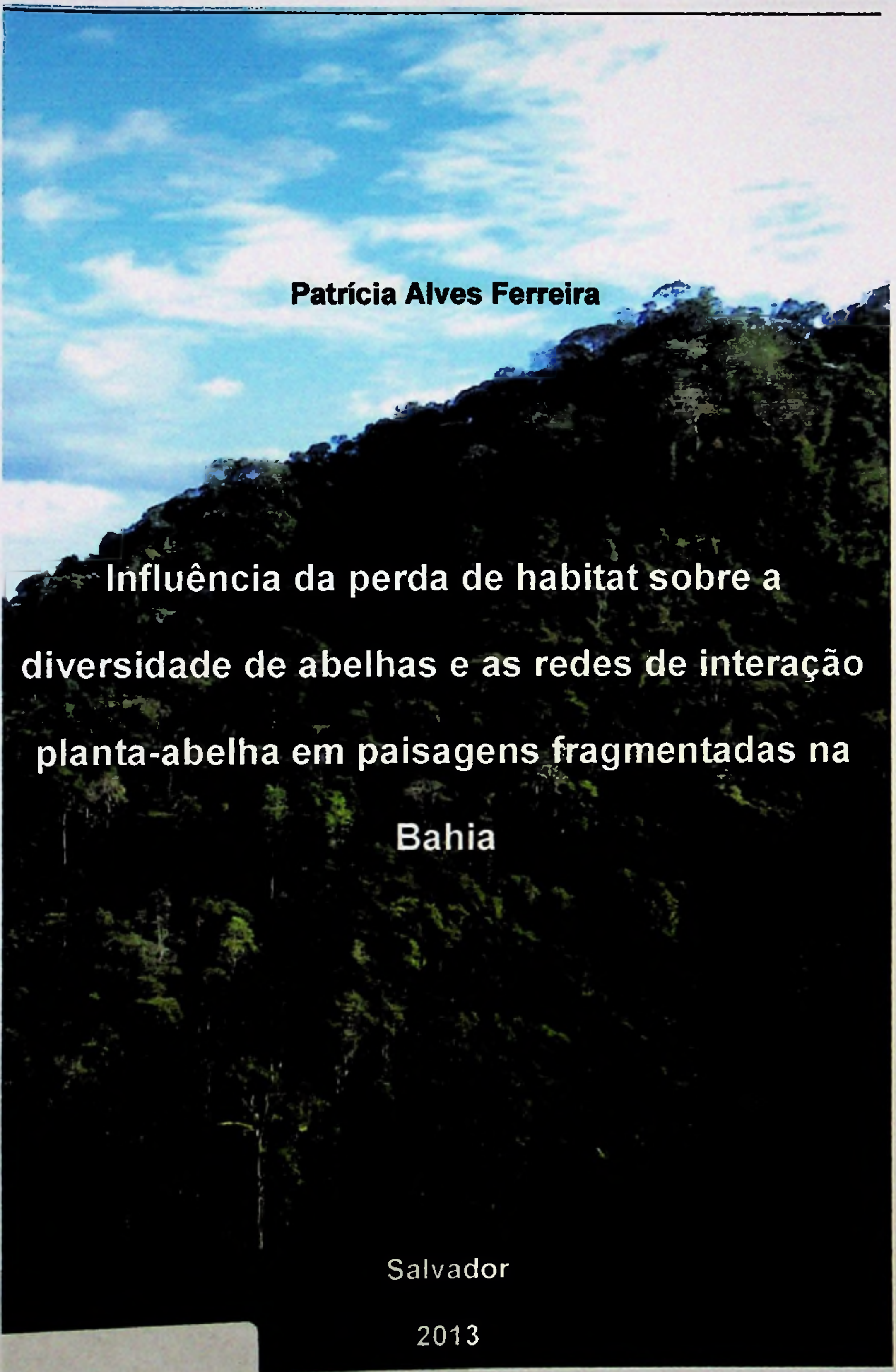


Patrícia Alves Ferreira

Influência da perda de habitat sobre a diversidade de abelhas e as redes de interação planta-abelha em paisagens fragmentadas na Bahia

Salvador

2013

Patrícia Alves Ferreira

Influência da perda de habitat sobre a diversidade de abelhas e as redes de interação planta-abelha em paisagens fragmentadas na Bahia

Tese apresentada ao Instituto de Biologia da Universidade Federal da Bahia, para a obtenção de Título de Doutor em Ecologia.
Orientadora: Profa.Dra. Blandina Felipe Viana.
Co-orientador: Prof.Dr. Danilo Boscolo.

Salvador

2013

Comissão Julgadora

Profa.Dra. Astrid de Matos Peixoto Kleinert
(USP)

Profa.Dra. Camila Magalhães Pigozzo
(UNIJORGE)

Prof.Dr. Eduardo Mariano Neto (UFBA)

Prof.Dr. Jean Paul Metzger (USP)

Profa.Dra. Blandina Felipe Viana (UFBA)
Orientadora

Prof.Dr. Danilo Boscolo (UNIFESP)
Co- Orientador

Sistema de Bibliotecas da UFBA

Ferreira, Patrícia Alves.
Influência da perda de habitat sobre a diversidade de abelhas e as redes de interação planta-abelha em paisagens fragmentadas na Bahia / Patrícia Alves Ferreira. - 2013.
104 p.: il.

Inclui apêndices.
Orientadora: Profª. Drª. Blandina Felipe Viana.
Co-orientador: Prof. Dr. Danilo Boscolo.
Tese (doutorado) - Universidade Federal da Bahia, Instituto de Biologia, Salvador, 2013.

1. Abelha. 2. Abelha - Pólen. 3. Fertilização de plantas. 4. Plantas. 5. Paisagens. 6. Florestas tropicais - Bahia. I. Viana, Blandina Felipe. II. Boscolo, Danilo. III. Universidade Federal da Bahia. Instituto de Biologia. IV. Título.

CDD - 595.799
CDU - 595.799

"Saber reconhecer o valor da natureza e de todo o ambiente na qual se encontra, é uma dádiva à espécie humana. Faltam-nos expressões suficientemente adequadas para descrevermo-nos. Das mais nobres virtudes da natureza, do mais simples gesto, da mais sábia realidade baseada na ciência, encontra-se o verdadeiro sentido de toda a existência, reconhecendo, assim, que com pequenos gestos vêm, também, grandes mudanças."

Jacqueline Ferreira

Dedicatória

Dedico esse trabalho, assim como tudo mais na minha vida, a minha família. Espero que os escritos nestas linhas possam de alguma forma, fazer suas vidas melhor. Obrigada por existirem e estarem sempre comigo.

Agradecimentos

Agradeço à Universidade Federal da Bahia e ao Instituto de Biologia.

Ao Programa de Pós-Graduação em Ecologia e Biomonitoramento, principalmente a Jussara.

A minha orientadora, Dra. Blandina Felipe Viana por ser muito mais que uma professora brilhante, uma orientadora genial e uma excelente profissional. Mas também por ser amiga, colega e "mãe".

A Dr. Danilo Boscolo, por ser muito mais que (co) orientador e me inspirar, incentivar e fazer acreditar na minha capacidade. Agradeço também a sua família por cuidar tão bem de mim.

Ao Dr. Koos Biesmeijer (Koos) por me receber, e orientar lindamente no NCB Naturalis, Leiden, Holanda. A Dra. Luisa G. Carvalheiro por me ensinar tanto. A Jesus Aguirre e Maria Pontes por todo o companheirismo, apoio e carinho. *Hartelijk dank aan al mijn nieuwe Nederlandse vrienden!*

Aos professores doutores Astrid Kleinert, Camila Pigozzo, Eduardo Mariano e Jean Paul Metzger por aceitarem avaliar esse trabalho.

A toda a minha segunda família que vive no LABEA-UFBA, por tudo!

Aos Lvtetes e ao Inomep!

Ao BIOSIS-UFBA, principalmente MsC. Thiago Mahlmann e Dra. Fávizia Oliveira, pela identificação e valiosas informações sobre a biologia dos hymenópteros. Ao FLORA-UFBA principalmente a Rodrigo Lopes e Dra. Nádia Roque por todo o apoio e identificação das plantas.

À Poliana Félix e Dr. André Freitas (UNICAMPI) e pela identificação dos lepdópteros; MsC. Laura Rocha e Dra. Sonia Casari (Museu de Zoologia - USP), e MsC. Daniela de Cássia Bená e Dr. Sergio Antonio Vanin (USP) pela identificação dos coleópteros; e Dra. Maria Virginia Guimarães e Luis Gustavo Tahuyl pela identificação dos dípteros.

À minha família, principalmente a Nenca (minha vó) que me iniciou no mundo da ciência alimentando minha curiosidade e bom senso.

A todos os meus amados amigos.

À Marinalva Ferreira por ser inspiração e exemplo.

A Luciano Lopes por ser e fazer muito mais!

À FAPESB, CAPES e CNPQ pelas bolsas de doutorado, doutorado sanduíche no exterior e suporte financeiro ao projeto.

Obrigada a todos! Não sei o que seria de mim sem vocês!

Índice

Resumo

Questões sobre como as modificações do habitat afetam a biodiversidade foram investigadas no projeto "Biogeografia, fragmentação florestal e limiares de extinção: um estudo *multi-táxon* na Mata Atlântica da Bahia, Brasil". Como parte desse projeto, na presente tese,verificamos como a redução de habitat afeta a diversidade de abelhas visitantes florais e a estrutura das redes planta-polinizador. A polinização é um dos principais processos ecológicos e é ameaçado pelo desmatamento e intensificação da agricultura. Entretanto, ainda há poucas evidências empíricas que analisaram esses efeitos. Este trabalho foi dividido em três capítulos. No primeiro capítulo, revisamos a literatura sobre os efeitos das alterações da paisagem natural e da intensificação da agricultura nas plantas, nos visitantes florais e nas redes de interação planta-polinizador. Vimos que as modificações nas paisagens diminuem a diversidade e disponibilidade de polinizadores, afetam a polinização cruzada e a reprodução sexual de plantas. Estes efeitos ocorrem, sobretudo, devido ao isolamento de habitats e a redução dos recursos florais e áreas para nidificação. Aproximadamente 50% dos 155 trabalhos analisados mostraram efeitos negativos da intensificação da agricultura sobre os polinizadores e o processo de polinização, como resultado da conversão de áreas naturais para usos agrícolas. Encontramos um trabalho que discutiu esses efeitos para redes de interação planta-polinizador. Vimos assim, que há uma lacuna no conhecimento sobre os efeitos das modificações das paisagens nas redes de interação planta-polinizador. No segundo capítulo, avaliamos como a perda de habitat afeta a diversidade de polinizadores no sub-bosque da Floresta Atlântica na Bahia. As abelhas são os principais polinizadores de angiospermas no mundo e são sensíveis as modificações do habitat natural. Nossos resultados mostram que as paisagens com maior proporção de floresta são importantes para as abelhas, mesmo quando a floresta é altamente fragmentada. No terceiro capítulo, questionamos como a perda de habitat afeta a estrutura das redes de interação planta-polinizador no sub-bosque de Floresta Atlântica na Bahia. Observamos que, nas paisagens com menos floresta, as redes são menores, têm menos espécies e são mais conectadas e aninhadas, *i.e.* apresentam mais interações entre espécies generalistas em um núcleo coeso, e há poucas espécies especialistas interagindo com generalistas nestas redes. Acreditamos que, devido a degradação ambiental, as espécies de visitantes florais generalistas são as mais capazes de permanecer nas paisagens mantendo as redes e também as populações vegetais. Concluindo, estudos sobre redes de interação na perspectiva da paisagem e em florestas tropicais podem fornecer informações para a conservação de plantas, polinizadores e da polinização. Habitats florestais são importantes para a manutenção da diversidade de abelhas, das redes planta-abelha, e dos serviços de polinização.

Palavras-chave: Abelhas, Polinizadores, Plantas, Redes de Interação, Paisagem, Sub-Bosque, Floresta Tropical, Bahia, Brasil.

Abstract

Questions about how landscape changes affect biodiversity were investigated in the project "Biogeography, forest fragmentation and extinction thresholds: a multi-taxon study in the Atlantic Rainforest of Bahia, Brazil." As part of this project, in this thesis we examine how habitat reduction affects the diversity of flower visiting bees and the structure of plant-pollinator networks. Pollination is a major ecological process and is threatened by deforestation and agricultural intensification. However, there is a lack of empirical evidence that analyzed these effects. This work encompasses three chapters. In the first chapter we review the literature on the effects of natural landscape changes and agricultural intensification on plants, pollinators and plant-pollinator networks. We have seen that changes in landscapes decrease the diversity and availability of pollinators, affect cross-pollination and sexual reproduction of plants. These effects occur, mainly, because habitat isolation and reduction of floral resources and nesting areas. Approximately 50% of the 155 analyzed studies showed negative effects of agricultural intensification, with conversion of natural areas into agricultural uses. We found one study that discussed these effects for plant-pollinator networks. So, there is a gap in knowledge about the effects of changes in landscapes on plant-pollinator networks. In the second chapter we evaluate how habitat loss affects pollinator diversity in the understory of the Atlantic Forest in Bahia. Bees are the main pollinators of flowering plants in the world and are sensitive to changes in the natural habitat. Our results show that landscapes with a higher proportion of forest are important to bees, even when the forest is highly fragmented. In the third chapter we question how habitat loss affects the structure of plant-pollinator networks in the understory of the Atlantic Rainforest in Bahia. We observed that in less forested landscapes networks are smaller, have fewer species and are more connected and nested, *i.e.* have more generalist species interacting with each other in a cohesive core, and there are few specialist species interacting with generalists in these networks. We believe that, due to environmental degradation, generalist flower visitor species are better able to remain in the landscapes, maintaining the networks and also the plant populations. In conclusion, studies on interaction networks from the perspective of the landscape and tropical forests can provide important insights for the conservation of plants, pollinators and pollination. Forest habitats are important for maintaining the diversity of bees, plant-bee networks, and pollination services.

Keywords: Bees, Pollinator, Plant, Networks, Habitat Changes, Landscape, Understory, Atlantic Rainforest, Bahia, Brazil.

Apresentação

> *"The loss and fragmentation of natural habitats by human activities are the main driving forces behind current biodiversity loss. Animal-mediated pollination is a key process for the sexual reproduction of most extant flowering plants, and the one most consistently studied in the context of habitat fragmentation."*
>
> Aguilar et al. 2006

As modificações do habitat põe em risco a biodiversidade. A partir de certos valores de redução de hábitat a perda de biodiversidade pode ser abrupta. Contudo são escassas as informações para quais comunidades essa perda abrupta de biodiversidade é observada, ou quais são os valores críticos de perda de hábitat, ou ainda como podem ser mitigados esses efeitos. Estas e outras questões estão sendo investigadas por pesquisadores e estudantes do Instituto de Biologia da Universidade Federal da Bahia vinculados ao projeto "Biogeografia, fragmentação florestal e limiares de extinção: um estudo *multi-táxon* na Mata Atlântica da Bahia". Os estudos desenvolvidos incluem desde a comparação da biodiversidade entre localidades que possuem diferentes quantidades de floresta e diferentes históricos biogeográficos até o desenvolvimento de modelos computacionais que simulam a resposta dessas comunidades à perda de hábitat. Uma das metas do projeto é contribuir para a produção de conhecimento científico que possa colaborar com a gestão da biodiversidade, principalmente no estado da Bahia.

A presente tese faz parte desse projeto, e procura verificar os efeitos da redução do habitat na diversidade de abelhas visitantes florais e na estrutura das redes de interação mutualísticas entre plantas e polinizadores. A polinização é um dos principais processos ecológicos em ambientes terrestres. Uma das principais ameaças a esse processo é a perda de habitat provocada pelo desmatamento e intensificação da agricultura. As mudanças da paisagem, assim como a quantidade e qualidade do hábitat e a configuração das paisagens podem modificar a diversidade, o comportamento dos polinizadores e consequentemente a reprodução sexual das plantas em sistemas naturais e agrícolas. Entretanto poucos trabalhos empíricos analisam as interações planta-polinizador e as respostas das comunidades às mudanças na paisagem.

Mais recentemente foram desenvolvidos modelos teóricos para acessar os efeitos das mudanças na paisagem sobre o mutualismo planta-polinizador. Esses modelos preveem que as comunidades de polinizadores e de plantas são afetadas através da desestabilização da estrutura das redes de interação planta-polinizador. Os modelos mostram também que, as comunidades persistem a vários níveis de extinção, mas que há um limiar, ou seja, um valor crítico no qual as comunidades colapsam e que os animais são mais rapidamente afetados que as plantas. Entretanto, ainda há poucas evidencias empíricas que suportem essas previsões.

Este trabalho foi dividido em três capítulos, que serão submetidos individualmente a periódicos científicos especializados para a divulgação dos principais resultados. O primeiro capítulo da tese apresenta uma revisão da literatura especializada na qual fizemos um levantamento sobre o conhecimento empírico e teórico acerca dos efeitos das alterações na paisagem, como a perda e a fragmentação de habitats nas interações planta-polinizador. Além disso, neste capítulo questionamos o que se sabe sobre os efeitos das modificações na paisagem nas redes de interação planta-polinizador, e como a intensificação da agricultura convencional afeta as interações planta-polinizador. Vimos que as modificações nas paisagens naturais afetam a polinização cruzada e a reprodução sexual de plantas. Porém, há uma lacuna no conhecimento sobre os efeitos das modificações nas paisagens naturais nas redes planta-polinizador. Abordagens integradas podem ser úteis para a conservação dessas interações e dos serviços de polinização em ecossistemas naturais e agrícolas. Esse capítulo foi publicado no periódico *Ecological Indicators* e está disponível *online* desde setembro de 2012.

No segundo capítulo, avaliamos como a perda de habitat afeta a diversidade de abelhas visitantes florais no sub-bosque da Floresta Atlântica remanescente na Bahia. As abelhas são os principais polinizadores de angiospermas no mundo. Por isso esses animais têm elevada importância ecológica e econômica. As abelhas são sensíveis às modificações do habitat natural, pois dependem desse para o uso de recursos alimentares e locais de nidificação. Neste capítulo levantamos três hipóteses: 1) Há maior diversidade de abelhas em paisagens com maior cobertura florestal; 2) Áreas com maior abundância de flores apresentam maior diversidade de abelhas; e 3) A perda do habitat natural afeta diferentemente os grupos funcionais de abelhas caracterizados pelos tipos de ninhos e de socialidade.

Finalmente, no terceiro capítulo, discutimos sobre como a perda de habitat afeta a estrutura das redes de interação planta-polinizador no sub-bosque de Floresta Atlântica na Bahia. Mais especificamente, caracterizamos e determinamos o padrão estrutural dessas redes, e hipotetizamos que a perda de habitat influencia negativamente o tamanho das redes (número total de espécies animais e plantas), a conectância e o aninhamento das redes.

Os métodos comuns aos capítulos 2 e 3 serão descritos nas seções "Área de Estudo" e "Coleta de Dados" nas páginas 20-27.

Introdução Geral

1. Introdução Geral

A perda de habitats naturais modifica a disponibilidade de recursos, o tamanho das populações e aumenta as probabilidades de extinção de espécies (Fahrig 2003). As alterações na paisagem são as maiores ameaças à biodiversidade, pois modificam a estrutura das comunidades, isolam populações, podem modificar os processos ecológicos, afetando negativamente a sobrevivência das espécies e interações entre espécies (Steffan-Dewenter & Tscharntke 2002, Steffan-Dewenter et al 2002, Tscharntke et al. 2002, Fahrig 2003, Bascompte 2009a). As interações entre espécies podem ser bons modelos para investigar a qualidade dos ambientes modificados, uma vez que sua conservação pode ser mais importante para a manutenção da biodiversidade e de serviços ecológicos do que a preservação de espécies isoladas em ambientes fragmentados (Steffan-Dewenter & Tscharntke 1999, Diaz & Cabido 2001, Forup & Memmott 2005).

A redução da quantidade de habitat pode modificar o comportamento de forrageio dos insetos visitantes florais, limitando ou impedindo a movimentação desses entre as manchas de habitat remanescentes (Brosi et al. 2007). Esses processos também modificam os padrões de transferência de pólen (Memmott et al. 2004, Fortuna & Bascompte 2006), restringindo a quantidade de pólen compatível depositado sobre os estigmas e afetando negativamente a reprodução sexual de plantas polinizadas por animais (Nazareno & Carvalho 2009). O isolamento espacial de manchas de habitat limita o número de polinizadores disponíveis, reduzindo o sucesso reprodutivo das plantas, aumentando a depressão endogâmica e a erosão genética de populações isoladas (Aizen & Feinsinger 1994a, 1994b, Steffan-Dewenter & Tscharntke 1999).

A polinização por animais é um processo ecológico chave nos ecossistemas terrestres que garante o sucesso reprodutivo das plantas e, indiretamente, mantém outras espécies animais que dependem dessas plantas (Kearns et al. 1998, Fortuna & Bascompte 2006). Em florestas tropicais, onde a diversidade vegetal é extremamente elevada, a polinização por animais, principalmente abelhas, é muito importante para a manutenção das comunidades vegetais (Bawa 1990, Tabarelli et al. 2008). Por exemplo, nas florestas tropicais da América Central, Amazônia e da costa atlântica brasileira, os animais são responsáveis pela reprodução da maioria das espécies vegetais (Bawa 1990, Ramalho & Batista 2005). Os animais visitantes florais parecem ser mais sensíveis e respondem mais rapidamente às mudanças no habitat do que as plantas (Aizen & Feinsinger 1994b, Steffan-Dewenter & Tscharntke 1999, Taki & Kevan 2007). As relações mutualistas entre plantas e animais são importantes para a manutenção da biodiversidade, principalmente em ambientes tropicais (Bascompte 2007).

A demanda por serviços de polinização aumenta, ao mesmo tempo em que a diversidade de polinizadores diminui nas regiões temperadas e tropicais. De todas as culturas ao redor do mundo, quase 5% (regiões temperadas) e 8% (regiões tropicais) são dependentes de polinização animal (Aizen et al. 2009). As abelhas apresentam grande importância ecológica e econômica (Brosi et al. 2007, Winfree et al. 2009, 2011), e são afetadas pela perda de suas fontes de alimento e locais de nidificação, devido à perda e fragmentação dos habitats naturais (Kearns et al. 1998, Potts et al. 2010). Nos trópicos, pouco se sabe sobre a diversidade das comunidades de abelhas em paisagens alteradas. Além disso, muitos estudos utilizam a comparação entre fragmentos de diferentes tamanhos em uma mesma paisagem e poucos estudos utilizam diferentes paisagens como unidades amostrais para avaliar como a estrutura da paisagem afeta abelhas e outros animais polinzadores (Viana et al. 2012).

Redes de interações bióticas desempenham um papel importante na organização e persistência da biodiversidade e podem afetar a resistência dos ecossistemas às alterações da paisagem (Fortuna & Bascompte 2006; Bascompte 2009a). Como essas mudanças afetam muitas espécies ao mesmo tempo, essas abordagens permitem análises de várias espécies e suas interações simultaneamente (Tylianakis et al. 2008). Por isso, as redes de interações são descritores úteis de sistemas ecológicos e fornecem um quadro conceitual para avaliar as consequências das perturbações nas comunidades ecológicas face às mudanças ambientais (Bascompte 2009a).

Estudos de conservação geralmente visam a preservação da diversidade de espécies. Contudo, a extinção de espécies como um resultado de alterações ambientais tais como a perda de habitat, pode levar à perda das interações entre espécies, quando um dos parceiros desaparece. Assim, a perda da interação propriamente dita entre as espécies pode também conduzir à extinção de um ou ambos os parceiros. Portanto, não considerar as redes ecológicas dentro das quais uma espécie ameaçada está incorporada pode levar a medidas de gestão contraproducentes (Tylianakis et al. 2010). Estudos sobre redes ecológicas permitem uma melhor avaliação dos efeitos de mudanças de habitat sobre a perda de biodiversidade e podem fornecer suporte para a conservação das espécies e dos ambientes (Forup & Memmott 2005, Sabatino et al. 2010).

Redes mutualistas têm distribuição heterogênea das interações, são aninhadas e podem ser compartimentalizadas. As redes aninhadas têm um núcleo coeso de interações assimétricas, onde as espécies generalistas interagem umas com outras e espécies especialistas interagem com o subgrupo de espécies generalistas, criando um centro denso de interações entre espécies. Por exemplo, plantas raras dependem, em grande parte, de polinizadores generalistas que, por sua vez, dependem de plantas generalistas, mais comuns nas comunidades (Bascompte et al. 2003, Bascompte 2009b). Essas características proporcionam estabilidade ao sistema e respostas alternativas das espécies de plantas e animais às mudanças ambientais (Bascompte et al. 2003, Jordano et al. 2007).

A arquitetura e a estrutura das redes mutualísticas podem fornecer informações importantes que ajudam a compreender como as espécies respondem às mudanças ambientais (Tylianakis et al. 2008, Bascompte 2010). Adicionalmente, através da compreensão da estrutura de redes ecológicas, é possível avaliar como estas redes são capazes de resistir à extinção de espécies em cenários que sofreram ou estão sofrendo perda de habitat, ou outras influências antropogênicas. Modelos sugerem que extinções aleatórias não são capazes de afetar a estrutura da rede, entretanto, quando as espécies generalistas, que interagem com muitas outras espécies nas redes, são extintas, as redes tendem a entrar em colapso muito rapidamente (Bascompte 2009a).

Poucos estudos analisaram as interações entre plantas e visitantes florais a partir da perspectiva das redes tróficas em ambientes tropicais brasileiros (Pigozzo & Viana 2010). Além disso, poucos estudos empíricos testaram os efeitos de mudanças na paisagem nas redes de interações planta-polinizador (Aizen & Feinsinger 1994b, Steffan-Dewenter & Tscharntke 1999, Memmott et al. 2004, Fortuna & Bascompte 2006, Ferreira et al. 2013), em comunidades naturais (Diaz & Cabido 2001), na escala da paisagem (Lennartsson 2002) e na Floresta Atlântica brasileira (Ramalho & Batista 2005).

A Floresta Atlântica brasileira é um ambiente extremamente diverso contendo cerca de 1-8% do total de espécies do mundo e apresentando altas taxas de endemismo de espécies. Este bioma tem sido historicamente submetido à degradação e restam apenas 12% de sua extensão original distribuídos em manchas remanescentes, muitas, menores do que 50 ha. Contudo esse importante ambiente foi pouco estudado (Ribeiro et al. 2009). Os pequenos fragmentos remanescentes da Floresta Atlântica brasileira podem não incluir toda a diversidade de plantas e da fauna associada. No entanto, a conservação de habitats florestais é importante para a manutenção das interações entre as espécies e da biodiversidade. Por isso, florestas tropicais devem ser mantidas e protegidas (Lopes et al. 2009).

1.1. Objetivos

Nesse contexto, a presente tese teve por objetivo (1) examinar o que há de conhecimento disponível sobre a influência da perda de habitat nos polinizadores, plantas e redes de interação planta-polinizador; (2) verificar a influência da perda de habitat em paisagens florestais fragmentadas na Bahia, Nordeste brasileiro sobre a riqueza e abundância de abelhas visitantes florais; e (3) sobre a estrutura das redes de interação entre plantas e abelhas. Neste estudo, concentramo-nos na comunidade vegetal do sub-bosque da Floresta Atlântica brasileira, um ambiente tropical pouco estudado, extremamente biodiverso e altamente ameaçado (Ribeiro et al. 2009, Lopes et al. 2009).

Inicialmente, para o primeiro capítulo, fizemos um levantamento da literatura especializada disponível e questionamos quais os efeitos das alterações na paisagem nas interações plantas-visitantes florais e como intensificação da agricultura afeta essas interações. Objetivamos entender se há informações suficientes para a criação de paisagens amigáveis às interações planta-polinizador com efeitos positivos para a conservação e manejo de plantas, polinizadores e serviços de polinização em habitats naturais, alterados e agrícolas, assim como sugerido por Viana et al. (2012).

Avaliamos, no segundo capítulo, como a perda de habitat afeta a diversidade de polinizadores no sub-bosque da Floresta Atlântica na Bahia. Apesar de nossos procedimentos de amostragem incluírem todos os insetos visitantes florais, focamos esse estudo particularmente nas abelhas, o principal grupo de polinizadores de angiospermas (Roubik 1995, Ramalho & Batista 2005), e o grupo mais abundante em nossas amostras para todos os locais de estudo (70% de todos os visitantes florais coletados). A diversidade de abelhas está positivamente associada com a diversidade de plantas nos habitats (Ramalho & Batista 2005, Grundel et al. 2010). As abelhas dependem do habitat natural para o uso de recursos alimentares e locais de nidificação (Brosi et al. 2007, Kremen et al. 2007, Ricketts et al. 2008). Sendo assim, hipotetizamos que há maior diversidade das comunidades de abelhas em paisagens onde há maior cobertura florestal no nível da paisagem e no nível dos fragmentos. Esperávamos, também, encontrar maior diversidade de abelhas em áreas com maior abundância de flores. Investigamos, ainda, como a perda de habitat natural afeta os grupos funcionais de abelhas caracterizados por tipos de ninhos e socialidade.

Finalmente, no terceiro capítulo, objetivamos entender como a perda de habitat afeta redes de interação planta-abelha no sub-bosque de Floresta Atlântica na Bahia. Mais especificamente, pretendemos caracterizar redes de interação planta-abelha e determinar o padrão estrutural dessas redes. Esperávamos que a redução da cobertura habitat afetasse a estrutura e topologia das redes de interação planta-abelhas (Guimarães et al. 2007). Assim, a nossa hipótese é que a perda de habitat influencia negativamente o tamanho das redes planta-abelhas, reduzindo o número de espécies de abelhas e plantas por rede, e influenciando positivamente a conectância e o aninhamento das redes.

1.2. Área de Estudo

Este estudo foi realizado no sub-bosque da Floresta Atlântica na Bahia, região Nordeste do Brasil, um ambiente extremamente diverso, pouco conhecido e que abriga espéces ameaçadas de extinção (Ribeiro et al. 2009). Clima dessa região é classificado com tropical umido (*Af* - Köppen-Geiger) com temperatura média entre 24ºC e 27°C, pluviosidade total anual superior a 2000 mm de precipitação e precipitação média mensal superior a 60 mm em todos os meses do ano (Peel et al. 2007). Sete paisagens quadradas de 36km^2 (6 x 6 km, totalizando 3600ha) foram amostradas em um gradiente de paisagens variando de 15 a 55% de cobertura de florestal. Amostramos a Floresta Atlântica em estágios de regeneração variando de médio a avançado e altitude variando entre 23m e 416m (ver Tabela 0). O tamanho das paisagens (36km^2) foi determinado arbitráriamente, pois esta escala pode permitir a observação de processos como a movimentação local de populações, por exemplo. Áreas desmatadas compostas de pastagem e/ou plantio de vegetação herbáceas/arbustivas foram consideradas matriz de não-habitat (Figura 1).

Tabela 0: Localização das sete paisagens de 36km^2 (3600ha) amostradas ao longo de um gradiente de cobertura florestal de 15% a 55%, de Floresta Atlântica na Bahia, Brasil.

Localização (cidades abrangidas)	Cobertura Florestal (%)	Altitude	Estádio Successional	Tipo de Floresta	Dossel (m)	Coordenadas Geográficas
Pres. Tancredo Neves	15	181	Médio	Ombrófila	8-11	13°23'28"S 39°19'06"W
Valença/Pres. T. Neves	25	144	Médio	Ombrófila	10-13	13°20'32"S 39°11'43"W
Amargosa/Ubaíra	30	416	Avançado	Ombrófila	12-15	13°07'19"S 39°39'34"W
Taperoá/Nilo Peçanha/Ituberá	35	31	Avançado	Ombrófila	11-14	13°38'58"S 39°12'37"W
Wenceslau Guimarães	40	249	Médio/Avançado	Ombrófila	11-14	13°33'14"S 39°42'07"W
Camamu	45	23	Médio/Avançado	Ombrófila	11-14	14°00'51"S 39°10'56"W
Jaguaripe	55	47	Médio	Ombrófila	10-13	13°11'44"S 39°01'26"W

Figura 1: Exemplos de áreas de matriz de não habitat compostas de plantio de culturas herbácea/arbustivas e/ou pastagens em paisagens de 36km^2 (3600ha) amostradas ao longo de um gradiente de cobertura florestal de 15% a 55%, na Floresta Atlântica da Bahia, Nordeste do Brasil.

Com base no Atlas de Remanescentes Florestais da Mata Atlântica (www.sosma.org.br e www.inpe.br), selecionamos as sete paisagens de 36km2 assumindo o intervalo entre 15, 25, 30, 35, 40, 45 e 55%, até ± 2% (Fig. 2A). Utilizamos imagens de satélite com projeção cartográfica LAT/LONG e datum WGS84 (World Geodetic System1984 - 24S), como resultado do mapeamento feito pelo SOS Mata Atlântica. Nós transformamos essas imagens em arquivos raster (Geo-TIFF) com pixels de 20m de lado (extensão de 300x300 pixels) no software ArcGIS 9.3. Os arquivos Geo-TIFF foram analisados por meio de métricas de classe no software FRAGSTATS 4.1. Devido à presença de manchas de floresta extremamente pequenas nas paisagens, decidimos usar as métricas ponderadas pela área dos fragmentos (McGarigal & Marks 1995).Estabelecemos três critérios para controlar a variabilidade ambiental entre as paisagens. Primeiro cada paisagem de 36km^2 deveria estar inserida em uma paisagem mais ampla (18km de lado, totalizando uma área de 324km^2) com percentual de cobertura florestal semelhante entre as escalas. Segundo, ambas as paisagens de 36km^2 e 324km^2 deveriam apresentar valores semelhantes para o índice de maior fragmento (*Large patch index - LPI*), que determina o percentual ocupado pela maior área de floresta na paisagem (McGarigal & Marks 1995). Este critério visou evitar a influência de fragmentos florestais que pudessem servir como áreas fonte nas proximidades das paisagens amostradas, que poderiam confundir os resultados (Fig. 2B). Terceiro, pelo menos 80% da matriz de ambas as paisagens deveria consistir de áreas de não-habitat compostas por áreas não florestadas de pastagem e/ou vegetação herbáceo/arbustiva. Dessa forma, evitamos que diferentes matrizes tivessem influência na resposta das espécies, por exemplo, matrizes de áreas urbanas que poderiam servir como barreira à dispersão e movimentação de espécies, ou matrizes arbóreas que poderiam servir como áreas fonte de espécies (Swift & Hannon 2010).

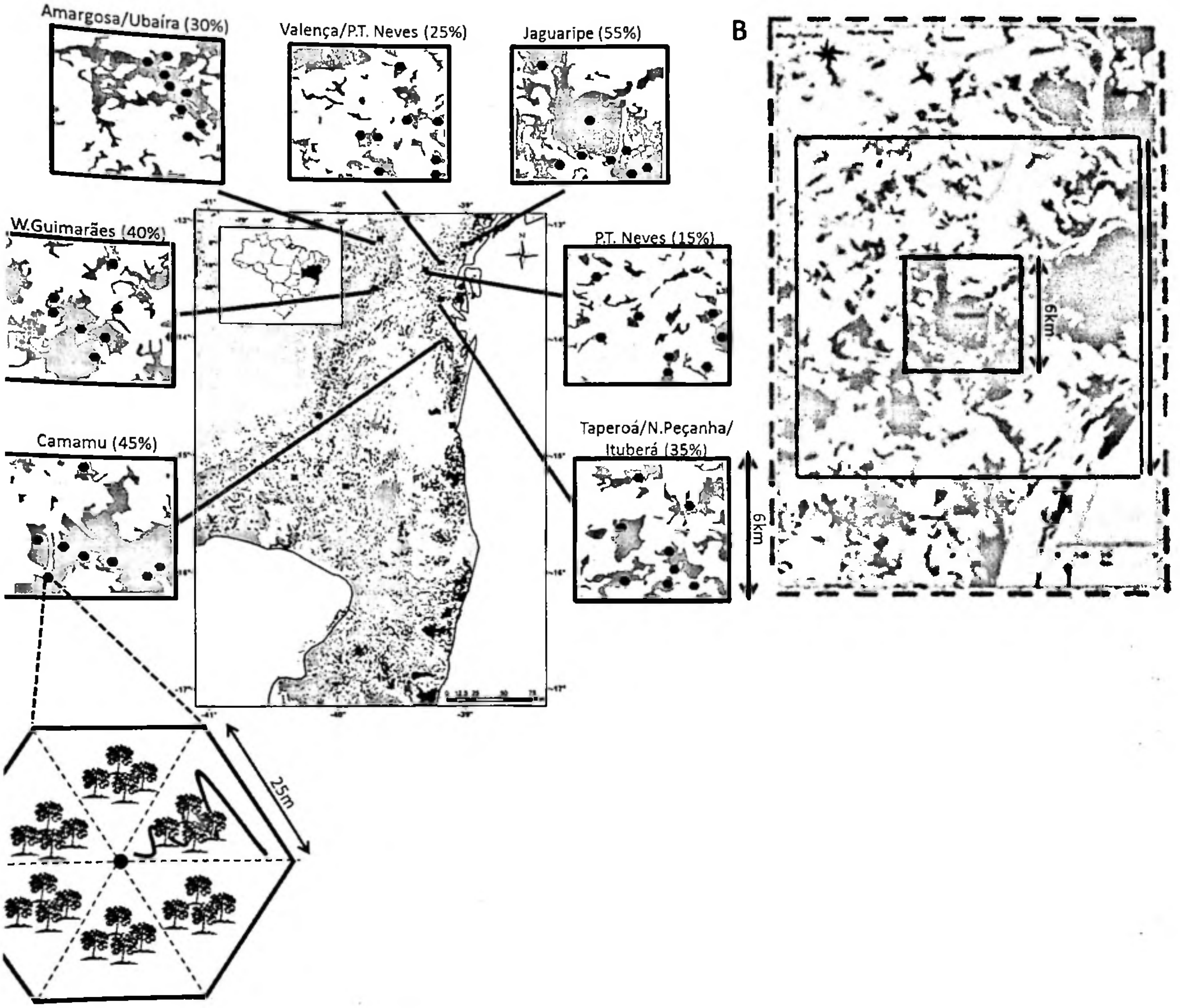


Figura 2: A) Paisagens 36km^2 (3600ha) amostradas, com respectivos percentuais de cobertura florestal ao longo de um gradiente de cobertura florestal de 5% a 60%, na Floresta Atlântica da Bahia Nordeste do Brasil. As paisagens foram selecionados a partir do Atlas de Remanescentes Florestais da Mata Atlântica em estágios de regeneração de médio a avançado (www.sosma.org.br e www.inpe.br). C) Parcelas hexagonais de 25m de lado (0.06ha). Em detalhe, a linha interna representa o caminho padronizado para amostragem de visitantes florais a partir do centro para as bordas de hexágonos. B) Paisagem 36km^2 (6 x 6km), cinza = floresta, branco = matriz não-florestal. Cada paisagem foi inserida numa área de 324km^2 (18 x 18km), com valor de percentagem de cobertura florestal semelhante à percentagem da paisagem com 36km^2.

1.3. Coleta dos dados

Os dados foram coletados em 2011, em dois períodos (de janeiro a abril e de agosto a novembro), para evitar o período mais chuvoso do ano e variações sazonais. Em cada uma das nove paisagens, foram selecionadas através de sorteio oito parcelas hexagonais regulares com 25m de lado (0.16ha), totalizando 63 parcelas e 11.5ha amostrados. As parcelas foram estabelecidas dentro dos fragmentos florestais, distando, pelo menos, 50m de todas as bordas (Fig. 2C), a uma distância de pelo menos 600m entre si para garantir a independência de dados (Taki & Kevan 2007). As unidades amostrais (parcelas hexagonais) apresentaram altura do dossel superior a oito metros. Em cada parcela, medimos a riqueza e abundância das espécies de abelhas, bem como a abundância de plantas com flores no sub-bosque. Abelhas visitantes florais foram coletadas em cada parcela durante um dia por parcela, totalizando oito dias por paisagem, em dias quentes e sem chuva (20-31°C), das 6:00-17:00h, totalizando 96 horas de amostragem por paisagem. Em cada parcela, nos orientamos por um caminho padronizado do centro para as bordas dos hexágonos, e fizemos observações de 15 minutos em todas as plantas com flores em alturas até dois metros acima do solo. Durante essas observações, as abelhas visitantes florais dessas plantas foram coletadas com redes entomológicas. Se abelhas visitantes florais escapassem antes de serem coletadas, nós registrávamos o morfotipo da abelha e o horário de visita. Quando possível os morfotipos foram identificados em gênero ou espécie.

Nós coletamos ramos floridos de todas as espécies de plantas encontradas no hexágono para identificação. A fim de estimar a abundância de flores por espécies por hexágono, contamos o número de flores por ramo de um indivíduo de cada espécie de planta com flor. Multiplicamos esse valor para todos os ramos da planta e para o número de indivíduos dessa espécie no hexágono.

Abelhas e plantas foram identificadas por especialistas no nível taxonômico mais específico possível, de acordo com a classificação proposta por Michener

(2000) e APG III (Bremer et al. 2009), respectivamente. As abelhas foram fixadas e depositadas no Museu de Zoologia - UFBA (Universidade Federal da Bahia). As plantas foram depositadas no Herbário Alexandre Leal Costa (ALCB) - UFBA.

Capitulo I

What do we know about the effects of landscape changes on plant-pollinator interaction networks?

Ecological Indicators 31 (2013) 35–40

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

What do we know about the effects of landscape changes on plant–pollinator interaction networks?

Patrícia Alves Ferreira [a,1], Danilo Boscolo [b,*], Blandina Felipe Viana [a,1]

[a] *Federal University of Bahia – UFBA, Biology Institute, Rua Barão de Geremoabo s/n, 40170-210 Salvador, BA, Brazil*
[b] *Federal University of São Paulo – UNIFESP, Rua Prof. Arthur Riedel, 275 – Jd. Eldorado, 09972-270 Diadema, SP, Brazil*

ARTICLE INFO

Keywords:
Landscape fragmentation
Pollination
Animal–plant interactions
Ecosystem services
Agricultural development

ABSTRACT

Biotic interactions play an important role on the organization and persistence of biodiversity. Unnatural modifications of landscape structure such as habitat loss and fragmentation can isolate populations and disrupt biological communities, affecting species survival and altering the complex set of relationships between plants and pollinators. Plant–pollinator interaction networks have characteristics such asymmetry and nestedness that may influence the stability and robustness of networks to landscape changes. Species in mutualistic networks might respond to landscape modifications with a sudden collapse at critical habitat destruction thresholds. In this work we review general trends in the scientific literature related to the effects of landscape changes on plant–pollinator networks. For this, a survey in Scopus and Web of Knowledge databases was conducted in May 2011 using all seven possible combinations of the terms "pollinat*" with the terms "landscape", "habitat loss" and "network". We found 155 papers and 92% of those showed significant effects of landscape changes on pollinator diversity and plant reproductive success. Approximately 50% of all analyzed papers showed effects of agriculture intensification as a result of increases in the conversion of natural areas into agricultural crops on plant–pollinator interactions. Landscape modifications affected cross-pollination and the sexual reproduction of plants largely because of reduced diversity and availability of pollinators due to increased habitat isolation and reduction of floral resources and nesting areas in the remaining available habitat. An integrated approach concerning the effects of modified landscapes on natural ecosystems regarding how these variations can affect the stability and robustness of pollination networks can be extremely useful for conservation of plant–pollinators interactions, with positive overall consequences for conservation of plant, pollinators and pollination services in natural and agricultural ecosystems.

1. Introduction

Biodiversity is more than a collection of species. Networks of biotic interactions involving predation, parasitism and pollination play an important role on the organization and persistence of biodiversity (Fortuna and Bascompte, 2006; Bascompte, 2009). In addition, biotic interactions may affect the resilience of ecosystems to landscape modifications (Montoya, 2008). Because of that, studies including information on ecological networks often allow a better assessment of the possible effects of habitat changes on biodiversity loss (Forup and Memmott, 2005; Montoya, 2008; Sabatino et al., 2010). These studies have great potential to assist in the conservation of biodiversity (Jongman, 2004).

Plant–pollinator networks consist of a special type of ecological network with specific characteristics, such as asymmetry of interactions, with specialist species frequently interacting with generalists and nestedness (Bascompte, 2009). These networks structural attributes may influence the stability and robustness of interactions and network responses to changes (Bascompte et al., 2003). Nestedness and asymmetry generate cohesive network cores which may help withstand species loss, since the most linked species play a central role in the network stability (Bascompte et al., 2003; Bascompte, 2009). For that reason plant–pollinator networks could be more resistant to negative effects of landscape changes (Ramos-Jiliberto et al., 2009; Olesen and Jordano, 2002; Memmott et al., 2004, 2005; Petanidou et al., 2008; Vilà et al., 2009). Species in mutualistic networks might also respond to landscape modifications with a sudden collapse at critical habitat destruction thresholds (Fortuna and Bascompte, 2006). Kaiser-Bunbury et al. (2010) showed that there must be a strong impact

---

[*] Corresponding author. Tel.: +55 11 33193300; fax: +55 11 40436428.
E-mail addresses: patybio13@yahoo.com.br (P.A. Ferreira), danilo.boscolo@unifesp.br, danilo.boscolo@gmail.com (D. Boscolo), blandefv@ufba.br (B.F. Viana).
[1] Tel.: +55 71 3283 6554; fax: +55 71 3283 6513.

1470-160X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2012.07.025

on networks stability when more than half of the most connected species is lost and most network cores can no longer be supported. At these critical values the extinction of pollinators may abruptly increase, leading to the disruption and collapse of plant–pollinator interactions (Viana et al., 2012).

Landscape changes caused by habitat loss and fragmentation have become a central issue in conservation biology (Haila, 2002; Fischer and Lindenmayer, 2007). Decreasing habitat availability at the landscape level can isolate populations and disrupt the structure of biological communities, directly affecting species survival and interactions. These processes can alter the complex set of relationships between plants and pollinators (Fortuna and Bascompte, 2006), promoting higher rates of plant self-fertilization and consequent inbreeding depression due to reduced success of animal driven cross-pollination (Lennartsson, 2002). This can lead to important changes in both presence and relative abundance of different reproductive traits of plant species, resulting in reduced functional diversity of plant communities in natural areas (Girão et al., 2007).

In this paper we aimed to search for general trends in the scientific literature dealing with the effects of landscape changes, including habitat loss and fragmentation on plant–pollinator interactions. We asked what is known about the effects of landscape changes on plant–pollinator interaction networks and inquired how agriculture intensification with increased conversion of natural areas into crops can affect plant–pollinator interactions. Overall, we want to understand if there is enough knowledge available to efficiently design plant–pollinator friendly landscapes with positive effects for the conservation and management of plants, pollinators and pollination services in changed habitats.

2. Procedures

We conducted a survey of the scientific literature in May 2011 using all seven possible combinations of the terms "pollinat*", "landscape", "habitat loss" and "network" in the Web of Science and Scopus databases. From the search results we selected all articles which dealt with the effects of landscape modifications on pollinators, plants and/or pollination. We did not include in the analysis papers that exclusively evaluated the responses of plant–pollinator networks without any explicit mention to the effects of landscape change. We performed exploratory analyses to identify general patterns in the scientific literature regarding the effects of habitat modification on plant–pollinator interactions. In cases where the same study measured more than one variable, we considered all response variables separately.

Many studies analyzed in the present review used some terms without an explicit or specific definition, what could make proper interpretations difficult. Definition of concepts and their standardization is also an important step when surveying scientific knowledge for environmental management purposes as attributing the effect of a certain term to a similar but essentially different factor can make it difficult to understand the available information and may lead to wrong conclusions. Therefore, to avoid the drawbacks derived from conceptual problems, we standardized all technical terminology related to landscape ecology in accordance with Metzger (2001) and Fahrig (2003), as suggested by Viana et al. (2012), and normalized papers analyzed according to the categories previously defined (Table 1).

3. Overview

We found 155 papers that evaluated directly or indirectly, explicitly or implicitly, the effects of landscape modifications on plant–pollinator interactions. Overall, 92% (143 papers) showed significant effects of landscape changes on the diversity, frequency and movement patterns of pollinators and/or on the diversity, reproductive systems, reproductive success and productivity of plants. Most effects were relative to changes of the spatial distribution of landscape elements (65%). About one quarter of the analyzed papers reported effects of landscape composition, specially the proportion of land covered by different types of environments (Supplementary material 1).

One of the most frequently observed patterns was that pollinators diversity is affected by habitat loss and fragmentation (Liow et al., 2001; Darvill et al., 2006; Nates-parra et al., 2008; Winfree et al., 2009; Quintero et al., 2010), mostly due to increased isolation of habitat patches (Greenleaf and Kremen, 2006; Brosi et al., 2007; Zurbuchen et al., 2010) and also because of reduced landscape complexity caused by environmental simplification (Steffan-Dewenter et al., 2001; Bartomeus et al., 2010; Hoehn et al., 2010; Holzschuh et al., 2010). From the pollinators point of view, loss of landscape complexity usually lead to the reduction of floral resources and nesting areas in the remaining available habitat patches, impairing population survival and reducing their overall diversity (Potts et al., 2003; Klein et al., 2004; Brosi et al., 2008; Jha and Vandermeer, 2009; Goulson et al., 2010). Reduced diversity was observed mainly for bees (Ahrne et al., 2009; Jauker et al., 2009; Hoehn et al., 2010; Quintero et al., 2010), the worldwide most important pollinators (Roubik, 1995), but also for other pollinator groups such as birds (Breitbach et al., 2010) and bats (Quesada et al., 2003, 2004; MacSwiney et al., 2007; Willig et al., 2007).

Landscape modifications also affected cross-pollination and the sexual reproduction of plants largely due to reduced diversity and availability of pollinators (Parra-Tabla et al., 2000; Dick et al., 2003; Aguilar et al., 2006). Reduced plant population density and number of pollen donors available in landscapes may also cause disruption of pollination processes (Fuchs et al., 2003; Uchiyama et al., 2009), which changes the selection pressures of floral traits, modifying the set of reproductive strategies of whole plant communities (Lopes et al., 2009). Plant population density changes may have deep effects on the amount (Fuchs et al., 2003) and quality of plant progeny (Cascante et al., 2002; Lennartsson, 2002; Lowe et al., 2005; Eckert et al., 2009).

We also found that 77 studies (approximately 50% of all 155 analyzed papers) showed effects of landscape changes caused by agriculture intensification on plant–pollinator interactions as a result of increased conversion of natural areas to agricultural crops (Kremen et al., 2007; Steffan-Dewenter and Westphal, 2008). Approximately 75% of these studies advocated that landscape changes affects the diversity, movement and frequency of pollinators, and 36% the diversity, reproductive systems, reproductive success, resources and productivity of plants.

Nevertheless we found only one paper explicitly assessing the effects of landscape changes from the perspective of complex networks of plant–pollinator interactions. Hagen and Kraemer (2010) observed significant structural differences of plants and floral visitors networks in structurally diverse landscape mosaic within forest, forest edge and farmlands in Kenya.

Overall, in our review we noted that most available studies focused mainly on the effects of landscape modifications on pollinator diversity and/or plant reproductive success. Nevertheless, there are some studies which indicate that nested and asymmetric mutualistic networks tend to be reasonably robust and resilient to most landscape changes (Olesen and Jordano, 2002; Memmott et al., 2004, 2005; Petanidou et al., 2008; Ramos-Jiliberto et al., 2009; Vilà et al., 2009). Theoretical, empirical or manipulative studies about mutualistic networks answers to landscape changes could reveal important information for the maintenance of these networks, and specifically of plant–pollinator interaction networks under modified environments.

Table 1
List of categories used for organizing and analyzing the selected papers found in May 2011 using all seven possible combinations of the terms "pollinat*" with the terms "landscape", "habitat loss" and "network" on Web of Science and Scopus.

Variables	Categories	Descriptions
Year		
Authors		
Journal		
Study location		
Climatic region	Tropical	
	Subtropical	
	Temperate	
Ecosystem	Agriculture	
	Forest	
	Savanna	
	Desert	
	Agro-forestry	
	Urban	
Matrix	Agriculture	
	Natural	
	Savanna	
	Forest	
	Agro-forestry	
	Urban	
	Mix	
Landscape	Agriculture	
	Natural	
	Savanna	
	Agro-forestry	
	Mix	
	Urban	
Study type	Empirical	
	Revision	
	Meta-analyze	
	Modeling	
	Theoretical	
Methods	Descriptive	
	Observational	
	Experimental	
	Literature survey	
	Modeling	
	Meta-analyze	
Objectives	Descriptive	
	Establish relations	
	Explicative	
	Modeling	
	Review	
Approach level	Landscape	
	Patches	
	Buffer	
Sample unity	Individuals	
	Population	
	Community	
Study object	Plant	
	Pollinator	
	Interaction	
Dependent variables	Plants diversity	Plants richness and abundances
	Plants reproductive systems	Plants reproductive traits as self compatibility
	Plants reproductive success	Fruit and seed set
	Plants productivity	Crops production
	Floral resources	Nectar and pollen available in the system
	Pollinators diversity	Pollinators richness and abundances
	Pollinator's visits frequency	
	Pollinators movements	

Table 1 (*Continued*)

Variables	Categories	Descriptions
Independent variables	Patches area	
	Patches isolation	
	Landscape composition	How landscape elements are spatially distributed
	Landscape configuration	Which are the landscape elements available
	Matrix	
	Edge	
	Floral resources	
Variables relationship	Positive	
	Negative	
	Unrelated	
	Differences	
	No differences	

We found several indications that landscape modifications affect plant–pollinator interactions by reducing the abundance and diversity of pollinators (Steffan-Dewenter and Tscharntke, 1999; Kremen et al., 2002; Chacoff and Aizen, 2006; Fujimori et al., 2006), which leads to lower seed production (Brudvig et al., 2009; Nazareno and Carvalho, 2009; Lander et al., 2010; Vesk et al., 2010). Deforestation can also affect plant reproductive processes by changing the foraging behavior of pollinators and consequently the quality of plant gene flow (Ghazoul and McLeish, 2001). In general the diversity of floral visitors and the frequency of observed visits decreased with increasing the distance to natural habitats (Chacoff and Aizen, 2006). The richness and abundance of flying floral visitors, for example, dropped more than 80% over a distance of 500 m from natural habitat in tropical and subtropical agro-forestry systems (Carvalheiro et al., 2010). Additionally, bees usual foraging distances, which depend on maximum efficiency foraging strategies, are smaller than their maximum measured flight distance, indicating that nearby areas can function as key habitat structures to preserve bee populations (Zurbuchen et al., 2010).

Trees with limited distribution and reduced genetic variation were more likely to go extinct in the face of landscape changes (Hamrick, 2004). Seed production may be affected by reduced amount of pollen transfer between flowers (Schmucki and Blois, 2009), but plants which can produce fruits by self-fertilization are usually favored in landscapes where plant individuals are isolated and pollinators and pollen flow is reduced or improbable (Pinto-Torres and Koptur, 2009). Composition of plant communities in landscapes, which have experienced severe fragmentation can be modified in favor of species pollinated and dispersed mainly by passive processes such as wind pollination and with detriment of species that are pollinated and dispersed by animals (Regal, 1982; Ghazoul and Shaanker, 2004).

A stochastic individual-based simulation model developed by Keitt (2009) suggests that as landscapes are changed and native habitat is removed, plant–pollinator systems tend to be altered and even small disturbances may cause plant–pollinator interactions collapse within the remaining habitat patches in fragmented landscapes. Keitt (2009) suggested that extinction thresholds for plant–pollinator interaction systems may occur at about 50–60% of habitat loss, when pollinators and plants generalist species start to disappear from communities. But not only habitat loss can cause the disruption of pollination interaction networks. According to the model developed by Kaiser-Bunbury et al. (2010), there must be a strong impact on networks stability when more than half of the most connected species is lost, which causes a sudden and rapid collapse of the total strength of the networks. These complementary results indicate that there is a pungent need to set which are the critical values of habitat loss that can increase pollinators' extinction up to the point where natural plant–pollinator interaction networks may collapse (Viana et al., 2012). However, strictly defined values may not really exist, with each case being unique. Also, empirical field studies concerning ecological networks often lack replication and these different responses associated with plants and pollinators make their results difficult to be understood (Dupont et al., 2009). In addition, both sides of the mutualistic interaction must be assessed in order to properly predict pollinators' extinction chances and plant reproductive vulnerability to landscape changes (Ashworth et al., 2004).

Moreover, studies about habitat fragmentation which focused solely on the differences of biodiversity patterns of non-fragmented versus fragmented landscapes are generally inadequate to represent the gradual effects of habitat changes. Nevertheless, this approach is still the more frequently used in empirical fragmentation studies (Ewers and Didham, 2006). On the other hand, simulations based on real landscapes and species with distinct life histories have been useful to increase our comprehension about the relationships between landscape dynamics and biodiversity (Burel et al., 1998). Approaches that take into account continuous measures of landscape changes along gradients of habitat degradation could be more thoroughly used to evaluate the effects of gradual habitat modifications on plant–pollinator interactions.

Agriculture intensification and conversion of natural to urban environments also changes natural habitats features, affecting plant and pollinators diversity (Ahrne et al., 2009; Frankie et al., 2009; Bommarco et al., 2011), pollinators community composition (Carre et al., 2009), pollinators floral visits behavior (Ricketts et al., 2008) and may influence plant reproductive success (Priess et al., 2007; Kim et al., 2006). Additionally, conventional agricultural management which uses large crop areas, insecticides, herbicides and exotic pollinators may also negatively influence local plant–pollinator interaction networks because of environmental simplification and resources reduction for pollinators, consequently lessening the availability of pollinators for plants (Klein et al., 2007; Jha and Vandermeer, 2010). These changes may have important implications for pollination processes, with important effects even for crop production (Richards, 2001), as pollinators are important for more than 75% of the world's most important agricultural plants species (Klein et al., 2007).

The value of ecosystem services promoted by standing forest patches for agriculture and other human-made systems is still little known. Ricketts et al. (2004), however, estimated that the actual costs of reduced pollination services are probably higher than previously expected. Spatially explicit land use change simulations clearly indicate that most of the ecological and economic values of natural habitats can potentially be saved over the coming decades if the remaining patches are preserved within agricultural landscapes (Priess et al., 2007). An approach which integrates agricultural areas, natural habitats and planned urban ecosystems may improve pollination services efficiency in these ecosystems. The maintenance of natural habitats surrounding agricultural areas may improve pollination services in the crops while the conservation of native pollinators may also be important for pollination of wild plants species. (Goulson et al., 2008; Hannon and Sisk, 2009; Hennig and Ghazoul, 2011).

Alternative management practices, such as organic farming (Andersson et al., 2012), and urban gardens (Ahrne et al., 2009) had positive effects on pollinator diversity at different landscape scales (Gabriel et al., 2010; Jha and Vandermeer, 2010; Van Rossum, 2010). However, Winfree et al. (2008) pointed out that the heterogeneity of habitats surrounding crops could be more important than the farm management system for maintaining the diversity of native bees. For example, the resource mass production offered by some crops can also promote the maintenance of pollinating bee species (Walther-Hellwig and Frankl, 2000). The proximity of natural areas to crops can facilitate pollination due to the higher diversity of pollinators in natural habitats, where they can find proper nesting sites and appropriate supplementary resources in times of scarcity (Ricketts, 2004; Klein, 2009; Lonsdorf et al., 2009; Tscharntke et al., 2011), allowing high seed-set and more stable reproductive success of both native and cultivated plants (Dick et al., 2003; Greenleaf and Kremen, 2006). Landscape heterogeneity and connectivity can also increase pollinator diversity and plant reproductive success (Van Rossum, 2010). Proximity of natural habitats, green areas in urban landscapes, proper environmental management and pollinator-friendly landscape arrangements can promote the conservation of pollination services in natural, urban and agricultural systems (Marshall and Moonen, 2002; Zhang et al., 2007; Klein et al., 2008; Ricketts et al., 2008; Brudvig et al., 2009; Keitt, 2009; Brittain et al., 2010; Jha and Vandermeer, 2010; Van Rossum, 2010; Hennig and Ghazoul, 2011; Viana et al., 2012).

4. Conclusions

Deforestation can affect the reproductive processes of plants by causing changes in the abundance and foraging behavior of pollinators and, consequently, the quality and quantity of plant gene flow (Ghazoul and McLeish, 2001). The maintenance of heterogeneous landscapes can increase local and regional biodiversity and possibly maintain ecosystem services (Morreale and Sullivan, 2010). The consolidation of knowledge concerning ecological processes such as pollination at the landscape level are of extreme importance for the management of natural areas with the aim of conserving ecosystem services (Tscharntke and Brandl, 2004; Nazareno and Carvalho, 2009; Olschewski et al., 2010). Overall, the papers we analyzed showed that it is possible to consider the creation of landscape designs which could maintain pollinators diversity (Priess et al., 2007; Goulson et al., 2008; Hannon and Sisk, 2009; Jauker et al., 2009; Hennig and Ghazoul, 2011), as well as plants and pollination services. However, we found only one paper (Hagen and Kraemer, 2010) which empirically analyzed the effects of landscape changes on plant–pollinator networks. Remaining papers studied the effects of landscape changes on pollinator diversity and/or the reproductive success of plants without directly assessing its consequences to the stability of pollination networks. This indicates that there still exist a profound need to increase scientific efforts on the study of landscape changes consequences on plant–pollinators networks structures and stability. An integrated approach concerning the study of the effects of modified landscapes on natural ecosystems and how these variations can affect the stability and robustness of pollination networks may be extremely useful for conservation of plant–pollinators interactions, with positive overall consequences for conservation of plant, pollinators and pollination services in natural and agricultural ecosystems. We believe that studies of interaction networks on landscapes perspective may provide important information and understanding of the best strategies for plant, pollinators and pollination conservation.

Acknowledgments

We would like to thank Luciano E. Lopes (UFSCAR), Luisa G. Carvalheiro (NCB Naturalis) and to the anonymous reviewers for their helpful and valuable comments and suggestions that helped to improve this paper. This research was supported by INOMEP-PRONEX-CNPq. Essential financial support was provided by FAPESB and CNPq.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2012.07.025.

References

Aguilar, R., Ashworth, L., Galetto, L., Aizen, M.A., 2006. Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. Ecol. Lett. 9 (8), 968–980.

Ahrne, K., Bengtsson, J., Elmqvist, T., 2009. Bumble bees (*Bombus* spp) along a gradient of increasing urbanization. PLoS ONE 4 (5), 1–9.

Andersson, G.K.S., Rundlöf, M., Smith, H.G., 2012. Organic farming improves pollination success in strawberries. PLoS ONE 7 (2), e31599.

Ashworth, L., Aguilar, R., Galetto, L., Aizen, M.A., 2004. Why do pollination generalist and specialist plant species show similar reproductive susceptibility to habitat fragmentation? J. Ecol. 92, 717–719.

Bartomeus, I., Vilà, M., Steffan-Dewenter, I., 2010. Combined effects of *Impatiens glandulifera* invasion and landscape structure on native plant pollination. J. Ecol. 98 (2), 440–450.

Bascompte, J., 2009. Mutualistic networks. Front. Ecol. Environ. 7 (8), 429–436.

Bascompte, J., Jordano, P., Mellián, C.J., Olesen, J.M., 2003. The nested assembly of plant–animal mutualistic networks. PNAS 100 (16), 9383–9387.

Bommarco, R., Lundin, O., Smith, H.G., Rundlöf, M., 2011. Drastic historic shifts in bumble-bee community composition in Sweden. Proc. R. Soc. B: Biol. Sci. 15, 1–7.

Breitbach, N., Laube, I., Steffan-Dewenter, I., Böhning-Gaese, K., 2010. Bird diversity and seed dispersal along a human land-use gradient: high seed removal in structurally simple farmland. Oecologia 162 (4), 965–976.

Brittain, C., Bommarco, R., Vighi, M., Settele, J., Potts, S.G., 2010. Organic farming in isolated landscapes does not benefit flower-visiting insects and pollination. Biol. Conserv. 143 (8), 1860–1867.

Brosi, B.J., Daily, G.C., Ehrlich, P.R., 2007. Bee community shifts with landscape context in a tropical countryside. Ecol. Appl. 17 (2), 418–430.

Brosi, B.J., Daily, G.C., Shih, T.M., Oviedo, F., Durán, G., 2008. The effects of forest fragmentation on bee communities in tropical countryside. J. Appl. Ecol. 45 (3), 773–783.

Brudvig, L.A., Damschen, E.I., Tewksbury, J.J., Haddad, N.M., Levey, D.J., 2009. Landscape connectivity promotes plant biodiversity spillover into non-target habitats. Proc. Natl. Acad. Sci. U.S.A 106 (23), 9328–9332.

Burel, F., Baudry, J., Butet, A., Clergeau, P., Delettre, Y., Coeur, D.L., Dubs, F., Morvan, N., Paillat, G., Petit, S., Thenail, C., Brune, E., Lefeuvre, J.C., 1998. Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecol. 19 (1), 47–60.

Carre, G., Roche, P., Chifflet, R., Morison, N., Bommarco, R., Harrison-Cripps, J., Krewenka, K., Potts, S.G., Roberts, S.P.M., Rodet, G., Settele, J., Steffan-Dewenter, I., Szentgyorgyi, H., Tscheulin, T., Westphal, C., Woyciechowski, M., Vaissiere, B.E., 2009. Landscape context and habitat type as drivers of bee diversity in European annual crops. Agric. Ecosyst. Environ. 133, 40–47.

Carvalheiro, L.G., Seymour, C.L., Veldtman, R., Nicolson, S.W., 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. J. Appl. Ecol. 47 (4), 810–820.

Cascante, A., Quesada, M., Lobo, J.J., Fuchs, E.A., 2002. Effects of dry tropical forest fragmentation on the reproductive success and genetic structure of the tree *Samanea saman*. Conserv. Biol. 16 (1), 137–147.

Chacoff, N.P., Aizen, M.A., 2006. Edge effects on flower-visiting insects in grapefruit plantations bordering premontane subtropical forest. J. Appl. Ecol. 43 (1), 18–27.

Darvill, B., Ellis, J.S., Lye, G.C., Goulson, D., 2006. Population structure and inbreeding in a rare and declining bumblebee, *Bombus muscorum* (Hymenoptera: Apidae). Mol. Ecol. 15 (3), 601–611.

Dick, C.W., Etchelecu, G., Austerlitz, F., 2003. Pollen dispersal of tropical trees (*Dinizia excelsa*: Fabaceae) by native insects and African honeybees in pristine and fragmented Amazonian rainforest. Mol. Ecol. 12 (3), 753–764.

Dupont, Y.L., Padrón, B., Olesen, J.M., Petanidou, T., 2009. Spatio-temporal variation in the structure of pollination networks. Oikos 118 (8), 1261–1269.

Eckert, C.G., Kalisz, S., Geber, M.A., Sargent, R., Elle, E., Cheptou, P.O., Goodwillie, C., Johnston, M.O., Kelly, J.K., Moeller, D.A., Porcher, E., Ree, R.H., Vallejo-Marín, M., Winn, A.A., 2009. Plant mating systems in a changing world. Trends Ecol. Evol. 25 (1), 35–43.

Ewers, R.M., Didham, R.K., 2006. Confounding factors in the detection of species responses to habitat fragmentation. Biol. Rev. 81 (1), 117–142.

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Evol. Syst. 34, 487–515.

Fischer, J., Lindenmayer, D.B., 2007. Landscape modification and habitat fragmentation: a synthesis. Glob. Ecol. Biogeogr. 16, 265–280.

Fortuna, M.A., Bascompte, J., 2006. Habitat loss and the structure of plant–animal mutualistic networks. Ecol. Lett. 9, 281–286.

Forup, M.L., Memmott, J., 2005. The restoration of plant-pollinator interactions in hay meadows. Restor. Ecol. 13, 265–274.

Frankie, G.W., Rizzardi, M., Vinson, S.B., Griswold, T.L., 2009. Decline in bee diversity and abundance from 1972 to 2004 on a flowering leguminous tree, *Andira inermis* in Costa Rica at the interface of disturbed dry forest and the urban environment. J. Kans. Entomol. Soc. 82 (1), 1–20.

Fuchs, E.J., Lobo, J.A., Quesada, M., 2003. Effects of forest fragmentation and flowering phenology on the reproductive success and mating patterns of the tropical dry forest tree *Pachira quinata*. Conserv. Biol. 17 (1), 149–157.

Fujimori, N., Samejima, H., Kenta, T., Ichie, T., Shibata, M., Iida, S., Nakashizuka, T., 2006. Reproductive success and distance to conspecific adults in the sparsely distributed tree *Kalopanax pictus*. J. Plant Res. 119 (3), 195–203.

Gabriel, D., Sait, S.M., Hodgson, J.A., Schmutz, U., Kunin, W.E., Benton, T.G., 2010. Scale matters: the impact of organic farming on biodiversity at different spatial scales. Ecol. Lett. 13 (7), 858–869.

Ghazoul, J., McLeish, M., 2001. Reproductive ecology of tropical forest trees in logged and fragmented habitats in Thailand and Costa Rica. Plant Ecol. 153, 335–345.

Ghazoul, J., Shaanker, R.U., 2004. Sex in space: pollination among spatially isolated plants. Biotropica 36 (2), 128–130.

Girão, L.C., Tabarelli, M., Lopes, A.V., Bruna, E.M., 2007. Changes in tree reproductive traits reduce functional diversity in a fragmented Atlantic forest landscape. PLoS ONE 2, e908.

Goulson, D., Lepais, O., O'Connor, S., Osborne, J.L., Sanderson, R.A., Cussans, J., Goffe, L., Darvill, B., 2010. Effects of land use at a landscape scale on bumblebee nest density and survival. J. Appl. Ecol. 47, 1207–1215.

Goulson, D., Lye, G.C., Darvill, B., 2008. Decline and conservation of bumble bees. Annu. Rev. Entomol. 53, 191–208.

Greenleaf, S.S., Kremen, C., 2006. Wild bees enhance honey bees' pollination of hybrid sunflower. Proc. Natl. Acad. Sci. U.S.A. 103 (37), 13890–13895.

Hagen, M., Kraemer, M., 2010. Agricultural surroundings support flower–visitor networks in an Afrotropical rain forest. Biol. Conserv. 143 (7), 1654–1663.

Hamrick, J., 2004. Response of forest trees to global environmental changes. For. Ecol. Manage. 197 (1–3), 323–335.

Hannon, L.E., Sisk, T.D., 2009. Hedgerows in an agri-natural landscape: potential habitat value for native bees. Biol. Conserv. 142 (10), 2140–2154.

Haila, Y., 2002. A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. Ecol. Appl. 12, 321–334.

Hennig, E.I., Ghazoul, J., 2011. Plant–pollinator interactions within the urban environment. Perspect. Plant Ecol. Evol. Syst. 13 (2), 137–150.

Hoehn, P., Steffan-Dewenter, I., Tscharntke, T., 2010. Relative contribution of agroforestry, rainforest and openland to local and regional bee diversity. Biodivers. Conserv. 19 (8), 2189–2200.

Holzschuh, A., Steffan-Dewenter, I., Tscharntke, T., 2010. How do landscape composition and configuration, organic farming and fallow strips affect the diversity of bees, wasps and their parasitoids? J. Anim. Ecol. 79 (2), 491–500.

Jauker, F., Diekötter, T., Schwarzbach, F., Wolters, V., 2009. Pollinator dispersal in an agricultural matrix: opposing responses of wild bees and hoverflies to landscape structure and distance from main habitat. Landscape Ecol. 24 (4), 547–555.

Jha, S., Vandermeer, J.H., 2009. Contrasting foraging patterns for Africanized honeybees, native bees and native wasps in a tropical agroforestry landscape. J. Trop. Ecol. 25, 13–22.

Jha, S., Vandermeer, J.H., 2010. Impacts of coffee agroforestry management on tropical bee communities. Biol. Conserv. 143 (6), 1423–1431.

Jongman, R., 2004. European ecological networks and greenways. Landscape Urban Plan. 68 (2–3), 305–319.

Kaiser-Bunbury, C.N., Muff, S., Memmott, J., Müller, C.B., Caflisch, A., 2010. The robustness of pollination networks to the loss of species and interactions: a quantitative approach incorporating pollinator behaviour. Ecol. Lett. 13 (4), 442–452.

Keitt, T.H., 2009. Habitat conversion, extinction thresholds, and pollination services in agroecosystems. Ecol. Appl. 19 (6), 1561–1573.

Kim, J., Williams, N., Kremen, C., 2006. Effects of cultivation and proximity to natural habitat on ground-nesting native bees in california sunflower fields. J. Kans. Entomol. Soc. 79 (4), 309–320.

Klein, A.M., 2009. Nearby rainforest promotes coffee pollination by increasing spatio-temporal stability in bee species richness. For. Ecol. Manage. 258 (9), 1838–1845.

Klein, A.M., Cunningham, S.A., Bos, M., Steffan-Dwenter, I., 2008. Advances in pollination ecology from tropical plantation crops. Ecology 89 (4), 935–943.

Klein, A.M., Steffan-Dewenter, I., Tscharntke, T., 2004. Foraging trip duration and density of megachilid bees, eumenid wasps and pompilid wasps in tropical agroforestry systems. J. Anim. Ecol. 73 (3), 517–525.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B: Biol. Sci. 274 (1608), 303–313.

Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. Proc. Natl. Acad. Sci. U.S.A 99 (26), 16812–16816.

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L., Potts, S.G., Roulston, T., Steffan-Dewenter, I., Vázquez, P., Winfree, R., Adams, L., Crone, E., Greenleaf, S.S., Keitt, T.H., Klein, A.M., Regetz, J., Ricketts, T.H., 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecol. Lett. 10, 299–314.

Lander, T.A., Boshier, D.H., Harris, S.A., 2010. Fragmented but not isolated: contribution of single trees, small patches and long-distance pollen flow to genetic connectivity for Gomortega *keule*, an endangered Chilean tree. Biol. Conserv. 143 (11), 2583–2590.

Lennartsson, T., 2002. Extinction thresholds and disrupted plant–pollinator interactions in fragmented plant populations. Ecology 83 (11), 3060–3072.

Liow, L.H., Sodhi, N.S., Elmqvist, T., 2001. Bee diversity along a disturbance gradient in tropical lowland forests of south-east Asia. J. Appl. Ecol. 38 (1), 180–192.

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N., Greenleaf, S., 2009. Modelling pollination services across agricultural landscapes. Ann. Bot. (Lond.) 103 (9), 1589–1600.

Lopes, A.V., Girão, L.C., Santos, B.A., Peres, C.A., Tabarelli, M., 2009. Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. Biol. Conserv. 142 (6), 1154–1165.

Lowe, A.J., Boshier, D., Ward, M., Bacles, C.F.E., Navarro, C., 2005. Genetic resource impacts of habitat loss and degradation; reconciling empirical evidence and predicted theory for neotropical trees. Heredity 95 (4), 255–273.

MacSwiney, M., Vilchisl, P., Clarke, F., Racey, P., 2007. The importance of cenotes in conserving bat assemblages in the Yucatan, Mexico. Biol. Conserv. 136 (4), 499–509.

Marshall, E., Moonen, A., 2002. Field margins in northern Europe: their functions and interactions with agriculture. Agric. Ecosyst. Environ. 89 (1–2), 5–21.

Memmott, J., Waser, N.M., Price, M.V., 2004. Tolerance of pollination networks to species extinctions. Proc. R. Soc. B 271, 2605–2611.

Memmott, J., Alonso, D., Berlow, E.L., Dobson, A., Dunne, J.A., Solé, R., Weitz, J., 2005. Biodiversity Loss and Ecological Network Structure. Oxford University Press, pp. 325–347.

Metzger, J.P., 2001. O que é ecologia de paisagens? Biota Neotrop. 1 (1), 1–9.

Montoya, D., 2008. Habitat loss, dispersal and the probability of extinction of tree species. Science 1 (2), 146–147.

Morreale, S.J., Sullivan, K.L., 2010. Community-level enhancements of biodiversity and ecosystem services. Front. Earth Sci. China 4 (1), 14–21.

Nates-parra, G., Palacios, E., Parra-H, A., 2008. Efecto del cambio del paisaje en la estructura de la comunidad de abejas sin aguijón (Hymenoptera: Apidae) en Meta, Colombia. Rev. Biol. Trop. 56 (3), 1295–1308.

Nazareno, A.A., Carvalho, D., 2009. What the reasons for no inbreeding and high genetic diversity of the neotropical fig tree *Ficus arpazusa*? Conserv. Genet. 10, 1789–1793.

Olesen, J.M., Jordano, P., 2002. Geographic patterns in plant–pollinator mutualistic networks. Ecology 83 (9), 2416–2424.

Olschewski, R., Klein, A.M., Tscharntke, T., 2010. Economic trade-offs between carbon sequestration, timber production, and crop pollination in tropical forested landscapes. Ecol. Complex. 7 (3), 314–319.

Parra-Tabla, V., Vargas, C.F., Magana-Rueda, S., Navarro, J., 2000. Female and male pollination success of *Oncidium ascendens* Lindey (Orchidaceae) in two contrasting habitat patches forest vs agricultural field. Biol. Conserv. 94 (3), 335–340.

Petanidou, T., Kallimanis, A.S., Tzanopoulos, J., Sgardelis, S.P., Pantis, J.D., 2008. Long-term observation of a pollination network: fluctuation in species and interactions, relative invariance of network structure and implications for estimates of specialization. Ecol. Lett. 11 (6), 564–575.

Pinto-Torres, E., Koptur, S., 2009. Hanging by a coastal strand: breeding system of a federally endangered morning-glory of the south-eastern Florida coast, *Jacquemontia reclinata*. Ann. Bot. (Lond.) 104 (7), 1301–1311.

Potts, S.G., Vulliamy, B., Dafni, A., Neeman, G., Willmer, P., 2003. Linking bees and flowers: how do floral communities structure pollinator communities? Ecology 84 (10), 2628–2642.

Priess, S., Mimler, M., Klein, A.M., Schwarze, S., Tscharntke, T., Steffan-Dewenter, I., 2007. Linkin deforestation and scenarios to pollination services and economic returns in coffee agroforestry systems. Ecol. Appl. 17 (2), 407–417.

Quesada, M., Stoner, K.E., Lobo, J.A., Herrerias-Diego, Y., Palacios-Guevara, C., Munguia-Rosas, M.A., Salazar, K.A.O., Rosas-Guerrero, V., 2004. Effects of forest fragmentation on pollinator activity and consequences for plant reproductive success and mating patterns in bat-pollinated bombacaceous trees. Biotropica 36 (2), 131–138.

Quesada, M., Stoner, K.E., Rosas-Guerrero, V., Palacios-Guevara, C., Lobo, J.A., 2003. Effects of habitat disruption on the activity of nectarivorous bats (Chiroptera: Phyllostomidae) in a dry tropical forest: implications for the reproductive success of the neotropical tree *Ceiba grandiflora*. Oecologia 135 (3), 400–406.

Quintero, C., Morales, C.L., Aizen, M.A., 2010. Effects of anthropogenic habitat disturbance on local pollinator diversity and species turnover across a precipitation gradient. Biodivers. Conserv. 19, 257–274.

Ramos-Jiliberto, R., Albornoz, A.A., Valdovinos, F.S., Smith-Ramírez, C., Arim, M., Armesto, J.J., Marquet, P.A., 2009. A network analysis of plant–pollinator interactions in temperate rain forests of Chiloé Island, Chile. Oecologia 160 (4), 697–706.

Regal, P.J., 1982. Pollination by wind and animals: ecology of geographic patterns. Annu. Rev. Ecol. Syst. 13 (1), 497–524.

Richards, A., 2001. Does low biodiversity resulting from modern agricultural practice affect crop pollination and yield? Ann. Bot. (Lond.) 88 (2), 165–172.

Ricketts, T.H., 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. Conserv. Biol. 18 (5), 1262–1271.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R., Michener, C.D., 2004. Economic value of tropical forest to coffee production. Proc. Natl. Acad. Sci. U.S.A. 101 (34), 12579–12582.

Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Gemmill-Herren, B., Greenleaf, S.S., Klein, A.M., Mayfield, M.M., Morandin, L.A., Ochieng, A., Viana, B.F., 2008. Landscape effects on crop pollination services: are there general patterns? Ecol. Lett. 11 (5), 499–515.

Roubik, D.W., 1995. Pollination of Cultivated Plants in the Tropics. Food and Agriculture Organization, Rome.

Sabatino, M., Maceira, N., Aizen, M.A., 2010. Direct effects of habitat area on interaction diversity in pollination webs. Ecol. Appl. 20 (6), 1491–1497.

Schmucki, R., Blois, S., 2009. Pollination and reproduction of a self-incompatible forest herb in hedgerow corridors and forest patches. Oecologia 160 (4), 721–733.

Steffan-Dewenter, I., Münzenberg, U., Tscharntke, T., 2001. Pollination, seed set and seed predation on a landscape scale. Proc. R. Soc. B: Biol. Sci. 268 (1477), 1685–1690.

Steffan-Dewenter, I., Tscharntke, T., 1999. Effects of habitat isolation on pollinator communities and seed set. Oecologia 121 (3), 432–440.

Steffan-Dewenter, I., Westphal, C., 2008. The interplay of pollinator diversity, pollination services and landscape change. J: Appl. Ecol. 45, 737–741.

Tscharntke, T., Brandl, R., 2004. Plant–insect interactions in fragmented landscape. Annu. Rev. Entomol. 49, 405–430.

Tscharntke, T., Clough, Y., Bhagwat, S.A., Buchori, D., Faust, H., Hertel, D., Hölscher, D., Juhrbandt, J., Kessler, M., Perfecto, I., Scherber, C., Schroth, G., Veldkamp, E., Wanger, T.C., 2011. Multifunctional shade-tree management in tropical agroforestry landscapes – a review. J. Appl. Ecol. 48 (3), 619–629.

Uchiyama, K., Goto, S., Ide, Y., 2009. Effects of population density on male and female reproductive success in the wind-pollinated, wind-dispersed tree species *Betula maximowicziana*. Conserv. Genet. 10, 1265–1275.

Van Rossum, F., 2010. Reproductive success and pollen dispersal in urban populations of an insect-pollinated hay-meadow herb. Perspect. Plant Ecol. Evol. Syst. 12 (1), 21–29.

Vesk, P.A., Davidson, A., Chee, Y.E., 2010. Spatial distribution and prediction of seed production by *Eucalyptus microcarpa* in a fragmented landscape. Austral Ecol. 35 (1), 60–71.

Viana, B.F., Boscolo, D., Mariano Neto, E., Lopes, L.E., Lopes, A.V., Ferreira, P.A., Pigozzo, C.M., Primo, L.M., 2012. How well do we understand landscape effects on pollinators and pollination services? J. Pollinat. Ecol. 7 (5), 31–41.

Vilà, M., Bartomeus, I., Dietzsch, A.C., Petanidou, T., Steffan-Dewenter, I., Stout, J.C., Tscheulin, T., 2009. Invasive plant integration into native plant–pollinator networks across Europe. Proc. Real Soc.: Biol. Sci. 276, 3887–4389.

Walther-Hellwig, K., Frankl, R., 2000. Foraging habitats and foraging distances of bumblebees, *Bombus* spp. (Hym., Apidae), in an agricultural landscape. J. Appl. Entomol. 124 (7–8), 299–306.

Willig, M.R., Presley, S.J., Bloch, C.P., Hice, C.L., Yanoviak, S.P., Díaz, M.M., Chauca, L.A., Pacheco, V., Weaver, S.C., 2007. Phyllostomid bats of lowland Amazonia: effects of habitat alteration on abundance. Biotropica 39 (6), 737–746.

Winfree, R., Aguilar, R., Vazquez, D.P., Lebuhn, G., Aizen, M.A., 2009. A meta-analysis of bees' responses to anthropogenic disturbance. Ecology 90 (8), 2068–2076.

Winfree, R., Williams, N.M., Gaines, H., Ascher, J.S., Kremen, C., 2008. Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. J. Appl. Ecol. 45, 793–802.

Zhang, W., Ricketts, T., Kremen, C., Carney, K., Swinton, S., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ. 64 (2), 253–260.

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., Dorn, S., 2010. Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. Biol. Conserv. 143 (3), 669–676.

Capitulo II

Effects of habitat loss on bees in the Brazilian Atlantic Rainforest

Article in Preparation

Effects of habitat loss on bees in the Brazilian Atlantic Rainforest

Patrícia Alves Ferreira[1], Danilo Boscolo[2], Luisa G. Carvalheiro[3,4], Jacobus C. Biesmeijer[4,5], Pedro Luis Bernardo da Rocha[1], Blandina Felipe Viana[1]

1 – Biology Institute – Federal University of Bahia – UFBA – Salvador-BA – Brazil.

2 – Biological Sciences Department – Federal University of São Paulo – UNIFESP – Diadema-SP – Brazil.

3 - Institute of Integrative and Comparative Biology – University of Leeds – Leeds - UK.

4 - Naturalis Biodiversity Center – Leiden University – Leiden – The Netherlands.

5 – Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam.

Abstract

Anthropogenic habitat loss and fragmentation tend to isolate pollinator populations negatively affecting sexual reproduction of animal-pollinated plants. We evaluated how habitat loss affects pollinator diversity in the understory of Atlantic Rainforest fragments in Northeastern Brazil. We focused on bees, the main group of pollinators for angiosperms and the most frequent group sampled in our study area (70% of all flower visitors). We assessed how forest cover at regional (landscape) and local scales affected bee diversity (richness, abundance and composition). We also examined how habitat loss affected trait groups of bees characterized by nesting types and levels of sociality. Our results showed that bee community diversity was positively influenced by forest cover at both regional and local scales; landscapes with greater forest cover had more diverse communities. These results suggest that landscapes where Atlantic Rainforest is abundant are important for bees, even when the forest is highly fragmented. Nevertheless, higher fragmentation could lead to higher spatial homogenization (or lower diversity) of bee communities. Our results also showed that the effect of deforestation on bees depends on their traits, social bees that nest above ground (e.g. in trees or dead wood) are positively influenced by forest cover; while solitary bees that nest in the ground benefited from some levels of deforestation, making use of open areas within large forested areas. However, this group were composed mostly generalist species. This result highlights the importance of considering species traits when evaluating impacts of deforestation.

Keywords: Bees, Forest Understory, Atlantic Rainforest, Landscape changes, Bahia, Brazil.

1. Introduction

Pollination is a key ecological process that ensures the reproductive success of plants and has indirect positive effects for other species that also depend on these plants (Kearns et al. 1998; Fenster et al. 2004; Fortuna and Bascompte 2006). Most plant species are pollinated by insects. When habitat is lost and fragmented the structure of biological communities may be disrupted, directly affecting ecological processes related to species survival and interactions (Tscharntke et al. 2002). These disturbances may modify the behavior of pollinators and the composition (Brosi 2009) of their communities (Brosi et al. 2007, 2008, 2009), potentially modifying species interactions and pollen transfer patterns (Fortuna and Bascompte 2006), limiting the amount of compatible pollen deposited on stigmas, thereby negatively affecting sexual reproduction of animal pollinated plants (Nazareno and Carvalho 2009; Lander et al. 2010; Vesk et al. 2010).

In tropical rainforests, where plant diversity is extremely high, pollination by animals, mostly bees, is very important for the maintenance of plant communities (Bawa 1990; Tabarelli et al. 2008). In the rainforests of Central America, the Amazon and the Brazilian Atlantic coast forests, these animals are responsible for the reproduction of most plant species (Bawa 1990; Ramalho 2004; Ramalho and Batista 2005). Among the tropical forests, due to its geographical and altitudinal range, the Brazilian Atlantic Rainforest is an extremely biodiverse environment containing about 1–8% of the world's total species and a high endemism rate. This still poorly studied biome has been historically submitted to degradation and only about 12% of its original extension remains, with most patches being very isolated and smaller than 50ha (Ribeiro et al. 2009). Hence, in the Brazilian Atlantic Rainforest most forest patches may not include all possible diversity of plants and its attendant mutualists. However, remnant tropical forest habitats provide several important ecosystem services and species interactions must be maintained if their protection is aimed for (Lopes et al. 2009).

Despite the well-established knowledge on the ecological and economic importance of bees (Brosi et al 2007; Winfree et al 2009, 2011), little is known of the effects of habitat loss on their food and nesting sources (Kearns et al. 1998; Ghazoul 2005, Steffan-Dewenter et al. 2005; Frankie et al. 2009; Potts et al. 2010). Even less information is available on the drivers of bee community change (richness and abundance) in tropical landscapes. Additionally, most studies compare patches within a landscape to assess how landscape structure affects pollinators and few studies use whole landscapes as sampling units (Viana et al. 2012; Ferreira et al. 2013).

In this study we evaluated how habitat loss affects pollinators diversity in the understory of fragmented Atlantic Rainforest in Bahia, Northeast Brazil. Although our sample procedures included all floral visitor insects, we particularly focused this study on bees, the main group of pollinators for angiosperms (Roubik 1995; Ramalho and Batista 2005), and the most abundant group in our study sites (70% of all flower visitors). Given the high dependency of bees on natural habitat for food resources and nesting sites (Brosi et al. 2007; Kremen et al. 2007; Ricketts et al. 2008) and that bee diversity is expected to be positively associated with plant diversity (Ramalho and Batista 2005; Grundel et al. 2010), we hypothesized that bee communities would be more diverse in landscapes where forest cover was higher at regional and local scales. Additionally, we expected that forest cover affected distinct bee trait groups defined by nest types and sociality.

2. Materials and methods

Study area and Methods were the same for Chapters 2 and 3 and are described in "Area de Estudo" and “Coleta de Dados" sections in page 20-27.

2.1. Landscape Analysis

Forest cover data was analyzed in two different spatial scales: regional scale, landscapes, and local scale. In this way we could access the effects of variations in forest cover on bee diversity at different complementary spatial scales. We calculated the percentage of forest cover at the regional scale considering all area of the 36km2 (3600ha) landscapes, and at local scale through concentric circular areas (buffers) with 300m radius (28.2ha), centered at the hexagonal plot center. This radius was based on the mean foraging range for solitary bees described by Gathmann and Tscharntke (2002). We used the Atlas of Forest Remnants of the Atlantic Forest (SOSMA, 2008) and Quantum GIS 1.8.0 software to calculate forest cover (%) at both scales.

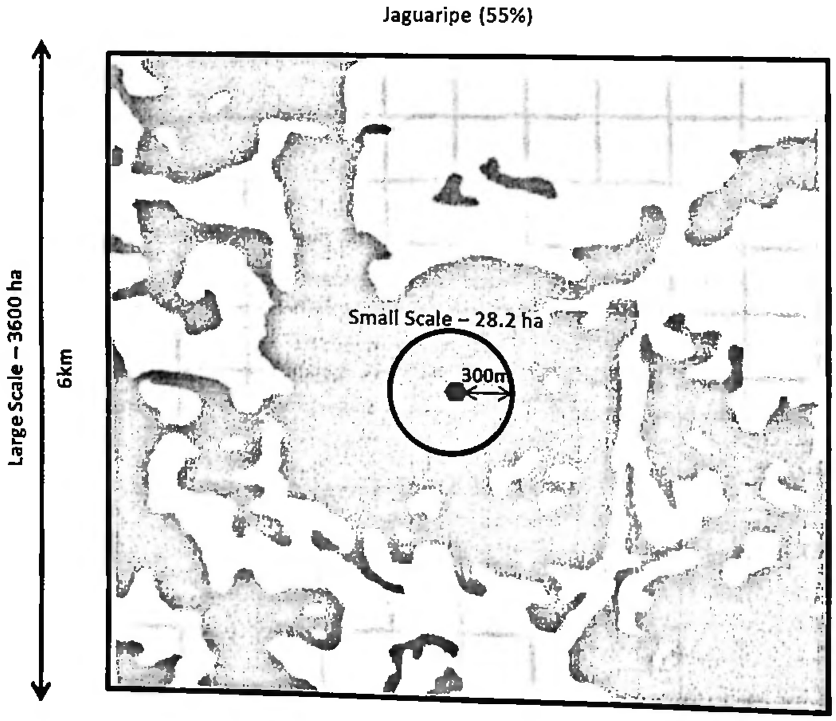


Figure 3: We calculated percentage of forest cover at landscape scale (large scale) with square areas of $36km^2$ (3600ha) and at local scale (small scale) with concentric circular areas of 300m (28.2ha) radius with hexagonal plots in the center.

2.2 Data Analyses

We calculated the Similarity in bee community structure among landscapes based on Bray-Curtis distances and tested for significant differences with different levels of forest cover by doing Analysis of Similarities (ANOSIM) test (Quinn and Keough 2002) in R 2.15.1 (R Development Core Team 2009).

Considering that the influence of landscape context on the biological populations tends to have high complexity, with several factors acting together, we choose a models selection approach. We used as selection criterion the maximum likelihood between models created in search of that model which best describe our dataset. For each selected response variable in this study, we ordered models using the lowest values of Akaike information criterion with a second-order correction for small sample sizes (AICc). The probability of a model being the one that best explains the data set was evaluated by the Akaike weight of evidence (w). We built simple generalized linear mixed models (GLMM) (Burnham and Anderson 2002) with one explanatory variable, and also additive and interactive models of the same kind with two or more explanatory variables.

To assess how forest cover affected bee composition we performed a Principal Coordinates Analysis (PCoA, Multidimensional scaling, MDS) with bray-curtis dissimilarities matrices. To assess how forest cover affected bee diversity (species richness and abundance) we used Generalized Linear Mixed Models (GLMM) assuming Poisson error distribution of data. A model selection procedure was carried out (in R package lme4) using forest cover at regional and local scales as fixed explanatory variables. All possible combinations of explanatory variables and their interactions were considered. The most parsimonious model was selected as that with the lowest AICc (Burnham and Anderson 2002).

To evaluate whether habitat loss affected bees differently depending on their traits, we grouped bees according to the type of nest (above ground, which includes bees that nest in the air, on trees and dead wood, for instance; and below ground, including bees that nest on the ground) and social structure (social species, for bees species that exhibits any level of sociality; and solitary species). From a biological point of view, most social bees that nest in the air tend to be generalists which are able to use all the available resources in the environment. Along with it, species that nest above the ground, in trees, logs sheets, etc. are dependent on forest. These characteristics may influence the resistance of those species to habitat modifications (Williams et al. 2010). Information on traits was compiled from the primary literature, from Moure's Bee Catalogue (Moure et al. 2012) and Bees of the World (Michener 2000). If published data were unavailable, we relied on a consensus of experts opinions. Whenever information about sociality and nest type for a given species was not available we used available knowledge on closely related species or genus of bees.

In order to assess the importance of traits in the response of bees to changes in forest cover we performed model selection with Generalized Linear Mixed Models, with Poisson error distribution. We considered the fixed explanatory variables forest cover at both scales, sociality and nest type. The best model was the one with the lowest value of AIC, Akaike information criterion (Burnham and Anderson 2002).

To handle overdispersion in GLMM with Poisson distribution, it was added a random factor (plot identity) which estimated an intercept for each plot for all performed models (Crawley 2007). All analyses were performed using the software R 2.15.1 (R Development Core Team 2009).

3. Results

Bees represented 70% of the flower visitors we found. We sampled a total of 492 bees from 59 species (see Supplementary Material 2). A new species of the genus Chilicola was recorded for the first time in Bahia (Oliveira et al. 2011). Bee communities varied among landscapes and their composition, number of different species per landscape was positively influenced by forest cover (ANOSIM: R= 0.4004; P < 0.001). Landscapes with lower forest cover had more similar bee communities among their constituent patches (beta diversity) than landscapes with higher forest cover, which support more diverse bee communities.

Forest cover significantly affected bee diversity (composition, richness and abundance). PCoA results evidenced difference in bee community composition along forest cover sampled gradient (Table 2). The best model according to AICc showed that bee richness increased significantly with forest cover at the Regional scale, and tending to increase (but not significantly) with forest cover at the local scale. However, the interaction between Regional and Local scales values of forest cover had a negative and not significantly effect on bee richness (Table 3, Figure 2). Bee abundance also significantly increased with forest cover at both scales. However, the positive effect of forest cover at local scale was significantly more accentuated when forest cover at regional scale was high (i.e. there was a significant interaction between forest cover at local and regional scales). The greater the quantity of forest in both scales greater bee abundance values (Table 3, Figure 2).

Table 2: Results of Principal Coordinates Analysis (PCoA, Multidimensional scaling, MDS) with Bray-curtis dissimilarities matrix. Bee communities' composition varies among sampled sites. Multidimensional scaling axis (MDS1 to MDS4).

	MDS1	MDS2	MDS3	MDS4
Site	30.540	-14.672	-5.619	-4.613
Abundance	28.180	13.655	1.094	4.169
Richness	13.000	0.375	4.546	6.811
	MDS1	MDS2	MDS3	MDS4
Eigenvalue	0.105	0.01604	0.00589	0.00333
Proportion Explained	0.8061	0.12313	0.04523	0.02558
Cumulative Proportion	0.8061	0.92919	0.97442	1

Table 3: Results of three best models for bee richness and abundance, from generalized linear mixed models, with *Poisson* error distribution ordered by AICc (corrected for small sample *Akaike* information criterion) and the probability of a model being the one that best explains the data set was evaluated by the *Akaike* weight of evidence (w). Models explanatory variables: regional scale (forest cover at landscape scale - Rs); local scale (forest cover at plot scale - Ls) and period (P).

Response Variables (Y)	**Intercept**	**Rs**	**Ls**	**P**	**Rs x Ls**	**P*Ls**	**AICc**	**w**
RICHNESS								
Model1 = Rs + Ls + (Rs * LS) (best model)		0.0190	ns	-	ns	-	76.1	0.185
Model2 = Rs + Ls		0.0550	ns	-	-	-	76.4	0.152
Model3 = null		-	-	-	-	-	76.8	0.125
Best model Estimates	0.2294	0.0364	0.0081	-	-0.0004	-		
Best model Std. Error	0.5356	0.0155	0.0096	-	0.0003	-		
Bee Richness = $e^{(0.2294 + 0.0081 \times Ls + 0.0364 \times Rs - 0.0004 \times Ls \times Rs)}$								
ABUNDANCE								
Model1= Rs + Ls + P + (Rs * Ls) + (P * Ls) (best model)		<0.001	0.008	ns	< 0.001	0.0472	115.5	-0.007
Model2 = Rs + Ls + (Rs * Ls)		0.0491	0.0095	-	ns	-	116.5	-0.004
Model3 = Rs + Ls + P + (Rs * Ls)		0.0422	0.0194	ns	0.01938	-	117.4	-0.003
Best model Estimates	1.2260	0.0440	0.0039	-0.0043	-0.0005	<0.001		
Best model Std. Error	0.5129	0.0152	0.0102	0.0019	0.0003	<0.001		
Bee Abundace = $e^{(1.2260 + 0.0039 \times Ls + 0.0440 \times Rs - 0.0005 \times Ls \times Rs)}$								

P-value obtained from a likelihood ratio test in which deviances with and without that term in the model were compared. 'ns', P >0.05. '–' Indicated variable not included in the model. Number of observations was 55 in seven sampled landscapes (random variable).

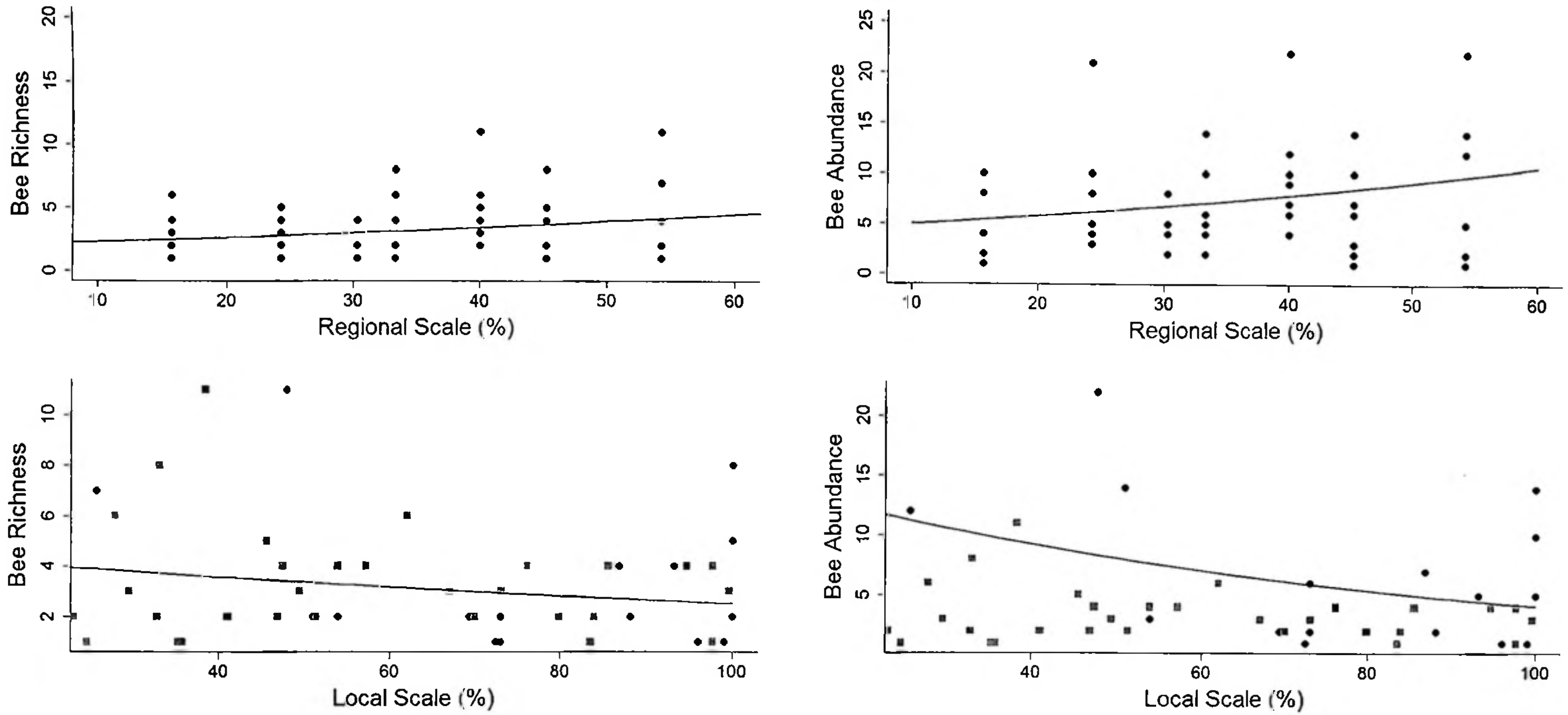


Figure 2: Positive effects of forest cover at Regional scale on bee richness and abundance, sampled in seven fragmented landscapes on the Atlantic Rainforest in Bahia Northeastern Brazil from January-November 2011. Results of the best model (Generalized Linear Mixed Models - GLMM), with *Poisson* error distribution selected by corrected for small sample *Akaike* information criterion (AICc). Line represents the best model predicted values for bee richness and abundance at regional scale, considering the constant average value (57.16%) of forest cover at local scale. Negative effects of forest cover at local scale on bee richness and abundance. Gray squares represent plots in landscapes with less than 40% forest cover. Black circles represent plots in landscapes with more than 40% forest cover. Line represents the best model predicted values for bee richness and abundance at local scale, considering the constant average value (35.12%) of forest cover at regional scale.

The majority of the sampled bee species (43 out of 59, 73%) exhibited some level of sociality and 16 species (27%) were considered solitary. We sampled 34 species of bees (58%) that nest above ground and 25 species (42%) that nest below ground. Among all social bees, 28 species (47%) nest above ground, while 15 social species nest below ground (25%). Six solitary bee species (10%) nest above ground and 10 solitary species (17%) make their nests below ground. The effect of forest cover (regional and local scales) on bee abundance depended on bee sociality and type of nest. Forest cover at regional scale positively affected the abundance of social bees that nest above ground, but at local scale had a negative effect on the abundance of social bees that nest above ground. Forest cover at both scales had a negative effect on the abundance of solitary bees that nest above ground (Figure 3, Table 4).

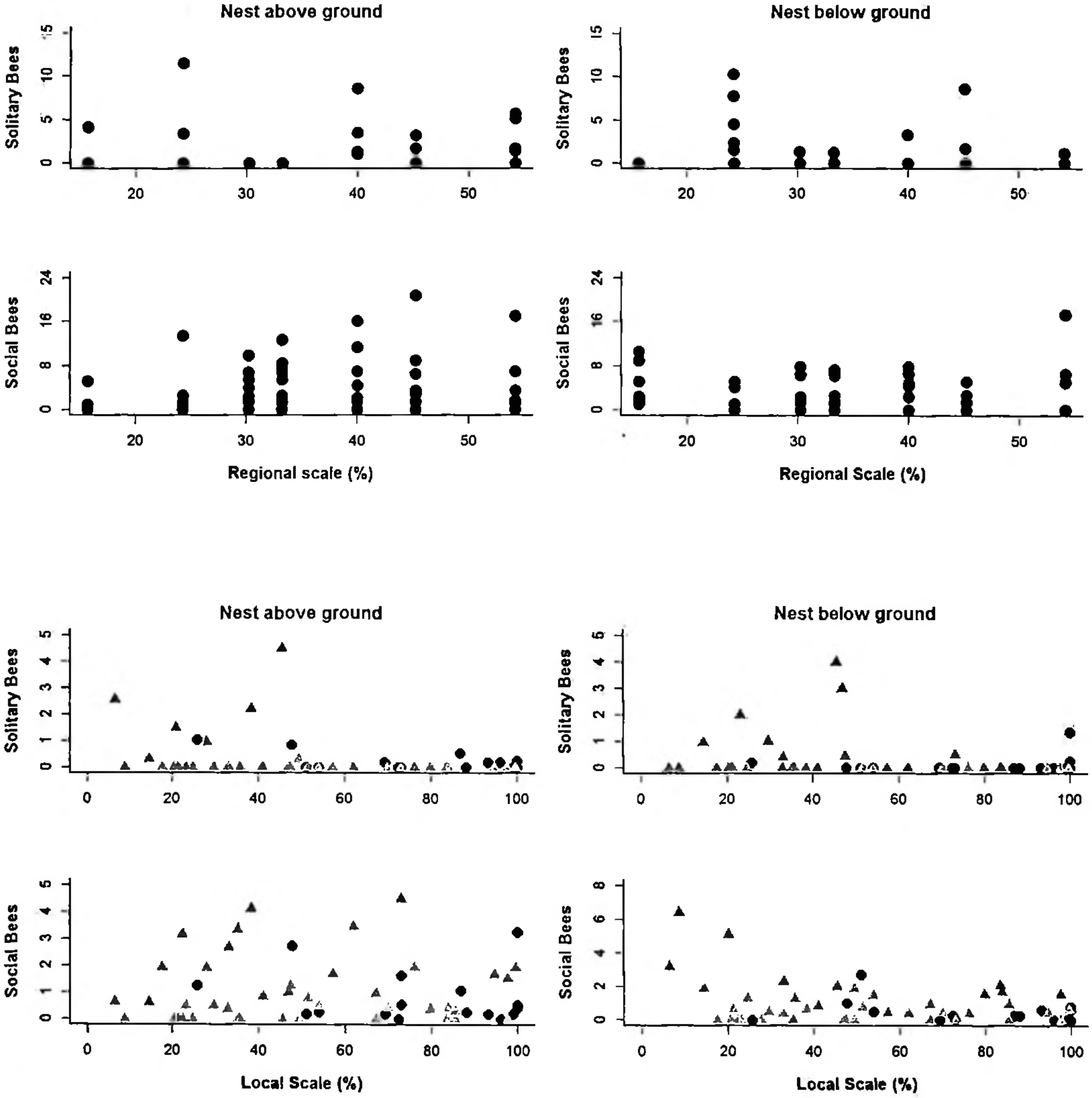


Figure 3: Effects of forest cover at regional and local scales on the abundance of social or solitary bees that nest above or below ground, sampled in seven fragmented landscapes on the Atlantic Rainforest in Bahia Northeastern Brazil from January-November 2011. Results of Generalized linear mixed models (GLMM), with *Poisson* error distribution selected by *Akaike* information criterion (AIC). Gray triangles represent plots in landscapes with less than 40% forest cover and black circles represent plots in landscapes with more than 40% forest cover.

Table 4: Results of bee abundance in functional groups characterized by sociality (social or solitary) and nesting types (above or below ground). Comparison of the three best models obtained for each response variable. Generalized linear mixed models, with Poisson error distribution ordered by AIC (Akaike information criterion). Explanatory variables in the models are forest cover at regional scale (Rs) and at local scale (Ls), Sociality (Social vs. Solitary), Nesting (above ground vs below ground).

Response Variables (Y)	Intercept	Rs	Ls	Sociality	Nesting	Rs*Social	Rs*Nest	Ls*Social	Ls*Nest	Social*Nest	Rs*Social*Nest	Ls*Social*Nest	AIC
ABUNDANCE													
Model1 (best model)		0.001	< 0.001	< 0.001	< 0.001	ns	< 0.001	< 0.001	0.0367	0.003	0.001	< 0.001	632.2
Model2		0.005	< 0.001	< 0.001	0.0001	ns	0.003	-	-	0.011	0.048	-	641.1
Model3		0.004	< 0.001	< 0.001	0.0002	-	-	0.002	ns	0.009	-	0.0142	643.7
Best model Estimates	0.2808	0.0289	-0.0055	-0.5783	0.933	0.019	-0.0317	-0.0269	-0.0018	-0.0964	-0.0325	0.0266	
Std. Error	0.2798	0.0075	0.0031	0.5558	0.4012	0.0149	0.0115	0.0074	0.0047	0.7936	0.0242	0.0109	

P-value obtained from a likelihood ratio test in which deviances with and without that term in the model were compared. 'ns', P >0.05. '–', indicated variable not included in the model. Number of observations was 219 for four functional group in seven sampled landscapes (random variable).

4. Discussion

Bees are considered the main pollinators of angiosperms, particularly in tropical forests (Roubik 1989). However, little information is available on pollinator abundance and diversity in tropical forest understory. Modern man driven landscape changes are an ongoing process, particularly within tropical environments (Hagen and Kraemer 2010, Melo et al. 2013). Here we showed that, in agreement to previous studies (e.g. Brosi et al. 2008), natural habitat availability at regional scale positively affects bee communities.

Bee communities were more diverse and spatially heterogeneous in landscapes with higher proportions of Atlantic Rainforest. As changes in natural bee communities can directly affect their interactions with plants (Winfree et al. 2009), the loss of bee diversity may have important ecological (78% of angiosperms depends on insects for pollination, Ollerton et al. 2011) and economic (e.g. crop pollination, see Garibaldi et al. 2013) impacts.

Around the world, natural habitat loss tends to encompass more generalist species in bee communities (Taki and Kevan 2007). Our results also suggest that generalist bee species are more persistent on occupy small forest patches (Table 4, Figure 4). This result may be due to edge effects, generalist bees possibly taking advantage of the higher flower abundance caused by the invasion by plant species in smaller and more irregular patches, which tend to have higher proportions of edge environments (Tabarelli et al. 2008; Lopes and Buzato 2007, Lopes et al. 2009). Some social generalist bee species (e.g. Trigona braueri) forage with large numbers of individuals, are able to explore a wide variety of floral resources, and are capable of forage in open areas and edges of patches. Additionally, some of these social species that nest below ground do not depend on forest because they need open soil to nest (Cane et al. 2006).

Bees are dependent on flowers throughout their life cycle and their existence is closely related to the presence and abundance of flowers (Potts et al. 2006;

Grundel et al. 2010). The availability of floral resources in remaining forests or its surroundings may be one of the most limiting factors for the maintenance of these floral visitor species (Ghazoul 2002; Potts et al. 2003; Ramalho 2004). Hegland and Boeke (2006), for instance, showed that the density of flowers were a better predictor of the presence of bees than plants species richness. Therefore, in landscapes with high deforestation, even the smallest forest patches are important. These areas might sustain generalist bee species, such as Trigona sp., which are important for maintaining pollination for native plant species and crops (Ricketts 2004; Ricketts et al. 2008; Taki et al. 2010).

Diversity of bees is also related to availability of nesting sites (Gathmann and Tscharntke 2002), since bees nest in different environments (soil, tree hollows, under fallen logs, etc. Michener 2000). As suggested by our results, the abundance of social above ground nesting bees was positively influenced by forest cover at regional scale and solitary bees that nest above ground were negatively affected by forest cover at both scales. Appropriate sites of natural forest available for bees to nests may be important as indicators on the risk of decline for bee species that depend on forest to nest (Cane et al. 2006; Osborne et al. 2008; Williams et al. 2010). The observed importance of forest to social bees that nest above ground maybe due to enhanced nesting opportunities available within the forest patches. For social bees that live in groups with many individuals the presence of forested habitat is important for enabling supply the need of these bees for nesting and food resources within forests. Therefore, the resources present in the forest are important for maintaining the social bee species that nest above ground. Solitary bees, and bees that live in small groups and nesting below ground in open areas with exposed soil, are less affected by the reduction of forest habitat. However, these are also the most common species foraging in small forest fragments and edges of the fragments. Therefore, despite this difference forest resources may also be important for solitary bees nesting below ground.

4.1. Implications for conservation and ecosystem services

Our results show that even though overall bee communities are positively influenced by forest cover at the regional scale, this effect will vary depending on bee functional groups. Forest resources are important for maintaining social bee species that nest above ground. While forest fragmentation, i.e. the transformation of continuous habitat into smaller patches of habitat fragments, may favor generalist solitary bee species (Pardini et al. 2009) an increase in the presence of generalist species may not represent a benefit for the pollination of more pollinator-specialized native plants of the Atlantic Rainforest. Moreover, bee species with different traits may have different functions (e.g. pollinating different species, Fontaine et al. 2006, Hoehn et al. 2008). Therefore, to ensure the reproductive success of a vast number of plant species, it is important to conserve trait diversity of bee communities.

Knowledge consolidation concerning ecological processes such as pollination at the landscape level is of extreme importance for the management of natural areas with the aim of conserving ecosystem functioning and services (Tscharntke and Brandl 2004; Nazareno and Carvalho 2009; Olschewski et al. 2010; Viana et al. 2012). Here we showed that in Atlantic Rainforest, natural habitat loss negatively affected bees, reducing richness and homogenizing bee communities. Such changes in pollinator communities of tropical forest landscapes are likely to be important for the reproduction of understory plants, affecting the quality and quantity of plant gene flow (Ghazoul and McLeish 2001) and also for pollination services in surrounding agricultural fields (Ricketts 2004; Klein et al. 2007; Morreale and Sullivan 2010). As we show that fragmentation has a negative impact for most groups of bees, management strategies that increase the area available for bee populations through the restoration of connectivity between habitats may be important for the maintenance and conservation of species, ecological functioning and ecological services (Ramalho and Batista 2005).

4.2. Conclusions

Our results showed that forest cover at both regional and local scales had a positive effect on bee communities (richness, abundance and composition). We also found that social bees that nest above ground are positively influenced by forest cover at regional scale while solitary bees that nest above ground were negatively influenced by forest cover at both scales. This result highlights the importance of forest to bees that nest above the ground (Williams et al. 2010). Further studies are also needed to better understand the gaps in the knowledge of critical values of habitat loss that may increase pollinator extinction rates (Viana et al. 2012), in order to evaluate the best strategies for pollinator management and conservation. We also suggest a more integrated approach for land use planning in tropical ecosystems, with more pollinator friendly agricultural practices, especially for bees (Melo et al. 2013).

5. Acknowledgements

We want to thank the financial research support by INOMEP-PRONEX-CNPQ, and essential financial support by FAPESB, CNPQ and CAPES. Jesus Aguirre-Gutierrez helped with forest cover calculations. Dra. Favízia F. Oliveira and MSc. Thiago Mahlmann aided in bee identification. Dr. Luciano E. Lopes, Dr. Jean Paul Metzger, Dra. Astrid M. P. Kleinert, Dra. Camila Magalhães Pigozzo and Dr. Eduardo Mariano Neto who provided helpful and valuable comments and suggestions in previous versions of this manuscript.

6. References

Bawa KS (1990) Plant-pollinator interactions in tropical rain forests. Annaul review of Ecology and Systematics 21: 399–422.

Bremer, B. Bremer, K. Chase, M. Fay, M. Reveal, J. Soltis, D. Soltis, P. & Stevens, P. (2009). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Botanical Journal of the Linnean Society, 161: 105-121.

Brosi BJ, Daily GC, Ehrlich PR (2007) Bee community shifts with landscape context in a tropical countryside. Ecological Applications, 17(2): 418-430.

Brosi BJ, Daily GC, Shih TM, Oviedo F, Duran G (2008) The effects of forest fragmentation on bee communities in tropical countryside. Journal of Applied Ecology 45(3): 773–783.

Brosi B (2009) The effects of forest fragmentation on euglossine bee communities (Hymenoptera: Apidae: Euglossini). Biological Conservation 142(2): 414–423.

Brosi BJ, Daily GC, Chamberlain CP, Mills MDA (2009) Detecting changes in habitat-scale bee foraging in a tropical fragmented landscape using stable isotopes. Forest Ecology and Management 258(9): 1846–1855.

Burnham KP, Anderson DR (2002) Model Selection and Multi-Model Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer, NewYork, NY, USA.

Cane JH, Minckley RL, Kervin LJ, Roulston TH, Williams NM (2006) Complex responses within a desert bee guild (Hymenoptera : Apiformes) to urban habitat fragmentation. Ecological Applications 16(2): 632–644.

Crawley MJ (2007) The R Book. Chichester, UK: John Wiley & Sons, Ltd. p. 952.

Fenster CB, Armbruster WS, Wilson P, Dudash MR, Thomson JD (2004) Pollination Syndromes and Floral Specialization. Annual Review of Ecology, Evolution, and Systematics 35(1): 375–403.

Ferreira PA, Boscolo D, Viana BF (2013) What do we know about the effects of landscape changes on plant–pollinator interaction networks? Ecological Indicators 31: 35-40.

Fortuna MA, Bascompte J (2006) Habitat loss and the structure of plant-animal mutualistic networks. Ecology letters 9(3): 281–286.

Fontaine C, Dajoz I, Meriguet J, Loreau M (2006) Functional diversity of plant–pollinator interaction webs enhances the persistence of plant communities. PLoS Biol. 4, 129–135.

Frankie GW, Rizzardi M, Vinson SB, Griswold TL (2009) Decline in Bee Diversity and Abundance from 1972-2004 on a Flowering Leguminous Tree, Andira inermis in Costa

Rica at the Interface of Disturbed Dry Forest and the Urban Environment. Journal of the Kansas Entomological Society 82(1): 1–20.

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, et al. (2013) Wild pollinators enhance fruit set of crops regardless of honey-bee abundance. Science 339:1608-1611

Gathmann A, Tscharntke T (2002) Foraging ranges of solitary bees. Journal of Animal Ecology 71(5): 757 –764.

Ghazoul J, McLeish M (2001) Reproductive ecology of tropical forest trees in logged and fragmented habitats in Thailand and Costa Rica. Plant Ecology 153(1-2): 335–345.

Ghazoul J (2002) Flowers at the front line of invasion? Ecological Entomology 27(5): 638–640.

Ghazoul J (2005) Pollen and seed dispersal among dispersed plants. Biological reviews of the Cambridge Philosophical Society 80(3): 413–43.

Grundel R, Jean R, Frohnapple K, Glowacki G, Scott P, Pavlovic N (2010) Floral and nesting resources, habitat structure, and fire influence bee distribution across an open-forest gradient. Ecological Applications 20(6): 1678–1692.

Hegland SJ, Boeke L (2006) Relationships between the density and diversity of floral resources and flower visitor activity in a temperate grassland community. Ecological Entomology 31: 532–538.

Hoehn P, Tscharntke T, Tylianakis JM, Steffan-Dewenter I (2008) Functional group diversity of bee pollinators increases crop yield. Proceedings. Biological sciences / The Royal Society, 275(1648), 2283–2291.

Kearns CA, Inouye DW, Waser NM (1998) Endangered mutualisms: The conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics 29: 83–112.

Klein AM (2009) Nearby rainforest promotes coffee pollination by increasing spatio-temporal stability in bee species richness. Forest Ecology and Management 258:1838-1845.

Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. Proceedings. Biological sciences / The Royal Society 274 (1608): 303-313.

Kremen C, Williams NM, Aizen MA, Gemmill-Herren B, LeBuhn G, Minckley R, Packer L, Potts SG, Roulston T, Steffan-Dewenter I, Vazquez DP, Winfree R, Adams L, Crone EE, Greenleaf SS,

Lander TA, Boshier DH, Harris SA (2010) Fragmented but not isolated: Contribution of single trees, small patches and long-distance pollen flow to genetic connectivity for Gomortega keule, an endangered Chilean tree. Biological Conservation 143(11): 2583–2590.

Lopes AV, Girão LC, Santos BA, Peres CA, Tabarelli M (2009) Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. Biological Conservation 142(6): 1154–1165.

Lopes LE, Buzato S (2007) Variation in pollinator assemblages in a fragmented landscape and its effects on reproductive stages of a self-incompatible treelet, Psychotria suterella (Rubiaceae). Oecologia 154: 305–314.

McGarigal K, and Marks BJ (1995) Fragstats: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-GTR-351. Cornvallis, Oregon.

Melo FPL, Arroyo-Rodríguez V, Fahrig L, Martínez-Ramos M, & Tabarelli M (2013) On the hope for biodiversity-friendly tropical landscapes. Trends in ecology & evolution in press, 1–7.

Michener CD (2000) The bees of the world. Johns Hopkins Press, Baltimore, Maryland, USA.

Morreale SJ, Sullivan KL (2010) Community-level enhancements of biodiversity and ecosystem services. Frontiers of Earth Science in China 4(1): 14–21.

Moure JS, Urban D, Melo GAR (2012) Catalogue of Bees (Hymenoptera, Apoidea) in the Neotropical Region - online version. Available at http://www.moure.cria.org.br/catalogue.

Nazareno AG, Carvalho D (2009) What the reasons for no inbreeding and high genetic diversity of the neotropical fig tree Ficus arpazusa? Conservation Genetics 10: 1789–1793.

Ollerton J, Winfree R, Tarrant S (2011) How many flowering plants are pollinated by animals? Oikos, 120: 321–326.

Oliveira FF, Mahlmann T, Engel MS (2011) A new species of Chilicola from Bahia, Brazil (Hymenoptera, Colletidae), with a key to the species of the megalostigma group. ZooKeys 153: 81-90.

Olschewski R, Klein AM, Tscharntke T (2010) Economic trade-offs between carbon sequestration, timber production, and crop pollination in tropical forested landscapes. Ecological Complexity 7(3): 314–319.

Osborne JL, Martin AP, Shortall CR, Todd AD, Goulson D, Knight ME, Hale RJ, Sanderson RA (2008) Quantifying and comparing bumblebee nest densities in gardens and countryside habitats. Journal of Applied Ecology 45(3): 784–792.

Pardini R, Faria D, Accacio GM, Laps RR, Mariano-Neto E, Paciencia MLB, Dixo M, Baumgarten J (2009) The challenge of maintaining Atlantic forest biodiversity: A multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. Biological Conservation 142(6): 1178–1190.

Peel MC, Finlayson BL, Mcmahon TA (2007) Updated world map of the Kooppen-Geiger climate classification. Hydrology and Earth System Sciences 11: 1633–1644.

Potts SG, Vulliamy B, Dafni A, Neeman G, Willmer P (2003) Linking bees and flowers: How do floral communities structure pollinator communities? Ecology 84(10): 2628–2642.

Potts SG, Petanidou T, Roberts S, Toole CO, Hulbert A, Willmer P (2006) Plant-pollinator biodiversity and pollination services in a complex Mediterranean landscape. Biological Conservation 29: 519–529.

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE (2010) Global pollinator declines: trends, impacts and drivers. Trends in Ecology and Evolution 25: 345-353.

Quinn GP, Keough MJ (2002) Experimental design and data analysis for biologists. Cambridge University Press, Cambridge.

Ramalho M (2004) Stingless bees and mass flowering trees in the canopy of Atlantic Forest: a tight relationship. Acta Botanica Brasilica 18(1): 37-47.

Ramalho M, Batista MA (2005) Polinização na Mata Atlântica: perspectiva ecológica da fragmentação. p.93-141. In: Franke CR, Rocha PLB, Klein W, Gomes SL (orgs). Mata Atlântica e Biodiversidade. Ed. Edufba.

Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM (2009) The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation 142(6): 1141–1153.

Ricketts TH (2004) Tropical forest fragments enhance pollinator activity in nearby coffee crops. Conservation Biology 18(5): 1262-1271.

Ricketts TH, Regetz J, Steffan-Dewenter I, Cunningham SA, Kremen C, Bogdanski A, Gemmill-Herren B, Greenleaf SS, Klein AM, Mayfield MM, Morandin LA, Ochieng A, Viana BF (2008) Landscape effects on crop pollination services: are there general patterns? Ecology letters 11(5): 499–515.

Roubik DW (1989) Ecology and Natural History of Tropical Bees. Cambridge Univ. Press, New York, 514 pp.

Roubik DW (1995) Pollination of Cultivated Plants in the Tropics. Food and Agricultural Organization of the United Nations. Agricultural Bulletin No. 118, Rome, Italy, 196 pp.

Steffan-Dewenter I, Potts SG, Packer L (2005) Pollinator diversity and crop pollination services are at risk. Trends in ecology & evolution 20(12): 651 – 652.

Tabarelli M, Lopes AV, Peres CA (2008) Edge-effects Drive Tropical Forest Fragments Towards an Early-Successional System. Biotropica 40(6): 657–661.

Taki H, Kevan PG (2007) Does habitat loss affect the communities of plants and insects equally in plant – pollinator interactions? Preliminary findings. Biodiversity & Conservation 16(11): 3147-3161.

Taki H, Okabe K, Yamaura Y, Matsuura T, Sueyoshi M, Makino S, Maeto K (2010) Effects of landscape metrics on Apis and non-Apis pollinators and seed set in common buckwheat. Basic and Applied Ecology 11(7): 594–602.

Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C (2002) Contribution of small habitat fragments to conservation of insect communities of grassland–cropland landscapes. Ecological Applications 12: 354–363.

Tscharntke T, Brandl R (2004) Plant-insect interactions in fragmented landscapes. Annual review of entomology 49: 405–430.

Veloso HP, Filho ALRR, Lima JCA (1991) Classificação da vegetação brasileira , adaptada a um sistema universal. Fundação Instituto Brasileiro de Geografia e Estatística – IBGE. Rio de Janeiro 124p.

Vesk PA, Davidson A, Chee YE (2010) Spatial distribution and prediction of seed production by Eucalyptus microcarpa in a fragmented landscape. Austral Ecology 35(1): 60–71.

Viana BF, Boscolo D, Neto EM, Lopes LE, Lopes AV, Ferreira PA, Pigozzo CM, Primo LM (2012) How well do we understand landscape effects on pollinators and pollination services? Journal of pollination ecology 7(5): 31–41.

Williams NM, Crone EE, Roulston TH, Minckley RL, Packer L, Potts SG (2010) Ecological and life-history traits predict bee species responses to environmental disturbances. Biological Conservation 143(10): 2280–2291.

Winfree R, Aguilar R, Vazquez DP, Lebuhn G, Aizen MA (2009) A meta-analysis of bees' responses to anthropogenic disturbance. Ecology 90(8): 2068–2076.

Winfree R, Bartomeus I, Cariveau DP (2011) Native Pollinators in Anthropogenic Habitats. Annual Review of Ecology, Evolution, and Systematics 42: 1-22.

Capitulo III

Forest fragmentation effects on plant-pollinator interaction networks in Northeastern Brazil

Article in Preparation

Forest fragmentation effects on plant-pollinator interaction networks in Northeastern Brazil

Patrícia Alves Ferreira[1], Danilo Boscolo[2], Luisa G. Carvalheiro[3,4], Jacobus C. Biesmeijer[4,5], Pedro Luis Bernardo da Rocha[1], Blandina Felipe Viana[1]

1 – Biology Institute – Federal University of Bahia – UFBA – Salvador-BA – Brazil.

2 – Biological Sciences Department – Federal University of São Paulo – UNIFESP – Diadema-SP – Brazil.

3 - Institute of Integrative and Comparative Biology – University of Leeds – Leeds - UK.

4 - Naturalis Biodiversity Center – Leiden University – Leiden – The Netherlands.

5 – Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam.

Abstract

Mutualistic interactions between plants and pollinators or plants and seed dispersers play an important role on the organization and persistence of biodiversity. The structure of the network of such interactions affects the resilience of ecosystems. The conservation of these interactions may be more important for maintaining biodiversity and ecological services than the preservation of isolated species in fragmented environments. In this study we investigate if there are effects of habitat loss and landscape changes on the structure of plant-pollinator networks in understory of Brazilian Atlantic Rainforest. Here we explore in more depth the role of landscape configuration, the quantity and spatial pattern of remnant forest patches, on the structure of plant-pollinator interaction networks. Our results indicate that habitat loss affects the structure of plant-bee networks in fragmented Atlantic Rainforest in Northeast Brazil. Network traits such as the number of bee species and network size were positively influenced by the amount of available forest in the landscape. Conversely, network connectance declined with increasing forest cover. Nestedness declined with mean patch area and increased with mean shape index (more irregular patch shapes). We consider that the reduction of habitat may have determined the loss of species and the reduction of network sizes. In those simplified networks, the increased connectance could mean that the remaining generalist plant and bee species tend to interact with each other in a more widespread way, and many of the possible interactions in the network are actually performed. Similarly, the positive effect of patch shape in network nestedness could also be an indication that more irregular shapes of forest patches might lead to higher frequency of interactions among generalist species, due to edge effects. This generalist species generate a cohesive interaction core in these networks. In summary, the reduction of forest habitat may simplified network structure by reducing number of species, network size, and increasing the tendency of interactions to occur in a more cohesive core of generalist species. Overall, the nested organization indicates that generalist bee species and plants are the ones that potentially drive and keep the entire interaction web in fragmented landscapes in Bahia. Our results add a new perspective to studies of plant-pollinator networks in fragmented landscapes. Interaction networks can also be indicators of effects of changes in natural habitat. We saw here that the network structure vary with the quality of the habitat and this variation can have important effects on pollinator and plant communities in these environments.

Keywords: Bees, plants, interaction networks, mutualistic web, fragmented landscapes, Brazilian Atlantic Rainforest.

1. Introduction

Mutualistic interactions between plants and pollinators or plants and seed dispersers play an important role on the organization and persistence of biodiversity and may affect the resilience of ecosystems (Fortuna & Bascompte 2006, Bascompte 2007, Bascompte 2009a). Species interactions are good models for investigate the quality of modified environments. The conservation of these interactions could be more important for maintaining biodiversity and ecological services than preservation of species isolated in fragmented environments (Steffan-Dewenter & Tscharntke 1999, Diaz & Cabido 2001, Forup & Memmott 2005).

Habitats loss and fragmentation of natural habitats are the greatest current threats to biodiversity, disrupting community structure and consequently the interactions between species (Steffan-Dewenter & Tscharntke 2002, Steffan-Dewenter et al. 2002, Fahrig 2003, Bascompte 2009a). Such changes can increase local species extinction and reduce landscapes functional connectivity (Lennartsson 2002). Additionally, cascading effects, e.g. secondary extinctions, may be more important than the initial species extinction for the ecosystems (Steffan-Dewenter & Tscharntke 1999). Habitat loss changes abundance and richness of pollinators by altering resources availability. Likewise, spatial isolation of habitat patches negatively affect plant pollinator interactions by limiting the number of available pollinators, reducing plant reproductive success and consequently increase inbreeding depression and genetic erosion of plants populations (Steffan-Dewenter & Tscharntke 1999).

The study of interaction networks structure may provide important information that helps to understand species and ecosystem responses to environmental changes (Tylianakis et al. 2008, Bascompte 2009a, Bascompte 2010). Those studies allow a better assessment of the effects of habitat changes on biodiversity loss and may provide support to conservation of biodiversity and environments (Forup & Memmott 2005, Sabatino et al. 2010, Ferreira et al. 2013). Theoretical models suggests that random extinctions may not affect the hole network structure, but when well-connected generalist species are extinct, networks tend to collapse very rapidly. It is predicted a structural threshold beyond that these networks collapse with secondary species extinctions (Bascompte 2009a, Kaiser-Bunbury et al. 2010).

However, few empirical studies have analyzed the structure of mutualistic interaction networks and tested the effects of landscape changes on plant-pollinator interactions (*e.g.* Aizen & Feinsinger 1994, Steffan-Dewenter & Tscharntke 1999, Memmott et al. 2004, Fortuna & Bascompte 2006, Ferreira et al. 2013), at the landscape scale (Lennartsson 2002) and from the perspective of trophic networks in tropical fragmented Brazilian environments (Pigozzo & Viana 2010). We practically do not know how fragmentation affects or has affected the dynamics of local interactions between flowers and pollinators in the Atlantic Forest. It is important to know these effects because there is an urgent need for information that allows better strategies on the conservation and maintenance of plants and pollinators in the Brazilian Atlantic Rainforest fragmented landscapes (Ramalho & Batista 2005).

In this study we investigate if there are structural changes in plant-pollinator interaction networks due to habitat loss and landscape modifications in understory of Northeast Brazilian Atlantic Rainforest remnants in fragmented landscapes. More specifically, we intended to characterize plant-pollinator interaction networks and to determine the structural pattern of these networks. We expect that habitat loss and landscape configuration affect size, number of species, connectance and nestedness of networks.

2. Materials and methods

Study area and Methods were the same for Chapters 2 and 3 and are described in "Area de Estudo" and "Coleta de Dados" sections in page 20-27.

2.1. Data Analyses

For each landscape, it were assessed eight indexes that describe structure of networks: 1. Network size - sum of the total number of bees and plants species per network; 2. Number of bee species per network; 3. Number of plants species per network; 4. Network connectance - ratio between the number of observed interactions and the total number of possible interactions, measures the percentage of interactions that occur in real (Biesmeijer et al. 2005); 5. Number of compartments - tendency of a network to become organized in "compartments" characterized by a group of species interacting more strongly among themselves than with other species in the web; 6. Nestedness - specialist species interact with specific subsets of generalist species, that interacts among themselves; 7. Interaction evenness; and 8. Interaction strength asymmetry - some species interact strongly with another that tends to depend less on the first one (Bascompte & Jordano 2007). We select those metrics because they were considered more sensitive to changes in landscapes (Biesmeijer et al. 2005, Tylianakys et al. 2007, Bascompte 2010). All metrics were calculated using bipartite package from R (R Development Core Team 2009) and we used these metrics as response variables.

To check the effects of landscape composition and configuration in the structure of sampled networks we used six landscape class metrics: 1. Percentage of landscape forest cover (PLAND); 2. Core area percentage of landscape (CPLAND) - (percentage of landscape comprised of forest core areas, considering edge depth as 50m; 3. Number of Patches (NP) - number of forest patches in the landscape; 4. Mean Patch Area (AREA_MN) - area of all forest patches in each landscape; 5. Mean of Shape Index (SHAPE_AM) - forest patches perimeter (m) divided by the square root of forest patch area (m^2), adjusted by a constant; and 6. Landscape proximity index (PROX_AM) - size and proximity of all forest patches whose edges are within 600m of search radius (Metzger 2003). We used 600m to ensure sampling independency (Taki & Kevan 2007). PLAND and CPLAND measured the amount of available forest habitat, yet, CPLAND measured area in forest patch interior disregarding the forest edges. Due to the presence of very small patches within the landscapes we used patches metrics weighted by the mean area of the patches. Due to the presence of extremely small forest patches in the landscape, we decided to use the metrics weighted by the area of the fragments. All landscape metrics were calculated on Fragstats 4.1 (McGarigal & Marks 1995). We used these metrics as explanatory variables.

Considering that the influence of landscape context on the biological populations tends to have high complexity, with several factors acting together, we choose an approach of models selection. We used as selection criterion the maximum likelihood between models created in search of that model which best describe our dataset. For each selected response variable in this study, we ordered models using the lowest values of AICc (*Akaike* information criterion with a second-order correction for small sample sizes). The probability of a model being the one that best explains the data set was evaluated by the weight of evidence Akaike (w). We build simple models with one explanatory variable, and additive and interactive models with two or more explanatory variables. The model coefficients were calculated from the class of generalized linear models (GLM) (Burnham & Anderson 2002)

To understand how landscape explanatory affected network structure, we applied a model selection procedure. To check if any explanatory and response variables were correlated with each other we used *Pearson's* product-moment correlation tests. We did not use correlated explanatory variables in the same additive model. We used Generalized Linear Models - GLM, with *Poisson* error distribution for count data and *Gaussian* error distribution for normal distributed data, in R package *nlme*. All possible combinations of explanatory variables and their interactions were considered. The most parsimonious model was selected as that with the lowest AICc, *Akaike* information criterion corrected for small samples

(Burnham & Anderson 2002). All analyses were performed using the software R, package (R Development Core Team 2009).

3. Results

We sampled 75 plant and 63 floral visitor bee species in understory of Brazilian Atlantic Rainforest fragmented landscapes (Figure 7). The list of plants and their bee floral visitors sampled in each landscape is available in Supplementary Material 3. Our results show that species numbers (network size and bee richness) and connectance were influenced by habitat quantity (forest cover) while nestedness was influenced by indicators of habitat quality (mean patch area and mean patch shape). Plant-bee interaction networks, in fragmented landscapes of Atlantic Rainforest in Bahia, Brazil are heterogeneous, nested, with asymmetric interactions (see Table 5). The graphs of the relationship between each network metric with forest cover (disregarding the edge areas of 50m depth - CPLAND) in sampled landscapes are presented in Supplementary Material 4. We observe that there were positive correlations between the number of bees and the size of the network, and between the number of bees and interactions asymmetry strength. We also observed negative correlations between size of networks and connectance and number of bees and networks connectance (Table 6).

As we expected there was a positive correlation between the metrics regarding percentage of forest (PLAND and CPLAND), and also between percentage of forest (PLAND + CPLAND) and mean patch area (AREA_MN). We observed negative correlations between the percentage of forest (PLAND + CPLAND) and patch area (AREA_MN) with the number of patches in the landscape (NP). We also observed a significant negative correlation between shape index (SHAPE_MN) and number of patches in the landscape (NP; Table 7).

Networks size and number of bee species in the networks were positively influenced by the percentage of forest in the landscapes. Network connectance index, *i.e.* the ratio between the number of observed interactions and the number of possible interactions in the networks, was negatively influenced by the percentage of forests in the landscapes. Despite nestedness was not influenced by forest cover. It declined with forest mean patch area in the landscapes and increased with landscape mean shape index (Table 8, Figure 8).

We did not observe significant effects of explanatory variables on network number of plant species, number of compartments, interactions strength asymmetry and interaction evenness. For these metrics the best models selected (with lower *AICc*) were the null models.

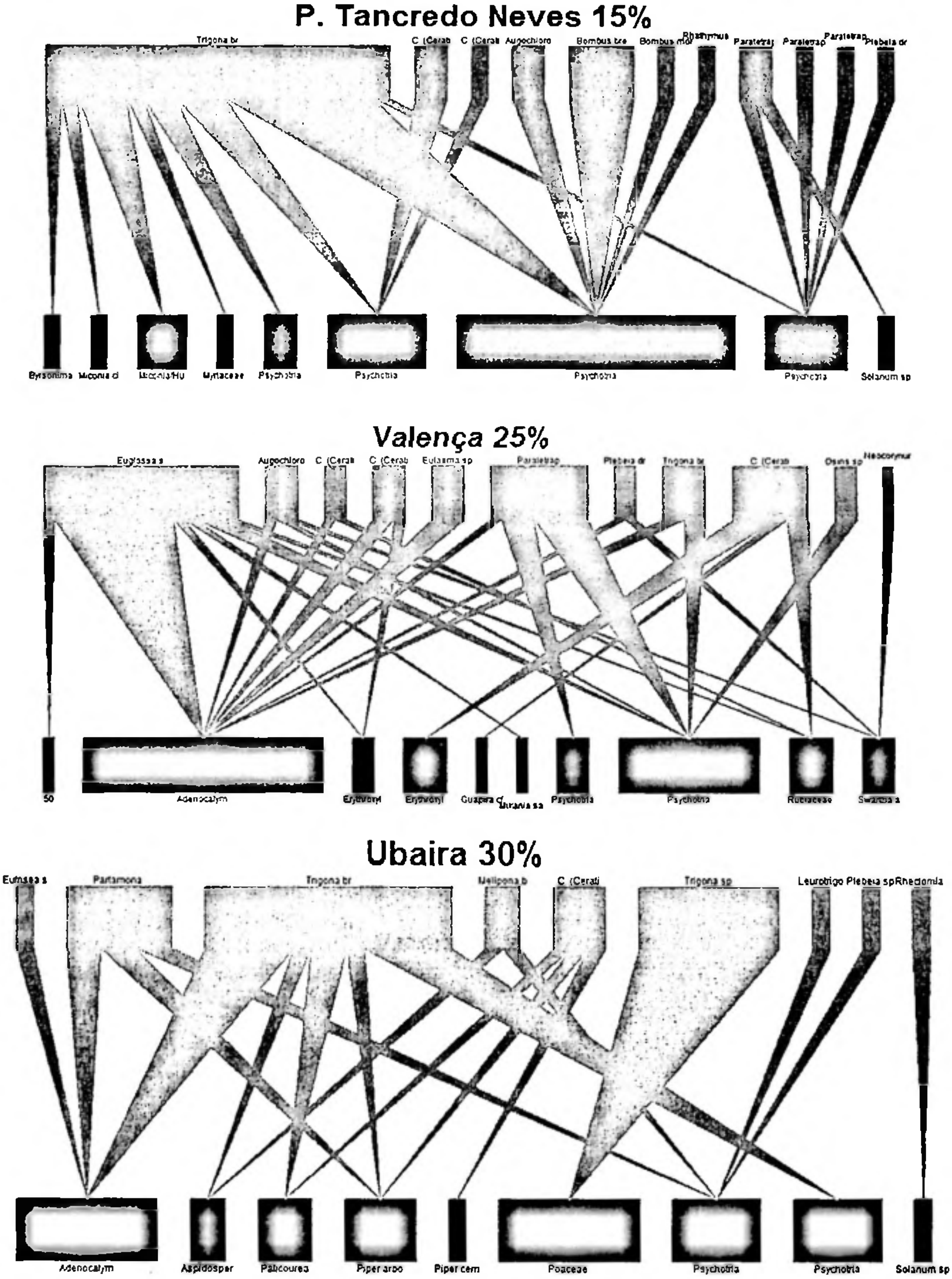
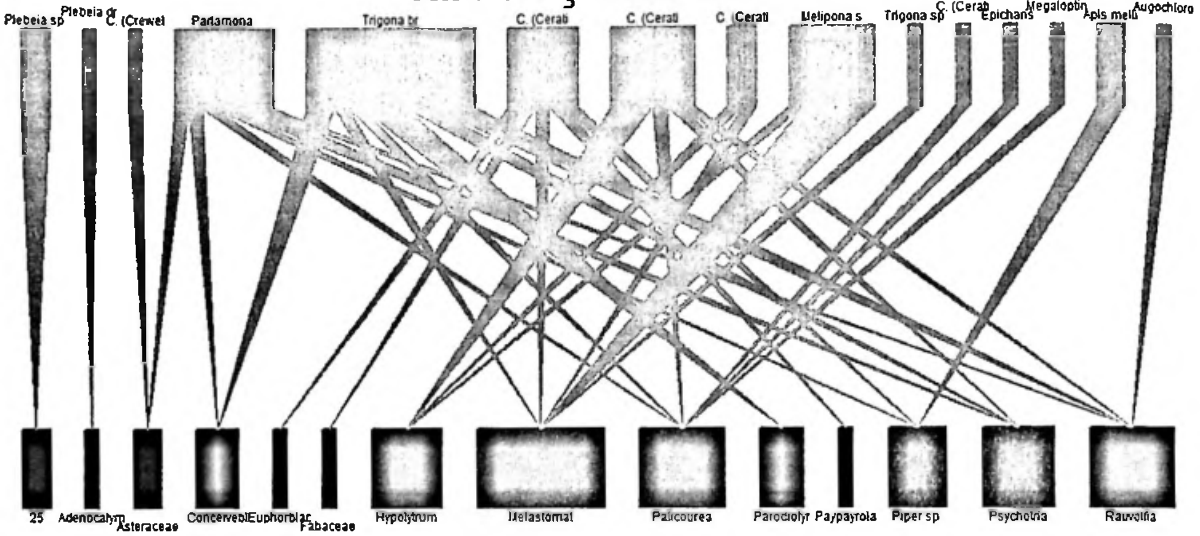
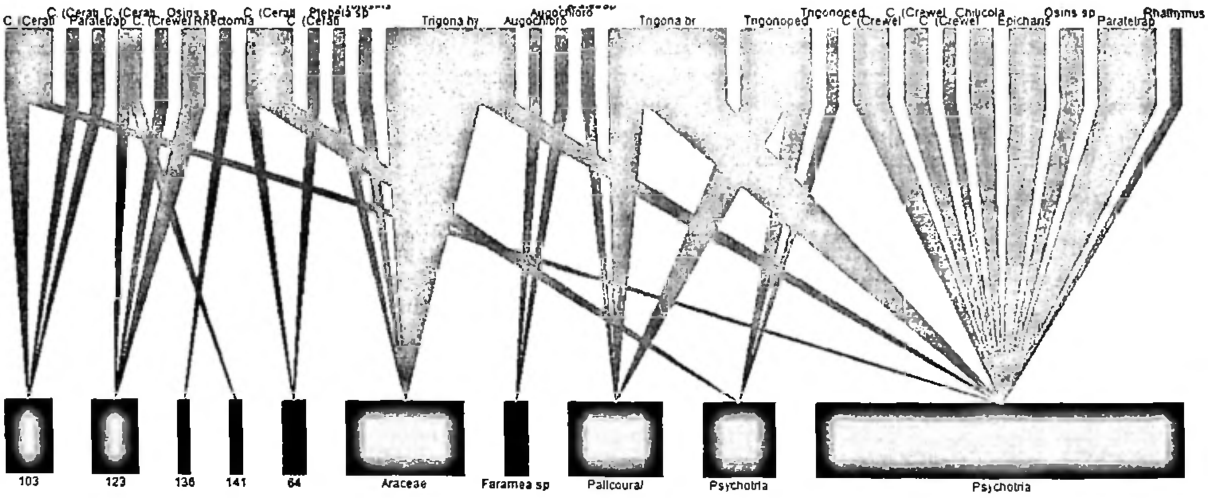


Figure 7: Plant-bee networks plots for each of the seven sampled landscapes on the Atlantic Rainforest in Bahia Northeastern Brazil from January to November of 2011. Plant (below) and bees (above) are represented by rectangles. The widths of the rectangles are proportional to the species abundance at landscape and the size of the triangles connecting the rectangles represents the frequency of interactions at landscape.

Nilo Peçanha 35%



Wenceslau Guimarães 40%



Camamu 45%

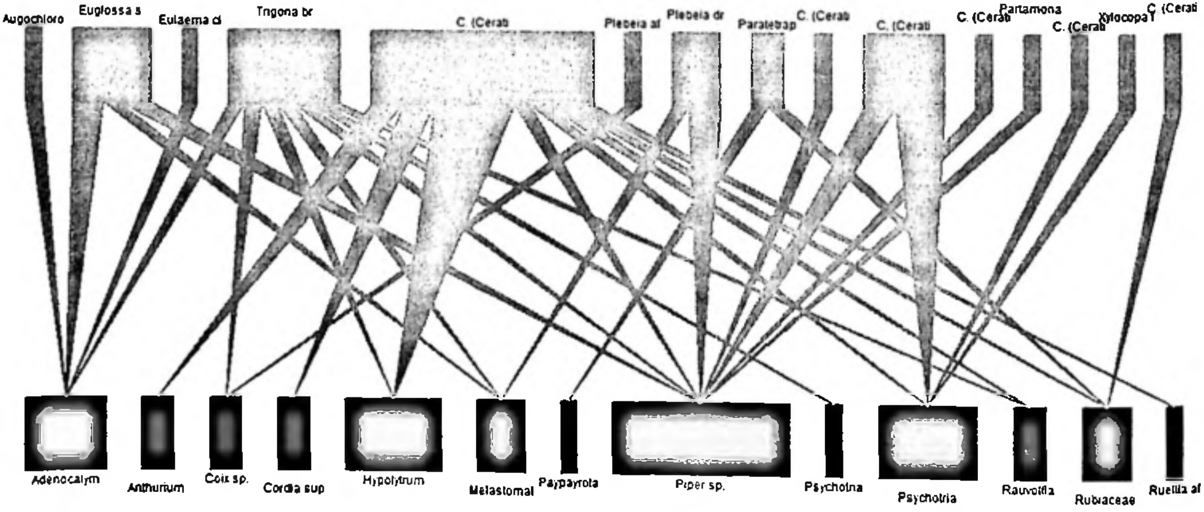


Figure 7: Continuation.

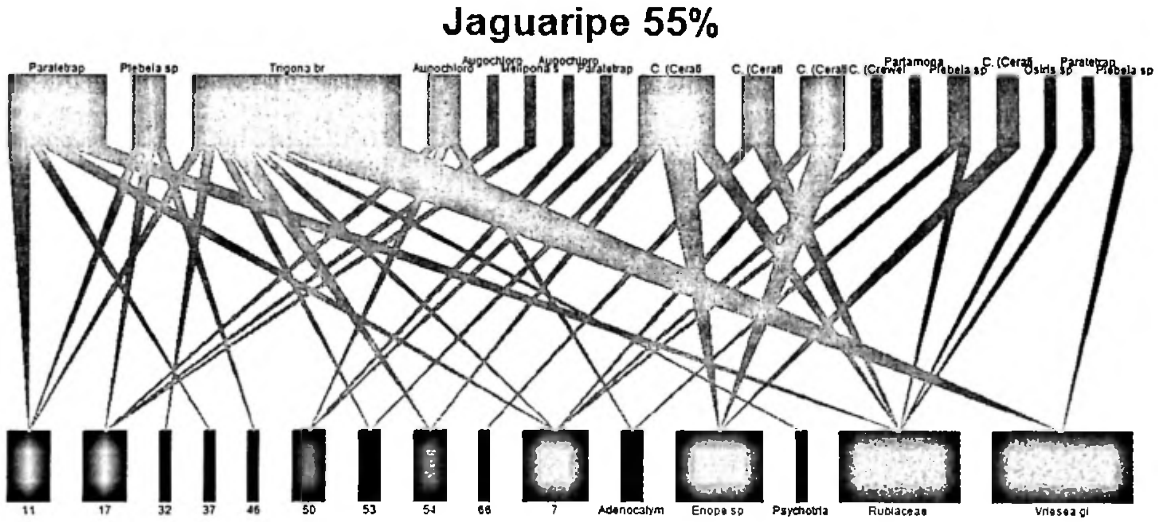


Figure 7: Continuation. Plant-bee networks plots for each of the seven sampled landscapes on the Atlantic Rainforest in Bahia Northeastern Brazil from January to November of 2011. Plant (below) and bees (above) are represented by rectangles. The widths of the rectangles are proportional to the species abundance at landscape and the size of the triangles connecting the rectangles represents the frequency of interactions at landscape. List of plant and bee species per landscape are provided in Supplementary Material 3.

Table 5: Results of analyses in R package bipartite of plant-bee network sampled in seven landscapes of 36km^2 (3600ha) along a gradient of forest cover from 15% to 55%, on the Atlantic Rain Forest in Bahia Northeastern Brazil.

Local	Network Size	N of Bees	N of Plants	Connectance	Nestedness	Compartments	Interaction Strength Asymetry	Interaction Evenness
P. Tancredo Neves 15%	20	11	9	0.19	16.7	1	0.02	0.90
Valença 25%	21	11	10	0.24	20.3	1	0.08	0.90
Ubaira 30%	18	9	9	0.22	28.1	3	-0.14	0.89
Nilo Peçanha 35%	29	15	14	0.16	16.1	3	-0.04	0.96
Wenceslau Guimarães 40%	36	26	10	0.12	23.2	4	0.38	0.93
Camamu 45%	28	15	13	0.17	13.1	1	-0.11	0.96
Jaguaripe 55%	33	18	15	0.14	17.3	1	0.05	0.91
Mean	**26.4**	**15**	**11.4**	**0.18**	**19.3**	**2**	**0.03**	**0.92**

Table 6: *Pearson's* correlations between all plant-bee network metrics sampled in seven landscapes of 36km^2 (3600ha) along a gradient of forest cover from 15% to 55%, on the Atlantic Rainforest in Bahia Northeastern Brazil. Significant correlations ($p<0.01$) are in boldface letters.

Network Metrics	N of Bees	N of Plants	Total Size	Connectance	Interaction Strength Asymetry	Compartments	Nestedness	Interaction Evenness
N of Bees	1	ns	**0.94**	**-0.89**	**0.80**	ns	ns	ns
N of Plants		1	ns	ns	ns	ns	ns	ns
Total Size			1	**-0.94**	ns	ns	ns	ns
Connectance				1	ns	ns	ns	ns
Interaction Strength Asymetry					1	ns	ns	ns
Compartments						1	ns	ns
Nestedness							1	ns
Interaction Evenness								1

'ns', P >0.05.

Table 7: *Pearson's* correlations between all landscape metrics of seven landscapes of 36km^2 (3600ha) along a gradient of forest cover from 15% to 55%, on the Atlantic Rainforest in Bahia Northeastern Brazil. Significant correlations ($p<0.01$) are in boldface letters.

Landscape Metrics	PLAND	CPLAND	NP	AREA_AM	SHAPE_AM	PROX_AM
PLAND	1	**0.99**	**-0.83**	**0.83**	ns	ns
CPLAND		1	**-0.82**	**0.86**	ns	ns
NP			1	**-0.83**	**-0.78**	ns
AREA_AM				1	ns	ns
SHAPE_AM					1	ns
PROX_AM						1

'ns', P >0.05.

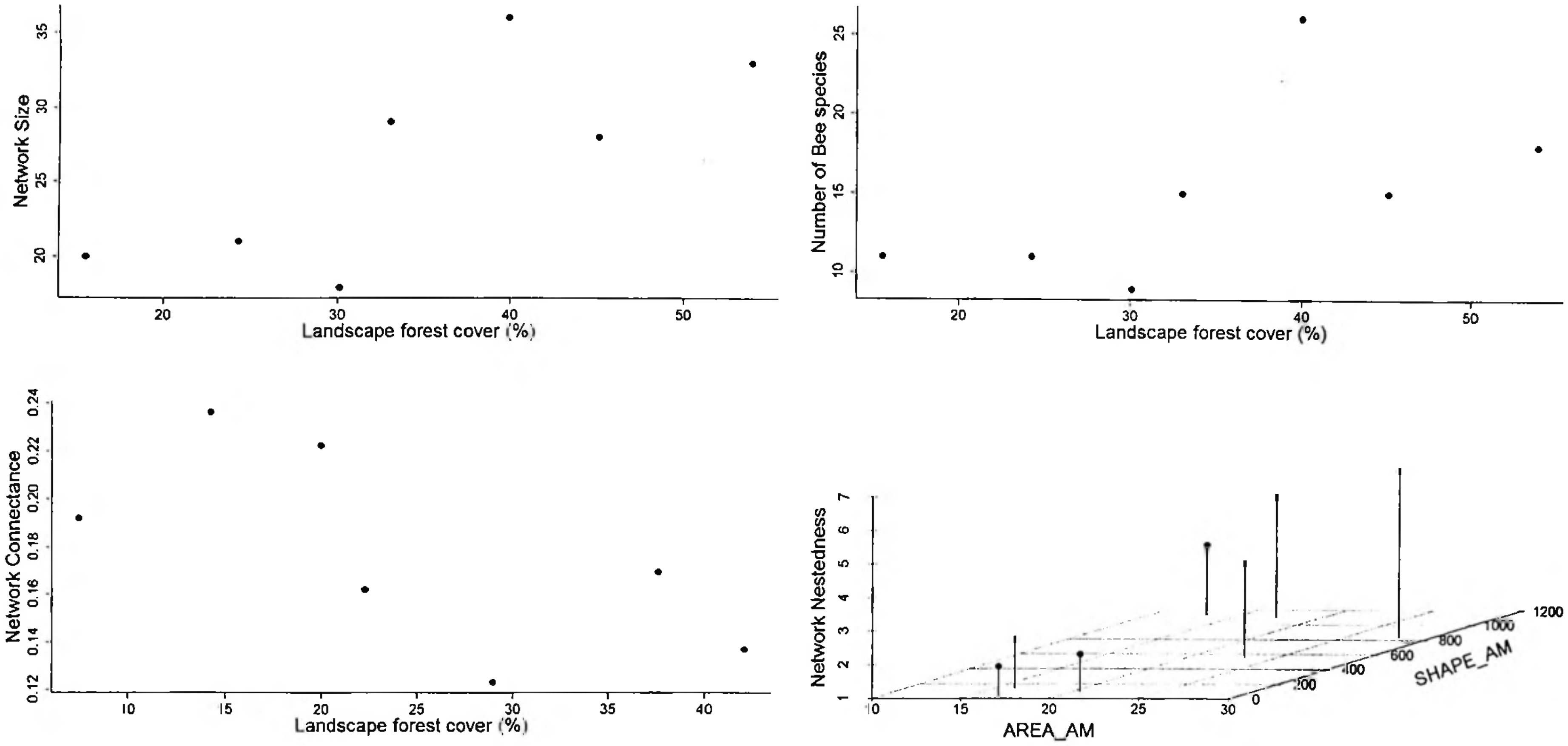


Figure 8: Results of best significant models of landscape explanatory variables effects on network structure, in seven fragmented landscapes on the Atlantic Rainforest in Bahia Northeastern Brazil from January to November of 2011. Networks size and number of bee species in the networks were positively influenced by the percentage of forest in the landscapes. Network connectance was negatively influenced by the percentage of forests in the landscapes. Nestedness declined with forest mean patch area (AREA_AM) and increased with landscape mean shape index (SHAPE_AM).

Table 8: Results of network models: comparison of the three best models obtained for each response variable, from generalized linear models, with *Poisson* and *Gaussian* error distribution ordered by AICc (corrected for small sample *Akaike* information criterion). Explanatory variables in the models, Percentage of Landscape (PLAND), Core Area Percentage of Landscape (CPLAND), Number of Patches (NP), Patch Area (AREA_AM), Shape Index (SHAPE_AM) and Proximity Index (PROX_AM).

Response Variables (Y)	**Intercept**	PLAND	CPLAND	AREA_AM	SHAPE_AM	PROX_AM	NP	AICc	W
Network Size									
Model1 (best model)		0.0128	-	-	-	-	-	47.3	0.3463
Model2		-	0.016	-	-	-	-	47.7	0.2821
Model3		-	-	-	-	-	-	49.3	0.1256
Best model Estimates	2.7271	0.0153	-	-	-	-	-		
Best model Std. Error	0.2383	0.0062	-	-	-	-	-		
Number of Bees Species									
Model1 (best model)		0.0342	-	-	-	-	-	46.3	0.2537
Model2		-	-	-	-	-	-	46.6	0.2166
Model3		-	0.0431	-	-	-	-	46.7	0.2069
Best model Estimates	2.086	0.017	-	-	-	-	-		
Best model Std. Error	0.319	0.008	-	-	-	-	-		
Network Connectance									
Model1 (best model)		0.0929	-	-	-	-	-	-20.9	0.2353
Model2		-	-	-	-	-	-	-20.8	0.2193
Model3		-	0.1017	-	-	-	-	-20.7	0.2107
Best model Estimates	0.2537	-0.0022	-	-	-	-	-		
Best model Std. Error	0.0390	0.0011	-	-	-	-	-		
Network Nestedness									
Model1 (best model)		-	-	0.0297	0.009	-	-	44.3	0.4379
Model2		-	-	-	-	-	-	46.3	0.1577
Model3		-	-	-	ns	-	-	46.5	0.1436
Best model Estimates	9.5499	0.0362	-	-0.0095	4.3714	-	-		

Response Variables (Y)	**Intercept**	PLAND	CPLAND	AREA AM	SHAPE AM	PROX AM	NP	AICc	W
Best model Std. Error	0.5685	0.0173	-	0.0029	0.9211	-	-		
Number of Plant species									
Model1 (null best model)		-	-	-	-		-	35.9	0.4231
Model2		ns	-	-	-		-	38.3	0.1308
Model3		-	ns	-	-		-	38.3	0.1282
Best model Estimates	2.4361	-	-	-	-		-		
Best model Std. Error	0.1118	-	-	-	-		-		
Network Compartments									
Model1 (null best model)		-	-	-	-	-	-	24.9	0.5039
Model2		-	-	-	-	-	ns	28.2	0.0995
Model3		-	-	-	-	ns	-	28.2	0.0949
Best model Estimates	0.6931	-	-	-	-	-	-		
Best model Std. Error	0.2673	-	-	-	-	-	-		
Network Interaction Strength Asymetry									
Model1 (null best model)		-	-	-	-	-	-	-0.8	0.5580
Model2		-	-	ns	-	-	-	3.1	0.0805
Model3		-	-	-	ns	-	-	3.3	0.0733
Best model Estimates	0.0339	-	-	-	-	-	-		
Best model Std. Error	0.0662	-	-	-	-	-	-		
Network Interaction Evenness									
Model1 (null best model)		-	-	-	-	-	-	-25.5	0.3937
Model2		-	ns	-	-	-	-	-23.2	0.1259
Model3		ns	-	-	-	-	-	-22.8	0.1056
Best model Estimates	0.9215	-	-	-	-	-	-		
Best model Std. Error	0.0114	-	-	-	-	-	-		

P-value obtained from a likelihood ratio test in which deviances with and without that term in the model were compared. 'ns', P >0.05. '–' Indicated variable not included in the model. Number of observations was 51 in seven landscapes. AIC weighted (W) values presented.

4. Discussion

We observed through our results that there is an effect of habitat loss and landscapes configuration in the structure of plant-bee interaction networks in fragmented Atlantic Rainforest in Bahia, Brazil. Species richness (network size and bee richness) and connectance were mostly influenced by habitat quantity (forest cover) while nestedness was influenced by indicators of habitat quality (mean patch area and shape). It is known that modifications in the structure of pollination networks may cause major consequences for plant population performance and local persistence (Gómez et al. 2011). Therefore, in sampled landscapes habitat loss may affect plant and bee diversity and ecological processes associated to these species, as pollination, through network structure changes.

Mutualistic interactions such as pollination and seed dispersal are known to form heterogeneous, nested networks built on weak and asymmetric links among animal and plant species. We observed in landscapes with less forest cover that few nodes (or species) are much more connected than would be expected by chance. Asymmetric interactions and nested organization make networks more robust to the extinction of species with few links (Memmott et al. 2004, Vázquez & Aizen 2004). Nestedness and asymmetry introduces functional redundancy and the possibility for alternative routes for system persistence if some of the interactions disappear (Bascompte & Jordano 2007). Asymmetry means that specialists tend to interact with the most generalist species (Vázquez & Aizen 2004, Bascompte & Jordano 2007). Thus, asymmetry provides pathways for the persistence of specialists (Bascompte et al. 2003). Yet, networks that are robust to random loss of nodes may be very fragile to the extinction of the most generalist species. Network robustness is measured as the fraction of the species that must become extinct to result in network species loss (Albert et al. 2000). Our results show that changes in forest habitat quantity and quality negatively affect the robustness of the networks, through the loss of species. These results show that species may have been lost due to habitat loss, but nestedness and connectance kept networks structure and species could be supported by this structure in these landscapes.

Network structure characteristics tend to be simplified according to habitat loss and natural landscape modification. Habitat loss have influenced loss of species and increased the tendency to structure simplification in these networks. As species were lost, the number of bee species and size of the network decreased and interactions tended to form more cohesive network cores in these landscapes. The suppression of links between highly connected nodes may reflect both differences in networks structure (species loss and more connected core of interactions) and in their response to different perturbations (Melián & Bascompte 2002).

Anthropogenic landscape changes that promote species extinction might induce a sudden collapse of pollination networks, by affecting the most connected species in the networks (Kaiser-Bunbury et al. 2010). In our study we saw that habitat loss reduced number of species, but the network structure was mantained in plant-bee webs. As also shown by Fortuna & Bascompte (2006), real networks start to lose species sooner than simulated networks, but the community structure as a whole persists for higher values of habitat loss. For instance, due to asymmetry both specialist and generalist plant species regarding pollination exhibit similar susceptibility to habitat loss. Specialist plants that depend on a single pollinator tend to interact with the most generalist animal species (Ashworth et al. 2004), and therefore more resistant to secondary extinctions.

Our results showed a negative correlation between the number of bees and networks connectance and size of networks and connectance. These results show that when there is fewer species in more connected networks those species tend to be more connected among themselves, since many of the possible connections are actually established. We observed that landscapes with lower proportion of remaining habitat supported networks that fulfill a higher proportion of the possible interactions. This means that the core of the interaction within networks tends to be more connected. This may be a result of the reduction of specialist species that interact weakly with fewer species in networks (Bascompte et al. 2003). These networks have less species, most of them highly conneceted generalist and the resulting networks tend to be more nested. Consequently, even in highly fragmented landscapes the structure of networks is maintained, and species are protected from secondary extinctions and failure of ecological process in the communities.

Gómez et al. (2011) suggest that nested and highly connected local pollinator assemblages might result in highly robust structured networks. As we saw in our results, the increased connectance of the networks in landscapes with less remaining forest could mean that networks have become more simplified and the generalist species are relativelly more abundant and play a more important role in the network. Our results suggest that network connectance could be an indicator of plant-bee network integrity were, within a certain range, more connected networks may be the most simplified ones, as a result of landscape changes.

The recognition of generalist and specialist species must be valuable for better understanding our results. Common and generalist species seem to interact unconstrained, while rare and specialized species are constrained in their low encounter rate due to its lower abundance (Olesen et al. 2011). The reduction of the diversity of bees observed in landscapes with lower forest cover (see chapter 2) may lead to greater frequency of interactions among generalist species remaining in these landscapes. Our result shows that network cores with more interactions among generalist species and few specialist interactions tend to be more common in landscapes with less habitat remaining.

The positive effect of patch shape in network nestedness could also be an indication that more irregular shape of forest patches might lead to higher frequency of interactions among generalist species remaining in networks. Irregular shapes can increase edge effects and invasion of more generalist species that use resources inside and/or outside forested areas. Additionally, we calculated that approximately

10% of all sampled area is composed of edges in the landscapes. Empirical evidence showed that increasing of edge density in agricultural lands, not by habitat fragmentation but through preservation and restoration of natural habitats, may favor the maintenance of diverse and abundant insect pollinators (Chacoff & Aizen 2006).

Our results show that network connectance and nestedness reveal that an interaction core provided by generalist species is kept in the networks in situations of high reduction of forest area and increased edge effects. In landscapes with less forested habitat the most sensitive species may disappear and the resilient species (which are usually the most generalist species) tends to be kept in these landscapes and interactions tend to be more frequently performed among this generalist species. Those results highlight the importance of maintaining forested areas for conservation of ecological processes such as pollination, at the landscape scale for the conservation of mutualistic networks (Fortuna & Bascompte 2006).

4.1. Conclusions

We have made the first attempt to empirically characterize the structure of plant-bee interaction networks in fragmented landscapes in Atlantic Rainforest in Bahia, Northeast Brazil. This is an important step for understanding the organizing patterns of such important associations and to produce knowledge to its conservation and management.

In summary, some studies have predicted that environmental changes that lead to species extinction in the networks could reduce networks size and the number of weak interactions of specialist species, keeping only the core of the generalist species interaction in the networks (Bascompte et al. 2003, Memmott et al. 2004, Fortuna & Bascompte 2006). Our data show that generalist species, even after species extinction, may sustain networks core of cohesive interactions, protecting the network as a whole. We observed that networks are smaller, with less species, the interactions happened among generalists species in a cohesive core, and there were few specialist species interacting with generalist species in these networks in landscapes with less forest habitat remaining. We believe that, due to the high degree of environmental degradation of these landscapes, generalist species are able to manage to stay in these landscapes and keep networks core of interactions and structure.

Our results showed empirical evidence that networks tend to simplify its structure when species are lost. Networks in landscapes with less forest may have already gone through this process. Overall, the nested and asymmetric organization indicates that generalist species of bees and plants are the ones that potentially are able to keep the entire web of interactions in fragmented landscapes in Bahia. Our findings add a new perspective to studies of plant-pollinator networks in fragmented landscapes. Interaction networks can also be indicators of effects of changes in natural habitat. We saw here that the network structure vary with the quality of the habitat and this variation can have important effects on pollinators and plant communities in these environments.

5. Acknowledgements

We want to thank the financial research support by INOMEP-PRONEX-CNPQ, and essential financial support by FAPESB, CNPQ and CAPES. Jesus Aguirre-Gutierrez for help on forest cover calculations. Favízia F. Oliveira and Thiago Mahlmann for bee identification and Nadia Roque and Rodrigo Lopes for plants identification. Luciano E. Lopes for his helpful and valuable comments and suggestions.

6. References

Aizen, M.A. & Feinsinger, P. (1994). Forest Fragmentation, Pollination, and Plant Reproduction in a Chaco Dry Forest, Argentina. Ecology, 75 (2): 330-351.

Albert R, Jeong H, Barabasi A.L. (2000). Error and attack tolerance of complex networks. Nature, 406: 378–382.

Ashworth, L. Aguilar, R. Galetto, L. Aizen, M.A. (2004). Why do pollination generalist and specialist plant species show similar reproductive susceptibility to habitat fragmentation? Journal of Ecology, 92: 717–719.

Bascompte, J. Jordano, P. Melián, C.J. & Olesen, J.M. (2003). The nested assembly of plant-animal mutualistic networks. Proceedings of the National Academy of Sciences of the United States of America, 100(16): 9383–9387.

Bascompte, J. (2007). Plant-animal mutualistic networks: the architecture of biodiversity, 101(2): 221–223.

Bascompte, J. & Jordano, P. (2007). Plant-Animal Mutualistic Networks: The Architecture of Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 38: 567-593.

Bascompte, J. (2009a). Disentangling the web of life. Science (New York, N.Y.), 325(5939): 416–419.

Bascompte, J. (2009b). Mutualistic networks. Frontiers in Ecology and the Environment, 7(8): 429–436.

Bascompte, J. (2010). Ecology. Structure and dynamics of ecological networks. Science (New York, N.Y.), 329(5993): 765–766.

Biesmeijer, J. Slaa, E.J. Castro, M.S. Viana, B.F. Kleinert, A.M.P & Imperatriz-Fonseca, V.L. (2005). Connectance of Brazilian social bee – food plant net- works is influenced by habitat, but not by latitude, altitude or network size. Biota Neotropica, 5(1), 1–9.

Burnham, K.P. & Anderson, D.R. (2002) Model Selection and Multi-Model Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer, NewYork, NY, USA.

Chacoff, N.P. & Aizen, M.A. (2006). Edge effects on flower-visiting insects in grapefruit plantations bordering premontane subtropical forest. Journal of Applied Ecology, 43(1): 18–27.

Diaz, S. & Cabido, M. (2001). Vive la différence: plant functional diversity matters to ecosystem processes. Trends in Ecology & Evolution, 16 (11): 646-656.

Fahrig, L. (2003). Effects of habitat fragmentation on Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34: 487–515.

Ferreira, P.A. Boscolo, D. & Viana, B.F. (2013). What do we know about the effects of landscape changes on plant–pollinator interaction networks? Ecological Indicators, 31: 35-40.

Fortuna, M. A. & Bascompte, J. (2006). Habitat loss and the structure of plant–animal mutualistic networks. Ecology Letters, 9: 281–286.

Forup M.L. & Memmott, J. (2005). The Restoration of Plant–Pollinator Interactions in Hay Meadows. Restoration Ecology, 13: 265–274.

Gómez, J.M. Perfectti, F. & Jordano, P. (2011). The Functional Consequences of Mutualistic Network Architecture. PLoS One, 6(1): e16143.

Kaiser-Bunbury, C.N. Muff, S. Memmott, J. Müller, C.B. & Caflisch, A. (2010). The robustness of pollination networks to the loss of species and interactions: a quantitative approach incorporating pollinator behaviour. Ecology letters, 13(4): 442–452.

Lennartsson, T. (2002). Extinction Thresholds and Disrupted Plant-Pollinator Interactions in Fragmented Plant Populations. Ecology, 83 (11): 3060-3072.

McGarigal, K. & Marks, B.J. (1995). Fragstats: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-GTR-351. Cornvallis, Oregon.

Melián, C. J., & Bascompte, J. (2002). Complex networks: two ways to be robust? Ecology Letters, 5(6), 705–708.

Memmott, J. Waser, N.M. & Price, M.V. (2004). Tolerance of pollination networks to species extinctions. Proceedings. Biological sciences / The Royal Society, 271(1557): 2605–2611.

Metzger, J.P. (2003). Estrutura da paisagem: o uso adequado de métricas. p. 423-453. In: L. Cullen Jr.; R. Rudran & C. Valladares-Padua (orgs.). Métodos de estudo em Biologia da Conservação e Manejo da Vida Silvestre. Editora UFPR e Fundação O Boticário de Proteção à Natureza, Curitiba.

Olesen, J.M. Bascompte, J. Dupont, Y.L. Elberling, H. Rasmussen, C. & Jordano, P. (2011). Missing and forbidden links in mutualistic networks. Proceedings. Biological sciences / The Royal Society, 278: 725–732.

Pigozzo, C.M. & Viana, B.F. (2010). Estrutura da rede de interações entre flores e abelhas em ambiente de caatinga. Oecologia Australis, 14(01): 100–114.

Ramalho, M. & Batista, M. (2005). Polinização na Mata Atlântica: perspectiva ecológica da fragmentação. p.93-141. In: Franke, C. R.; Rocha, P. L. B.; Klein, W.; Gomes, S. L. (orgs).Mata Atlântica e Biodiversidade. Ed. Edufba.

Sabatino, M. Maceira, N. & Aizen, M.A. (2010) Direct effects of habitat area on interaction diversity in pollination webs. Ecological Applications, 20: 1491–1497.

Steffan-Dewenter & Tscharntke (1999). Effects of habitat isolation on pollinator communities and seed set. Oecologia, 121: 432–440.

Steffan-Dewenter, I. & Tscharntke, T. (2002). Insect communities and biotic interactions on fragmented calcareous grasslands - a mini review. Biological Conservation, 104: 275–284.

Steffan-Dewenter, I. Munzenberg, U. Burger, C. Thies, C. & Tscharntke, T. (2002). Scale-Dependent Effects of Landscape Context on Three Pollinator Guilds. Ecology, 83 (5): 1421-1432.

Taki, H. & Kevan, P.G. (2007). Does habitat loss affect the communities of plants and insects equally in plant–pollinator interactions? Preliminary findings. Biodiversity and Conservation, 16 (11): 3147-316.

Tylianakis, J.M. Tscharntke, T. & Lewis, O.T. (2007). Habitat modification alters the structure of tropical host-parasitoid food webs. Nature, 445(7124): 202–205.

Tylianakis, J. M. Didham, R.K. Bascompte, J. & Wardle, D.A. (2008). Global change and species interactions in terrestrial ecosystems. Ecology Letters, 11: 1351–1363.

Vázquez, D.P. & Aizen, M.A. (2004) Asymmetric specialization: a pervasive feature of plant-pollinator interactions. Ecology 85: 1251-1257.

Considerações Finais

Considerações Finais

A consolidação do conhecimento sobre os processos ecológicos como a polinização no nível da paisagem é de extrema importância para a gestão de áreas naturais e manutenção dos serviços ecossistêmicos (Tscharntke & Brandl 2004, Nazareno & Carvalho 2009, Viana et al. 2012). Abordagens integradas entre o estudo dos efeitos de paisagens naturais modificadas sobre os ecossistemas naturais e como estas variações afetam a estabilidade das comunidades (Viana et al. 2012) e a estrutura das redes de interação planta-polinizador (Memmott et al. 2004, Fortuna & Bascompte 2006) são úteis para a conservação dessas interações, bem como para a conservação de plantas, polinizadores e serviços de polinização em ecossistemas naturais e agrícolas.

A conservação destas interações pode ser mais importante para a manutenção da biodiversidade, do que a preservação de espécies isoladas (Steffan-Dewenter & Tscharntke 1999, Diaz & Cabido 2001, Forup & Memmott 2005). Através da investigação dos efeitos da perda de habitat, nas comunidades de abelhas visitantes florais e nas interação planta-abelha avaliamos a qualidade desses ambientes modificados, em paisagens florestais fragmentadas na Bahia, nordeste do Brasil. Percebemos através da revisão da literatura que há lacunas no conhecimento sobre valores críticos de perda de habitat que podem aumentar as taxas de extinção de polinizadores e sobre os efeitos das mudanças das paisagens naturais na estrutura das redes de interação planta-polinizador.

As abelhas são importantes para a manutenção de plantas nativas (Winfree *et al* 2009, 2011) e também importantes agentes polinizadores de culturas agrícolas essenciais para a vida humana (Klein et al. 2007, Brosi et al. 2008). Vimos através dos nossos resultados que a perda de habitat afeta negativamente a diversidade de abelhas. Além disso, a presença de floresta é importante para as abelhas sociais que nidificam acima do solo.

Vimos também que a quantidade e qualidade de floresta nas paisagens amostradas influenciou as variáveis estruturais das redes planta-abelha, principalmente o tamanho (numero total de espécies), o numero de espécies de abelhas, a conectância e o aninhamento das redes. O tamanho e o número de espécies foram positivamente influenciados pela quantidade de habitat. Enquanto a conectância foi inversamente relacionada à quantidade de floresta. O aninhamento foi negativamente influenciado pela área média dos fragmentos e positivamente influenciado pelo índice de forma médio dos fragmentos nas paisagens.

As alterações ambientais que levam a extinção espécies nas redes mutualísticas podem reduzir o tamanho e o número de interações entre espécies especialistas. No entanto, estas redes, mesmo após a extinção de espécies tendem a manter um núcleo coeso de interações entre espécies generalistas, protegendo a rede como um todo (Bascompte et al. 2003). Nas paisagens com menor proporção de florestas, observamos que as redes de interação planta-abelha são menores (com menos espécies). Nessas redes as interações ocorrem principalmente entre as espécies generalistas em um núcleo coeso, e há poucas espécies especialistas interagindo com espécies generalistas. Acreditamos que, devido ao elevado grau de degradação ambiental dessas paisagens as espécies generalistas são as mais capazes de se manter e compor o núcleo de interações das redes planta-polinizador.

Nós acreditamos que os estudos de redes de interação na perspectiva de paisagens em florestas tropicais e no sub-bosque podem fornecer informações importantes e permitem a compreensão das melhores estratégias para conservação de plantas, polinizadores e dos serviços de polinização. Sugerimos para a conservação das redes de interação abelhas e plantas em paisagens fragmentadas na Bahia a manutenção de paisagens com habitats florestais disponíveis. Esses habitats são importantes para a manutenção da diversidade de abelhas e da estrutura de suas redes de interação com as espécies vegetais.

Literatura Citada

(Introdução Geral e Considerações Finais)

Aguilar, R. Ashworth, L. Galetto, L. & Aizen, M.A. (2006). Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. Ecology letters, 9(8): 968–980.

Aizen, M.A. & Feinsinger, P. (1994a). Forest Fragmentation, Pollination, and Plant Reproduction in a Chaco Dry Forest, Argentina. Ecology, 75(2): 330-351.

Aizen, M.A. & Feinsinger, P. (1994b). Habitat Fragmentation, Native Insect Pollinators, and Feral Honey Bees in Argentine 'Chaco Serrano'. Ecological Applications, 4(2): 378-392.

Aizen, M.A. Garibaldi, L.A. Cunningham, S.A. & Klein, A.M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of botany, 103(9): 1579–1588.

Bascompte, J. Jordano, P. Mellián, C.J. & Olesen, J.M. (2003). The nested assembly of plant-animal mutualistic networks. Proceedings of the National Academy of Sciences of the United States of America, 100(16): 9383-9387.

Bascompte, J. (2007). Networks in ecology. Basic and Applied Ecology, 8(6): 485–490.

Bascompte, J. (2009a). Disentangling the web of life. Science (New York, N.Y.), 325(5939): 416–419.

Bascompte, J. (2009b). Mutualistic networks. Frontiers in Ecology and the Environment, 7(8): 429–436.

Bascompte, J. (2010). Ecology. Structure and dynamics of ecological networks. Science (New York, N.Y.), 329(5993): 765–766.

Bawa, K.S. (1990). Plant-pollinator interactions in tropical rain forests. Annaul review of Ecology and Systematics, 21: 399–422.

Bremer, B. Bremer, K. Chase, M. Fay, M. Reveal, J. Soltis, D. Soltis, P. & Stevens, P. (2009). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Botanical Journal of the Linnean Society, 161: 105-121.

Brosi, B.J. Daily, G.C. & Ehrlich, P.R. (2007). Bee community shifts with landscape context in a tropical countryside. Ecological applications, 17(2): 418 – 430.

Brosi, B.J. Daily, G.C. Shih, T.M. Oviedo, F. & Duran, G. (2008). The effects of forest fragmentation on bee communities in tropical countryside. Journal of Applied Ecology, 45(3): 773–783.

Diaz, S. & Cabido, M. (2001). Vive la différence: plant functional diversity matters to ecosystem processes. Trends in Ecology & Evolution, 16(11): 646-656.

Fahrig, L. (2003). Effects of habitat fragmentation on Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34: 487–515.

Faria, D. Soares-santos, B. & Sampaio, E. (2006). Bats from the Atlantic rainforest of southern Bahia, Brazil. Mammalia, 6(2): 1-13.

Ferreira, P.A. Boscolo, D. & Viana, B.F. (2013). What do we know about the effects of landscape changes on plant–pollinator interaction networks? Ecological Indicators, 31: 35-40.

Fortuna, M.A. & Bascompte, J. (2006). Habitat loss and the structure of plant–animal mutualistic networks. Ecology Letters, 9: 281–286.

Forup M.L. & Memmott, J. (2005). The Restoration of Plant–Pollinator Interactions in Hay Meadows. Restoration Ecology, 13: 265–274.

Grundel, R. Jean, R. Frohnapple, K. Glowacki, G. Scott, P. & Pavlovic, N. (2010). Floral and nesting resources, habitat structure, and fire influence bee distribution across an open-forest gradient. Ecological Applications, 20(6): 1678–1692.

Guimarães, P.R. Machado, G. Aguiar, M.A.M. Jordano, P. Bascompte, J. Pinheiro, A. & Reis, S.F. (2007). Build-up mechanisms determining the topology of mutualistic networks. Journal of theoretical biology, 249(2): 181–189.

Jordano, P. Bascompte, J. Rezende, E. L. Lavabre, J.E. & Guimarães, P.R. (2007). Non-random coextinctions in phylogenetically structured mutualistic networks. Ecology, 448(23): 925–929.

Kearns, C.A. Inouye, D.W. & Waser, N.M. (1998). Endangered mutualisms: The conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics, 29: 83–112.

Klein, A.M. Vaissière, B.E. Cane, J.H. Steffan-Dewenter, I. Cunningham, S.A. Kremen, C. & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings. Biological sciences / The Royal Society, 274 (1608): 303-313.

Kremen, C. Williams, N.M. Aizen, M.A. Gemmill-Herren, B. LeBuhn, G. Minckley, R. Packer, L. Potts, S.G. Roulston, T. Steffan-Dewenter, I. Vazquez, D.P. Winfree, R. Adams, L. Crone, E.E. Greenleaf, S.S. Keitt, T.H. Klein, A.M. Regetz, J. & Ricketts, T.H. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology Letters, 10: 299–314.

Lennartsson, T. (2002). Extinction thresholds and disrupted plant-pollinator interactions in fragmented plant populations. Ecology, 83(11): 3060-3072.

Lopes, A.V. Girao, L.C. Santos, B.A. Peres, C.A. & Tabarelli, M. (2009). Long-term erosion of tree reproductive trait diversity in edge-dominated Atlantic forest fragments. Biological Conservation, 142(6): 1154–1165.

Memmott, J. Waser, N.M. & Price, M.V. (2004). Tolerance of pollination networks to species extinctions. Proceedings. Biological sciences / The Royal Society, 271(1557): 2605–2611.

McGarigal, K. & Marks, B.J. 1995. Fragstats: spatial pattern analysis program for quantifying landscape structure. U.S. Forest Service General Technical Report PNW 351.

Michener, C.D. 2000. The bees of the world. Johns Hopkins Press, Baltimore, Maryland, USA.

Nazareno, A.G., & Carvalho, D. (2009). What the reasons for no inbreeding and high genetic diversity of the neotropical fig tree Ficus arpazusa? Conservation Genetics, 10: 1789–1793.

Peel, M.C. Finlayson, B.L. & Mcmahon, T.A. (2007). Updated world map of the Kooppen-Geiger climate classification. Hydrology and Earth System Sciences, 11: 1633–1644.

Pigozzo, C.M. & Viana, B.F. (2010). Estrutura da rede de interações entre flores e abelhas em ambiente de caatinga. Oecologia Australis, 14(01): 100–114.

Potts, S.G. Biesmeijer, J.C. Kremen, C. Neumann, P. Schweiger, O. & Kunin, W.E. (2010). Global pollinator declines: trends, impacts and drivers. Trends in Ecology & Evolution, 25(6): 345–353.

Ramalho, M. & Batista, M. (2005). Polinização na Mata Atlântica: perspectiva ecológica da fragmentação. p. 93-141. In: Franke, C. R.; Rocha, P. L. B.; Klein, W.; Gomes, S. L. (orgs).Mata Atlântica e Biodiversidade. Ed. Edufba.

Ribeiro, M.C. Metzger, J.P. Martensen, A.C. Ponzoni, F.J. & Hirota, M.M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation, 142(6): 1141–1153.

Ricketts, T.H. Regetz, J. Steffan-Dewenter, I. Cunningham, S.A. Kremen, C. Bogdanski, A. Gemmill-Herren, B. Greenleaf, S.S. Klein, A.M. Mayfield, M.M. Morandin, L.A. Ochieng, A. Viana, B.F. (2008). Landscape effects on crop pollination services: are there general patterns? Ecology letters, 11(5): 499–515.

Roubik, D.W. (1995). Pollination of Cultivated Plants in the Tropics. Food and Agricultural Organization of the United Nations. Agricultural Bulletin No. 118, Rome, Italy, 196 p.

Sabatino, M. Maceira, N. & Aizen, M.A. (2010). Direct effects of habitat area on interaction diversity in pollination webs. Ecological Applications, 20 (6): 1491-1497.

Steffan-Dewenter, I. & Tscharntke, T. (1999). Effects of habitat isolation on pollinator communities and seed set. Oecologia, 121: 432–440.

Steffan-Dewenter, I. & Tscharntke, T. (2002). Insect communities and biotic interactions on fragmented calcareous grasslands - a mini review. Biological Conservation, 104: 275–284.

Steffan-Dewenter, I. Munzenberg, U., Burger, C., Thies, C. & Tscharntke, T. (2002). Scale-Dependent Effects of Landscape Context on Three Pollinator Guilds. Ecology, 83(5): 1421-1432.

Swift, T.L. & Hannon, S.J. (2010). Criticai thresholds associated with habitat loss : a review of the concepts, evidence, and applications. Biological Reviews, 85: 35–53.

Tabarelli, M., Lopes, A. V, & Peres, C. A. (2008). Edge-effects Drive Tropical Forest Fragments Towards an Early-Successional System. Biotropica, 40(6), 657–661.

Taki, H. & Kevan, P.G. (2007). Does habitat loss affect the communities of plants and insects equally in plant–pollinator interactions? Preliminary findings. Biodiversity and Conservation, 16(11): 314-316.

Tscharntke, T. Steffan-Dewenter, I. Kruess, A. & Thies, C. (2002) Contribution of small habitat fragments to conservation of insect communities of grassland–cropland landscapes. Ecological Applications, 12: 354–363.

Tscharntke, T. & Brandl, R. (2004). Plant-insect interactions in fragmented landscapes. Annual review of entomology, 49: 405–30.

Tylianakis, J.M. Didham, R.K. Bascompte, J. & Wardle, D.A. (2008). Global change and species interactions in terrestrial ecosystems. Ecology Letters, 11(12): 1351–1363.

Tylianakis, J.M. Laliberté, E. Nielsen, A. & Bascompte, J. (2010). Conservation of species interaction networks. Biological Conservation, 143(10): 2270–2279.

Viana, B.F. Boscolo, D. Neto, E.M. Lopes, L.E. Lopes, A.V, Ferreira, P.A. Pigozzo, C.M. & Primo, L.M. (2012). How well do we understand landscape effects on pollinators and pollination services? Journal of pollination ecology, 7(5): 31–41.

Winfree, R. Aguilar, R. Vázquez, D.P. Lebuhn, G. & Aizen, M.A. (2009). A meta-analysis of bees' responses to anthropogenic disturbance. Ecology, 90(8): 2068–2076.

Winfree, R. Bartomeus, I. & Cariveau, D.P. (2011). Native Pollinators in Anthropogenic Habitats. Annual Review of Ecology, Evolution, and Systematics, 42: 1-22.

Material Suplementar

Supplementary material 1 (Chapter 1): Papers found in May 2011 using all seven possible combinations of the terms "pollinat*" with the terms "landscape", "habitat loss" and "network" in the titles, abstract and keywords in Scopus and with the filter 'topic' in Web of Science.

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Aguilar, R et al	2006	Ecology Letters 9: 968–980	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Aguirre, A et al	2011	Journal of Tropical Ecology 27: 25 –33	Mexico	Tropical	Pollinators diversity	Landscape resources	Positive
Ahrne, K et al	2009	Plos One 4: 1-9	Switzerland	Temperate	Pollinators diversity	Landscape configuration	Negative
Aizen, MA & Feinsinger, P	1994	Ecological Applications 4: 378-392	Argentina	Tropical	Visits frequency	Landscape composition	Negative
Aizen, MA & Rovere, AE	2010	Oikos 119: 696–706	Argentina	Tropical	Plants reproductive success	Landscape resources	Different
Altermatt, F & Ebert, D	2010	Ecology 91: 2975–2982	Baltic Sea	Temperate	Another	Landscape resources	Positive
Anitha, K et al	2010	Ecological Complexity 7: 217–224	India	Tropical	Plants diversity	Landscape configuration	Negative
Archer, S & Pyke, DA	1991	Journal of range management 44: 558-565	Do not apply	Do not apply	Plants reproductive success	Landscape resources	Positive
Artz, DR & Waddington, KD	2006	Journal of Ecology, 94: 597-608	USA	Temperate	Pollinators diversity	Patches area	Positive
Bartomeus, I et al	2010	Journal of Ecology 98: 440–450	Germany	Temperate	Pollinators diversity	Landscape resources	No related
Bernard, E & Fenton, MB	2003	Biotropica 35: 262-277	Brazil	Tropical	Pollinators movements	Landscape configuration	No related
Biswas, SR & Mallik, AU	2010	Ecology 91: 28–35	Canada	Temperate	Plants reproductive systems	Landscape configuration	Negative
Bommarco, R et al	2011	Proceedings of the royal society b-biological sciences 15. doi:10.1098/rspb.2011.0647	Switzerland	Temperate	Pollinators diversity	Landscape configuration	Negative
Born, C et al	2008	Molecular Ecology 17: 2041–2050	Africa	Tropical	Plants diversity	Landscape configuration	Negative
Breitbach, N et al	2010	Oecologia 162: 965–976	Germany	Temperate	Pollinators diversity	Landscape configuration	Negative
Brittain, C et al	2010	Biological Conservation 143: 1860–1867	Italy	Temperate	Pollinators diversity	Landscape configuration	Negative
Brosi, JB et al	2007	Ecological Applications 17: 418–430	Costa Rica	Tropical	Pollinators diversity	Patches area	Positive
Brosi. BJ et al	2008	Journal of Applied Ecology 45:773-783	Costa Rica	Tropical	Pollinators diversity	Landscape configuration	Negative
Brosi, Bj et al	2009	Forest Ecology and Management 258: 1846–1855	Costa Rica	Tropical	Pollinators diversity	Patches area	No related
Brudvig, LA et al	2009	PNAS 106: 9328–9332	USA	Temperate	Plants productivity	Patches isolation	Negative
Bruna, EM et al	2005	Biological Conservation 124: 209–216	Brazil	Tropical	Another	Landscape configuration	Positive
Byrne, M et al	2008	Conservation Genetics 9: 97–105	Australia	Tropical	Plants reproductive success	Landscape configuration	Negative
Cane, JH & Tepedino, VJ	2001	Conservation Ecology 5: 1-6	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Carre, G et al	2009	Agriculture, Ecosystems and Environment 133: 40–47	UK	Temperate	Pollinators diversity	Landscape composition	Positive
Carvalheiro, LG et al	2010	Journal of Applied Ecology 47: 810–820	Africa	Tropical	Pollinators diversity	Landscape configuration	Positive
Carvell, C et al	2007	Journal of Applied Ecology 44: 29-40	England	Temperate	Floral resources	Landscape configuration	Positive
Cascante, A et al	2002	Conservation Biology 16: 137–147	Costa Rica	Tropical	Plants reproductive success	Landscape configuration	Negative
Chacoff, NP & Aizen, MA	2006	Journal of Applied Ecology 43: 18-27	Argentina	Tropical	Pollinators diversity	Patches isolation	Negative
Corlett, RT	2001	Journal of Tropical Ecology 17: 155-161	China	Temperate	Pollinators diversity	Landscape configuration	Negative
Craft, KJ & Ashley, MV	2007	Forest Ecology and Management 239: 13–20	USA	Temperate	Plants reproductive success	Landscape configuration	Negative
Cruz-Neto, O et al	2011	Biodiverity Conservation 20: 751–765	Brazil	Tropical	Pollinators diversity	Landscape resources	Positive
Cussans, J et al	2010	Plos One 5: e11753	UK	Temperate	Plants reproductive success	Landscape composition	Negative
Darvill, B et al	2006	Molecular Ecology 15: 601–611	UK	Temperate	Pollinators diversity	Landscape configuration	Negative
Dauber, J et al	2010	Journal of Ecology 98: 188–196	Europe	Temperate	Plants reproductive success	Patches area	Negative
Dick, CW et al	2003	Molecular Ecology 12: 753-764	Brazil	Tropical	Pollinators movements	Landscape configuration	Negative
Didham, RK et al	1996	Tree 2: 255-260	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Eckert, CG et al	2009	Trends in Ecology and Evolution 25: 35-43	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Ewers, RM & Didham, RK	2006	Biological Review 81: 117–142	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Farwig, N et al	2009	Landscape Ecology 24: 919–927	Switzerland	Temperate	Pollinators diversity	Landscape composition	No related
Frankie, GW et al	2009	Journal of the Kansas entomological society 82: 1–20	Costa Rica	Tropical	Pollinators diversity	Landscape configuration	Negative
Fuchs, EJ et al	2003	Conservation Biology 17: 149–157	Costa Rica	Tropical	Another	Patches isolation	Negative
Fujimori, N et al	2006	Journal of Plant Research 119: 195–203	Japan	Temperate	Pollinators diversity	Patches isolation	Negative
Gabriel, D et al	2010	Ecology Letters 13: 858–869	UK	Temperate	Pollinators diversity	Another	Negative
Ghazou, J	2004	Biotropica 36: 156-164	Thailand	Tropical	Plants reproductive success	Landscape configuration	Negative
Ghazou, J & Shaanker, RU	2004	Biotropica 36: 180-183	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Ghazou, J & Shaanker, RU	2004	Biotropica 36: 128-130	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Ghazoul, J & McLeish, M	2001	Plant Ecology 153: 335–345	Thailand / Costa Rica	Tropical	Plants reproductive success	Landscape configuration	Negative
Goldman, RL et al	2007	Ecological Economics 64: 333-343	Do not apply	Do not apply	Another	Landscape composition	Different
González-Varo, JP et al	2009	Biological Conservation 142: 1058–1065	Spain	Temperate	Plants reproductive success	Landscape configuration	Negative

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Gorresen, PM & Willig, MR	2004	Journal of Mammalogy 85: 688–697	Paraguay	Tropical	Pollinators diversity	Landscape configuration	Negative
Goulson, D et al	2008	Journal of Applied Ecology 47: 1207–1215	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Goulson, D et al	2010	Annual Review of Entomology 53: 191–208	UK	Temperate	Another	Landscape configuration	No related
Goverde, M et al	2002	Biological Conservation 104: 293–299	Switzerland	Temperate	Visits frequency	Patches area	Positive
Greenleaf, SS & Kremen, C	2006	PNAS 103: 13890–13895	USA	Temperate	Plants reproductive success	Another	Positive
Grundel, R et al	2010	Ecological Applications 20: 1678–1692	USA	Temperate	Pollinators diversity	Landscape configuration	Negative
Hagen, M & Kraemer, M	2010	Biological Conservation 143: 1654–1663	Kenya	Tropical	Plants diversity	Landscape composition	Different
Hamrick, JL	2004	Forest Ecology and Management 197: 323–335	Do not apply	Do not apply	Plants diversity	Another	Different
Hannon, LE & Sisk, TD	2009	Biological Conservation 142: 2140–2154	USA	Temperate	Pollinators diversity	Landscape configuration	Negative
Hendrix, SD et al	2010	Biodiversity Conservation 19: 1699–1709	USA	Temperate	Pollinators diversity	Landscape composition	Negative
Hennig, EI & Ghazoul, J	2011	Perspectives in Plant Ecology, Evolution and Systematics 13: 137–150	Switzerland	Temperate	Visits frequency	Landscape configuration	Negative
Hoehn, P et al	2010	Biodiversity Conservation 19: 2189–2200	Indonesia	Tropical	Pollinators diversity	Landscape resources	Positive
Holzschuh, A et al	2010	Journal of Animal Ecology 79: 491–500	Germany	Temperate	Pollinators diversity	Landscape composition	Different
Honnay, O et al	2005	New Phytologist 166: 723-736	Do not apply	Do not apply	Plants diversity	Landscape configuration	Negative
Jauker, F et al	2009	Landscape Ecology 24: 547–555	Germany	Temperate	Pollinators diversity	Landscape configuration	Positive
Jha, S & Dick, CW	2008	Current Biology 18: 1126-1128	Mexico	Tropical	Plants diversity	Landscape configuration	Positive
Jha, S & Dick, CW	2010	PNAS 107: 13760–13764	Mexico	Tropical	Pollinators diversity	Landscape configuration	Negative
Jha, S & Vandermeer, JH	2010	Biological Conservation 143: 1423–1431	Mexico	Tropical	Pollinators diversity	Landscape composition	Positive
Jha, S & Vandermeer, JH	2009	Journal of Tropical Ecology 25:13–22.	Mexico	Tropical	Visits frequency	Landscape configuration	Negative
Jules, ES & Priya, S	2003	Journal of Vegetation Science 14: 459-464	Do not apply	Do not apply	Pollinators diversity	Matrix	Different
Kamm, U et al	2010	Landscape Ecology 25: 903–911	Switzerland	Temperate	Pollinators movements	Landscape composition	Positive
Keitt, TH	2009	Ecological Applications 19: 1561–1573	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Kim, J et al	2006	Journal of the Kansas Entomological Society 79: 309-320	USA	Temperate	Another	Landscape configuration	Negative
Klein, A et al	2003	Ecology 89: 935–943	Indonesia	Tropical	Plants reproductive success	Landscape configuration	Negative
Klein, A et al	2007	Proceedings the Royal of Society Biological Sciences 270: 955-961	Do not apply	Do not apply	Plants productivity	Landscape configuration	Negative

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Klein, AM	2009	Proceedings the Royal of Society Biological Sciences 274: 303–313	Indonesia	Tropical	Pollinators diversity	Landscape resources	Positive
Klein, AM et al	2008	Forest Ecology and Management 258: 1838–1845	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Klein, AM et al	2002	Journal of Animal Ecology 73: 517–525	Indonesia	Tropical	Pollinators diversity	Landscape configuration	Negative
Klein, AM et al	2004	Conservation Biology 16: 1003-1014	Indonesia	Tropical	Pollinators movements	Landscape configuration	Negative
Krauss, J et al	2009	Journal of Applied Ecology 46: 194–202	Germany	Temperate	Pollinators diversity	Patches area	Positive
Kremen, C et al	2007	PNAS 99: 16812–16816	Do not apply	Do not apply	Plants reproductive success	Landscape configuration	Negative
Kremen, C et al	2002	Ecology Letters 10: 299–314	USA	Temperate	Pollinators diversity	Patches isolation	Negative
Kreyer, D et al	2004	Biological Conservation 116: 111–118	Germany	Temperate	Pollinators movements	Landscape configuration	No Different
Laborde, J et al	2008	Ecoscience 15: 6-16	Mexico	Tropical	Plants reproductive success	Landscape configuration	Negative
Lacerda, AEB & Kanashiro, M	2008	Biotropica 40: 462–470 2008	Brazil	Tropical	Plants diversity	Patches isolation	Negative
Lander, TA et al	2010	Biological Conservation 143: 2583–2590	Chile	Tropical	Plants reproductive success	Patches isolation	Negative
Lennartsson, T	2002	Ecology 83: 3060–3072	Switzerland	Temperate	Plants reproductive success	Landscape configuration	Negative
Liow, LH et al	2001	Journal of Applied Ecology 38: 180-192	Singapore / Malaysia	Tropical	Pollinators diversity	Landscape configuration	Negative
Lonsdorf, E et al	2009	Annals of Botany 103: 1589–1600	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Lopes, AV et al	2009	Biological Conservation 142: 1154–1165	Brazil	Tropical	Plants reproductive systems	Landscape configuration	Negative
Lowe, AJ et al	2005	Heredity 95: 255–273	Do not apply	Do not apply	Another	Landscape configuration	Negative
MacSwiney, MC et al	2007	Biological Conservation 136: 499 – 509	Mexico	Tropical	Pollinators diversity	Landscape configuration	Negative
Marshall, EJP & Moonen, AC	2002	Agriculture, Ecosystems and Environment 89: 5–21	Do not apply	Do not apply	Plants productivity	Edge	Positive
Meyer, JY	1998	Biotropica 30: 609-624	Tahiti	Tropical	Plants reproductive systems	Another	Different
Mimura, M et al	2009	Molecular Ecology 18: 4180–4192	Australia	Tropical	Plants reproductive systems	Landscape configuration	Negative
Morreale, SJ & Sullivan, KL	2010	Revista de Biologia Tropical 56: 1295-1308	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
Murua, M et al	2010	Acta Oecologica 36: 191-196	Chile	Tropical	Pollinators diversity	Landscape configuration	Negative
Nates-Parra, G et al	2008	Conservation Genetics 10: 1789–1793	Colombia	Tropical	Pollinators diversity	Landscape configuration	Negative
Nayak, KG & Davidar, P	2010	Ecological Complexity 7: 314–319	India	Tropical	Plants reproductive success	Another	Different
Nazareno, AG & Carvalho, D	2009	Journal of Applied Ecology 36: 519-533	Brazil	Tropical	Plants reproductive success	Patches isolation	Negative

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Olschewski, R et al	2010	Biological Conservation 142: 888–898	Ecuador	Tropical	Another	Landscape configuration	Negative
Osborne, JL et al	1999	Biological Conservation 94: 335-340	UK	Temperate	Pollinators movements	Landscape configuration	Negative
Ottewell, KM et al	2009	Perspectives in Plant Ecology, Evolution and Systematics 11: 157–189	Australia	Subtropical	Plants reproductive success	Patches isolation	No related
Parra-Tabla, V et al	2000	Revista de Biologia Tropical 56: 1295-1308	Mexico	Tropical	Plants reproductive success	Landscape configuration	Negative
Pautasso, M	2009	Acta Oecologica 36: 191-196	Do not apply	Do not apply	Plants diversity	Landscape configuration	Negative
Pejchar, L et al	2008	Biological Conservation 141: 536-544	Costa Rica	Tropical	Another	Landscape configuration	Negative
Philpott, SM et al	2009	Ecological Applications 19: 1858–1867	Do not apply	Do not apply	Another	Landscape composition	Positive
Pinto-Torres, & Koptur, S	2009	Annals of Botany 104: 1301–1311	USA	Tropical	Plants reproductive systems	Landscape configuration	Negative
Potts, SG et al	2003	Ecology 84: 2628-2642	Israel	Temperate	Pollinators diversity	Landscape configuration	Negative
Potts, SG et al	2010	Trends in Ecology and Evolution 25: 345-353	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Priess, JA et al	2007	Ecological Applications 17: 407–417	Indonesia	Tropical	Pollinators diversity	Landscape configuration	Negative
Prober, SM & Smith, FP	2009	Agriculture, Ecosystems and Environment 132: 173–191	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
Quesada, M et al	2003	Oecologia 135:400–407	Mexico	Tropical	Plants reproductive success	Landscape configuration	Negative
Quesada, M et al	2004	Biotropica 36: 131-138	Mexico e Costa Rica	Tropical	Plants reproductive success	Patches isolation	Negative
Quesada, M et al	2009	Forest Ecology and Management 258: 1014–1024	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
Quintero, C et al	2010	Biodiversity Conservation 19: 257–274	Argentina	Temperate	Pollinators diversity	Landscape configuration	Negative
Quintero, I & Roslin, T	2005	Ecology 86: 3303–3311	Brazil	Tropical	Another	Landscape configuration	Negative
Ramos-Jiliberto, R et al	2009	Oecologia 160: 697–706	Chile	Temperate	Plants diversity	Landscape resources	Negative
Regal, PG	1982	Annual Review of Ecology, Evolution and Systematics 13: 497-524	Do not apply	Do not apply	Plants reproductive systems	Another	Different
Renner, SS & Feil, JP	1993	American journal of botany 80: 1100-1107	Do not apply	Do not apply	Pollinators diversity	Landscape resources	Positive
Richards, AJ	2001	Annals of Botany 88: 165-172	Do not apply	Do not apply	Pollinators diversity	Another	Negative
Ricketts, TH	2004	Conservation Biology 18: 1262–1271	Costa Rica	Tropical	Pollinators diversity	Landscape configuration	Negative
Ricketts, TH et al	2004	PNAS 101: 12579–12582	Costa Rica	Tropical	Pollinators diversity	Landscape configuration	Negative
Ricketts, TH et al	2008	Ecology Letters 11: 499–515	Do not apply	Do not apply	Plants reproductive success	Patches isolation	No related

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Rooney, TP et al	2004	Conservation Biology 18: 787–798	USA	Temperate	Plants diversity	Landscape configuration	Negative
Roubik, DW	2001	Conservation Ecology 5: 1-14	Panama	Tropical	Pollinators diversity	Another	No related
Rusterholz, HP & Baur, B	2010	Oecologia 163: 141–152	Switzerland	Temperate	Plants diversity	Landscape configuration	No related
Sande, SO et al	2009	Biological Conservation 142: 2703–2709	Kenya	Tropical	Another	Patches isolation	Negative
Schmucki, R & Blois, S	2009	Oecologia 160:721–733	Canada	Temperate	Pollinators diversity	Patches area	Negative
Slagle, MW & Hendrix, SD	2009	Oecologia 161:813–823	USA	Temperate	Plants reproductive success	Patches area	Negative
Sobek, S et al	2009	Forest Ecology and Management 258: 609–615	Germany	Temperate	Pollinators diversity	Landscape resources	Positive
Sodhi, NS et al	2004	Annual Review of Ecology, Evolution and Systematics 35: 323–345	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Steffan-Dewenter, I & Tscharntke, T	1999	Oecologia 121: 432–440	Germany	Temperate	Pollinators diversity	Patches isolation	Negative
Steffan-Dewenter, I et al	2001	Proceedings Biological sciences The Royal Society 268 (1477), 1685-1690	Germany	Temperate	Pollinators diversity	Landscape configuration	Negative
Taki, H et al	2010	Basic and Applied Ecology 11: 594–602	Japan	Temperate	Pollinators movements	Landscape configuration	Negative
Tscharntke, T & Brandl, R	2004	Annual Review of Entomology 49: 405–430	Do not apply	Do not apply	Pollinators diversity	Landscape composition	Positive
Tscharntke, T et al	2011	Journal of Applied Ecology 48 (3), 619-629	Do not apply	Do not apply	Plants productivity	Another	Positive
Tscheulin,T et al	2011	Bulletin of Entomological Research 1-8	Greece	Temperate	Pollinators diversity	Landscape composition	Positive
Uchiyama, K et al	2009	Conservation Genetics 10, 1265-1275	Japan	Temperate	Plants reproductive success	Landscape resources	Positive
Uriarte, M et al	2011	Ecology 92: 924–937	Brazil	Tropical	Floral resources	Landscape composition	Negative
Uriarte, M et al	2010	Ecology 91: 1317–1328	Brazil	Tropical	Plants reproductive success	Landscape configuration	Negative
Van Geert, A et al	2010	Journal of Ecology 98 (1), 178-187	Belgium	Temperate	Pollinators movements	Landscape composition	Positive
Van Rossum, F	2010	Perspectives in Plant Ecology, Evolution and Systematics 12 (1), 21-29.	Belgium	Temperate	Plants reproductive success	Landscape configuration	Negative
Veddeler, D et al	2010	Oecologia 162: 755–762	Ecuador	Tropical	Pollinators diversity	Landscape resources	Negative
Vermaat, JE et al	2004	Journal of Sea Research 52: 321– 328	Filipinas	Tropical	Plants reproductive success	Landscape configuration	Negative
Vesk, PA et al	2010	Austral Ecology 35: 60–71	Australia	Tropical	Plants reproductive success	Patches isolation	Negative
Vieira, FA & Carvalho, D	2008	Biodiversity and Conservation 17 (10), 2305-2321	Brazil	Tropical	Plants diversity	Landscape configuration	Positive
Walther-Hellwig, K & Frankl, R	2000	Journal of Applied Entomology 124 (7-8), 299-306	Germany	Temperate	Pollinators movements	Landscape resources	Positive
Ward, M et al	2005	Heredity 95: 246–254	Do not apply	Do not apply	Plants reproductive systems	Landscape configuration	Negative
Williams, NM &	2007	Ecological Applications 17 (3), 910-921	USA	Temperate	Another	Patches isolation	Negative

Kremen, C

Autors	Year	Journal	Study Location	Climatic region	Dependent variables	Independent variables	Variables relationship
Willig, MR et al	2007	Biotropica 39 (6) 737-746	Peru	Tropical	Pollinators diversity	Landscape configuration	Negative
Winfree, R et al	2007	Conservation Biology 21: 213–223	USA	Temperate	Pollinators diversity	Patches area	Negative
Winfree, R et al	2008	Journal of Applied Ecology 45: 793–802	USA	Temperate	Pollinators diversity	Landscape composition	No related
Winfree, R et al	2009	Ecology 90: 2068–2076	Do not apply	Do not apply	Pollinators diversity	Landscape configuration	Negative
Zhang, W et al	2007	Ecological Economics 64 (2), 253-260	Do not apply	Do not apply	Plants productivity	Floral resources	Positive
Zurbuchen, A et al	2010	Biological Conservation 143 (3), 669-676	Switzerland	Temperate	Pollinators movements	Patches isolation	Negative

Supplementary material 2 (Chapter 2): Bee sampled in seven fragmented landscapes on the Atlantic Rainforest in Bahia Northeast Brazil from January to November of 2011. Information on sociality (in social species, for bees species that exhibits any level of sociality, and solitary species) and nest type (in above ground, *e.g.* bees that nest on trees or dead wood and below ground).

Family	Species	Nest**	Sociality**	Local	N. Individuals
Apidae	*Apis mellifera*	Above Ground	Social	Nilo Peçanha	2
	Bombus brevivillus	Below Ground	Social	P. Tancredo Neves	4
	Bombus morio	Below Ground	Social	P. Tancredo Neves	1
	Ceratina (*Ceratinula*) sp.1	Above Ground	Social	Camamu, Itamaraju, Jaguaripe, Nilo Peçanha, Valença, Wenceslau Guimarães	46
	Ceratina (*Ceratinula*) sp.2	Above Ground	Social	Camamu, Jaguaripe, Wenceslau Guimarães	7
	Ceratina (*Ceratinula*) sp.3	Above Ground	Social	Itamaraju, Nilo Peçanha, Wenceslau Guimarães	12
	Ceratina (*Ceratinula*) sp.4	Above Ground	Social	Camamu, Itamaraju, Jaguaripe, Nilo Peçanha, P. Tancredo Neves, Valença, Wenceslau Guimarães	24
	Ceratina (*Ceratinula*) sp.5	Above Ground	Social	Ubaira, Wenceslau Guimarães	5
	Ceratina (*Ceratinula*) sp.6	Above Ground	Social	Camamu, Ilhéus, Jaguaripe, Valença	13
	Ceratina (*Ceratinula*) sp.8	Above Ground	Social	Camamu, Nilo Peçanha, P. Tancredo Neves	3
	Ceratina (*Ceratinula*) sp.9	Above Ground	Social	Camamu	1
	Ceratina (*Crewella*) sp.1	Above Ground	Social	Jaguaripe, Nilo Peçanha, Wenceslau Guimarães	5
	Ceratina (*Crewella*) sp.2	Above Ground	Social	Wenceslau Guimarães	2
	Ceratina (*Crewella*) sp.3	Above Ground	Social	Wenceslau Guimarães	1
	Ceratina (*Crewella*) sp.4	Above Ground	Social	Wenceslau Guimarães	1
	Epicharis cockerelli	Below Ground	Solitary	Wenceslau Guimarães	3
	Epicharis flava	Below Ground	Solitary	Ilhéus, Itamaraju, Nilo Peçanha	5
	Eufriesea sp.1	Below Ground	Solitary	Ubaira	1
	Euglossa sp.1	Below Ground	Solitary	Camamu, Ilhéus, Jaguaripe, Valença	37
	Eulaema athleticana	Below Ground	Solitary	Ilhéus	1
	Eulaema cingulata	Below Ground	Solitary	Camamu	1
	Leurotrigona muelleri	Above Ground	Social	Ubaira	1
	Melipona scutellaris	Above Ground	Social	Jaguaripe, Nilo Peçanha	7
	Melipona bicolor	Above Ground	Social	Ubaira	2
	Osiris sp.1	Below Ground	Solitary	Valença, Wenceslau Guimarães	4

Family	Species	Nest**	Sociality**	Local	N. Individuals
	Osiris sp.2	Below Ground	Solitary	Itamaraju, Wenceslau Guimarães	3
	Osiris sp.3	Below Ground	Solitary	Jaguaripe	1
	Paratetrapedia sp.1	Above Ground	Solitary	Wenceslau Guimarães	1
	Paratetrapedia sp.2	Above Ground	Solitary	Camamu, Jaguaripe, Wenceslau Guimarães	4
	Paratetrapedia sp.3	Above Ground	Solitary	Jaguaripe, P. Tancredo Neves, Valença	20
	Paratetrapedia sp.4	Above Ground	Solitary	Jaguaripe, P. Tancredo Neves, Wenceslau Guimarães	7
	Paratetrapedia sp.5	Above Ground	Solitary	P. Tancredo Neves	1
	Paratrigona subnuda	Below Ground	Social	Ilhéus	1
	Partamona sp.1	Above Ground	Social	Camamu, Ilhéus, Jaguaripe, Nilo Peçanha, Ubaira	17
	Plebeia aff. *droryana*	Above Ground	Social	Camamu	1
	Plebeia droryana	Above Ground	Social	Camamu, Ilhéus, Itamaraju, Nilo Peçanha, P. Tancredo Neves, Valença	10
	Plebeia sp.1	Above Ground	Social	Ilhéus, Itamaraju, Jaguaripe, Nilo Peçanha	8
	Plebeia sp.2	Above Ground	Social	Jaguaripe	1
	Plebeia grapiuna	Above Ground	Social	Jaguaripe	2
	Plebeia sp.4	Above Ground	Social	Wenceslau Guimarães	1
	Plebeia sp.5	Above Ground	Social	Ubaira	1
	Protosiris sp.1	Below Ground	Solitary	Wenceslau Guimarães	1
	Rhathymus sp.1	Below Ground	Social	P. Tancredo Neves, Wenceslau Guimarães	2
	Trigona braueri	Below Ground	Social	Camamu, Ilhéus, Itamaraju, Jaguaripe, Nilo Peçanha, P. Tancredo Neves, Ubaira, Valença	129
	Trigona hyalinata	Above Ground	Social	Wenceslau Guimarães	11
	Trigona spinipes	Above Ground	Social	Ilhéus, Nilo Peçanha, Ubaira	47
	Trigonopedia sp.1	Below Ground	Social	Wenceslau Guimarães	6
	Trigonopedia sp.2	Below Ground	Social	Wenceslau Guimarães	1
	Xylocopa frontalis	Above Ground	Solitary	Camamu	1
Colletidae	*Chilicola kevani**	Above Ground	Social	Wenceslau Guimarães	2
Halictidae	*Augochlorodes* sp.1	Below Ground	Social	Wenceslau Guimarães	1

Family	Species	Nest**	Sociality**	Local	N. Individuals
	Augochlorodes sp.2	Below Ground	Social	Wenceslau Guimarães	1
	Augochloropsis sp.1	Below Ground	Social	Camamu, Jaguaripe, Nilo Peçanha, P. Tancredo Neves, Valença	10
	Augochloropsis sp.2	Below Ground	Social	Itamaraju	4
	Augochloropsis sp.3	Below Ground	Social	Jaguaripe	1
	Augochloropsis sp.4	Below Ground	Social	Jaguaripe	1
	Megaloptina sp.1	Below Ground	Social	Nilo Peçanha	1
	Neocorynura sp.1	Below Ground	Social	Itamaraju, Valença	3
	Rhectomia mourei	Above Ground	Social	Ubaira, Wenceslau Guimarães	2
Total	-	-	-	-	492

*New species describe (Oliveira et al. 2011).

**Information from Moure's Bee Catalogue (Moure et al. 2012), Bees of the World (Michener 2000) and experts opinions. Whenever information for a given species was not available we used available knowledge on the closely related species or genus of bees.

Supplementary Material 3 (Chapter 3): Lists of plant and bees sampled in seven fragmented landscapes on the Atlantic Forest in Bahia Northeastern Brazil from January to November of 2011.

Landscape	Plant	*Bees*
P. Tancredo Neves (15%)		
	Byrsonima sericea	*Trigona braueri*
	Miconia ciliate	*Trigona braueri*
	Miconia/Huberia	*Trigona braueri*
	Myrtaceae	*Trigona braueri*
	Psychotria carthagenensis	*Trigona braueri*
	Psychotria hoffmannseggiana	*C. (Ceratinula) sp.4*
		C. (Ceratinula) sp.8
		Trigona braueri
	Psychotria schlechtendaliana	*Augochloropsis sp.1*
		Bombus brevivillus
		Bombus morio
		Rhathymus sp.
		Trigona braueri
	Psychotria sp.	*Paratetrapedia sp.3*
		Paratetrapedia sp.4
		Paratetrapedia sp.5
		Plebeia droryana
		Trigona braueri
	Solanum sp.	*Rhectomia mourei*
Valença (25%)		
	50	*Euglossa sp.*
	Adenocalyma coriaceum	*Augochloropsis sp.1*
		C. (Ceratinula) sp.4
		C. (Ceratinula) sp.6
		Euglossa sp.
		Eulaema sp.
		Paratetrapedia sp.3
		Plebeia droryana
		Trigona braueri
	Erythroxylum magnoliifolium	*C. (Ceratinula) sp.6*
		Euglossa sp.
	Erythroxylum sp.	*C. (Ceratinula) sp.1*
	Guapira cf.	*C. (Ceratinula) sp.1*
	Mikania salzmannifolia	*Euglossa sp.*
	Psychotria hoffmannseggiana	*Paratetrapedia sp.3*
	Psychotria martiana	*Augochloropsis sp.1*
		Euglossa sp.
		Osiris sp.1

Landscape	*Plant*	*Bees*
		Paratetrapedia sp.3
		Trigona braueri
	Rubiaceae	*C. (Ceratinula) sp.1*
		C. (Ceratinula) sp.4
		Euglossa sp.
	Swartzia apetala	*Augochloropsis sp.1*
		Neocorynura sp.1
	Solanum sp.	*Paratetrapedia sp.3*
Ubaira (30%)		
	Adenocalyma coriaceum	*Eufrisea sp1*
		Partamona sp.
		Trigona braueri
	Aspidosperma pyrifolium	*Melipona bicolor*
		Trigona braueri
	Palicourea guianensis	*C. (Ceratinula) sp.5*
		Trigona braueri
	Piper arboretum	*C. (Ceratinula) sp.5*
		Partamona sp.
		Trigona braueri
	Piper cernuum	*C. (Ceratinula) sp.5*
	Poaceae	*Trigona spinipes*
	Psychotria purpurascens	*Leurotrigona muelleri*
		Melipona bicolor
		Partamona sp.
		Plebeia sp.5
	Psychotria schlechtendaliana	*Trigona braueri*
		Trigona braueri
Nilo Peçanha (35%)		
	25	*Plebeia sp.1*
	Adenocalyma coriaceum	*Plebeia droryana*
	Asteraceae	*C. (Crewella) sp.1*
		Partamona sp.
	Conceiveblastrum sp	*Partamona sp.*
		Trigona braueri
	Euphorbiaceae	*C. (Ceratinula) sp.4*
	Fabaceae	*C. (Ceratinula) sp.4*
	Hypolytrum schraderianum	*C. (Ceratinula) sp.1*
		C. (Ceratinula) sp.3
		Melipona scutellaris
	Melastomataceae	*C. (Ceratinula) sp.3*
		C. (Ceratinula) sp.4
		Melipona scutellaris

Landscape	*Plant*	*Bees*
		Trigona braueri
		Trigona spinipes
	Palicourea rigida	*C. (Ceratinula) sp.1*
		C. (Ceratinula) sp.8
		Epicharis flava
		Megaloptina sp.1
		Partamona sp.
		Trigona braueri
	Parodiolyra sp.	*Trigona braueri*
	Paypayrola blanchetiana	*C. (Ceratinula) sp.4*
	Piper sp.	*Apis mellifera*
		C. (Ceratinula) sp.4
		Partamona sp.
	Psychotria sp.	*C. (Ceratinula) sp.1*
		Partamona sp.
		Trigona braueri
	Rauvolfia grandiflora	*Augochloropsis sp.1*
		C. (Ceratinula) sp.1
		Partamona sp.
		Plebeia droryana
Wenceslau Guimarães (40%)		
	64	*C. (Ceratinula) sp.2*
		C. (Ceratinula) sp.3
	103	*C. (Ceratinula) sp.4*
		C. (Ceratinula) sp.5
		Paratetrapedia sp.1
	123	*C. (Ceratinula) sp.1*
		C. (Crewella) sp.4
		Osiris sp.2
	136	*Rhectomia mourei*
	141	*C. (Ceratinula) sp.1*
	Araceae	*Plebeia sp.4*
		Protosiris sp.
		Trigona hyalinata
	Faramea sp.	*Augochlorodes sp.1*
		Augochlorodes sp.2
	Palicoura/Psycotria	*Paratetrapedia sp.2*
		Trigona braueri
		Trigonopedia sp.1
	Psychotria hoffmannseggiana	*C. (Ceratinula) sp.2*
		Trigonopedia sp.1
		Trigonopedia sp.2

Landscape	Plant	Bees
	Psychotria schlechtendaliana	*C. (Ceratinula) sp.4*
		C. (Crewella) sp.1
		C. (Crewella) sp.2
		C. (Crewella) sp.3
		Chilicola kevani
		Epicharis cockerelli
		Osiris sp.1
		Paratetrapedia sp.4
		Rhathymus sp.
		Trigona braueri
		Trigona hyalinata
Camamu (45%)		
	Adenocalyma coriaceum	*Augochloropsis sp.1*
		Euglossa sp1
		Eulaema cingulata
		Trigona braueri
	Anthurium affine	*C. (Ceratinula) sp.1*
	Coix sp.	*Plebeia aff. droryana*
		Trigona braueri
	Cordia superba	*C. (Ceratinula) sp.1*
	Hypolytrum schraderianum	*C. (Ceratinula) sp.1*
		Trigona braueri
	Melastomataceae	*Euglossa sp1*
		Plebeia droryana
		Trigona braueri
	Paypayrola blanchetiana	*Paratetrapedia sp.2*
	Piper sp.	*C. (Ceratinula) sp.1*
		C. (Ceratinula) sp.4
		C. (Ceratinula) sp.6
		C. (Ceratinula) sp.8
		Euglossa sp1
		Partamona sp.
		Plebeia droryana
		Trigona braueri
	Psychotria purpurascens	*Trigona braueri*
	Psychotria sp.	*C. (Ceratinula) sp.1*
		C. (Ceratinula) sp.6
		C. (Ceratinula) sp.9
		Xylocopa frontalis
	Rauvolfia grandiflora	*C. (Ceratinula) sp.1*
		Trigona braueri

Landscape	*Plant*	*Bees*
Jaguaripe (55%)	*Rubiaceae*	*C. (Ceratinula) sp.1* *C. (Ceratinula) sp.2* *Paratetrapedia sp.2*
	Stromanthe porteana	*Trigona braueri*
	7	*C. (Ceratinula) sp.6* *C. (Crewella) sp.1* *Paratetrapedia sp.3* *Partamona sp.* *Trigona braueri*
	11	*Paratetrapedia sp.3* *Plebeia sp.1* *Trigona braueri*
	17	*Augochloropsis sp.1* *Augochloropsis sp.3* *Melipona scutellaris* *Plebeia sp.1*
	32	*Trigona braueri*
	37	*Paratetrapedia sp.3*
	46	*Plebeia sp.1*
	50	*Augochloropsis sp.1* *Augochloropsis sp.4* *Paratetrapedia sp.2*
	53	*C. (Ceratinula) sp.4* *Trigona braueri*
	54	*C. (Ceratinula) sp.4* *Trigona braueri*
	66	*C. (Ceratinula) sp.1*
	Adenocalyma coriaceum	*Augochloropsis sp.1* *Plebeia grapiuna*
	Eriope sp.	*C. (Ceratinula) sp.2* *C. (Ceratinula) sp.4* *C. (Ceratinula) sp.6*
	Psychotria schlechtendaliana	*Trigona braueri*
	Rubiaceae	*C. (Ceratinula) sp.1* *C. (Ceratinula) sp.4* *Osiris sp.* *Paratetrapedia sp.3* *Paratetrapedia sp.4* *Plebeia grapiuna*
	Vriesea gigantean	*Plebeia sp.2*

Supplementary Material 4 (Chapter 3): Graphs of each network metric in function of forest cover (disregarding the edge areas of 50m depth - CPLAND) in seven fragmented landscapes on the Atlantic Tropical Rainforest in Northeastern Brazil Bahia from January to November of 2011.