating birds, particularly when they are large and/or extensively used. We expect that this low occurrence of large frugivorous birds in forest tracts highly disturbed by paths may affect local seed dispersal processes. Park managers should be aware of these factors and care about management and the public use of the pathway network, in order to maintain the services provided by frugivorous birds.

**Key words:** frugivores, conservation, linear gaps, tropical forest, pathway management, Carlos Botelho State Park.

## Introduction

Tropical forests have been rapidly devastated due to habitat loss and fragmentation (Laurance et al. 1997; Gascon et al. 2000), and initiatives in forest conservation have led to the establishment of many protected areas in tropical countries (Bruner et al. 2001, Myers et al. 2000). The Atlantic Forest is one of the world's biodiversity hotspots, with high levels of endemism, threatened species and subject to high rates of species loss (Brooks et al. 1999; Myers et al. 2000). The current area covered by the Atlantic Forest remnants represents approximately 11% of its original extent (Ribeiro et al. 2011). Most Atlantic forest remnants are parks located in southeastern Brazil, home to the majority of remaining viable populations of endemic plant and animal species, but also the most populous region in the country (Aleixo and Galetti 1997; SNUC 2000).

Forest disturbance and fragmentation occurs even when a given habitat area is not directly affected, e.g., when the Atlantic forest parks are intersected by linear gaps, as roads, railways, river channels, power lines, firebreaks, or other barriers to organismal dispersal (Schonewald-Cox and Buechner 1992; Laurance et al. 2014). The presence of linear gaps in forested areas can create edges, which favour the arrival and establishment of exotic and/or invasive species, and access to hunters and other illegal activities that affect both the flora and fauna, as well as an increase in roadkill (i.e. animals ran over by motor vehicles) and changes in animal behaviour (Forman and Alexander 1998).

The edge effect generated by linear forest gaps of varying widths affects habitat in several ways, such as in vegetation structure and composition (Couto-Santos et al. 2015; Silva et al. 2017a), phenological processes (Reznik et al. 2012), and resource availability for fauna (Silva et al. 2017b). Moreover, the type of pathway usage is an important aspect in faunal maintenance near those areas (Forman and Alexander 1998). Changes generated by pathways may affect the relationships between fauna and its habitat, depending on the response of species with different degree of sensitivity to disturbances and dependence on a fruit diet (Hasui et al. 2007), considering that the degree of frugivory affect sensitivity of birds to habitat components (Aleixo 1999; Hasui et al. 2007). The more habitat sensitive bird species may be absent or leave the area and stop foraging and nesting (Helldin and Seiler 2003; Kangas et al. 2010), which may result

in a gradual loss of species diversity near pathways (Reijnen et al. 1995; Martínez-Abraín et al. 2010; Jack et al. 2015).

The understanding of how animals respond to roads and trails disturbance in space and time is an urgent and important question to be addressed. Birds are related with several ecological process in tropical forest, as seed dispersal, and pathways are recognized for negatively affecting bird communities in several natural environments (Helldin and Seiler 2003; Laurance et al. 2004; Marsden et al. 2004; Kangas et al. 2010; Ahmed et al. 2014). It is known that the presence of these anthropogenic gaps cause changes in bird community composition and species behavior, e.g. the movement of dispersal agents, in a tropical forest in the Amazon (Laurance et al. 2004; Ahmed et al. 2014). However, the relationship between pathways width and usage and bird communities in tropical forests is poorly understood. Birds with specialized fruit diets are responsible for most of the seed dispersal processes of plants with fleshy fruits in the Atlantic forest. These frugivores are usually more sensitive to disturbances and may have their abundance reduced in disturbed areas (Staggemeier and Galetti 2007; Almeida-neto et al. 2008; Galetti et al. 2013).

In this context, we aimed to assess the impact of pathways on the fruit-eating forest birds, considering that vegetation structure and composition, as well fruit availability, are also affected by pathway (Silva et al. 2016a; Silva et al. 2016b). We hypothesize that abundance, richness, diversity and community composition of fruit-eating birds respond to habitat changes caused by pathways. These effects should be modulated by width and usage intensity of pathways and by the sensitivities of different bird species, here represented by dependence on fruits in the diet. We expect to find a different bird community composition, with high abundance and richness of disturbance-sensitive and diet specialist species in areas without pathways or in low-use pathways, while in the vicinity of high-use or wide pathways we expect to find high abundance and richness of diet opportunist and disturbance-tolerant species. We also expect to find higher diversity at the areas without pathways.

## Material and Methods

### Study area

Fieldwork was carried out at Carlos Botelho State Park (CBSP), a 37,644.36 ha area located between 24° 06' 55" – 24° 14' 41" S and 47° 47' 18" – 48° 07' 17" W, in São Paulo state, southeastern Brazil (Figure 1 A), with altitudes ranging between 20 and 1000 m. Mean annual temperature is 18°C and annual precipitation varies between 1500 - 2200 mm (Ferraz and Varjabedian 1999). The park is integrates in the Atlantic forest continuum and the predominant vegetation type is Dense Ombrophilous Forest (Kronka et al. 2005; SMA 2008). The study sites are located at Montane Dense Ombrophilous Forest areas, around 800 m a.s.l. We collected data in four areas intersected by different types of pathways: a main road (wide pathway with high usage), a secondary road (wide pathway with low usage), a trail (narrow pathway with high usage) and a control area (without pathway and usage, reputedly close to a reference state of conservation). Since several ecological processes, such as species composition and plant density, are more affected within the first 35 m from forest edges (Rodrigues 1998), and that vegetation structure and composition, besides fruit availability, are affected by the pathways sampled at this distance (Silva et al. 2017a; Silva et al. 2017b), we set up plots alternately adjacent to the path and 35 m distant from them (Fig. 1 B, C). We used a single path per pathway type because the characteristics as width, soil and usage are very specific for each pathway, and there are no similar areas in the same forest continuum and elevation.

In each type of pathway we selected a stretch of 1400 m along its total extension, along which eight 10 x 10 m sampling plots were established, completing 32 plots. To ensure independent samples these plots were separated by at least 200 m from one another along the path (Fig. 1 C). At the control area, we set up the plots in the same manner, except that there was no pathway. In this design, type of pathway (including control area) was considered as treatment.



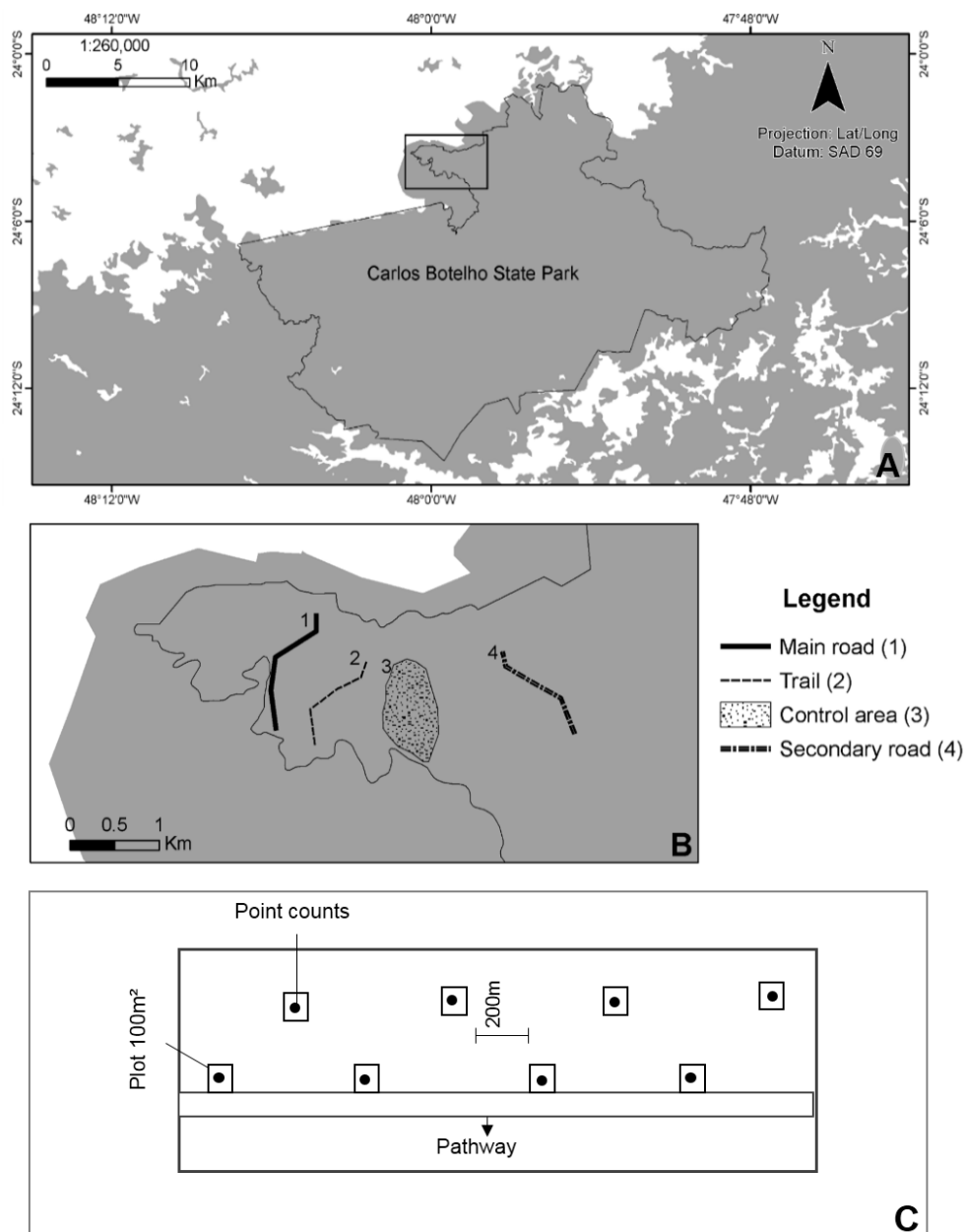


Fig. 1. A: Location of Carlos Botelho State Park, São Paulo state, SE Brazil. B: Different pathways used as treatments: (1) main road (wide pathway - high usage), (2) trail (narrow pathway - high usage), (3) control area (without pathway and usage), (4) secondary road (wide pathway - low usage), C: Distribution of plots along the pathway. In green the forest remnants - (SOS - Mata Atântica 2015)

### *Types of pathways*

We surveyed the following characteristics of each type of pathway: width, use intensity (vehicle traffic and people movement) and intensity of maintenance. Pathway

width was measured at each of the eight sampling points established according to figure 1C, starting from the forest edge. Use intensity of the main road and trail, which consists of vehicle and/or people numbers, were accounted by park staff. The intensity of use of the secondary road was estimated through interviews with the park personnel. Park staff also provided information for the intensity of maintenance for all pathways, which consists to terrain conservation, handrails and stairs on the trail, and recovery from the slopes on the road. For maintenance we elaborated an index for this variable, ranging from 0 to 2, where 0 indicates absence of maintenance (control area), 1 indicates moderate maintenance with about one intervention per month (secondary road) and 2 indicates high maintenance with at the least one intervention per week (main road and trail).

The main road within the CBSP is a 20 m wide dirt pathway that intersects the park along 33 km with a completely open canopy (Fig. 2 A), being intensively used by people and vehicles (average of 6000 vehicles and 90 people walking per month) and need high maintenance. The secondary road is about 10 m wide and extends approximately 12 km with the canopy partially covered (Fig. 2 B). This pathway is sporadically used for researchers, surveillance, maintenance, and small groups of visitors (average of 20 vehicles and 40 people per month). Vegetation structure and composition for main and secondary roads are similar, with reduced tree height and diameter, high liana density, few exotic species, and a high proportion of pioneer and anemochorous species (Silva et al. 2017a), yet they differ in the degree of usage, which is higher for main road.

The trail is a narrow (1.5 to 2.0 m wide) pathway, being part of the surveillance walking trail network, with approximately 4.5 km long, a complete canopy cover along its total extension (Fig. 2 C), is heavily used by the park visitors (average of 200 people per month) and need high maintenance. The control area is representative of the mature forest occurring in most of the park (Fig. 2D), without apparent anthropic influence (SMA 2008; Silva pers. obs). Vegetation structure of the trail is similar to the control area (Silva et al. 2017a), with high tree height and diameter, high density of epiphytes, and high proportion of zoochorous and non-pioneer species.



Fig. 2. Sampled areas at Carlos Botelho State Park, São Paulo state, SE Brazil. Different pathways used as treatments: A: main road (20m wide - high usage), B: secondary road (10m wide - low usage), C: trail (2m wide - high usage), D: control area (no pathway).

## Data sampling

### *Fruit-eating birds*

We measured the relative abundance and richness of fruit-eating birds monthly during two years at each plot. We observed the avifauna for a total of 128 h in the 32 fixed hearing points. Each point was surveyed 24 times, resulting in a total 240 min of observation per survey point. We used the unlimited fixed-point count method (Bibby et al. 1992). The points were located in the center of each plot, where the observer stood for 10 min recording all bird species seen or heard (Develey 2004). Observations occurred during the first three hours after dawn.

Observations were made with a 10x36 binocular and birds were identified by both visualization and vocalization. The adopted nomenclature followed the species list of the Brazilian Committee of Ornithological Records (Piacentini et al. 2015). To represent the sensitivity to disturbance we used as reference the degree of dependence on a fruit diet (Aleixo 1999; Hasui et al. 2007). To characterize fruit-eating birds as to the diet we used two types of diet: frugivores and omnivores, based on the guild classification proposed by Wilman et al. (2014) and Poulin et al. (1994). Threatened species were classified according to the São Paulo state endangered species list (São Paulo 2014).

### *Influence of habitat*

**Vegetation structure** – Vegetation structure in the plots was characterized by quantitative observations on the phytophysiology (Durigan 2003; Silva et al. 2017a), considering the following variables: diameter at breast height (*DBH*), total tree height, tree crown diameter and canopy openness. We collected these variables only from individuals that met the inclusion criterion: perimeter at breast height (*PBH*)  $\geq 10$  cm. Based on the total tree height we considered two arboreal strata to evaluate density of trees and shrubs: understory (1.50 – 5 m) and canopy (above 11 m). Individuals in the intermediate stratum were not considered because their densities did not differ among pathways (see in Silva et al. 2016a).

Canopy cover was measured using hemispherical photographs (Frazer et al. 2001), taken with a Nikon Coolpix 4500 camera with a fish-eye FC-E8 lens. We positioned the camera, with the aid of a tripod, at an approximate 60 cm height, at the center of each plot. Photographs were taken in cloudy days to avoid over exposure due to direct sunlight, which may influence image analysis (Frazer et al. 2001). We converted the resulting images in black and white colors in ImageJ software (Rasband 2015). The canopy cover was estimated based on white pixels, which correspond to the percentage of gaps.

**Zoochorous fruits** – Direct plant observations at each plot were conducted with the aid of a 10x36 binocular. We observed and identified the dispersal syndrome of each fruiting species. Only individuals with zoochorous fruits were included (Van der Pijl 1982). We included woody plants taller than 50 cm. We recorded fruit presence or absence on a monthly basis (between July 2013 and June 2015). Observations were conducted preferentially during the last fortnight of each month, assuring a 30-day interval between each data collection event. For fruit quantification we used the Fournier's intensity index

– *FI* (Fournier 1974). According to the index, each phenophase is classified in a scale from 0 to 4, in which: 0 = absence of resource; 1 = presence of fruit in 1 to 25% of branches; 2 = 26 to 50%; 3 = 51 to 75%; 4 = 76 to 100% of branches. To measure total fruit availability per plot we summed FIs of each individual weighted by DBH as a surrogate for plant size (Reznik et al. 2012). This was then standardized as a percentage of maximum fruit availability (Eq. 1).

$$\%FI = \left[ \frac{\sum_{i=1}^n (xi \times DBH)}{(\sum DBH) \times 4} \right] \times 100$$

Eq. 1 Fournier's intensity index – *FI*, where  $n$  is the number of individuals sampled in the plot,  $xi$  is the value of the semi quantitative scale attributed to the individual, and *DBH* is the individual diameter at breast height.

All woody fruiting individuals (trees and shrubs) were tagged and identified for fruit size characterization. Species identification was based on literature and specialist determination. The fruits were grouped into two categories according to their size: up to 14 mm, and larger than 14 mm (Cardoso da Silva and Tabarelli 2000). Dehiscent zoochorous fruits were classified according to the seed width, as vertebrates directly manipulate seeds (Cardoso da Silva and Tabarelli 2000).

## Data analyses

### *Fruit-eating birds*

We performed a diversity profile analysis, where  $\alpha = 0$  corresponds to richness values in different pathways,  $\alpha = 1$  equivalent to Shannon's diversity index ( $H'$ ) and  $\alpha = 2$  equivalent to Simpson's diversity index ( $D$ ). Therefore, we were able to compare treatments according to equitability ( $\alpha \geq 2$ ) and richness ( $\alpha \leq 1$ ).

The abundance and richness of fruit-eating birds were treated as the response variables in a linear mixed-effects model (Zuur et al. 2009) designed to assess the importance of a suite of factors related to spatial and temporal variation and to variation in the survey effort that might potentially affect  $p$ . We tested whether these response variables are influenced by type of pathway and type of diet (frugivore and omnivore) (fixed effects) considering the monthly and annual variation (random effects) (Crawley

2007). These models were compared using the corrected Akaike Information criterion –  $AICc$  (Akaike 1974). The model with the lowest  $AICc$  and delta values indicate the model with the best fit ( $dAICc = 0$ ) (Zuur et al. 2009). The assumptions of normality and homogeneity of variance were examined visually and through the Shapiro-Wilk test. We used the R package lme4 (Bates et al. 2015). A post hoc HSD Tukey test was used to investigate differences between the types of pathway for abundance and richness of fruit-eating birds. Both analyses were held in the R statistical software (R Core Team 2016).

We tested the difference in bird species composition among the pathways using a permutational multivariate analysis of variance (Permanova, Anderson 2001). We used the “adonis” function of the R package vegan (Oksanen et al. 2016) with Bray-Curtis dissimilarity and 10,000 permutations. In order to verify general tendencies of variation in bird composition we performed an ordination analysis with non-metric multidimensional scaling (nMDS, Minchin 1987). We adopted this approach to better identify and interpret similarities between pathways. These analyses were performed in the R environment (R Core Team 2016) and  $p < 0.05$  was considered significant.

#### *Influence of habitat and types of pathways*

We used model selection to test the effect of habitat and type of pathway on the bird community. For pathways, we used pathway width (1) and a composite variable for pathway usage (2) that was obtained as the first axis of a principal component analysis (PCA) (Pearman 2002) of log base 10 of vehicle traffic, people movement and maintenance intensity. For habitat, we used vegetation structure (3) also as a composite variable measured as the first axis of a PCA with  $DBH$ , total tree height, tree crown diameter, canopy cover, understory tree density and canopy tree density. Zoochorous fruits were represented by amount of large fruits (4) and amount of small fruits (5). To test the explanation power of these five explanatory variables over the response-variables (abundance and richness of fruit-eating birds, abundance and richness by type of diet) we used model selection (Zar 1996). Initially, we tested the null hypothesis that none of the explanatory variables is related to the response variables creating two models: a maximum model with all explanatory variables and a null one, containing only the response variable (Crawley 2007). These models were compared via the Akaike criterion –  $AICc$  (Akaike 1974). For each maximum model that presented a low  $AICc$  value compared to the null model, we performed model simplification, by gradually suppressing the least significant variables (i.e., with high p-values) up to a minimum

model, with the best fit to the data (Crawley 2007). We included variables when their presence decreased the  $AICc$  value, since they contributed to a best fit to the model ( $dAIC = 0$ ) (Crawley 2007). The minimum model capable of explaining the ecological pattern was considered the one that presented the lowest  $AICc$  value (Crawley 2007). Residues distribution normality was tested using the Shapiro-Wilk test and variance homoscedasticity assessed via graphical analysis. As the data presented a normal distribution and homogeneous variance, we used linear models (LM). We used the R lme4 package in the R statistical software (R Core Team 2016).

Avifauna composition was related to the types of pathways and habitat using Canonic Correspondence Analysis (CCA) (Ter Braak 1986; Palmer 1993). The following variables were considered: width (1); in this case, pathway usage was separated into its three components: vehicle traffic (adjusted values in log 10) (2), people movement (3) and maintenance intensity (4) to assess whether these components affect bird fauna differently; vegetation structure (5), large fruits (6) and small fruits (7). CCA represents a special case of multivariate regression (Ter Braak 1986), and explains community variation detecting patterns of variation in species abundance that may be best explained by the set of environmental variables (i.e., habitat and pathway variables) with no *a priori* knowledge of potential predictor variables (Ter Braak 1986; Palmer 1993). The significance of constraining factors was assessed by means of a permutational ANOVA with 999 iterations. We used the R statistical software and for all analyses we considered  $p < 0.05$  significant (R Core Team 2016).

## Results

### *Fruit-eating birds*

We recorded 80 bird species, with a total of 4,818 contacts between frugivores and omnivores (Appendix). Considering all bird species and abundances, the main road and control area had practically the same diversity with high values among the four areas regarding the Shannon index (when more weight is assigned to richness,  $\alpha = 1$ ) but the control area had the highest diversity regarding the Simpson index (when more weight is assigned to equitability,  $\alpha = 2$ ) (Fig. 3).

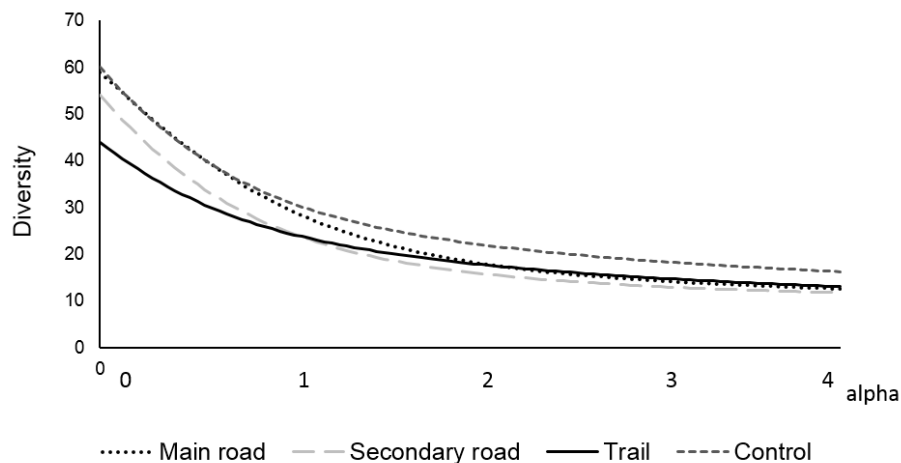


Fig. 3. Community's diversity profile analysis of fruit-eating birds for four areas in the Carlos Botelho State Park – SP, Brazil.  $\alpha = 1$  equivalent to Shannon's diversity index ( $H'$ ) and  $\alpha = 2$  equivalent to Simpson's diversity index ( $D$ ).

Type of pathway and dependence on a fruit diet (frugivore and omnivore) affect the bird relative abundance and richness (Table 1, Fig. 4A). Frugivore abundance was higher in the control area compared to the pathways (Fig. 4A). The secondary road (a pathway with low usage) presented high frugivore abundance compared to the main road and trail (high usage pathways) (Fig. 4A). Frugivore richness was higher in the control area and secondary road compared to the trail and main road (Fig. 4B). Omnivore abundance was higher in the main road, but the control area had high omnivore abundance compared to trail and secondary road (Fig. 4A). The omnivore richness was higher in the main road and control area compared to the other pathways (Fig. 4B) (HSD Tukey < 0.05).

Table 1. Table 1 Relative abundance and richness of fruit-eating birds by diet (frugivores and omnivores) among the types of pathways during two consecutive years at Carlos Botelho State Park, Brazil, (n = 24 sampling in 32 plots). Selected models by Akaike criteria ( $AIC_c$ ).



Relative abundance by diet specialization			
	<i>AICc</i>	<i>dAICc</i>	<i>Df</i>
Type of pathway * type of diet	2498.6	0	11
Type of pathway + type of diet	2602.5	103.9	8
Type of diet	2676.7	178.1	5
Type of pathway	2744.1	245.5	7
NULL	2794.3	295.8	4
Richness by diet specialization			
	<i>AICc</i>	<i>dAICc</i>	<i>Df</i>
Type of pathway * type of diet	2020.5	0	11
Type of pathway + type of diet	2065.8	45.3	8
Type of diet	2120.9	100.3	5
Type of pathway	2282.4	261.9	7
NULL	2311.4	290.9	4

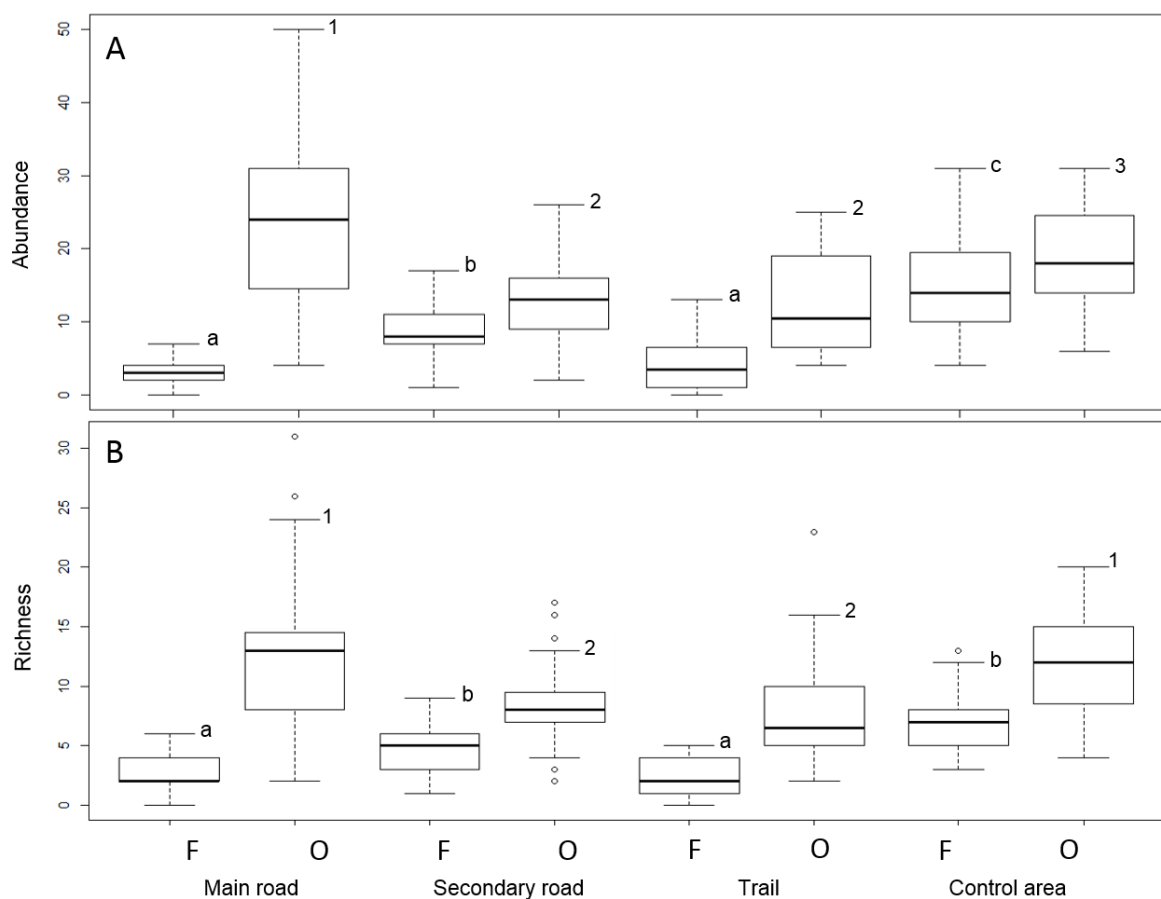


Fig. 4. Relative abundance (A) and richness (B) of frugivorous (F) and omnivorous (O) birds in pathways during two consecutive years at Carlos Botelho State Park, Brazil (n =

32 plots, eight per area). Symbols above the plots (letters in frugivores and numbers in omnivores) represent the significant differences (HSD Tukey  $< 0.05$ ) in the datasets.

Five, two and one exclusive omnivore species were recorded in the main road, secondary road and the trail respectively. Nine were recorded for the control, of which six are canopy frugivores and three are omnivores (Appendix). Many canopy frugivorous species had higher relative abundance in the control area, compared to the main road (Appendix). Only 28 species were shared by all areas (Appendix).

Type of pathway influenced avifauna composition (PERMANOVA,  $F_{3,28} = 5.59$ ,  $P < 0.0001$ ) and community data ordination (nMDS) was consistent with the PERMANOVA's result (Final stress: 0.20) (Fig. 5). We found a strong separation among plots surveyed in the main road, trail and control area, what highlights the significant difference in bird community composition among pathways. The secondary road and control area plots were closely grouped, revealing the similarity in bird communities between the two areas (Fig. 5). The first axis separated the pathways with more intense use (trail and main road) from the low use locations.

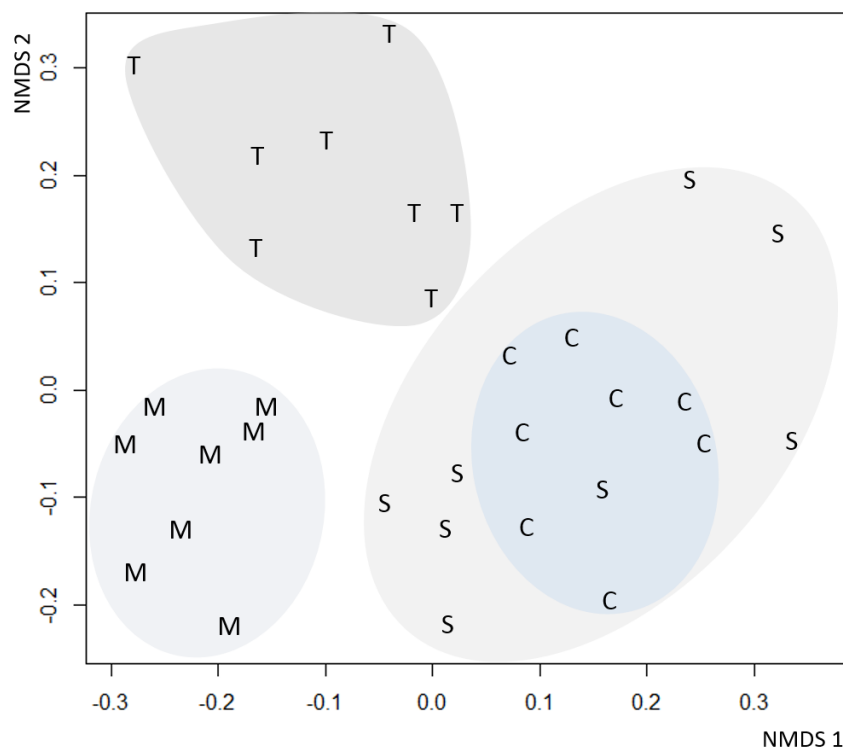


Fig. 5. Ordination analysis (nMDS) for bird species composition among plots surveyed in different types of pathway during two consecutive years at Carlos Botelho State Park, Brazil. (Final stress: 0.20). M: main road, S: secondary road, T: trail, C: control area.

#### *Influence of habitat and types of pathways*

Fruit-eating bird community differs in terms of habitat sensitivity and types of pathways (Table 2). The bird total richness and abundance were negatively affected by usage and positively affected by small-fruit production and pathway width (Table 2). Frugivore abundance and richness were negatively affected by pathway use and positively affected by small fruit production, and the richness was also affected by vegetation structure (Table 2). Omnivore abundance was affected by vegetation structure, positively affected by pathway width and small fruit production (Table 2). Omnivore richness could not be explained by any of the surveyed variables.

Table 2. Explanatory variables for relative abundance of fruit-eating birds, total richness of fruit-eating birds, frugivore abundance and richness, and omnivore abundance and richness for types of pathways and control area sampled during two consecutive years at Carlos Botelho State Park, Brazil, (n = 24 sampling in 32 plots). Linear models selected according to the Akaike information criteria (*AICc*)

Response variable	Explanatory variables	<i>dAIC</i>	<i>AICc</i>	<i>R</i> <sup>2</sup>	<i>Df</i>
Total relative abundance	Small fruits (+)				
	Width (+)	0	337.3	0.41	5
	Pathway use (-)				
Total richness	Small fruits (+)				
	Width (+)	0	217.9	0.29	5
	Pathway use (-)				
Frugivore relative abundance	Small fruits (+)	0	276.8	0.76	4
	Pathway use (-)				
Frugivore richness	Vegetation structure				
	Small fruits (+)	0	103.3	0.86	5
	Pathway use (-)				
Omnivore relative abundance	Vegetation structure				
	Width (+)	0	326.1	0.24	5
Omnivore richness	Small fruits (+)				
	NULL	0	119.23	_	2

Habitat components and type of pathway affected the bird community composition (Fig. 6 – CCA permutation test:  $F_{7,24} = 2.03$ ,  $p < 0.001$ ). Pathway width, vegetation structure and quantity of zoochorous fruits clearly separated the bird community in two groups: (i) the main and secondary road and (ii) control area and trail (Fig. 6). The variables accounting for pathway usage also separated the community in two groups: (i) trail and main road and (ii) control area and secondary road. Vegetation structure was strictly related to pathway width (Fig. 6). When the first two axes of canonical correspondence analysis (CCA) are considered there is a 22% explanation of the variation in bird community composition by habitat and types of pathways (Fig. 6).

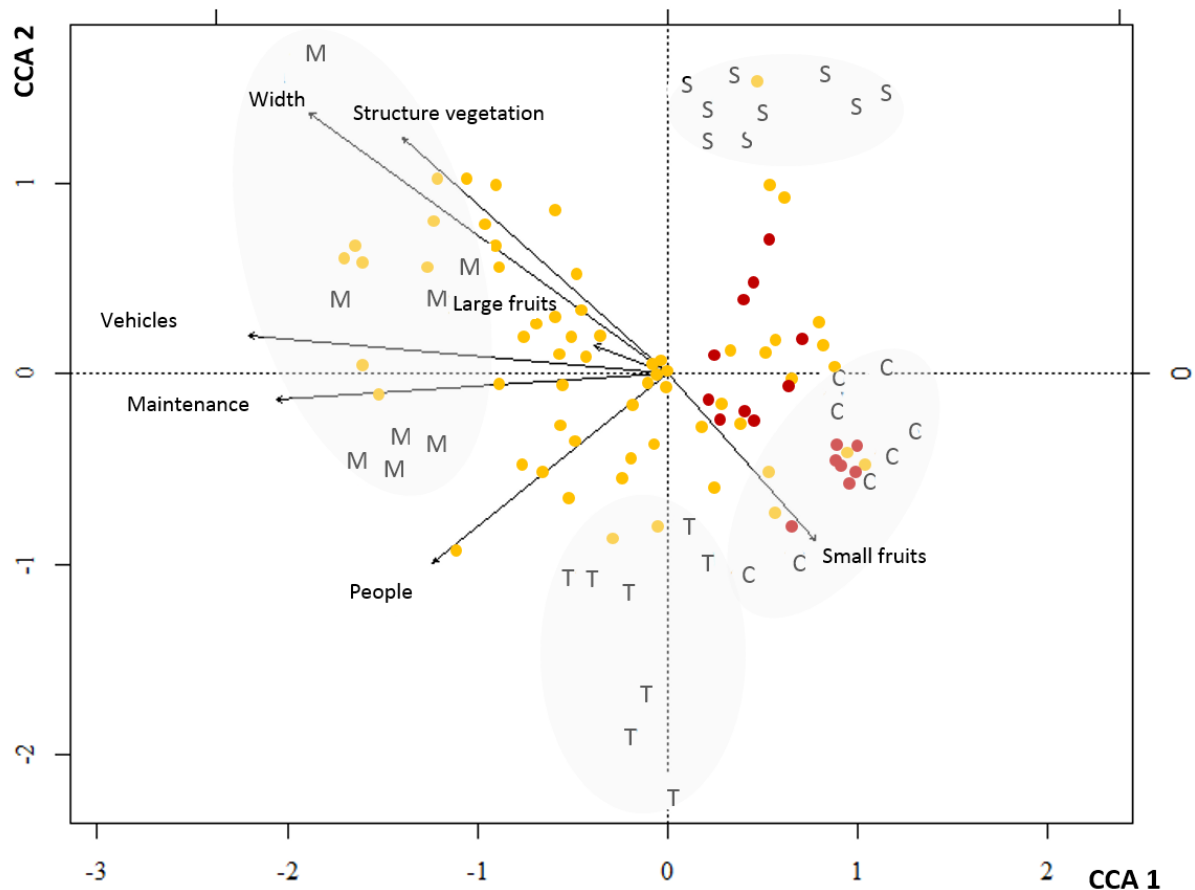


Fig. 6. Ordination diagram of the canonical correspondence analysis (CCA) showing the association between habitat and types of pathways (explanatory variables: width, vehicle traffic, people movement, maintenance intensity, vegetation structure and quantity of small and large fruits) and fruit-eating bird composition (response variable). Arrows

length and position indicate the correlation between the explanatory variable and the axes of the *CCA*. Small angles between arrows indicate strong correlation between variables. Circles refer to species (red to frugivores and yellow to omnivores). Plots are indicated with letters: M-main road, S-secondary road, T-trail, C-control area. Correlation coefficients among explanatory variables and the first two axes of the *CCA* – axis 1 and 2, respectively: Width: -0.79, 0.57; Maintenance: -0.86, -0.06; Vehicles: -0.88, 0.35; People: -0.51, -0.41; Vegetation structure: -0.58; 0.52; Large fruits: -0.16, 0.06; Small fruits: 0.32, -0.36.

## Discussion

Pathway usage and width, coupled with habitat changes caused by pathways presence, as fruit availability, were the most important components in determining the fruit-eating bird community. However, distinctively from vegetation (Silva et al. 2017a), fruit-eating birds were more strongly affected by the intensive use than the pathway width. Differences found between pathways can be assigned to changes in the ecological processes generated by the presence of the linear gap, width and usage, because the areas were very close to each other, minimizing spatial effects (Blake 2007; Silva et al. 2010). The wide pathways, with a similar vegetation structure, but different fruit availability (Silva et al. 2017a; Silva et al. 2017b) and usages, differed in the bird community attributes. The narrow pathway and control area, with a similar vegetation structure and different fruit availability also differed in the bird community. The control area showed the highest diversity, richness and abundance of large frugivores, whereas the main road had the lowest. This pattern highlights the impact caused by the intensive use of a pathway. Anthropogenic disturbances in tropical forests may affect bird communities in different ways depending on the type of change in habitat parameters (Aleixo 1999). The edge effect generated by the presence of pathways in forested areas changes habitat characteristics (Silva et al. 2017a), to which fauna may respond reducing their densities near these structures (Benítez-lópez et al. 2010). As expected, bird responses vary according to the degree of dependence on forested habitats (Watson et al. 2004). Forest-dependent birds are sensitive to changes occurring at forest edges, such as changes in habitat complexity (Watson et al. 2004) and increased light availability (Oliveira et al.

2011). Food resource availability, which may be altered by anthropic disturbance (Laurance et al. 2003; Silva et al. 2017b), can also affect bird species distribution in the landscape (Malizia 2001; Hasui et al. 2007).

Mature tropical forests naturally combine a diverse array of microhabitats due to forest succession dynamics, which is one of the main processes that allows the high biological diversity found in tropical forests (Tonhasca 2005). Rare and endemic bird species with a strict frugivore diet are more abundant in primary tropical forests and may be absent in secondary forests or disturbed areas (Aleixo 1999). Mature forests may also hold high species richness of fruit-eating birds (Robinson and Terborgh 1997; Develey 2004) and present a different composition compared to disturbed areas (Ahmed et al. 2014). The same pattern for rare species was found in our study, with higher occurrence of threatened frugivorous species (e.g. *Aburria jacutinga*, *Triclaria malachitacea*, *Selenidera maculirostris*, *Pteroglossus bailloni*, *Lipaugus lanioides*) and high species richness of fruit-eating birds in the control area, which has a vegetation structure that closely resembles that of a primary tropical forest (Silva et al. 2017a). The high diversity in the control area was also a result of the high equitability found in mature forests, as pointed out by Tonhasca (2005).

Considering the different composition of mature and disturbed forests, areas near road edges may have their total bird abundance and richness increased by the blend of species from open and forested habitats (Ahmed et al. 2014; Yrjölä and Santaharju 2015), as well as by the increase of their habitat heterogeneity (Helldin and Seiler 2003; Morelli et al. 2014). These areas, intensely disturbed in space and time, may attract less specialist species (Robinson and Terborgh 1997), as we found in the main road. Possibly, the increase we verified in the total bird abundance, richness and diversity in the main road plots occurred because this pathway crosses a highly preserved ecosystem (Aleixo 1999; Bojorges-Baños and López-Mata 2006).

Species abundance near transportation structures may be reduced due to birds withdrawing in response to motor vehicles' noise (Reijnen et al. 1995; Wiacek et al. 2015). Intensive human use of forested areas for recreational purposes is also determinant in reducing some bird species (Kangas et al. 2010; Wolf et al. 2013). Frequent and intense human presence may scare birds away due to noise and human presence (Kangas et al. 2010).

Species substitution in a local scale is generated by changes in habitat conditions and contributes to differences in fruit-eating bird species composition (Thiollay 2002; Cohn-haft et al. 2012). Habitat loss for frugivores at road edges and touristic pathways is a pattern evidenced in our study, in which we found low bird occurrence in areas with intense human use (i.e., main road and trail). Despite the similarity in vegetation structure between the trail and control area (Silva et al. 2017a), the first differed from the latter with regard to bird abundance and richness, possibly as a result of the trail use in tourism activities. Communities of temperate forest birds respond similarly to anthropic impacts in forests in Australia and Finland (Kangas et al. 2010; Wolf et al. 2013), demonstrating a generalization of avifauna responses to intense human presence. Likewise, the absence of intensive human use in the secondary road allowed more frugivore species to occur in this area, compared to the main road. The presence of typical forest species in the secondary road (e.g. *Carpornis cucullata*, *Brotogeris tirica* and *Pyrrhura frontalis*) gave this area a species composition more closely related to the control area, suggesting that park managers should be careful about managing the use of pathways within protected areas.

Frugivorous birds differ in their sensitiveness to vegetation composition according to their fruit diet (Hasui et al. 2007). Changes in vegetation composition may influence the predominance of dispersal syndromes, and consequently, fruit size and type (Jara-Guerrero et al. 2011). We found a predominant production of small fruits (up to 14 mm in diameter) for all areas, which represented more than 80% of the total zoochorous fruit production. Fruit size is an important component that determines community abundance and richness between frugivorous and omnivorous birds (Galetti et al. 2013). Plant species with large diaspores may face constraints in seed dispersal as a result of the absence of large frugivores. Conversely, plants with small-sized fruits can be dispersed by a plethora of birds varying in size and diet (Galetti et al. 2013).

The low occurrence of large and rare frugivorous bird species in disturbed areas may result in changes in plant population dynamics (Wolf et al. 2013; Jack et al. 2015; Yrjölä and Santaharju 2015), with consequences to bird-plant interactions (Staggemeier and Galetti 2007), and to the integrity of ecological processes (Leitão et al. 2016). Many large-seeded plants may have a reduction in the dispersal and recruitment mechanisms under low density of seed dispersers (Chapman and Chapman 1995). On the other hand, an increase in the density of generalist small-sized bird species may favour the dispersal

of plant species with small-seeded fruits (Silva et al. 2002). Despite the high fruit availability of the studied areas (Silva et al. 2017b), in the long term, a change in the composition and functional role of seed dispersers, which can vary according to the type of disturbance, could result in a sequential selection of plant species (Galetti et al. 2013). Consequently, this process could spatially limit fruit availability for birds with varied diet specializations (Cardoso da Silva and Tabarelli 2000).

Our study revealed the impact of pathways on the fruit-eating forest birds, highlighted that habitat changes caused by pathways and heavily use may have consequences for the conservation of frugivorous birds in the Atlantic Forest. As we continuously lose forested areas and the primary forest remnants are increasingly fragmented by pathways, it is very important to adequately manage the existing infrastructure intersecting native vegetation, as well as to be cautious when implanting new pathways. Anthropogenic impacts in mature forests usually leads to an increase in the extinction of rare species, severely undermining the integrity of ecological processes (Leitão et al. 2016). Since frugivores are extremely important in the maintenance, functioning, and connectivity of ecosystems (McConkey et al. 2012; Díaz Vélez et al. 2015; Jordano 2016), we expect that the environmental disturbances caused by pathways can affect seed dispersers in space and time, compromising the conservation and structure of animal-plant interactions (Cardoso da Silva and Tabarelli 2000; Galetti et al. 2013; Morellato et al. 2016)

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**Appendix.** Number of fruit-eating birds recorded in the fixed-points in different types of pathways at Carlos Botelho State Park, Brazil. Diet: F – Frugivores, O – Omnivores. Status: CR – Critically endangered, VU – Vulnerable, NT – Near threatened.

<b>Fruit-eating birds</b>	<b>Diet</b>	<b>Status</b>	<b>Main road</b>	<b>Secondary road</b>	<b>Trail</b>	<b>Control</b>
<b>Galliformes</b>						
<b>Cracidae</b>						
<i>Penelope obscura</i> Temminck, 1815	F		0	0	0	1
<i>Aburria jacutinga</i> (Spix, 1825)	F	CR	0	0	0	4
<b>Columbiformes</b>						
<b>Columbidae</b>						
<i>Patagioenas picazuro</i> (Temminck, 1813)	F		5	31	1	22
<i>Patagioenas plumbea</i> (Vieillot, 1818)	F		3	8	0	35
<b>Psittaciformes</b>						
<b>Psittacidae</b>						
<i>Pyrrhura frontalis</i> (Vieillot, 1817)	F		37	88	27	99
<i>Forpus xanthopterygius</i> (Spix, 1824)	F		0	0	0	15
<i>Brotogeris tirica</i> (Gmelin, 1788)	F		3	24	7	13
<i>Pionopsitta pileata</i> (Scopoli, 1769)	F		7	30	29	56
<i>Pionus maximiliani</i> (Kuhl, 1820)	F		15	34	25	79
<i>Trichilaria malachitacea</i> (Spix, 1824)	F	VU	0	2	7	14
<b>Trogoniformes</b>						
<b>Trogonidae</b>						
<i>Trogon viridis</i> Linnaeus, 1766	O		2	0	1	10
<i>Trogon surrucura</i> Vieillot, 1817	O		31	36	36	90
<i>Trogon rufus</i> Gmelin, 1788	O		10	17	13	37
<b>Coraciiformes</b>						
<b>Momotidae</b>						
<i>Baryphthengus ruficapillus</i> (Vieillot, 1818)	O		0	3	2	4
<b>Piciformes</b>						
<b>Ramphastidae</b>						
<i>Ramphastos dicolorus</i> Linnaeus, 1766	F		17	13	11	38
<i>Selenidera maculirostris</i> (Lichtenstein, 1823)	F	VU	0	0	0	8
<i>Pteroglossus bailloni</i> (Vieillot, 1819)	F	VU	0	0	0	5
<b>Passeriformes</b>						
<b>Tyrannidae</b>						
<i>Mionectes rufiventris</i> Cabanis, 1846	O		9	0	6	4
<i>Tyranniscus burmeisteri</i> (Cabanis & Heine, 1859)	O		0	2	0	11
<i>Phyllomyias fasciatus</i> (Thunberg, 1822)	O		0	0	0	5
<i>Phyllomyias griseocapilla</i> Sclater, 1862	O		7	0	11	10



<i>Camptostoma obsoletum</i> (Temminck, 1824)	O		33	14	7	9
<i>Legatus leucophaeus</i> (Vieillot, 1818)	O		9	2	0	0
<i>Myiozetetes similis</i> (Spix, 1825)	O		4	3	0	0
<i>Pitangus sulphuratus</i> (Linnaeus, 1766)	O		37	0	0	0
<i>Conopias trivirgatus</i> (Wied, 1831)	O		0	2	0	0
<i>Myiodynastes maculatus</i> (Statius Muller, 1776)	O		8	0	0	4
<i>Megarynchus pitangua</i> (Linnaeus, 1766)	O		4	0	0	0
<i>Empidonomus varius</i> (Vieillot, 1818)	O		5	2	0	0
<i>Sirystes sibilator</i> (Vieillot, 1818)	O		5	0	0	6
<i>Myiarchus swainsoni</i> Cabanis & Heine, 1859	O		20	18	13	24
<i>Attila rufus</i> (Vieillot, 1819)	O		16	20	6	40
<b>Cotingidae</b>						
<i>Carpornis cucullata</i> (Swainson, 1821)	F		8	126	36	180
<i>Procnias nudicollis</i> (Vieillot, 1817)	F	VU	41	70	43	92
<i>Lipaugus lanioides</i> (Lesson, 1844)	F	VU	0	0	0	3
<i>Pyroderus scutatus</i> (Shaw, 1792)	F	VU	26	9	7	60
<b>Pipridae</b>						
<i>Neopelma chrysolophum</i> Pinto, 1944	O		4	2	0	0
<i>Ilicura militaris</i> (Shaw & Nodder, 1809)	O		0	4	0	2
<i>Chiroxiphia caudata</i> (Shaw & Nodder, 1793)	O		142	127	106	128
<b>Oxyruncidae</b>						
<i>Oxyruncus cristatus</i> Swainson, 1821	O		8	2	0	6
<b>Tityridae</b>						
<i>Schiffornis virescens</i> (Lafresnaye, 1838)	O		162	118	54	71
<i>Tityra inquisitor</i> (Lichtenstein, 1823)	O		0	1	5	2
<i>Tityra cayana</i> (Linnaeus, 1766)	O		0	0	2	0
<i>Pachyramphus castaneus</i> (Jardine & Selby, 1827)	O		0	0	2	4
<i>Pachyramphus polychopterus</i> (Vieillot, 1818)	O		0	0	0	4
<i>Pachyramphus validus</i> (Lichtenstein, 1823)	O		7	0	4	4
<b>Vireonidae</b>						
<i>Cyclarhis gujanensis</i> (Gmelin, 1789)	O		22	10	19	29
<i>Vireo olivaceus</i> (Linnaeus, 1766)	O		64	12	62	57
<i>Hylophilus poicilotis</i> Temminck, 1822	O		132	38	43	67
<b>Turdidae</b>						
<i>Turdus flavipes</i> Vieillot, 1818	O		16	18	22	36
<i>Turdus rufiventris</i> Vieillot, 1818	O		8	7	6	0
<i>Turdus leucomelas</i> Vieillot, 1818	O		5	0	0	0

<i>Turdus amaurochalinus</i> Cabanis, 1850	O		5	0	0	0
<i>Turdus albicollis</i> Vieillot, 1818	O		67	48	44	84
<b>Mitrospingidae</b>						
<i>Orthogonys chloricterus</i> (Vieillot, 1819)	O		4	2	0	4
<b>Thraupidae</b>						
<i>Saltator similis</i> d'Orbigny & Lafresnaye, 1837	O		4	0	2	0
<i>Orchesticus abeillei</i> (Lesson, 1839)	O		6	3	0	0
<i>Cissopis leverianus</i> (Gmelin, 1788)	O	NT	0	4	0	0
<i>Trichothraupis melanops</i> (Vieillot, 1818)	O		8	10	4	0
<i>Tachyphonus coronatus</i> (Vieillot, 1822)	O		16	2	2	5
<i>Tangara sayaca</i> (Linnaeus, 1766)	O		8	9	5	0
<i>Tangara cyanoptera</i> (Vieillot, 1817)	O		16	13	9	12
<i>Tangara ornata</i> (Sparman, 1789)	O		3	7	2	13
<i>Tangara palmarum</i> (Wied, 1823)	O		5	3	0	0
<i>Pipraeidea melanonota</i> (Vieillot, 1819)	O		4	0	0	5
<i>Tangara seledon</i> (Statius Muller, 1776)	O		18	9	0	8
<i>Tangara cyanocephala</i> (Statius Muller, 1776)	O		22	17	4	9
<i>Tangara desmaresti</i> (Vieillot, 1819)	O		19	6	0	7
<i>Tangara cayana</i> (Linnaeus, 1766)	O		0	0	0	4
<i>Tersina viridis</i> (Illiger, 1811)	O		11	2	0	0
<i>Dacnis cayana</i> (Linnaeus, 1766)	O		5	0	2	3
<i>Hemithraupis ruficapilla</i> (Vieillot, 1818)	O		16	4	4	5
<b>Cardinalidae</b>						
<i>Habia rubica</i> (Vieillot, 1817)	O		27	0	45	27
<b>Parulidae</b>						
<i>Setophaga pitiayumi</i> (Vieillot, 1817)	O		103	13	41	49
<b>Icteridae</b>						
<i>Cacicus chrysopterus</i> (Vigors, 1825)	O		17	8	2	12
<i>Icterus pyrrhopterus</i> (Vieillot, 1819)	O		5	0	0	0
<b>Fringillidae</b>						
<i>Euphonia chlorotica</i> (Linnaeus, 1766)	O		0	2	0	5
<i>Euphonia violacea</i> (Linnaeus, 1758)	O		0	3	0	4
<i>Euphonia chalybea</i> (Mikan, 1825)	O	VU	0	3	0	4
<i>Euphonia pectoralis</i> (Latham, 1801)	O		4	2	3	0

#### **CAPÍTULO IV – Impactos causados por vias de uso intensivo sobre a flora e a fauna do Parque Estadual Carlos Botelho: implicações e estratégias para a conservação**

A vegetação de Mata Atlântica, que originalmente cobria mais de 1,5 milhões de km<sup>2</sup> ao longo da área costeira do Brasil oriental, foi submetida a um processo gradual de destruição nos últimos 500 anos e hoje cerca de 83% de sua área remanescente consiste de fragmentos com menos de 50 ha, sendo que somente 0,03% são maiores que 10.000 ha (Ribeiro et al. 2011). A maior parte desses remanescentes localiza-se no interior de Unidades de Conservação (UCs), que têm como principal objetivo a conservação da natureza (SNUC 2000; SOS - Mata Atlântica 2015). No entanto, muitas das UCs no Brasil são intersectadas por infraestruturas de transporte, como rodovias e trilhas (MMA 2000), o que gera uma série de impactos no habitat (Machlis and Neumann 1986; Schonewald-Cox and Buechner 1992). Apesar desses impactos, a regulamentação de vias que cortam as áreas protegidas, e o manejo adequado, podem fomentar o turismo e criar oportunidades para a economia local (Dourojeanni 2003).

As “Estrada Parque”, propostas a partir do Plano do Sistema de Unidades de Conservação do Brasil, II Etapa (Padua et al. 1982), que precederam o atual SNUC (SNUC 2000), são definidas como uma *“unidade de conservação linear de alto valor educativo, cultural e recreativo que visa proteger a paisagem ao longo das vias de acesso, cujos limites são estabelecidos com vistas à proteção de suas características e mantidos em estado natural ou semi-natural, evitando-se intervenções que desfigurem a estética da paisagem”*. No entanto, essa definição não tem o objetivo primário de conservar, mas sim de proteger paisagens e belezas cênicas vistas da estrada, o que resulta na demanda de estratégias de manejo conciliatórias entre a destinação à proteção da biodiversidade proposta pelas UCs de proteção integral (SNUC 2000) e o uso das Estradas Parque (Dourojeanni 2003). Adicionalmente, outras vias de transporte, como as trilhas em UCs, também existem em apoio às funções de acesso, educação ambiental e ecoturismo, e são consideradas como uma necessidade em parques. Exigem, entretanto, manutenção e proteção. À medida em que as condições de funcionalidade e o controle do impacto dessas vias são mantidos, é possível alcançar a sustentabilidade das atividades desenvolvidas nesse recurso (Griswold 1995).

Apesar de já existirem alguns indicadores de impactos de clareiras lineares, como vias, em florestas tropicais (Forman e Alexander, 1998; Goosem, 1997), os impactos

podem ser distintos dependendo do tipo de clareira linear, como estradas, rodovias, linhas de alta tensão, gasodutos, trilhas, ou mesmo as de origem natural, como rios. Além disso, a formação vegetacional em que está inserida, como florestas estacionais ou ombrófilas, deve ser considerada (Gressler 2010; Kangas et al. 2010; Reznik et al. 2012; Ahmed et al. 2014; Prieto et al. 2014; Couto-Santos et al. 2015). Assim, para uma compreensão efetiva dos impactos de estradas na Mata Atlântica é importante associar a caracterização detalhada das vias que atravessam as formações florestais e realizar diagnósticos de seus impactos locais, considerando a grande heterogeneidade gerada por sua extensão latitudinal (3 S a 30 S) e longitudinal (35W a 60W), a variação altitudinal (0–2900 m) e os gradientes de solo e clima (por exemplo, precipitação 1000-4200 mm anuais) (Ribeiro et al. 2011).

As implicações dos impactos devem ser discutidas para terem seus efeitos monitorados e, muitas vezes, manejados (Blockhus et al. 1992; Spellerberg 1994). As informações locais melhoram o direcionamento das ações de conservação, além de contribuírem com as decisões de implantação de futuras vias de transporte em meio às florestas. Nesse contexto, é apresentado o diagnóstico dos impactos gerados na flora e em alguns grupos da fauna por duas vias de uso intensivo em meio ao Parque Estadual Carlos Botelho – Núcleo São Miguel Arcanjo - Unidade de Conservação da Mata Atlântica, e de suas implicações para conservação. Além disso, são sugeridas estratégias de manejo aplicáveis no contexto local do Parque.

### **O Parque Estadual Carlos Botelho e suas vias de uso intensivo**

O Parque Estadual Carlos Botelho (PECB) é uma unidade de conservação (UC) de proteção integral (São Paulo, 1982), que se localiza na região sudeste do Brasil (Figura 1). Ocupa uma área de 37.644,36 ha, distribuída pelos municípios de Capão Bonito, São Miguel Arcanjo, Sete Barras e Tapiraí. A amplitude altitudinal na área do PECB vai de 20 a 1000 m. A temperatura média anual varia entre 18° e 20°C e a pluviosidade anual entre 1500 e 2200 mm. A vegetação predominante é a Floresta Ombrófila Densa (Ferraz e Varjabedian, 1999; Kronka et al., 2005). O PECB conta com dois núcleos com estrutura para visitação pública, um localizado no município de São Miguel Arcanjo a cerca de 800m de altitude e outro no município de Sete Barras a cerca de 95m de altitude (Figura 1).

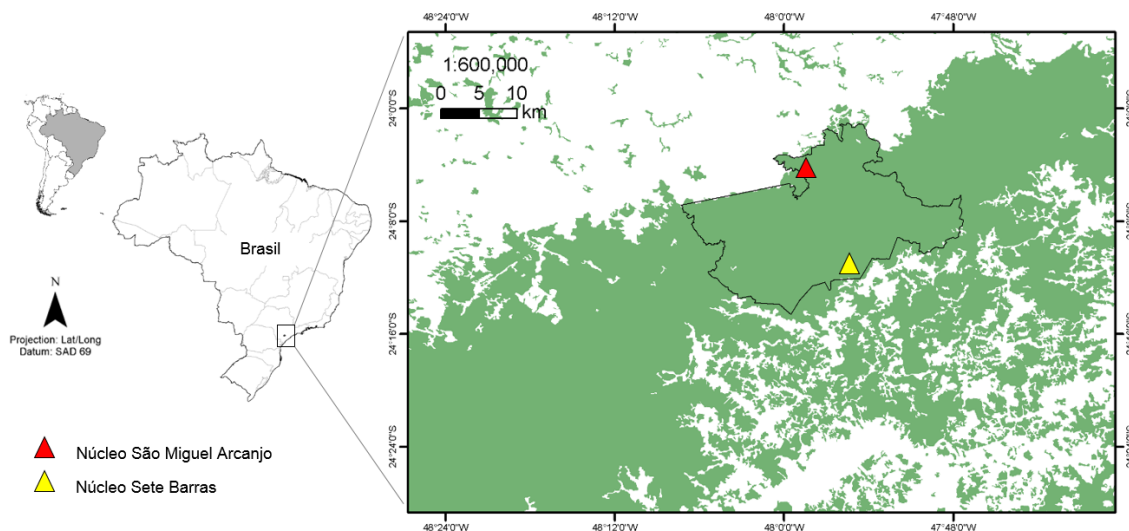


Figura 1. Localização do Parque Estadual “Carlos Botelho”, estado de São Paulo, sudeste do Brasil.

O PECB possui em seu interior um sistema de trilhas regulamentadas destinadas ao ecoturismo, que possui cerca de 45 km de extensão em sua totalidade (SMA 2008). O Parque recebe cerca de 14.000 visitantes anualmente, que desfrutam de diversos atrativos turísticos conectados por esse sistema de trilhas (SMA 2008). Além disso, a rodovia SP-139 atravessa a extensão territorial do PECB por 33 km, dividindo a área do parque em dois fragmentos e ligando os dois núcleos da UC. Esse trecho da rodovia no PECB é localmente conhecido como Serra da Macaca e foi decretado uma Estrada Parque, inaugurada em 22 de novembro de 2015 (São Paulo 2008). Segundo o Plano de manejo do PECB, na região do Núcleo São Miguel Arcanjo o parque conta com dois trajetos caracterizados como de uso intensivo: o sistema de trilhas destinadas à visitação pública e a Estrada Parque Serra da Macaca (EPSM) (SMA 2008).

### *Trilha*

A trilha Represa-Fornos é um dos trechos do sistema de trilhas do PECB e possui uma extensão de cerca de 4,5 km com aproximadamente 2 m de largura. O dossel é conectado na maior parte da extensão da trilha (Figura 2 A). Dados históricos indicam que a trilha foi aberta durante um período extrativista (próximo à década de 40), anterior à criação do Parque (1982), para viabilizar a retirada de madeira e produção de carvão. Ainda hoje são encontradas ruínas de cinco fornos de carvão ao longo do percurso da

trilha, que se tornaram um atrativo histórico-cultural. A trilha é percorrida por visitantes acompanhados por monitor, podendo ser percorrida diversas vezes no mesmo dia. A trilha Represa-Fornos é a mais utilizada para o ecoturismo no Parque, quando comparada aos demais pontos turísticos que necessitam de monitoria (SMA 2008).

O Parque recebe muitas excursões com grupos que podem alcançar 50 pessoas, sendo o percurso da trilha realizado por subgrupos de até 15 pessoas. Em períodos de alta visitação transitam pela trilha cerca de 50 pessoas por dia. O tempo de duração do percurso para cada grupo é de aproximadamente 3,5 h. Segundo o Plano de Manejo do PECEB, o grau de visitação para essa via é considerado entre mediano e alto e os cuidados de manutenção e de infraestrutura são intensos, principalmente em corrimãos, pontes, escadarias simples e área de pisoteio (SMA 2008).

A estrutura da vegetação da trilha Represa-Fornos é similar à estrutura de uma floresta madura sem uso antrópico (Capítulo 1), mas, apesar de se tratar de uma clareira linear estreita (2m de largura) houve sazonalidade na produção de frutos e esta sazonalidade foi verificada até pelo menos 35 m da borda. Nos arredores da trilha ocorreram picos na produção de frutos para fauna ao longo do tempo, com baixa produção principalmente nos meses de janeiro e fevereiro. Na floresta madura, distante de trajetos, a oferta de frutos para a fauna se manteve estável ao longo do ano (Capítulo 2).

A sensibilidade das espécies de aves ao distúrbio do habitat é relacionada à especialidade na dieta, ou seja, espécies com dietas mais restritivas, como por exemplo os frugívoros, tipicamente ocupam áreas com baixo impacto antrópico (Aleixo 1999; Hasui et al. 2007). Isso pode ser verificado na área de Carlos Botelho pela menor abundância e riqueza de aves frugívoras ao longo da trilha em relação a uma área de floresta sem uso antrópico e com estrutura de vegetação semelhante (Capítulo 3). Embora a disponibilidade temporal de frutos seja importante para a manutenção da fauna frugívora, o uso intensivo da trilha também foi detectado como um fator prejudicial à permanência da avifauna nas imediações dessa via (Capítulo 3). Quando comparados os dados verificados nesta trilha com aqueles obtidos em uma via mais larga (10m) sem uso antrópico intensivo, na mesma região do parque, com tempo de abertura da clareira linear semelhante, e que apresenta vegetação alterada pelo efeito de borda e picos na produção de frutos (Capítulos 1 e 2), registrou-se uma maior abundância de aves frugívoras (Capítulo 3). Isso indica que as aves podem estar deixando de utilizar o entorno da trilha

devido ao uso antrópico intenso e não por alterações na estrutura do habitat e oferta de recursos.

### *Estrada Parque*

A Serra da Macaca interliga o planalto com a planície costeira. A estrada foi construída por volta de 1937, anterior à criação do Parque (1982), e possui 112 km, atravessando o PECB num trecho de 33 km, onde se apresenta com cerca de 20 m de largura, incluindo o acostamento. É uma rodovia (SP-139) homogênea quanto à largura e com dossel completamente aberto (Figura 2 B e C). Na estrada circulam veículos de passeio, caminhões, motocicletas, caminhonetes, ônibus, bicicletas, cavalos e caminhantes. A estrada não era considerada oficialmente uma Estrada Parque até o ano de 2015, ano em que o trecho que corta o PECB, que consistia em uma estrada de terra (Figura 2 B), foi pavimentado com bloquetes de concreto - uma tecnologia intermediária entre asfalto e terra. Naquele ano foi então inaugurada oficialmente a Estrada Parque Serra da Macaca (Figura 2 C).

O fluxo de circulação na Estrada Parque antes da pavimentação era de, em média, 6.000 veículos por mês, podendo alcançar cerca de 10.000 veículos por mês entre dezembro e janeiro. Esse fluxo era limitado pelas condições de manutenção do leito, que apresentava muitos buracos, além de trechos com formação de lama. Após a pavimentação, a estrada teve seu fluxo aumentado pela melhora nas condições da via, passando para uma média de 12.200 veículos por mês, atingindo 20.000 veículos por mês entre dezembro e janeiro ( $t = -3.29$ ,  $df = 13$ ,  $p = 0,005$ ). As atividades de manutenção são responsabilidade do Departamento de Estradas de Rodagem, que as realiza periodicamente. Essas atividades incluem conservação do leito e intervenção nas encostas, buscando evitar desmoronamentos (SMA 2008).

No momento da implementação de uma Estrada Parque, os órgãos gestores que articulam essa implantação devem contar com um plano de mitigação. Neste plano devem constar medidas como a implantação de redutores de velocidade e de passagens superiores e subterrâneas de fauna. No entanto, a inauguração Estrada Parque Serra da Macaca ocorreu sem a implantação imediata dos redutores de velocidade, sinalização adequada e atividades de monitoramento, contando apenas com 16 passagens superiores de fauna em sistema de cordas. A Estrada Parque conta com oito pontes, e as margens dos cursos d'água sob essas infraestruturas foram consideradas como utilizáveis pela

fauna para transpor a barreira imposta pela presença da estrada, não tendo sido implantadas passagens subterrâneas específicas para fauna. O funcionamento da Estrada é restrito ao período diurno, com tráfego liberado apenas entre 06h e 20h, e esse uso restrito colabora para a conservação.

A estrutura e a composição da vegetação nas imediações da EPSM são afetadas pela presença dessa clareira linear (20 m de largura), até uma distância de pelo menos 35 m da borda (Capítulo 1). A altura e o diâmetro do tronco das árvores são reduzidos, há uma alta densidade de lianas e uma alta proporção de espécies pioneiras com dispersão anemocórica (Capítulo 1). Além disso, nas bordas são registradas espécies de plantas exóticas como *Urochloa* sp. (= *Brachiaria* sp.), *Citrus x limon* (L.) Osbeck (limão), *Eucalyptus* sp. (eucalipto) e *Musa balbisiana* Colla (banana). A produção de frutos dispersos por animais é reduzida nas bordas da Estrada Parque e desigual ao longo do tempo, quando comparada com as áreas de interior de floresta (Capítulo 2).

A ocorrência de aves frugívoras de grande porte nas imediações da estrada foi reduzida, provavelmente por afugentamento decorrente do uso intensivo, pela alteração do habitat e pela redução na oferta de frutos carnosos nas bordas (Capítulo 3). Ao longo da estrada verificou-se riqueza e abundância baixas para frugívoros grandes e altas para onívoros de pequeno porte, o que resultou em uma composição da comunidade de aves bastante diferenciada nas imediações da estrada quando comparada com as vias sem uso intensivo e com áreas no interior da floresta (Capítulo 3).

A EPSM atua como barreira para alguns grupos de animais, como aves e mamíferos (Talebi, 2005; Oliveira et al., 2011). Espécies de aves de sub-bosque sensíveis à perturbação do habitat, como *Chamaeza campanisona* (tovaca-campainha), nunca cruzam a estrada, mesmo quando estimuladas por *playback* a partir da borda oposta (Oliveira et al. 2011). Além disso, não há registros de indivíduos de *Brachyteles arachnoides* (muriqui-do-sul), uma espécie de primata ameaçada de extinção, cruzando a Estrada Parque (Talebi, 2005; SMA, 2008).

Os registros de atropelamentos de fauna, realizados antes da pavimentação, apontam os invertebrados como o principal grupo atingido, seguido pelos répteis, anfíbios e pequenos mamíferos (Fogaça et al., Unpub.). No caso das espécies noturnas, como besouros e mariposas, a presença da EPSM associada à atração pelas lâmpadas dos faróis dos automóveis pode ter um impacto considerável sobre espécies locais raras, como o



escaravelho *Megasoma gyas* (Antunes et al. 2007). No entanto, há também, registros de atropelamento de grandes mamíferos, como *Tapirus terrestris* (anta) e *Mazama bororo* (veado-mateiro) (Gestão PECB, comunicação pessoal).



Figura 2. Vias em meio ao Parque Estadual “Carlos Botelho”, Estado de São Paulo, sudeste do Brasil. A. Trilha destinada ao ecoturismo, trecho Represa-Fornos; B. Estrada Parque Serra da Macaca anterior à pavimentação; C. Estrada Parque Serra da Macaca após a pavimentação.

### **Implicações para a conservação**

Ao considerar o contexto de implantação das vias, anteriores à criação do PECB, é importante pontuar que a criação dessa unidade de conservação impediu que as bordas das vias fossem aumentadas, e conseqüentemente, que houvesse aumento da fragmentação e dos impactos descritos acima.

Considerando, entretanto, os impactos destas vias após a implantação do PECB, as mudanças na vegetação implicam na perda de espécies típicas de florestas maduras e alterações no habitat utilizado pela fauna (Capítulo 1; Couto-Santos et al., 2015), e as alterações na disponibilidade de frutos carnosos influenciam o uso da área para forrageamento por animais frugívoros (Capítulo 2 e 3; Reznik et al., 2012). O afugentamento das aves que ocorre próximo aos trajetos resulta também na redução de locais adequados para a construção de seus ninhos, recursos necessários para a manutenção de suas populações (Kangas et al. 2010; Wiacek et al. 2015). A perda de

indivíduos da fauna por atropelamento na EPSM e a interrupção do fluxo de indivíduos entre os dois fragmentos do Parque que são divididos pela Estrada podem acarretar uma redução nas populações do PECB (Primack e Rodrigues, 2001; SMA, 2008). O isolamento das populações pela presença da barreira linear e consequente redução na dispersão de indivíduos entre ambos os lados da estrada pode gerar perdas de variabilidade genética com o tempo, contribuindo para o declínio populacional (Young et al. 1996; Keller e Largiadé 2003).

Considerando que alguns grupos faunísticos podem deixar de utilizar as imediações das vias de uso intensivo como área de forrageio e reprodução, ficando mais restritos às regiões distantes das bordas e das áreas de uso antrópico, pode ocorrer uma perda de espécies sensíveis e de diversidade, tendo implicações para a conservação das populações (Helldin and Seiler 2003; Kangas et al. 2010; Wiacek et al. 2015). Adicionalmente, processos ecológicos importantes também podem ser perdidos, envolvendo alterações na estrutura da vegetação, fenologia de plantas e conservação das interações planta-animal (Morellato et al. 2016) e a ocorrência de extinções locais ou funcionais (Galetti et al. 2013; Leitão et al. 2016).

Para avaliar as implicações destas vias para a conservação, caso permaneçam com suas características atuais, é importante considerarmos a extensão das mesmas (Trilha Represa-Fornos - 4,5 km e Estrada Parque Serra da Macaca – 33 km), e os efeitos diagnosticados até 35 m de distância da borda. A partir destes dados estima-se que ao menos 1.312.500 m<sup>2</sup> ou 131 ha de floresta estão sob efeito dos impactos gerados pela presença e uso intensivo dessas vias. Estes efeitos podem ser ainda mais impactantes e alcançar até 400 metros de distância em direção ao interior, como demonstrado para efeitos de borda na Amazônia (Laurance et al. 1997). Além disso, os impactos descritos foram detectados por estudos realizados em período anterior à pavimentação da Estrada Parque e poderão ser intensificados devido ao aumento do fluxo de veículos na Estrada Parque, que ocorreu após a pavimentação. Os padrões ecológicos detectados nas vias do PECB provavelmente irão se manter ao longo do tempo, considerando que são clareiras antrópicas permanentes, o que aponta para a necessidade de implementar estratégias de manejo visando minimizar seus impactos.

## **Estratégias de conservação**

As estratégias de manejo para conservação devem buscar o envolvimento das comunidades humanas da região e gerar subsídios para os programas de educação ambiental das áreas protegidas (Padua et al. 2012). As atividades de monitoramento nas vias devem ser desenvolvidas de forma participativa, com treinamento e envolvimento das comunidades locais e monitores ambientais, que percorrem as trilhas e atrativos da UC diariamente, e de pesquisadores-colaboradores que podem fornecer apoio técnico-científico com a transmissão de dados de interesse ao setor de pesquisa científica da gestão. Algumas estratégias de manejo aplicáveis no contexto local do Parque são descritas a seguir.

### Redução de acidentes e do afugentamento da fauna

#### *Controle do número de visitantes e direcionamento de fluxo nas trilhas*

Primeiramente é importante lembrar que o uso intensivo de trilhas não deve se estender para áreas mais centrais da UC, conforme recomendações da Secretaria do Meio Ambiente e que o zoneamento delineado do plano de manejo seja rigorosamente respeitado (SMA 2008), para evitar a ampliação dos impactos já verificados. O direcionamento do fluxo de visitantes aos trechos de trilha mais próximos às regiões de borda pode auxiliar na redução do afugentamento da fauna, uma vez que as espécies da fauna que são mais sensíveis costumam deixar de utilizar essas áreas pela simples alteração do habitat devido ao efeito de borda (DeWalt et al. 2003; Watson et al. 2004).

#### *Controle do fluxo e sinalização na Estrada Parque*

Uma característica mitigadora da Estrada Parque Serra da Macaca é seu horário de funcionamento restrito ao período diurno, o que reduz o impacto do uso intensivo, principalmente em populações da fauna que possuem hábito noturno. Além disso, sugerimos a implantação de um posto de controle com pedágio e sinalização massiva com informações sobre as características de fauna e flora local e indicação da passagem de animais. Sugerimos também a construção de quebra-molas, instalação de radares e a proibição do trânsito de caminhões, como indicado para estradas nessa categoria (Dourojeanni 2003). Com o apoio e concordância das partes envolvidas na instalação de um pedágio, este poderá, além de restringir o trânsito, trazer recursos para a implantação

e manutenção de estruturas e para a contratação de pessoas que auxiliarão nas ações para reduzir os impactos nas biotas locais (Dourojeanni 2003). Adicionalmente, deve haver a manutenção constante da sinalização, a presença de patrulhas policiais e um plano de contingência para acidentes com cargas perigosas.

#### *Implantação de passagens de fauna na Estrada Parque*

Sugerimos a construção de passagens de fauna na forma de viaduto vegetado sobre o pavimento em pontos estratégicos indicados através de dados gerados pelo monitoramento de atropelamentos ao longo do trecho da estrada (Figura 3 A). As passagens devem contar com barreiras nas bordas, tais como alambrados, direcionando os animais para os pontos de conexão. Outro tipo de passagem, mais comumente utilizada, é a de pontes de cordas como as já instaladas ao longo da EPSM (Figura 3 B) (Teixeira et al. 2013). Consideramos, entretanto, que estas estão em baixo número e que apenas algumas espécies conseguem utilizar essas pontes de cordas para cruzar as estradas, ao passo que a implantação de viadutos vegetados gera a continuidade da vegetação e facilita o fluxo de indivíduos de espécies que não cruzam áreas abertas, o que seria uma vantagem na conexão entre os dois fragmentos do PECB.

A implantação das passagens de fauna deve considerar que as populações podem usar a paisagem de maneira distinta ao longo do ano em resposta à disponibilidade de recursos, gerando mudanças nos pontos de travessia da estrada ao longo do tempo (Vanthomme et al. 2015). Estudos de modelagem de movimento considerando as espécies e épocas específicas podem embasar a implantação destas passagens, buscando garantir a conectividade da paisagem em longo prazo (Vanthomme et al. 2015). A instalação dessas estruturas de conexão deve ser seguida de um monitoramento sistemático, visando à avaliação de seu uso e efetividade e a geração de informações para seu manejo.



Figura 3. Medidas mitigadoras para conexão da vida selvagem em paisagem fragmentada por estradas. A. Viaduto vegetado construído para passagem da vida selvagem em Montana, USA. B. Ponte de cordas para passagem de fauna, Estrada Parque Serra da Macaca, Parque Estadual Carlos Botelho, Brasil.

### Envolvimento da comunidade e educação ambiental

#### *Uso direcionado ao ecoturismo*

Pelo funcionamento atual da EPSM ela opera mais como uma rota entre o interior e o litoral do que como uma Unidade de Conservação Linear. Sugerimos que esta opere também como uma trilha contemplativa e interpretada a ser percorrida em veículos adaptados para esta atividade. Os veículos poderão ser oferecidos pela própria unidade ou por agências de turismo e educação locais autorizados, e os visitantes deverão ser acompanhados por monitores ambientais que podem explorar assuntos ligados à conservação da Mata Atlântica durante o trajeto. O desenvolvimento de atividades como essa é uma opção interessante de lazer até mesmo para quem usa a estrada atualmente apenas como rota de passagem. O fato da EPSM interligar dois núcleos de atendimento à visitação pública (nos municípios de São Miguel Arcanjo e de Sete Barras) pode facilitar a logística e manejo da visitação. Com esse tipo de operação a Estrada atenderia aos objetivos de proteger paisagens e belezas cênicas e de fomentar o turismo controlado e a educação ambiental, mantendo ao mesmo tempo a integridade do ecossistema em questão.

#### *Educação Ambiental*

Incentivamos também a adequação dos programas de educação ambiental já realizados pela UC ao tema dos impactos gerados pelas estradas e trilhas e principalmente pelo seu uso. É possível incorporar o assunto dos impactos gerados por essas vias nos programas de educação ambiental realizados com os visitantes do PECB. Esse mesmo trabalho pode ser realizado com os usuários da Estrada Parque que, dada a sua categoria de estrada, permite a intervenção para a realização de trabalhos de educação ambiental. Para as trilhas indicamos a transmissão oral das informações em atividades educacionais dinâmicas que abordem, por exemplo, a redução dos ruídos durante o passeio. E para a EPSM sugerimos a intervenção dos mediadores que se encontram nos portais de entrada da estrada, que podem transmitir informações de cuidados a serem tomados durante o trajeto pela via e distribuir panfletos ou “folders” educativos sobre a presença da fauna na Estrada, seguindo o exemplo do “Guia de aves da Serra da Macaca” (Apêndice).

### Monitoramento

#### *Monitoramento da fauna para avaliação dos impactos ao longo do tempo*

Sugerimos utilizar um grupo bem conhecido e relativamente fácil de amostrar como indicador nas atividades de monitoramento. As aves destacam-se para a inclusão em programas como esse por se encaixarem nesses requisitos quando comparadas a outros grupos de animais (Bispo et al. 2016). A abundância relativa e a densidade de aves podem indicar a qualidade do habitat e a efetividade das ações de manejo das infraestruturas (SMA, 2008). A amostragem das espécies de aves pode ser concentrada nos meses de sua maior atividade reprodutiva, de setembro a fevereiro, quando a detecção é favorecida. E levando-se em conta as condições locais, a abordagem mais adequada para a avaliação do impacto do uso público sobre a avifauna em cada uma das vias é o monitoramento da presença e abundância relativa de algumas espécies através de método de “ponto fixo” conforme protocolo proposto por Bispo et al. (2016) para unidades de conservação em formações de Cerrado, Mata Atlântica e Amazônia. O protocolo propõe a adoção de estações de monitoramento constituídas por 12 pontos fixos com uma distância mínima de 200 metros entre eles e raio de detecção máximo de 50 metros (Bispo et al. 2016). Para amostrar as variações altitudinais e climáticas que existem ao longo da EPSM sugere-se a implementação de uma estação de monitoramento a cada 10 km de extensão da via, enquanto que para a trilha Represa-Fornos uma estação seria suficiente.

As espécies de aves mais indicadas para esta finalidade são alguns frugívoros de grande porte já amostrados no parque (Capítulo 3), como: *Aburria jacutinga* (jacutinga), *Penelope obscura* (jacuaçu), *Ramphastos dicolorus* (tucano-de-bico-verde), *Selenidera maculirostris* (araçari-poca), *Carpornis cucullata* (corocochó), *Procnias nudicollis* (araponga), *Pyroderus scutatus* (pavó) e *Trichloria malachitacea* (sabiá-cica). Estas são espécies de fácil visualização (Apêndice), ou com vocalizações bem conspícuas, possibilitando seu registro por parte dos monitores ambientais e demais pesquisadores da UC. São espécies sensíveis a perturbações e associadas a habitats mais preservados, respondendo negativamente à presença de impactos antrópicos.

Outros dados importantes para o monitoramento da fauna são provenientes do inventário dos atropelamentos na Estrada Parque, abrangendo invertebrados e vertebrados. Esse monitoramento pode orientar a colocação das placas de advertência nos locais de travessia, estes locais podem mudar de acordo com a variação temporal na disponibilidade de recursos para fauna, que pode alterar suas rotas na paisagem, assim as placas de advertência também devem ser alteradas em determinadas épocas do ano (Vanthomme et al. 2015). Esse trabalho pode ser realizado percorrendo-se a via com veículos ou caminhando e fazendo-se o registro quantitativo e qualitativo dos atropelamentos, conforme protocolo proposto por Para e Campo (2013).

É interessante que o monitoramento através de caminhadas seja implementado, pois o número de registros é significativamente maior quando comparados aos realizados com veículos (Teixeira e Kindel, 2013). Esses registros geram dados que podem alimentar o Banco de Dados Brasileiro de Atropelamento de Fauna Selvagem (BAFS), que serve como subsídio para a implantação e adequação das medidas de mitigação dos impactos à fauna no âmbito nacional. No caso da EPSM, os dados poderiam também alimentar um banco de dados interno que auxiliaria no manejo das medidas de proteção à fauna que utiliza a estrada, como o acréscimo de sinalização ou de novas passagens de fauna, superiores ou subterrâneas.

#### *Controle e erradicação de espécies exóticas*

O monitoramento e controle de espécies exóticas, que são importantes para a manutenção da integridade da vegetação nativa em uma UC (Leão et al., 2011; Sampaio e Schmidt, 2013) estão previstos no Plano de Manejo do PECB como uma das principais linhas de ação a serem desenvolvidas. A implantação das ações de manejo para as

espécies exóticas pode seguir a sequência proposta por Leão et al. (2011), composta por: 1) diagnóstico das ocorrências de populações e/ou indivíduos das espécies; 2) estabelecimento de prioridades para manejo, priorizando as espécies com maior potencial de invasão; e 3) estratégias de manejo, que abrangem a erradicação, contenção e controle, e mitigação de impactos gerados pela espécie. Sugerimos especial atenção para as espécies exóticas detectadas na Estrada Parque, como *Urochloa* sp. (= *Brachiaria* sp.), *Citrus x limon* (L.) Osbeck (limão), *Eucalyptus* sp. (eucalipto) e *Musa balbisiana* Colla (banana). Após a implantação das ações é importante um monitoramento anual para a detecção de espécies exóticas e, se necessário, devem ser realizadas novas ações de manejo (Leão et al. 2011).

### Ações de compensação

#### *Ampliação da área da Unidade de Conservação*

Embora esta medida envolva o comprometimento de muitas instâncias, a ampliação da área efetiva da UC na Zona de Amortecimento é uma estratégia compensatória para os impactos causados. Essa ação deve ser subsidiada por estudos que indiquem o tamanho da área impactada pela via. Para isso, estudos que considerem maiores distâncias a partir das bordas das vias devem ser priorizados pelo setor de pesquisa científica da UC.

### **Considerações finais**

Apesar de ser de extrema importância a realização de mais estudos nas imediações das vias de transporte, como trilhas e estradas, que cortam Unidades de Conservação, envolvendo diversos grupos de fauna e flora, as interações entre eles e com seu habitat, o conhecimento já existente, combinado com diagnósticos locais, pode e deve ser utilizado para um direcionamento das estratégias de conservação.

Ainda faltam diretrizes para a implantação de Estradas-Parque no Brasil, o que traz dificuldades nas ações de articulação entre os gestores das UCs, órgãos de planejamento viário e órgãos ambientais, no momento de implementação destas vias. O enquadramento das vias que intersectam UCs de proteção integral na categoria “Estrada



Parque”, por si só, não diminui os conflitos gerados por seu uso. No caso da Estrada Parque Serra da Macaca observamos que é preciso atenção dos responsáveis da UC com as operações realizadas na estrada, para que esta não se torne mais um exemplo da deficiência no manejo de infraestruturas de transporte que cruzam as UCs. Verificamos também que há um grande potencial para que a EPSM seja um atrativo com retornos positivos para o lazer e a educação ambiental.

O fato da Estrada Parque Serra da Macaca ter sido inaugurada após a pavimentação, sem a implantação de todas as medidas de mitigação, veio demonstrar a necessidade de maior diálogo entre os órgãos de planejamento viário, os órgãos ambientais ligados à conservação e a equipe de gestão das áreas protegidas afetadas pela implantação de infraestruturas de transporte. Uma maior colaboração entre os agentes envolvidos possibilitaria a criação de programas de implementação conjuntos e melhor planejamento das estratégias de conservação, considerando-se as condições regionais e locais.

As sugestões derivadas de diagnósticos de impactos de vias de transporte podem ser incentivadas junto aos órgãos responsáveis pela gestão das UCs. Os estudos e a necessidades de monitoramento podem ser facilitados junto ao setor responsável pelos trâmites de pesquisas científicas do PECB, que já possui um Plano de Manejo onde são indicadas áreas prioritárias para o desenvolvimento de pesquisa científica. Desse modo poderá haver melhor integração entre a conservação e o uso de infraestruturas antrópicas na Unidade de Conservação, permitindo que os gestores dos parques possam ajustar as medidas prioritárias para a conservação com base nos orçamentos e metas de gestão.

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## **Apêndice**

### **Guia de aves da Serra da Macaca**

# AVES DA SERRA DA MACACA

ESTRADA PARQUE

PARQUE ESTADUAL CARLOS BOTELHO



Elaboração: Bruna Gonçalves da Silva

Revisão Técnica: Alexsander Zamorano Antunes

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22 p.

Aves, Mata Atlântica, Estrada Parque, Conservação, Identificação, Educação Ambiental.

Dezembro de 2016

Capa: *Ramphocelus bresilius* (5.)\*, *Tinamus solitarius* (1.), *Dacnis cayana* (9.), *Trogon viridis* (7.), *Rupornis magnirostris* (5.), *Penelope obscura* (6.)

\* Números entre parênteses representam os fotógrafos



## PARQUE ESTADUAL CARLOS BOTELHO

O Parque Estadual Carlos Botelho é uma das áreas mais importantes para a preservação da natureza no país. No Parque foram registradas até o momento 370 espécies de aves<sup>1</sup>, várias consideradas ameaçadas de extinção<sup>2,3</sup>.

Este guia apresenta uma parte dessa grande riqueza de espécies, que pode ser visualizada na Estrada Parque **Serra da Macaca**.



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<sup>2</sup> Categoria de ameaça no Estado de São Paulo: São Paulo (Estado). 2014, Decreto nº 60.133, de 7 de fevereiro de 2014. Declara as espécies da fauna silvestre ameaçadas de extinção, as quase ameaçadas e as deficientes de dados para avaliação no Estado de São Paulo e dá providências correlatas Diário Oficial do Estado de São Paulo, Poder Executivo, São Paulo, 08 fev. 2014. Seção I, n.124 (27), p.25-32.

<sup>3</sup> Categoria de ameaça no Brasil: União. 2014. Portaria MMA nº 444 de 17 de dezembro de 2014. Lista nacional oficial de espécies da fauna ameaçadas de extinção. Diário Oficial da União, 18 dez. 2014. Seção I, n.245, p.121-126.

## APRECIE AS AVES

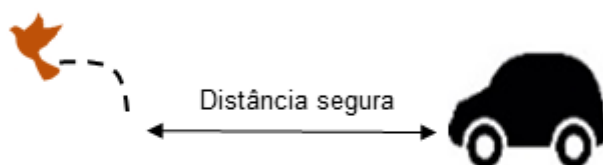
Para que seja possível apreciar a beleza das aves, esse trajeto deve ser realizado com atenção e de maneira contemplativa, respeitando os limites de velocidade e evitando excesso de ruídos. Assim será possível impedir atropelamentos e reduzir o afugentamento dos animais. Para ter o prazer de observar a grande variedade de cores, formas e comportamento das aves fique atento ao seu redor.



## CUIDADO

Ao avistar uma ave no meio da estrada:

- Reduza a velocidade de maneira compatível com a segurança
- Assim haverá tempo para que ela afaste-se para a borda da mata



Evite o atropelamento

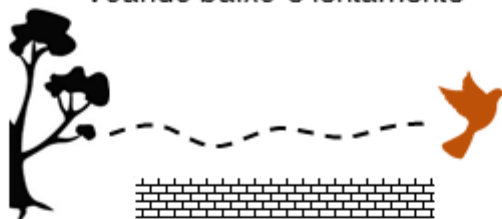


Reduza os ruídos para não assustar os animais

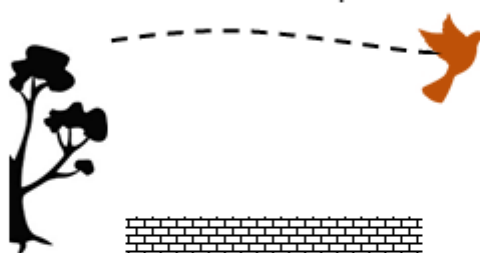


## AS AVES PODEM USAR A ESTRADA:

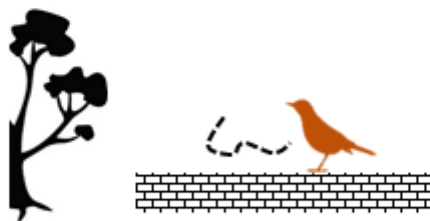
Voando baixo e lentamente



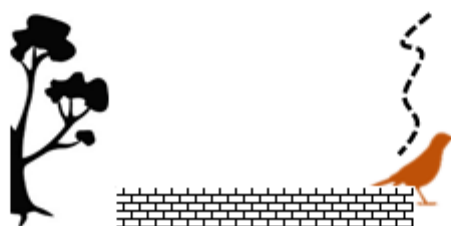
Voando alto e rápido



Caminhando no meio da estrada



Caminhando no canto da estrada



## COMO USAR O GUIA

Atividade  Diurno  Noturno

Chance de avistar

Risco de atropelar


 Alta  
Média  
Baixa


 Alto  
Médio  
Baixo


### Alimentação

        
Carnívoro Frugívoro Onívoro Piscívoro Granívoro Nectarívoro Insetívoro

### Categorias de ameaça

 Nacional (BRA):  
CR = Criticamente em Perigo  
EN = Em Perigo  
Estadual (SP):  
A = Ameaçada  
QA = Quase ameaçada.

 Não ameaçada

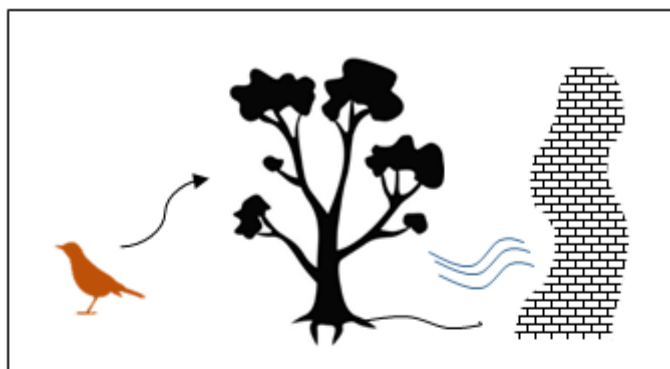
Tamanho 

**Referências:**

Nomenclatura das aves: Comitê Brasileiro de Registros Ornitológicos. 2014. Lista das Aves do Brasil.

Tamanho das aves: Guia de campo – Aves do Brasil Oriental. 2007. São Paulo, Avis Brasilis, 448p.

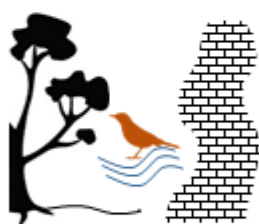
## Uso do habitat



Árvores da borda da mata



Chão da mata



Rios e brejos



Sobrevoando



Chão da estrada



Tronco das árvores

As aves podem utilizar mais de um habitat.

Ordem: Tinamiformes, Família: Tinamidae



1.



Macuco - *Tinamus solitarius* A

↕ 42-48 cm

Ordem: Galliformes, Família: Cracidae



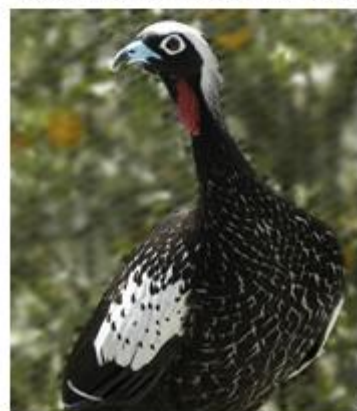
6.



Jacuguaçu - *Penelope obscura* D

↕ 68-75 cm

Ordem: Galliformes, Família: Cracidae



4.



7 Jacutinga- *Aburria jacutinga*

A

EN

↕ 63-74 cm

Ordem: Galliformes, Família: Odontophoridae



Uru - *Odontophorus capueira*

↕ 24 cm

Ordem: Cathartiformes, Família: Cathartidae



Urubu-de-cabeça-vermelha - *Cathartes aura*

↕ 62-76 cm

Ordem: Cathartiformes, Família: Cathartidae



Urubu-preto - *Coragyps atratus*

↕ 56-74 cm



Ordem: Accipitriformes, Família: Accipitridae



5.



Gavião-carijó - *Rupornis magnirostris*



31-42 cm

Ordem: Accipitriformes, Família: Accipitridae



4.



Gavião-tesoura - *Elanoides forficatus*



52-62 cm

Ordem: Falconiformes, Família: Falconidae



5.



Caracará - *Caracara plancus*



51-64 cm

Ordem: Falconiformes, Família: Falconidae



6.

Carrapateiro – *Milvago chimachima*

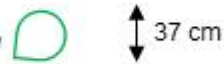


Ordem: Gruiformes, Família: Rallidae



10.

Saracura-do-mato – *Aramides saracura*



Ordem: Cariamiformes, Família: Cariamidae



5.

Seriema - *Cariama cristata*



Ordem: Columbiformes, Família: Collumbidae



3.

Alta

Baixo

Asa-branca – *Patagioenas picazuro*

34 cm

Ordem: Psittaciformes, Família: Psittacidae



6.

Alta

Baixo

Maitaca-verde – *Pionus maximiliani*

27 cm

Ordem: Psittaciformes, Família: Psittacidae



5.

Alta


Baixo

Periquito-rico - *Brotogeris tirica*

21 cm

Ordem: Apodiformes, Família: Trochilidae



Beija-flor-preto – *Florisuga fusca* 


↕ 12 cm

Ordem: Apodiformes, Família: Trochilidae



(Na foto: fêmea)




Beija-flor-de-fronte-violeta – *Thalurania glaucopis* 

↕ 11 cm

Ordem: Trogoniformes, Família: Trogonidae



Surucuá-de-barriga-dourada – *Trogon viridis* 

↕ 30 cm



Ordem: Trogoniformes, Família: Trogonidae



2.

Surucua-variado – *Trogon surrucura*

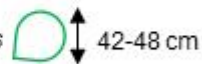


Ordem: Piciformes, Família: Ramphastidae



4.

Tucano-de-bico-verde - *Ramphastos dicolorus*



Ordem: Piciformes, Família: Ramphastidae



2.

Araçari-poca – *Selenidera maculirostris*



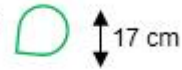
Ordem: Piciformes, Família: Picidae



2.



Benedito-de-testa-amarela – *Melanerpes flavifrons*



17 cm

Ordem: Piciformes, Família: Picidae



2.



Pica-pau-velho – *Celeus flavescens*



25-30 cm

Ordem: Piciformes, Família: Picidae



5.



Pica-pau-rei – *Campephilus robustus*



30-37 cm

Ordem: Passeriformes, Família: Pipridae



5.




Tangará-dançarino – *Chiroxiphia caudata*  15 cm

Ordem: Passeriformes, Família: Cotingidae



4.



Araponga – *Procnias nudicollis* 


29 cm

Ordem: Passeriformes, Família: Cotingidae



5.



Pavó – *Pyroderus scutatus* 

43-46 cm

Ordem: Passeriformes, Família: Hirundinidae



Andorinha-grande – *Progne chalybea*



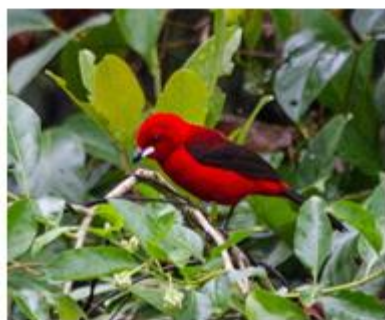
Ordem: Passeriformes, Família: Turdidae



Sabiá-laranjeira – *Turdus rufiventris*



Ordem: Passeriformes, Família: Thraupidae



Tiê-sangue - *Ramphocelus bresilius*





Ordem: Passeriformes, Família: Thraupidae



9.



Saíra-militar – *Tangara cyanocephala*



↕ 13,5 cm

Ordem: Passeriformes, Família: Thraupidae



8.



Saíra-sete-cores – *Tangara seledon*



↕ 13,5 cm

Ordem: Passeriformes, Família: Thraupidae



8.



Sanhaço-da-serra – *Tangara cyanoptera*



↕ 18 cm

Ordem: Passeriformes, Família: Thraupidae



Sanhaço-do-coqueiro – *Tangara palmarum*   18 cm

Ordem: Passeriformes, Família: Thraupidae



Sai-azul – *Dacnis cayana*



Ordem: Passeriformes, Família: Parulidae

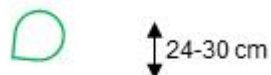


Pula-pula-coroado – *Basileuterus culicivorus*   12 cm

Ordem: Passeriformes, Família: Icteridae



Guaxe - *Cacicus haemorrhous*



Ordem: Passeriformes, Família: Fringilidae



Gaturamo-verdadeiro - *Euphonia violacea*



Ordem: Passeriformes, Família: Fringilidae



Ferro-velho - *Euphonia pectoralis*



**TENHA UM AGRADÁVEL  
MOMENTO DE  
CONTEMPLAÇÃO DA  
NATUREZA!**

**APRECIE AS AVES**



*Ramphastos dicolorus* ♂



## Considerações finais

Nesse estudo foi possível verificar que a presença de clareiras lineares e o seu uso geram respostas na comunidade de plantas, alterações em processos reprodutivos como a produção de frutos, e afetam a comunidade de aves consumidora de frutos. A largura da clareira linear é um fator que direciona as respostas da comunidade de plantas, enquanto que para comunidade de aves frugívoras a intensidade de uso e a disponibilidade de alimentos são determinantes. A presença de um trajeto com mais de 10 m de largura combinado com seu uso intensivo, em meio a uma floresta, traz acentuadas mudanças nas comunidades da fauna e da flora. Destacou-se também a necessidade de avaliar os trajetos e seus impactos de maneira independente para cada tipo de clareira linear que cruze uma área florestal, considerando suas características físicas e de uso, assim como as demais condições locais.

Os resultados corroboraram as previsões iniciais apontadas para a vegetação, baseadas em estudos do efeito de borda de clareiras lineares realizados com outros grupos de plantas ou em outras áreas de mata atlântica com outras características climáticas (Couto-Santos et al., 2015; Prieto et al., 2014). Além disso, contribuem para o conhecimento sobre o impacto de clareiras lineares na comunidade arbórea de Floresta Ombrófila Densa em Mata Atlântica, pois revelam que a vegetação difere entre trajetos largos e estreitos. Em trajetos largos (entre 10 e 20 m) houve maior ocorrência de plantas com baixa altura e diâmetro a altura do peito, e uma proporção maior de pioneiras e espécies anemocóricas quando comparadas às encontradas em trajetos estreitos (2 m de largura) ou áreas sem trajetos. Além disso, destacou-se a ocorrência de espécies exóticas nas imediações dos trajetos largos. Esses resultados reforçam a existência de respostas da comunidade de plantas às alterações causadas pela presença da clareira linear, revelando o impacto de um trajeto largo (com mais de 10 metros de largura) na estrutura do habitat e na composição da comunidade.

No que concerne aos padrões de frutificação, os expressivos efeitos espaciais e temporais da presença de trajetos com diferentes larguras na disponibilidade de frutos obtidos nesse estudo fornecem informações que ainda estavam inconsistentes na literatura (Ramos e Santos, 2006; Reznik et al., 2012). A produção de frutos para a fauna é maior em áreas de floresta madura sem a presença de clareiras lineares, havendo produção ao longo do ano todo, ao passo que nas áreas afetadas pelos trajetos ocorrem épocas com

picos e depressões de produção, com oscilação na disponibilidade de frutos. Além disso, nosso estudo revelou que há uma diferença nos tipos de frutos produzidos entre as áreas afetadas pelas clareiras lineares, com predominância de espécies não zoocóricas nas bordas dos trajetos largos e de zoocoria nas áreas sem trajetos, informações que ainda não eram conclusivas na literatura pois ainda não haviam sido detectados efeitos na distribuição das síndromes de dispersão em área afetadas por trajetos. Foi observado também que ao longo do trajeto mais largo a produção de frutos não zoocóricos não diferiu entre borda e as parcelas a 35 m da borda, enquanto a proporção de zoocoria aumentou nas parcelas a 35 m da borda. Na posse desses resultados foi possível perceber que a variação na predominância das síndromes é sensível à intensidade com que o efeito de borda penetra sentido interior, dependendo da largura da clareira e que isso afeta diferentemente as diferentes síndromes de dispersão. Apesar de ser conhecido que as espécies podem responder distintamente à uma alteração ambiental, esse padrão observado traz questionamentos sobre as respostas ao efeito de borda entre grupos de plantas que apresentam as diferentes síndromes de dispersão. Esses questionamentos poderiam ser abordados em estudos futuros sobre as diferenças fisiológicas que poderão ser consistentes entre espécies que apresentam uma mesma síndrome de dispersão.

A alteração na composição, riqueza e abundância de aves frugívoras da Mata Atlântica nas proximidades de trajetos com uso intensivo corrobora as hipóteses iniciais baseadas em estudos conduzidos em formações florestais da Austrália e da Amazônia (Ahmed et al., 2014; Develey e Stouffer, 2001; Goosem, 2004, 2001; Laurance et al., 2004; Wolf et al., 2013). Os trajetos largos favoreceram a ocupação e o aumento da abundância de espécies mais generalistas nas bordas, que encontraram ali as condições favoráveis para sua manutenção. Verificamos também que os trajetos sem uso intensivo possibilitam a ocorrência de espécies mais sensíveis a perturbações, como as grandes aves frugívoras. No entanto, nos trajetos com uso intensivo, largos ou estreitos, os grandes frugívoros podem ser afugentados, havendo uma diminuição na sua ocorrência e abundância. A implantação de trajetos como rodovias, que combinam a necessidade de um leito normalmente superior a 20m e o uso intensivo por diversos meios de transporte, resulta em grandes impactos no ambiente natural. O uso de trilhas de turismo também deve ser manejado de forma adequada, já que foi possível observar que o uso público, mesmo em um ambiente com vegetação madura, como a trilha amostrada nesse estudo, pode afetar fortemente o comportamento da fauna.

A alteração do habitat, a limitação de recursos alimentares, e a presença de distúrbios que afugentem a fauna geram o desaparecimento de algumas espécies das áreas adjacentes aos trajetos amostrados. A diminuição de grandes aves frugívoras nas imediações de clareiras antrópicas com uso intensivo pode implicar em alterações nos processos de dispersão de sementes, e isso pode se refletir nas diferenças na composição da vegetação observadas nas imediações das bordas. Esse processo tende a alterar a dinâmica do ecossistema, pois com a ausência da fauna capaz de dispersar grandes sementes, e a conseqüente seleção das espécies de plantas, pode ocorrer uma alteração das comunidades florestais e o aumento de extinções locais. É recomendado que essas hipóteses sejam futuramente investigadas.

O diagnóstico local dos impactos das vias de uso intensivo do Parque Estadual Carlos Botelho possibilitou o direcionamento de estratégias de conservação às vias consideradas, visando a melhor integração entre a conservação da floresta e o uso de infraestruturas antrópicas no Parque. As estratégias de conservação sugeridas para serem consideradas pelos gestores e demais órgãos envolvidos incluíram medidas mitigatórias que visam a redução de acidentes e do afugentamento da fauna, o envolvimento da comunidade e educação ambiental, monitoramento, e ações de compensação. Quando se trata de ambientes sob pressão, como a Mata Atlântica, o manejo dessas estradas e trilhas deve ser tratado com bastante atenção, observando-se as possíveis conseqüências para espécies raras e ameaçadas, bem como as transformações nas comunidades e processo ecológicos fundamentais para a manutenção do sistema, como as interações ecológicas. Com isso, destaca-se o valor de se manter extensas áreas de florestas maduras sem trajetos e com uso restrito. E quando houver necessidade de implementação de trajetos em meio a florestas, que sejam realizados esforços visando um manejo adequado e utilização controlada, principalmente quando ocorrerem no interior de áreas protegidas.

Os dados obtidos revelaram o impacto gerado pela implantação de trajetos em uma Unidade de Conservação da Mata Atlântica no sudeste do Brasil. No entanto, apesar de ser possível estender os principais padrões aqui encontrados para outras florestas ombrófilas do Brasil, mais estudos são necessários para esta extrapolação. Para consolidar as informações sobre esse tipo de impacto é recomendado que esforços similares sejam conduzidos em outras regiões intersectadas por trajetos, envolvendo a flora e também outros grupos da fauna. Contemplar diferentes distâncias de amostragem a partir da borda no sentido do interior da floresta também é desejável pois, os resultados poderiam indicar

qual a real permeabilidade dos impactos gerados pela presença dessas infraestruturas lineares em meio a um contínuo florestal. É importante também conduzir um aprofundamento em outros processos ecológicos que podem ser impactados, incluindo os diversos processos das interações entre animais e plantas.

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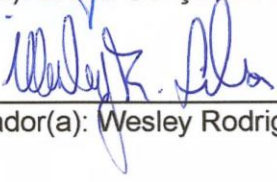
**ANEXOS****Anexo I – Declaração referente a bioética e biossegurança**

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**DECLARAÇÃO**

Em observância ao **§5º do Artigo 1º da Informação CCPG-UNICAMP/001/15**, referente a Bioética e Biossegurança, declaro que o conteúdo de minha Tese de Doutorado, intitulada **“EFEITOS DE ESTRADAS E TRILHAS NA VEGETAÇÃO, DISPONIBILIDADE DE FRUTOS E AVIFAUNA EM UMA ÁREA PROTEGIDA DE MATA ATLÂNTICA DO SUDESTE DO BRASIL”**, desenvolvida no Programa de Pós-Graduação em Ecologia do Instituto de Biologia da Unicamp, não versa sobre pesquisa envolvendo seres humanos, animais ou temas afetos a Biossegurança.

Assinatura:   
Nome do(a) aluno(a): Bruna Gonçalves da Silva

Assinatura:   
Nome do(a) orientador(a): Wesley Rodrigues Silva

Data: 12 de junho de 2017

**Anexo II – Declaração referente a direitos autorais****Declaração**

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Campinas, 12 de junho de 2017

Assinatura : \_\_\_\_\_

Nome do(a) autor(a): **Bruna Gonçalves da Silva**

RG n.º 43196138-4

Assinatura : \_\_\_\_\_

Nome do(a) orientador(a): **Wesley Rodrigues Silva**

RG n.º 7.690.326-6