UNIVERSIDADE DO VALE DO RIO DOS SINOS
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COMPOSIÇÃO E DIVERSIDADE DE BORBOLETAS FRUGÍVORAS (LEPIDOPTERA: NYMPHALIDAE) EM UNIDADES DE CONSERVAÇÃO E FRAGMENTOS FLORESTAIS ADJACENTES DE MATA ATLÂNTICA NO SUL DO BRASIL

São Leopoldo
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Orientador: Prof. Dr. Everton Nei Lopes Rodrigues

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Muito obrigada!

AS BORBOLETAS

Brancas
Azuis
Amarelas
E pretas
Brincam
Na luz
As belas
Borboletas.

Borboletas brancas
São alegres e francas.

Borboletas azuis
Gostam muito de luz.

As amarelinhas
São tão bonitinhas!

E as pretas, então...
Oh, que escuridão!

Autor: Vinicius de Moraes (RJ, 1970)

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RESUMO

Muitas são as ameaças ao Bioma Mata Atlântica, como exemplo a fragmentação, a qual representa uma ameaça à diversidade de Lepidoptera. As borboletas frugívoras correspondem a um grupo taxonômico numeroso, fiéis aos seus hábitats, bem conhecidas e rapidamente amostradas. A diversidade de borboletas frugívoras é influenciada pelas variáveis abióticas e bióticas. A tese apresenta informações sobre 1) a lista de espécies de borboletas frugívoras e análise da composição (similaridade), 2) análises da composição e diversidade (abundância e riqueza de espécies), 3) influência das variáveis abióticas e bióticas na composição, abundância e riqueza de espécies de borboletas frugívoras amostradas em Unidades de Conservação (UC) e respectivos fragmentos florestais adjacentes (FF), em Floresta Ombrófila Mista, na Região Oeste de Santa Catarina, Brasil. O estudo foi realizado na Floresta Nacional de Chapecó (FLONA), Estação Ecológica Mata Preta (ESEC) e Parque Estadual das Araucárias (PAEAR), e respectivos fragmentos florestais adjacentes. As borboletas frugívoras foram coletadas utilizando-se armadilhas Van Someren-Rydon. As coletas ocorreram entre dezembro de 2017 e março de 2018, totalizando 24 dias de amostragem. Foram registradas 4231 borboletas frugívoras pertencentes a quatro subfamílias, 12 tribos e 49 espécies. Na FLONA foram registradas 37 espécies e 29 nos FF; na ESEC 29 espécies e 33 nos FF, e no PAEAR 33 espécies e 28 nos FF. Das espécies registradas, 15 espécies são novos registros para Santa Catarina e 10 são novos registros para a Região Oeste do estado. As espécies mais abundantes no estudo foram: *Manataria hercyna* (Hübner, [1821]), *Hermeuptychia* sp., *Yphthimoides ordinaria* Freitas, Kaminski & Mielke, 2012, *Forsterinaria quantius* (Godart, [1824]), *Eryphanes reevesii* (Doubleday, 1849), *Moneuptychia soter* (Butler, 1877) e *Morpho epistrophus* (Fabricius, 1796). Satyrinae apresentou maior riqueza (S=34) e abundância (90.58%) em todas as áreas amostradas. A cobertura estimada de amostragem para as UC e fragmentos florestais ficou acima de 97%. A abundância e riqueza de espécies de borboletas frugívoras diferiram entre as unidades de conservação e seus fragmentos florestais adjacentes, e a composição mostrou-se alterada, com perda de espécies de um ambiente para outro. Houve um padrão agrupado separando as amostras das UC e FF. Tanto a similaridade quanto à abundância e composição das espécies variou de 50 a 55%. As espécies de borboletas frugívoras amostradas apresentaram uma variação de ocorrência nas amostras de 85,23% na Floresta Nacional de Chapecó, 75,92% na Estação Ecológica Mata Preta e 66,28% no Parque Estadual das Araucárias. Observou-se aninhamento das assembleias na Floresta Nacional de

Chapecó e Parque Estadual das Araucárias e respectivos fragmentos adjacentes. A abundância e riqueza de espécies de borboletas frugívoras da FLONA e PAEAR estiveram correlacionadas positivamente como umidade relativa do ar, temperatura e luminosidade. As variáveis abióticas explicaram entre 23,3% e 39,1% das assembleias de borboletas frugívoras, sendo a luminosidade e a umidade relativa do ar as variáveis significativas. Houve uma relação positiva entre a riqueza de espécies de borboletas frugívoras e a altura e abertura do dossel, e em relação à abundância de borboletas frugívoras e a abertura do dossel para as áreas da FLONA. Para a ESEC houve correlação positiva entre a abundância e riqueza de espécies e a abertura do dossel. A composição de borboletas frugívoras na FLONA variou com a altura e abertura do dossel e na ESEC variou com a abertura do dossel. A abundância de borboletas frugívoras relacionou positivamente com o nível de isolamento da FLONA e foi negativa com a área. O estudo contribuiu para o conhecimento e caracterização da guilda de borboletas frugívoras do estado de Santa Catarina. A fauna de borboletas frugívoras da Região Oeste de Santa Catarina, investigada pela primeira vez em áreas de UC, mostrou-se expressiva e bem representativa para o Bioma Mata Atlântica. Além disso, enfatiza-se o importante papel das UC na manutenção da diversidade de borboletas frugívoras em FF e a relevância das variáveis ambientais. Constata-se a necessidade da conservação dos fragmentos florestais adjacentes em paisagens altamente fragmentadas, muito comuns na Mata Atlântica, evitando a perda da diversidade de borboletas frugívoras. Constatou-se a necessidade de outros inventariamentos e estudos direcionados a compreensão das relações entre as espécies de borboletas frugívoras e a influência de outras variáveis ambientais principalmente num cenário de degradação ambiental e alteração climática global. Contudo, espera-se que esse conhecimento seja útil para a elaboração de futuros planos de manejo e conservação da fauna de borboletas subtropical em Floresta Ombrófila Mista no sul do Brasil.

Palavras-chave: Floresta Ombrófila Mista. Fragmentação. Riqueza de espécies. Inventariamento. Biodiversidade

ABSTRACT

COMPOSITION AND DIVERSITY OF FRUIT-FEEDING BUTTERFLIES (LEPIDOPTERA: NYMPHALIDAE) IN CONSERVATION UNITS AND ADJACENT FRAGMENTS OF ATLANTIC FOREST IN SOUTHERN BRAZIL

Many are the threats to the Atlantic Forest biome, e.g., fragmentation represents a threat to the diversity of Lepidoptera. Fruit-feeding butterflies make up a species-rich taxonomic group, being loyal to their habitats, well known and rapidly sampled. The diversity of fruit-feeding butterflies is influenced by abiotic and biotic variables. This thesis presents information on 1) the list of fruit-feeding butterflies species and composition analysis (similarity), 2) analysis of composition and diversity (abundance and species richness), 3) and influence of abiotic and biotic variables on composition, abundance and richness of fruit-feeding butterflies sampled in Conservation Units (CU) and respective adjacent forest fragments (FFs), in Mixed Ombrophilous Forest, Western Santa Catarina, Brazil. The study was conducted in the Chapecó National Forest (FLONA), Mata Preta Ecological Station (ESEC) and Araucárias State Park (PAEAR) and their respective adjacent forest fragments. Fruit-feeding butterflies were collected using Van Someren-Rydon traps. Collections occurred between December 2017 and March 2018, totaling 24 sampling days. We recorded 4,231 fruit-feeding butterflies belonging to four subfamilies, 12 tribes and 49 species. In FLONA, we recorded 37 species, with 29 in its FFs; ESEC included 29 species with 33 in its FFs; and PAEAR included 33 species with 28 in its FFs. Of the recorded species, 15 are new records for state of Santa Catarina and 10 are new records for the Western region of the state. The most abundant species in our study were: *Manataria hercyna* (Hübner, [1821]), *Hermeuptychia* sp., *Yphthimoides ordinaria* Freitas, Kaminski & Mielke, 2012, *Forsterinaria quantius* (Godart, [1824]), *Eryphanes reevesii* (Doubleday, 1849), *Moneuptychia soter* (Butler, 1877) and *Morpho epistrophus* (Fabricius, 1796). Satyrinae had the highest richness (S=34) and abundance (90.58%) in all sampled areas. The estimated sampling coverage for the CU and forest fragments was above 97%. Species richness and abundance of fruit-feeding butterflies differed between the Conservation Units and their adjacent forest fragments and composition was shown to be altered, with species loss from one environment to another. There was a grouped pattern separating the samples of CU and FF. Both the similarity regarding abundance and species composition varied from 50 to 55%. The sampled fruit-feeding butterflies species showed a variation of occurrence in the samples of 85.23% in the Chapecó National Forest, 75.92% in the Mata Preta Ecological Station and 66.28% in the Araucárias State Park. We observed a nested pattern of the assemblages in the Chapecó National Forest and Araucárias State Park and their respective adjacent forest fragments. Abundance and species richness of fruit-feeding butterflies of FLONA and PAEAR were positively related to relative air humidity, temperature and luminosity. The abiotic variables explained between 23.3% and 39.1% of the fruit-feeding butterflies assemblages, with luminosity and relative air humidity being the most significant variables. There was a positive relation of the richness of fruit-feeding butterflies to canopy height and openness, and, regarding abundance, to canopy openness in the areas of FLONA. For ESEC, there was a positive relation of abundance and richness to canopy openness. The composition of fruit-feeding butterflies in FLONA varied with canopy height and openness, and in ESEC it varied with canopy openness. The abundance of fruit-feeding butterflies was positively related to the isolation level of FLONA, and negatively to the area. This study contributed to the knowledge and characterization of the guild of fruit-feeding butterflies in the state of Santa Catarina. The fauna of fruit-feeding butterflies of Western Santa Catarina, investigated for the first time in CU, was shown to be expressive and with good representativeness for the Atlantic Forest biome. Moreover, we emphasize the important role of CU in maintaining the diversity of fruit-feeding butterflies in FFs and the relevance of environmental variables. We perceive the need to conserve adjacent forest fragments in highly fragmented areas, a common situation in the Atlantic Forest, thus avoiding the loss of fruit-feeding butterflies diversity. We highluminosity the need for other surveys and studies directed to understand the relationships between fruit-feeding butterflies and the influence of other environmental variables, especially in a scenario of environmental degradation and global climate change. However, we expect that the generated knowledge will be useful for the elaboration of plans for the management and conservation of subtropical butterflies in Mixed Ombrophilous Forest of Southern Brazil.

Keywords: Mixed Ombrophilous Forest. Fragmentation. Species Richness. Survey. Biodiversity.

APRESENTAÇÃO

Esta tese tem os aspectos ecológicos, efeitos da fragmentação e influência das variáveis abióticas e bióticas sobre as assembleias de borboletas frugívoras, como elementos centrais para o marco teórico e para os objetivos propostos. A tese será apresentada em capítulos. Além dos capítulos, consta uma introdução geral, que apresenta o marco teórico da tese. Na sequência constam as hipóteses e objetivos e a tese finaliza com as considerações finais e os anexos. Os três capítulos foram formatados de acordo com as normas das revistas às quais foi submetido (capítulo I) e serão submetidos (capítulo II e III). Os demais tópicos da tese foram formatados de acordo com as normas da Associação Brasileira de Normas Técnicas (ABNT).

O primeiro capítulo da tese apresenta a lista das espécies de borboletas frugívoras amostradas nas Unidades de Conservação (UC) e fragmentos florestais (FF) adjacentes, na Região Oeste de Santa Catarina. Também, no capítulo são analisados e discutidos os dados de composição das assembleias de borboletas frugívoras das UC e FF. Neste capítulo, foram apresentadas as estimativas de riqueza de espécies e a cobertura amostral estimada das UC e FF e feita análise de similaridade usado o índice de SIMPSON e as diferenças estatísticas, entre a composição das assembléias de borboletas frugívoras, testadas com ANOSIM. Também, realizamos uma análise da porcentagem de similaridade (SIMPER), buscando identificar os táxons responsáveis pelas diferenças observadas na composição das espécies entre as áreas amostradas. Esse capítulo da tese foi publicado na Revista Biota Neotropica em 2019, no volume 19, número 4. A versão on-line do artigo está disponível em: https://doi.org/10.1590/1676-0611-bn-2018-0722, recebido em 20 de dezembro de 2018, publicado em 12 de setembro de 2019. ISSN 1676-0611 (edição online) (ANEXO 1).

O segundo capítulo analisa com mais ênfase a composição e a diversidade (abundância e riqueza de espécies) de borboletas frugívoras em Unidades de Conservação e fragmentos florestais adjacentes na Região Oeste de Santa Catarina. Neste capítulo a composição foi analisada a partir da ordenação de escala multidimensional não-métrica (NMDS). O método SIMPROF foi utilizado para apoiar a interpretação das análises NMDS e identificar grupos significativos na análise de agrupamentos. Também, para composição foi feita a análise de componentes principais (PCA), aplicada para verificar a associação de espécies com as unidades de amostragem nas Unidades de Conservação e respectivos fragmentos florestais adjacentes. A riqueza de espécies, de cada Unidade de Conservação e respectivos fragmentos florestais adjacentes, foi comparada, usando a análise de rarefação individual. Para verificar diferenças na abundância e riqueza de espécies de borboletas frugívoras na Unidade de Conservação, fragmentos florestais adjacentes e suas interações, bem como verificar a contribuição relativa de cada unidade de amostragem na estrutura da assembléia de borboletas, aplicou-se uma análise multivariada permutacional de variância (PERMANOVA). Além disso, no capítulo é analisado se as Unidades de Conservação mantem a biodiversidade de borboletas frugívoras nos fragmentos florestais adjacentes. Para isso, foi utilizada a análise do aninhamento, onde foi calculado o índice NODF. O capítulo segue as normas da Revista Biodiversity Data Journal (https://bdj.pensoft.net/about#Forauthors) e será submetido para publicação após a avaliação da banca.

O último capítulo analisa a influência das variáveis abióticas (temperatura, umidade relativa, luminosidade e velocidade do vento) e bióticas (altura e abertura do dossel) sobre a composição, abundância e riqueza de espécies de borboletas frugívoras amostradas nas UC e FF na Região Oeste de Santa Catarina. A relação entre variáveis abióticas, abundância e riqueza de espécies de borboletas frugívoras foi avaliada a partir de uma análise de regressão linear múltipla. A associação entre a composição das borboletas frugívoras de cada Unidade de Conservação com variáveis abióticas (temperatura, umidade relativa do ar, luminosidade e velocidade do vento) foi analisada por meio de análises de correspondência canônica (CCA). Foram testados os Modelos Lineares Generalizados (GLMs) para análise das variáveis bióticas (altura e cobertura do dossel) e composição, abundância e riqueza de espécies de borboletas frugívoras. Além disso, com os mesmos modelos, foi analisada a relação da abundância e riqueza de espécies de borboletas frugívoras com a área do fragmento florestal e seu nível de isolamento. Esse capítulo está apresentado de acordo com as normas da Revista Journal of Insect Conservation (https://www.springer.com/journal/10841/submission-guidelines) e será submetido para publicação após a avaliação da banca.

Na parte final da tese são apresentadas as considerações finais, assim como é apresentada uma conclusão geral e onde constam as sugestões de continuidade das pesquisas. E por fim, constam os anexos onde são apresentadas as pranchas de todas as espécies de borboletas frugívoras amostradas nas UC e FF, além de imagens das coleções científicas que foram organizadas e estão disponíveis no Laboratório de Entomologia Ecológica (LABENT-Eco) da Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ), em Chapecó, Santa Catarina e na Coleção Zoológica da Universidade do Vale do Rio dos Sinos (MZ UNISINOS), São Leopoldo, Rio Grande do Sul. Também, outras imagens são apresentadas, como: das atividades de coletas das borboletas frugívoras, da licença de autorização de coleta emitida pelo ICMBio/SISBio, da atividade de Educação Ambiental realizada na FLONA e da palestra ministrada no evento dos 50 anos da FLONA.

INTRODUÇÃO GERAL

O Bioma Mata Atlântica

A Mata Atlântica brasileira é um dos cinco principais "hotspots" mundiais, sendo um bioma muito devastado e ameaçado do planeta, devido a modificação da paisagem, mudança climática e introdução de espécies invasoras (MITTERMEIER *et al.*, 2011; BELLARD *et al.*, 2014; JOLY *et al.*, 2014; REZENDE *et al.*, 2018; CROUZEILLES *et al.*, 2019), sendo um bioma prioritário em ações de conservação (MORELLATO e HADDAD, 2000; CONSERVAÇÃO INTERNACIONAL, 2013; REZENDE *et al.*, 2018; CROUZEILLES *et al.*, 2019). A importância da conservação do bioma está relacionada à elevada heterogeneidade na sua composição, por abrigar alta diversidade da fauna e flora e por manter altos níveis de endemismo (BROWN JÚNIOR, 1992; MITTERMEIER *et al.*, 2004; RIBEIRO *et al.*, 2009). Estimativas referentes à diversidade da Mata Atlântica apontam que o mesmo abriga mais de oito por cento do total de espécies existentes no mundo (SILVA e CASTELETI, 2003).

O território brasileiro era coberto por aproximadamente 13% de Mata Atlântica (CABRAL e CESCO, 2008), em uma área original de aproximadamente 131.546.000 hectares sendo que no cenário territorial atual, existem menos de 12,4% da área original (FUNDAÇÃO SOS MATA ATLÂNTICA, 2019) as áreas remanescentes correspondem a mais de 245.000 fragmentos, dos quais mais de 95% com tamanhos menores do que 100 hectares, e isolados em meio a paisagens altamente antropizadas (GALINDO-LEAL e CÂMARA, 2003; METZGER *et al.*, 2009; RIBEIRO *et al.*, 2012; FUNDAÇÃO SOS MATA ATLÂNTICA, 2019) e pouco conectados aos remanescentes florestais maiores (RIBEIRO *et al.*, 2009). Para Silva *et al.* (2007), áreas maiores de Mata Atlântica são encontradas em regiões íngremes onde não há ocupação humana tendo em vista as características do relevo local. Ribeiro *et al.* (2009) sinalizam para a importância dos remanescentes florestais pequenos, sendo que estes garantem a conectividade entre as áreas florestais maiores.

Como consequência disso, os remanescentes florestais continuam sob forte pressão e ameaça de fatores como a aceleração do crescimento populacional, a expansão urbana, o desmatamento ilegal, o uso inadequado do solo para a produção agrícola, a deterioração da qualidade da água pelo lançamento de esgoto não tratado, o uso excessivo de fertilizantes e agrotóxicos e a poluição industrial (CONSERVAÇÃO INTERNACIONAL, 2013).

O estado de Santa Catarina abrange 95.985 km^2 do território nacional, estando originalmente 85% desta área coberta por fisionomia florestal e os outros 15% constituídos por outras formações, totalmente inseridos no Bioma Mata Atlântica, na Região Sul do país (VIBRANS *et al*., 2013). O estado contempla três diferentes fitofisionomias: Floresta Ombrófila Densa (FOD), Floresta Ombrófila Mista (FOM) e Floresta Estacional Decidual (FED) (VIBRANS *et al*., 2013). A partir do Inventário Florístico Florestal do estado, realizado por Vibrans *et al*. (2013), verifica-se que a cobertura florestal nativa remanescente é de aproximadamente 29%, sendo que na região oeste a cobertura florestal da FED soma entre 16 e 24% da FOM.

A aceleração do desmatamento de Mata Atlântica na Região Oeste de Santa Catarina ocorreu ao longo do século XX e se estendeu até meados dos anos 1970, sendo um reflexo do desenvolvimento econômico pós-colonização europeia, que foi intensificado pela extração das madeiras (CABRAL e CESCO, 2008). Os primeiros colonizadores encontraram na região uma área coberta por Floresta Atlântica densa, composta principalmente de FOM nas áreas mais altas e Floresta Estacional Semi-Decidual nas áreas mais baixas. As primeiras empresas colonizadoras propagaram a ideia de que era preciso desmatar para que se procedesse à instalação dos núcleos coloniais (CABRAL e CESCO, 2008).

Esse processo extrativista fez com que grandes áreas florestais locais fossem transformadas em pequenos fragmentos isolados (CERQUEIRA *et al.*, 2003; CABRAL e CESCO, 2008). Apesar de fortemente ondulado e com presença de muitas áreas de afloramentos rochosos, o território do oeste catarinense, após a devastação da floresta, deu lugar à exploração agroindustrial (PERTILE, 2011). Evidencia-se ao longo dos séculos a intensificação no processo de fragmentação florestal, devido às ações antrópicas, tendo como consequência, a expansão e formação das áreas urbanas, o aumento das atividades agropecuárias e a construção de estradas (HADDAD *et al.*, 2015).

A implantação de Unidades de Conservação no Brasil é uma das estratégias para a conservação da biodiversidade, sendo que, no Brasil, estas totalizam aproximadamente 17% do território do país (COSTA-PEREIRA *et al*., 2013). Pinto *et al.* (2005), ao considerarem a cobertura das Unidades de Conservação na Mata Atlântica, evidenciam um problema. Os autores sinalizam que as Unidades de Conservação de proteção integral possuem restrições de uso e são de grande relevância para a conservação da biodiversidade, ocupando menos de dois por cento da área do bioma. Ainda, mesmo considerando que o número de Unidades de Conservação seja expressivo, ao somar todas as unidades de proteção integral, totaliza aproximadamente 2.500.000 hectares. Nesse sentido, a conservação da biodiversidade da Mata Atlântica dependerá da expansão da rede de Unidades de Conservação, nas mais diferentes categorias, bem como da conservação de áreas que não estão inseridas em um sistema oficial de proteção (PINTO *et al.*, 2005).

Em Santa Catarina estão instituídas 16 Unidades de Conservação federais e 10 estaduais. No que tange as Unidades de Conservação municipais, existem 163 áreas protegidas, muitas das quais não são reconhecidas como categorias de Unidades de Conservação e não implantadas efetivamente (65 Unidades de Conservação enquadradas e 98 não enquadradas no Sistema Nacional de Unidades de Conservação) (MARTINS *et al*., 2015).

Contudo, o futuro da Mata Atlântica depende do manejo das espécies e ecossistemas para garantir a proteção da biodiversidade. No entanto, a conservação dos remanescentes florestais desse "hotspot" é um grande desafio, pois o ritmo de mudanças no bioma está entre os mais rápidos (PINTO *et al.*, 2005). Os autores ainda sinalizam que as estratégias, ações e intervenções necessárias esbarram em dificuldades impostas pela ausência ou fragmentação do conhecimento sobre os seus ecossistemas, num ambiente sob forte pressão antrópica, marcado pela complexidade nas relações sociais e econômicas.

O processo de fragmentação e a relação com a biodiversidade

Historicamente as ações humanas vêm modificando os ambientes originais, alterando-os e resultando em elevados índices de fragmentação (DEAN, 1997). Assim, a fragmentação é um processo gradativo de transformação de grandes áreas florestais em habitat reduzidos (WILCOVE *et al.*, 1986), ocasionando mudanças na qualidade e dinâmica dos processos ecossistêmicos (BRITO, 2017).

A fragmentação é o resultado da redução da área original da Mata Atlântica, iniciada há cinco séculos (TABARELLI *et al.*, 2004, 2005, 2012; RIBEIRO *et al.*, 2009; ZIEMBOWICZ *et al*., 2017). Estudo realizado por Silva *et al.* (2016) mostrou que, nos últimos dez anos, na Mata Atlântica brasileira, houve uma diminuição do desmatamento, mas a degradação dos ecossistemas e ameaças às espécies persistem.

Muitas são as consequências do processo de fragmentação da Mata Atlântica, como as mudanças na dinâmica dos ecossistemas e no arranjo dos recursos naturais nas paisagens, e assim, provocando ameaças à biodiversidade local (BOND-BUCKUP e DREIER, 2008; TABARELLI *et al.*, 2012; SILVA *et al.*, 2016). O bioma apresenta um grande número de espécies de animais ameaçados, sendo 50,5% das espécies registradas no Brasil e 38,5% endêmicas da Mata Atlântica (ICMBio, 2018).

De maneira geral, a abordagem sobre o efeito da fragmentação de habitats e a permanência de espécies ameaçadas está relacionada com a teoria das metapopulações que trata da diminuição dos fragmentos e do aumento do seu isolamento, com isso as chances de extinção local aumentam e as possibilidades de recolonização diminuem (HANSKI, 1997). Para Pinto *et al.* (2005) um dos principais desafios para a conservação da biodiversidade é o crescente isolamento das florestas originais. Como a conservação da biodiversidade envolve não somente a conservação das espécies, mas também da diversidade genética de diferentes populações, é essencial proteger múltiplas populações de uma espécie, que na Mata Atlântica estão cada vez mais isoladas e suscetíveis a eventos ao acaso, de natureza genética ou demográfica, portanto, com maiores probabilidades de extinção local (BROOKS *et al.*, 2002). As estratégias de conservação devem, portanto, abordar a dinâmica da paisagem e as inter-relações entre unidades de conservação, além dos aspectos relacionados às áreas isoladas (PINTO *et al.*, 2005).

No Brasil, somente 14% dos remanescentes da Mata Atlântica constituem Unidades de Conservação (RIBEIRO *et al.*, 2012) onde a legislação tem se mostrado mais eficiente em conservar a vegetação original (SPAROVEK *et al.*, 2012). Contudo, mesmo sendo áreas florestais originais, muitos fragmentos de Mata Atlântica encontram-se em áreas de domínio privado (RODRIGUES *et al.*, 2011; SPAROVEK *et al.*, 2012; SILVA *et al.*, 2016), e deficiências no sistema de gestão e fiscalização não asseguram a conservação do bioma (TABARELLI *et al.*, 2005, 2012; SILVA *et al.*, 2016). Nesse sentido, as UC possuem um papel muito importante para a conservação da biodiversidade, pois sendo áreas florestais protegidas pelo poder público, devem garantir a proteção da flora, fauna, corpos d'água e do solo (HENRY-SILVA, 2005).

Pinto *et al.* (2005) relatam que as implicações da fragmentação florestal sobre a biodiversidade da Mata Atlântica ainda necessitam de melhor entendimento. Os resultados do estudo de Pinto *et al.* (2005) sobre os desafios para a conservação da biodiversidade da Mata Atlântica descrevem a complexidade da abordagem e indicam que a fragmentação da paisagem natural afeta a quantidade e a qualidade do habitat disponível e, consequentemente, a sobrevivência de espécies, especialmente daquelas endêmicas e ameaçadas de extinção. Muitos grupos de animais são fortemente ameaçados pela fragmentação, incluindo os lepidópteros (BONEBRAKE *et al.*, 2010).

As borboletas

Lepidoptera inclui as borboletas e mariposas, atualmente é considerada a segunda maior ordem de insetos, com aproximadamente 157.000 espécies descritas (STORK, 2018), distribuídas em 124 famílias (KRISTENSEN *et al.*, 2007). Destas, 15.207 espécies são registradas em todo o Brasil (CASAGRANDE e DUARTE, 2020). O Brasil é o terceiro país com maior diversidade de lepidópteros do mundo, atrás somente do Peru e da Colômbia (FREITAS *et al.*, 2011).

Aproximadamente 18.000 espécies de borboletas são registradas no mundo, e cerca de 10% da riqueza já descrita para a ordem (VAN NIEUKERKEN *et al.*, 2011). Na Região Neotropical, foram registradas aproximadamente 7.784 espécies de borboletas (LAMAS, 2004). Para o Brasil, a riqueza de espécies de borboletas conhecida é de 3.834 espécies (CASAGRANDE e DUARTE, 2020), destas, em torno de 2.200 com ocorrência registrada para a Mata Atlântica (WAHLBERG *et al.*, 2013). No entanto, é provável que o número de espécies existentes seja muito maior, pois todos os anos muitas espécies novas são descritas e novos registros de ocorrência são adicionados.

As borboletas pertencem à Papilionoidea, subdivide-se em: Nymphalidae com 1.869 espécies (CASAGRANDE e DUARTE, 2020), Hesperiidae com 1.692 espécies (MIELKE *et al.*, 2020), Riodinidae com 1.170 (DOLIBAINA *et al.*, 2020), Lycaenidae com 428 (DUARTE e ROBBINS, 2020), Papilionidae com 185 (CARNEIRO, 2019) e Pieridae com 182 (LEVISKI e CASAGRANDE, 2020).

As borboletas apresentam escamas nas asas e na superfície de todo seu o corpo, e um aparelho bucal sugador-labial, conhecido como espirotromba, estas associadas não somente à regulação da temperatura e aerodinâmica, mas também são estruturas coloridas, sejam elas pigmentadas ou estruturais (KRISTENSEN e SIMONSEN, 1998). Já a espirotromba é uma modificação das maxilas dos insetos mastigadores, correspondendo à gálea. As gáleas são extremamente alongadas e, juntas, formam um tubo que possibilita a ingestão de conteúdos líquidos. Em repouso, as gáleas permanecem enroladas em espiral, protegidas lateralmente pelos palpos labiais. Para alimentação distendem-se orientando o ápice para o local de sucção, usualmente néctar, pólen, frutas fermentadas, entre outros alimentos (CHAPMAN, 2013).

Os lepidópteros são insetos terrestres, diurnos e noturnos, e holometábolos (BROWN JÚNIOR e FREITAS, 1999), estão envolvidos em vários processos e interações ecológicas, destacando-se a polinização e herbivoria, além de estarem associados como base de inúmeras cadeias tróficas importantes em todos os biomas (FREITAS e MARINI-FILHO, 2011).

Além disso, é importante enfatizar que os lepidópteros, especialmente as borboletas, são importantes bioindicadores ambientais, demonstrando associação com a abundância de plantas hospedeiras, estrutura e composição vegetal, microclima e padrões de disponibilidade de recursos (FURLANETTI, 2010). Alguns grupos de borboletas têm associações íntimas com outros táxons, respondendo rapidamente a perturbações nas condições de habitat, características de bons indicadores biológicos (BROWN JÚNIOR e FREITAS, 2000; BARLOW *et al.*, 2007). Borboletas frugívoras têm sido utilizadas como bioindicadores em programas de monitoramento para avaliar a eficácia de unidades de conservação no Brasil (COSTA-PEREIRA *et al.*, 2013; SANTOS *et al.*, 2016).

As borboletas estão fortemente correlacionadas com o tipo de vegetação (NEW *et al.*, 1997). A composição e abundância de espécies de borboletas são alteradas, conforme sua composição e a estrutura da vegetação, sendo os recursos alimentares, tanto para as lagartas como para os adultos, crucial para a manutenção das populações (EHRLICH, 1984). Também, são utilizadas em estudos ecológicos para avaliação do efeito de borda, estratificação de florestas e fragmentação ou perda de hábitat (UEHARA-PRADO *et al.*, 2005).

As borboletas são agrupadas em guildas de acordo com a preferência alimentar dos indivíduos adultos, sendo nectarívoras ou frugívoras (DEVRIES, 1987). As borboletas nectarívoras alimentam-se de néctar e em alguns casos pólen, já as borboletas frugívoras alimentam-se de frutas fermentadas, excrementos ou exsudados de plantas e animais em decomposição (DEVRIES, 1987). Na guilda das borboletas frugívoras estão inseridas representantes das subfamílias: Satyrinae (incluindo as tribos Satyrini, Brassolini e Morphini), Charaxinae, Biblidinae e Nymphalinae (tribo Coeini) (FREITAS e BROWN JÚNIOR, 2004; WAHLBERG *et al.*, 2009). Essa guilda é taxonomicamente e ecologicamente diversa em ambientes tropicais, ocorrendo em todos os biomas brasileiros (FREITAS *et al*., 2014).

As borboletas frugívoras podem compreender de 50-75% de toda a riqueza Neotropical de Nymphalidae, dependendo da localidade (BROWN JÚNIOR, 2005). Resultados importantes sobre borboletas frugívoras foram obtidos em estudos comparando o grau de perturbação do habitat entre os locais (UEHARA-PRADO *et al.*, 2007, RIBEIRO e FREITAS, 2012), estudo de ecologia populacional (GROTAN *et al.*, 2012), padrões de diversidade e distribuição (RIBEIRO e FREITAS, 2011), pesquisa de monitoramento e conservação ambiental (POZO *et al.*, 2008; SANTOS *et al.*, 2016).

As borboletas são provavelmente o grupo de insetos mais conhecido em termos de taxonomia e ecologia (THOMAS, 2005), e sua contribuição histórica para o desenvolvimento de campos científicos como ecologia, evolução e conservação é amplamente reconhecida (BOGGS *et al.*, 2003).

Santos *et al.* (2018) reuniram informações (registros de presença de espécies) sobre comunidades de borboletas frugívoras de mais de uma centena de localidades da Mata Atlântica. Os autores registraram 279 espécies de borboletas frugívoras, representando 122 comunidades geograficamente distribuídas por toda a Mata Atlântica no Brasil e na vizinha Argentina. Esse conjunto de dados representa um grande esforço para compilar inventários de comunidades de borboletas alimentadoras de frutas, preenchendo uma lacuna de conhecimento sobre a diversidade e distribuição dessas borboletas na Mata Atlântica (SANTOS *et al.*, 2018).

Lepidoptera é um grupo ameaçado pela fragmentação (BONEBRAKE *et al.*, 2010). Evidencia-se que muitas populações de borboletas são encontradas em pequenos fragmentos, assim mostram-se adaptadas e muitas vezes tornam-se mais abundantes (BROWN JÚNIOR E FREITAS 2002; UEHARA-PRADO *et al.*, 2007). Por outro lado, em uma paisagem fragmentada a instabilidade das populações de borboletas é muito alta, fazendo com que muitas espécies migrem (BROWN JÚNIOR e FREITAS, 2002). Contudo, o processo de fragmentação facilita a emigração das espécies generalistas/oportunistas e consequentemente ocorre uma diminuição da diversidade de espécies endêmicas (SHAHABUDDIN e PONTE, 2005; UEHARA-PRADO *et al.*, 2005).

Portanto, entende-se que a importância em estudar as borboletas veio com o avanço das pesquisas buscando a conservação da biodiversidade, dada a sensibilidade desses insetos às mudanças ambientais, a fragmentação e redução das áreas naturais (FREITAS, 2010). Isso se explica pelo fato das borboletas serem um grupo taxonômico numeroso, fiéis aos seus hábitats, bem conhecidas e rapidamente amostradas (BROWN JÚNIOR e FREITAS, 2000).

Pesquisas sobre borboletas em Santa Catarina

Em Santa Catarina os estudos científicos sobre Lepidoptera vem ocorrendo à bastante tempo e em diferentes regiões do estado (HOFFMANN, 1932; CARNEIRO *et al.*, 2008; SILVA, 2008; SILVA *et al.*, 2011; CORSO e HERNANDEZ, 2012; FAVRETTO, 2012; SCHMIDT *et al.*, 2012; FANTON, 2014; FAVRETTO e SANTOS, 2014; FAVRETTO *et al.*, 2015; SILVA, 2015; ORLANDIN *et al.*, 2016; SABEDOT-BORDIN *et al.*, 2019; ORLANDIN *et al.*, 2020). As pesquisas são direcionadas, principalmente, para levantamento de espécies (CARNEIRO *et al.*, 2008; SILVA, 2008; SILVA *et al.*, 2011; CORSO e

HERNANDEZ, 2012; FAVRETTO, 2012; FAVRETTO e SANTOS, 2014; FAVRETTO *et al.*, 2015; SABEDOT-BORDIN *et al.*, 2019) e apresentam reduzido esforço amostral (SILVA, 2008; SILVA *et al.*, 2011; FAVRETTO, 2012; SCHMIDT *et al.*, 2012; SILVA, 2015). Apesar de alguns pesquisadores terem realizado coletas de borboletas utilizando rede entomológica, os dados disponíveis atualmente em publicações ainda podem ser considerados escassos (PIOVESAN *et al.*, 2014).

O conhecimento da fauna de borboletas da Região Oeste de Santa Catarina teve seu início através da contribuição do antigo naturalista Fritz Plaumann, o qual deixou uma coleção de aproximadamente 80.000 exemplares de insetos, 17 mil espécies dentre essas 1.500 descobertas pelo colecionador e descritas por pesquisadores tanto brasileiros como estrangeiros (LUBENOW, 2016). Foram mais de 60 anos coletando espécimes de insetos, na região do Alto Uruguai Catarinense (LUBENOW, 2016). Lepidoptera corresponde a segunda ordem mais bem representada do Museu Entomológico Fritz Plaumann, em Nova Teotônia, no município de Seara, totalizando 413 gêneros e 1.260 espécies (SILVA, 1998).

Nas últimas décadas, foram realizados alguns inventários de borboletas, utilizando redes entomológicas, no oeste de Santa Catarina. O primeiro levantamento de espécies de borboletas na região foi feito por Silva *et al.* (2011), na Floresta Nacional de Chapecó (FLONA), uma Unidade de Conservação Federal localizada na região oeste, em Guatambú. Na sequência, na mesma Unidade de Conservação, Silva (2015) avaliou a diversidade de borboletas em duas áreas (nativa e *Pinus*). Foram realizadas amostragens mensais, no período de novembro de 2014 a abril de 2015. Após esforço amostral total de 72 horas/rede foram coletadas 388 borboletas, pertencentes a 62 espécies, a seis famílias e 15 subfamílias. Ainda, Colpani (2018) analisou a composição, riqueza e abundância das assembleias de borboletas frugívoras na UC e fragmentos florestais adjacentes, além de analisar a influência das variáveis abióticas (temperatura, umidade, velocidade do vento). Também verificou a similaridade na composição das assembleias de borboletas frugívoras entre diferentes áreas amostradas no período de dezembro de 2017 a março de 2018.

Em outra UC, o Parque Estadual das Araucárias (PAEAR), sendo esta estadual, Dorneles (2019) analisou a composição e riqueza de espécies de borboletas frugívoras do Parque Estadual das Araucárias (PAEAR) e fragmentos florestais adjacentes, e também analisou a similaridade entre as áreas amostradas.

Também é importante citar o estudo de Fanton (2014) que analisou os padrões de composição, abundância e riqueza de espécies de borboletas ocorrentes no Parque Estadual Fritz Plaumann, uma UC estadual de proteção integral, composta pela Floresta Estacional

Decidual, em Concórdia. As coletas foram mensais, de outubro de 2011 a setembro de 2012. A cada evento amostral foi percorrida uma trilha no interior da Unidade de Conservação e todas as borboletas avistadas foram coletadas com rede entomológica. Com um total de 12 horas-rede foram coletados 187 indivíduos, 51 espécies, cinco famílias e 15 subfamílias. Próximo de Concórdia, no município de Seara, Schmidt *et al.* (2012) compararam a diversidade de borboletas, e avaliaram a variação sazonal, ocorrentes no interior e na borda de um fragmento de Mata Atlântica, localizado no perímetro urbano do município, cuja mata é secundária. Os autores percorreram as trilhas do fragmento florestal e coletaram as borboletas com rede entomológica.

Em outras regiões de Santa Catarina, também são registrados estudo sobre a fauna de lepidópteros. Importante aqui sinalizar os estudos de Hoffmann (1932) registrando muitas borboletas e mariposas em Jaraguá do Sul e demais municípios. Um estudo foi realizado em remanescentes florestais, estabelecidos como Unidades de Conservação, no Sul da ilha de Santa Catarina, Carneiro *et al.* (2008) caracterizaram a fauna de borboletas Hesperioidea e Papilionoidea. A diversidade de borboletas Nymphalidae na Mata Atlântica do Parque Municipal da Lagoa do Peri em Florianópolis foi estudada por Silva (2008). A autora avaliou a variação sazonal e analisou a composição, abundância e riqueza de espécies. As borboletas foram coletadas com armadilhas com isca atrativa. Uma lista de espécies de borboletas frugívoras e descrições das subfamílias e das espécies registradas no Parque Estadual da Serra do Tabuleiro e estão apresentadas na publicação de Corso e Hernandez (2012). Nesse estudo foi feita a coleta de borboletas frugívoras utilizando armadilha com isca atrativa em Floresta Ombrófila Densa.

Orlandin *et al.* (2016) elaboraram uma lista das espécies de Lepidoptera (borboletas e mariposas) registradas no estado, com acréscimo de registros pessoais e informações de diversos livros e artigos adicionais, resultando no registro de 1.637 espécies de borboletas e mariposas. Recentemente, Orlandin *et al.* (2020) apresentam informações sobre adultos e imaturos de borboletas, ocorrentes no município de Joaçaba.

Favretto (2012) apresenta uma lista de borboletas e mariposas registradas em Joaçaba, durante o período de 2006 a 2010, coletando exemplares de Lepidoptera de forma esporádica, em deslocamentos de rotina, sem a utilização de metodologia padronizada. Ainda, Favretto *et al.* (2015) apresentaram os resultados de um levantamento de Lepidoptera realizado em trilhas de um fragmento florestal urbano em Joaçaba. As borboletas foram coletadas com rede entomológica ou eram registradas a partir de observações no campo. Outro estudo de Favretto e Santos (2014) realizaram um levantamento das espécies de lepidópteros nas matas ciliares do Rio do Peixe, que faz fronteira com os municípios de Ouro e Capinzal. Para isso os autores definiram transectos lineares ao longo da área amostrada para a coleta de exemplares, bem como o registro de observações.

Bellaver *et al.* (2012) elaboraram uma lista de espécies de borboletas em uma área (Passo de Torres) em Santa Catarina, e em diferentes ambientes de Mata Paludosa e Mata de Restinga em uma ampla área na Planície Costeira norte do Rio Grande do Sul, visando contribuir para o conhecimento da fauna de borboletas através do registro de novas ocorrências para a Mata Atlântica. Os autores realizaram amostragens utilizando armadilhas com isca atrativa para borboletas frugívoras de Nymphalidae e rede entomológica para as borboletas Papilionoidea e Hesperioidea.

As variáveis ambientais e as borboletas

Uma ameaça importante para a biodiversidade corresponde às mudanças climáticas (CAHILL *et al.*, 2013). Essa afirmação é sustentada a partir da compreensão do grande aumento na atmosfera da concentração de gases do efeito estufa, como o dióxido de carbono, resultante das ações humanas, sendo o clima dependente das variações de temperatura, precipitação e radiação solar (CAIN *et al.*, 2011) e responsável pelas mudanças sazonais e pelas mudanças nas abundâncias das espécies (WOLDA, 1988).

As variáveis climáticas mais significativas para as espécies que ocupam determinado local são a temperatura, umidade relativa, velocidade do vento, precipitação, pressão atmosférica e a correlação entre essas variáveis define a qualidade do ambiente, garantindo ou não a sobrevivência das espécies (CAIN *et al.*, 2011). Além disso, as espécies respondem diferentemente as variáveis, possuindo sensibilidades distintas (CHECA *et al.*, 2014).

As borboletas são organismos ectotérmicos suscetíveis às mudanças ambientais, assim, respondem rapidamente às variações da qualidade dos habitats (BONEBRAKE *et al.*, 2010). Nesse sentido, a composição, abundância e riqueza de espécies podem ser explicadas pelas variações dos fatores ambientais (BONEBRAKE *et al.*, 2010; ZIPF *et al.*, 2017). Essas variações podem afetar o desenvolvimento dos insetos e diapausa das espécies, como também comprometer as atividades fisiológicas e processos migratórios (WESTWOOD e BLAIR, 2010).

O clima pode atuar sobre a comunidade de borboletas de forma direta, através de aumentos das taxas de mortalidade dos adultos, e indireta, através de alterações na disponibilidade de alimentos, ou ainda, na combinação dos dois fatores (CHECA *et al.*, 2009).

Consequentemente, as mudanças ambientais são extremamente perigosas, mesmo quando as espécies encontram-se dentro das Unidades de Conservação (MONZO'N *et al.*, 2011), pois estas alterações ambientais podem diminuir a complexidade estrutural do habitat (RIBEIRO *et al.*, 2008).

As comunidades de borboletas podem ser afetadas pela frequência e intensidade de clareias, microclima, luminosidade, presença de plantas hospedeiras para as lagartas e recursos alimentares para os adultos (BROWN JÚNIOR e FREITAS, 2000; RIBEIRO, 2006; BASSET *et al.*, 2012). Há uma relação positiva entre os fatores citados com a estrutura da vegetação (VEDDELER *et al.*, 2005), sendo este um fator do habitat importante e essencial para as borboletas, considerando a relação das espécies com a termo-regulação, refúgio e ambiente para acasalamento (SHREEVE *et al.*, 2001). As comunidades de borboletas de florestas também são influenciadas por fatores estruturais do habitat, tais como topografia, estratificação vertical, efeito de borda, qualidade da matriz, assim como por distintos níveis de perturbação (RAMOS, 2000; DEVRIES e WALLA, 2001).

Considerando definir o melhor período do ano para a amostragem de borboletas, Brown (1992) sinaliza que é importante observar as estações do ano e as diferentes áreas no Brasil, sendo que verificou com base nos métodos de coleta intensiva, um número significativo de espécies em cada um dos grandes grupos de lepidópteros diurnos nas diferentes áreas e períodos sazonais. Mais recentemente, Kinouchi (2014) relata que é o melhor período do ano para a amostragem de borboletas é no final da estação chuvosa, quando a umidade permanece alta e com chuvas mais esparsas. Porém, enfatiza que precisamos considerar que o Brasil possui grandes extensões continentais, assim nos biomas os períodos favoráveis para a amostragem de borboletas frugívoras variam bastante. Para a Mata Atlântica do Sudeste, Brown Júnior (1992) e Ribeiro *et al.* (2010) sinalizam que o período entre fevereiro e abril é o mais propício para as amostragens.

Objetivos e hipóteses

Esta tese tem como objetivo geral analisar a composição, abundância e riqueza de espécies de borboletas frugívoras, bem como a influência das variáveis abióticas e bióticas, em Unidades de Conservação e fragmentos florestais adjacentes na Região Oeste de Santa Catarina.

A tese teve como hipóteses:

- Existem diferenças na composição, abundância e riqueza de espécies de borboletas frugívoras entre as Unidades de Conservação e os fragmentos florestais adjacentes;
- Existe influência das variáveis abióticas (temperatura, umidade relativa do ar, luminosidade e velocidade do vento) sobre a composição, abundância e riqueza de espécies de borboletas frugívoras nas Unidades de Conservação e fragmentos florestais adjacentes;
- A altura e cobertura do dossel apresentam efeito positivo sobre a composição, abundância e riqueza de espécies de borboletas frugívoras;
- A abundância e riqueza de espécies de borboletas frugívoras aumentam com a área do fragmento florestal e diminuem com o nível de isolamento.

A partir das hipóteses, são objetivos específicos da tese:

- Elaborar uma lista das espécies de borboletas frugívoras das Unidades de Conservação e respectivos fragmentos florestais adjacentes, na Região Oeste de Santa Catarina (Capítulo I);
- Avaliar a composição e comparar a similaridade das assembleias de borboletas frugívoras nas diferentes Unidades de Conservação, com seus respectivos fragmentos florestais (Capítulo I);
- Analisar a composição e diversidade (abundância e riqueza de espécies) de borboletas frugívoras em Unidades de Conservação e em fragmentos florestais adjacentes de Floresta Ombrófila Mista, no Sul do Brasil (Capítulo II);
- Analisar a influência das variáveis abióticas (temperatura, umidade, luminosidade, velocidade do vento) sobre a composição, riqueza de espécies e abundância das assembleias de borboletas frugívoras nas Unidades de Conservação e fragmentos florestais adjacentes (Capítulo III).
- Analisar a influência de variáveis bióticas, representadas pela altura e cobertura do dossel da floresta, na composição, abundância e riqueza de espécies de borboletas frugívoras das Unidades de Conservação e fragmentos florestais adjacentes (Capítulo III).

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CAPÍTULO 1

Frugivorous butterflies from the Atlantic Forest in Southern Brazil (Lepidoptera: Nymphalidae)[1]

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***Abstract*:** This study aimed to present a list of the species of frugivorous butterflies occurring in Atlantic Forests, in the Conservation Units: National Forest of Chapecó (FLONA), Ecological Station of Mata Preta (ESEC) and State Park of Araucárias (PAEAR) and adjacent forest fragments, located in the Western region of the state of Santa Catarina. Three samplings were conducted between December 2017 and March 2018, totaling 24 days of collection in each sampling area. Van Someren-Rydon traps were used to capture frugivorous butterflies. There were 4,231 frugivorous butterflies belonging to four subfamilies, 12 tribes and 49 species. In all, 37 species of frugivorous butterflies were sampled in FLONA and 29 in adjacent forest fragments. In ESEC, 29 species and 33 in adjacent forest fragments. In PAEAR, 33 species and 28 in adjacent forest fragments. Of the total species registered, 15 species are new records for the state of Santa Catarina and 11 are new records for the Western region of the state. The most abundant species for FLONA were: *Manataria hercyna* (Hübner, [1821]) and *Hermeuptychia* sp. In ESEC, were *Hermeuptychia* sp. and *Yphthimoides ordinaria* Freitas, Kaminski & Mielke, 2012. In PAEAR, greater abundance of *Forsterinaria quantius* (Godart, [1824]) and *Eryphanes reevesii* (Doubleday, 1849) were verified. For the adjacent forest fragments to Conservation Units, there was a greater abundance of *Hermeuptychia* sp., *Moneuptychia soter* (Butler, 1877), *Morpho epistrophus* (Fabricius, 1796) e *Forsterinaria quantius* (Godart, [1824]). Satyrinae presented higher richness (S = 34) and abundance (90.58%) in all areas sampled. The rarefaction and extrapolation curves for the Conservation Units and adjacent forest fragments showed a greater rise in the FLONA and PAEAR sampling units and their adjacent forest fragments. The estimated sampling coverage for

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Conservation Unit and forest fragments was above 97%. The richness calculated through the Jackknife 1 estimator, for the FLONA and PAEAR samplings, presented a value of 50.75 and 37.09, respectively. The fauna of frugivorous butterflies from this region, first investigated in areas of Conservation Units, showed to be expressive and well represented in the Atlantic Forest Biome, indicating its potential as a refuge for biodiversity

Keywords: *conservation, diversity, ecology, forest fragmentation, species richness*.

Borboletas frugívoras da Mata Atlântica no Sul do Brasil (Lepidoptera: Nymphalidae)

Resumo: O estudo teve como objetivo elaborar uma lista das espécies de borboletas frugívoras ocorrentes em florestas da Mata Atlântica, nas Unidades de Conservação: Floresta Nacional de Chapecó (FLONA), Estação Ecológica da Mata Preta (ESEC) e Parque Estadual das Araucárias (PAEAR) e fragmentos florestais adjacentes, localizados na Região Oeste de Santa Catarina. Foram realizadas três campanhas de coletas entre dezembro de 2017 e março de 2018, totalizando 24 dias de coletas em cada área amostral. Para a captura das borboletas frugívoras, foram utilizadas armadilhas Van Someren-Rydon. Foram registradas 4231 borboletas frugívoras pertencentes a quatro subfamílias, 12 tribos e 49 espécies. Foram amostradas 37 espécies de borboletas frugívoras na FLONA e 29 nos fragmentos florestais adjacentes. Na ESEC 29 espécies e 33 nos fragmentos florestais adjacentes. No PAEAR 33 espécies e 28 nos fragmentos florestais adjacentes. Do total de espécies registradas, 15 espécies de borboletas frugívoras são novos registros para o estado de Santa Catarina e 11 são novos registros para a região oeste do estado. As espécies mais abundantes para a FLONA foram: *Manataria hercyna* (Hübner, [1821]) e *Hermeuptychia* sp. Na ESEC, foram *Hermeuptychia* sp. e *Yphthimoides ordinaria* Freitas, Kaminski & Mielke, 2012. No PAEAR verificou-se maior abundância das espécies *Forsterinaria quantius* (Godart, [1824]) e *Eryphanes reevesii* (Doubleday, 1849). Para os fragmentos florestais adjacentes das Unidades de Conservação houve maior abundância das espécies: *Hermeuptychia* sp., *Moneuptychia soter* (Butler, 1877), *Morpho epistrophus* (Fabricius, 1796) e *Forsterinaria quantius* (Godart, [1824]). Satyrinae apresentou maior riqueza (S=34) e abundância (90,58%) de borboletas frugívoras em todas as áreas amostradas. As curvas de rarefação e extrapolação, para as Unidades de Conservação e fragmentos florestais adjacentes mostraram uma maior ascendência nas unidades amostrais da FLONA e PAEAR e seus fragmentos florestais adjacentes. A cobertura estimada de amostragem para as borboletas frugívoras, para as Unidades de Conservação e fragmentos florestais, ficou acima de 97%. A riqueza calculada através do estimador Jackknife 1, mostrou-se superior à riqueza observada, sendo que para as amostragens na FLONA e PAEAR, o estimador apresentou um valor de 50,75 e 37,09, respectivamente. A fauna de borboletas frugívoras da região, investigada pela

primeira vez em áreas de Unidades de Conservação, mostrou-se bastante expressiva e bem representada no Bioma Mata Atlântica, indicando seu potencial como refúgio da biodiversidade.

Palavras-chave: *conservação, diversidade, ecologia, fragmentação das florestas, riqueza de espécies.*

Introduction

The Atlantic Forest is among the five main hotspots in the world (Morellato & Haddad 2000; Conservação Internacional 2013), considered one of the most important biomes worldwide due to its high biodiversity, high number of endemic species and deforestation rate (Myers et al. 2000). This biome covered approximately 13% of the Brazilian territory (Cabral & Cesco 2008), currently there are less than 12% of the original area, and the remaining areas are represented by more than 245,000 fragments, of which more than 95% are smaller than 250 hectares (Ribeiro et al. 2009).

The Western region of the state of Santa Catarina was severely deforested throughout the 20th century, mainly by the economic development after European colonization, characterized by logging (Cabral & Cesco 2008). As a consequence, large forest areas were gradually transformed into isolated fragments (Cerqueira et al. 2003, Cabral & Cesco 2008). It is notable that over the centuries the process of forest fragmentation has intensified due to human activities on a continuous basis, generating effects such as the expansion of agricultural areas, the formation of urban areas and the construction of roads (Haddad et al. 2015).

Vibrans et al. (2013) present data from the Forest Floristic Survey of Santa Catarina highluminositying that the state covers three different phytophysiognomies that make up the Atlantic Forest: Dense Ombrophilous Forest, Mixed Ombrophilous Forest and Decidual Seasonal Forest. The results show that the remaining native forest cover in the state is approximately 29%. In the Western of Santa Catarina, the forest cover of the Decidual Seasonal Forest is between 16 and 24% of the Mixed Ombrophilous Forest (Vibrans et al. 2013).

Due to the rapidity with which anthropic impacts occur, selecting species or assemblages of species to establish conservation and monitoring priorities is critical (Kremen 1992). The composition, richness and abundance of Lepidoptera in the environments can be indicators of the degree of environmental preservation, being its study of fundamental importance in the understanding of the ecological interactions between the different environments (Duarte et al. 2012).

Considering this, the importance of studying butterflies came with the progress of research on biodiversity conservation, given the sensitivity to environmental changes, the fragmentation and reduction of natural areas (Freitas 2010). This is explained by the fact that butterflies are a large taxonomic group, faithful to their habitats, well known, quickly sampled and easily identified (Brown Jr. & Freitas 2000).

Lepidoptera correspond to approximately 15,207 species registered throughout Brazil (Duarte & Casagrande 2020), of which more than 3,250 are butterflies (Freitas & Marini-Filho 2011). In Brazil, strictly frugivorous butterflies are represented by four subfamilies of Nymphalidae: Satyrinae, Charaxinae, Biblidinae and some genera of Nymphalinae (Freitas et al. 2014). This guild comprises 50-75% of the Neotropical Nymphalidae fauna (Brown Jr. 2005), and because they are taxonomically and ecologically diverse in tropical environments, occur in all Brazilian biomes (Freitas et al. 2014).

Despite the diversity of habitats, there is little research concerning the order Lepidoptera in the state of Santa Catarina (Hoffmann 1932, Carneiro et al. 2008, Siewert et al. 2010a, Corso & Hernandez 2012, Belaver et al. 2012, Orlandin et al. 2016). An extensive study was conducted by Ferro et al. (2012) with the moths Arctiinae and Siewert et al. (2010b) with Sphingidae. The knowledge of the fauna of butterflies in the Western region of the state began with the contribution of the ancient naturalist Fritz Plaumann, who left a collection of approximately 4,000 butterflies, deposited at the Fritz Plaumann Entomological Museum in the municipality of Seara (Lubenow 2016). Some recent surveys of Lepidoptera (considering butterflies and/or moths), using entomological nets, were conducted in the Western region in Santa Catarina, highluminosityingthe research done by Silva et al. (2011), Favretto (2012), Schmidt et al. (2012), Favretto et al. (2013), Favretto & Santos (2014), Fanton (2014), Favretto et al. (2015), Silva (2015) and Colpani (2018).

Santos et al. (2018) compiled information from records of the presence of frugivorous butterflies species in more than a hundred locations in the Atlantic Forest, including Santa Catarina. However, the study did not record the presence of frugivorous butterflies species in the Western region of the state. The Brazilian Nymphalid Database (DnB) presented by Shirai et al. (2019) centralizes the state of the art of all lists of species of Nymphalidae already reported in Brazil. For Santa Catarina, Shirai et al. (2019) reports that the best sampled city was Florianópolis and it is observed in the publication that the Western region of the state was poorly sampled.

Although some researchers have made collections of butterflies in the state of Santa Catarina using an entomological net, the data currently available in publications can still be considered scarce (Piovesan et al. 2014). The lack of publications on frugivorous butterflies in Conservation Units and adjacent forest fragments, in the Western region in Santa Catarina, is evidenced through the bibliographic search, using trap with attractive bait as a collection technique. With the purpose of contributing to the knowledge about the fauna of butterflies of Santa Catarina and in order to provide subsidies for the conservation of species, the study aimed to elaborate a list of frugivorous butterflies species of the Western region of the state.

Material and Methods

1. Study areas

The study was conducted in two Federal Conservation Units: National Forest of Chapecó (FLONA) (27°06'24.8"S and 52°46'59.3"W) and Ecological Station of Mata Preta (ESEC) (26°30'57.31"S and 52°7'59.69"W) and a State Conservation Unit: State Park of Araucárias (PAEAR) (26º27'08"S and 52º33'56"W). All Conservation Units are fully protected and are located in the Western region of the state of Santa Catarina, Southern Brazil (Figure 1). The Conservation Units are inserted in areas that during the last decades suffered from intense pressure of forest exploitation and agricultural expansion. Around the Conservation Units, there are monocultures such as soybean and corn, grown by the conventional method and often occurring the use of transgenics (Apremavi 2009). All Conservation Units are inserted in the Atlantic Forest Biome with forest phytophysiognomies classified as Mixed Ombrophilous Forest with different successional stages (Dick et al. 2013).

FLONA is located in the municipalities of Chapecó and Guatambú, was created in 1968 and has an area of 1,590 hectares. Samplings of frugivorous butterflies were performed in fragment I of FLONA with an area of 1,287.54 hectares, located in Guatambú (ICMBio 2013).

The ESEC of Mata Preta was established in 2005, has an area of 6,536 hectares and is located in the municipality of Abelardo Luz. Extensions of the ESEC of Mata Preta constitute private areas whose owners present legal proceedings in progress regarding the formation of the Conservation Unit (Apremavi 2009).

PAEAR was created in 2003 and covers an area of 612.5 hectares. PAEAR is located between the municipalities of São Domingos and Galvão. The creation of the park was a compensatory action established by the formation of the reservoir of the Quebra Queixo Hydroelectric Power Plant, located in the Chapecó River, in the municipalities of Ipuaçu and São Domingos (Fatma 2016).

The climate of the Western region of the state of Santa Catarina is cfa, subtropical humid, with abundant rainfall well distributed throughout the year. The average annual temperature is lower than 18ºC and with average temperatures ranging from 13ºC and 25ºC (Alvares et al. 2014).

2. Sampling design

In order to collect the frugivorous butterflies, five sampling units (five for FLONA and PAEAR, three for ESEC) were defined inside the Conservation Units (CU) and a single sampling unit in each of the adjacent forest fragments of each CU. Five adjacent forest fragments were defined for FLONA and ESEC, and four for PAEAR (Figure 1). Adjacent forest fragments were different in size and had different distances from CU. Among the adjacent forest fragments there was a minimum distance of 250 meters (Santos et al. 2014). The sampling unit was formed by a linear transect. At the transect, the first trap was allocated at a distance of at least 50 meters from the edge (Uehara-Prado 2003). In each transect, there were a set of five traps for the capture of butterflies (Freitas et al. 2014), distanced from 30 to 50 meters (Santos et al. 2014) from each other, depending on the availability of places to hang them in the trees. The other transects of the sampling units with a minimum distance of 250 meters between them. A total of 135 traps were installed, 50 traps in FLONA/fragments (25/25); 40 traps in ESEC/fragments (15/25) and 45 in PAEAR/ fragments (25/20).

Three samplings were conducted in each CU and respective adjacent forest fragments, from December 2017 to March 2018, totaling 21 days of collection. The traps were left active on the field for seven consecutive days, being inspected every 48 hours for removal of the captured frugivorous butterflies and bait replacement.

The procedure for the collection of frugivorous butterflies followed the protocol established by the National Lepidoptera Research and Conservation Network (RedeLep). Van Someren-Rydon traps were used to collect frugivorous butterflies. The traps were suspended in trees by ropes, at a height of approximately 1.5 m above the ground level (Uehara-Prado 2005). Each trap was supplied with a 50 mL plastic bottle containing an attractive bait. The bait used consisted of a mixture of sugarcane juice with well-ripe bananas at a proportion of 1/3, which was prepared 48 hours before the beginning of the sampling, time required to occur to the fermentation (Uehara-Prado 2003).

The collected frugivorous butterflies were sacrificed by thoracic pressure at the base of the wings and conditioned in properly identified entomological envelopes (Almeida et al. 1998). The collected butterflies were taken to the Laboratory of Entomology of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ) in Santa Catarina, Brazil, for freezer storage and subsequent identification of the species. Species identification was carried out through specialized literature of Canals (2003), Lamas (2004) and using online identification site (http://butterfliesofamerica.com). Identification was also performed with the help of experts.

Specimens of each sampled species were deposited in the reference collection of the Laboratory of Entomology of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ), Chapecó, Santa Catarina; in the Zoological Collection of the Universidade do Vale do Rio dos Sinos (MZ UNISINOS), São Leopoldo, Rio Grande do Sul, Brazil.

The collections were performed under the license issued by ICMBio (ICMBio/SISBio Collection License 60789-1).

To represent the composition, richness and abundance of frugivorous butterflies in CU and adjacent forest fragments, the species were listed according to their respective taxa of subfamilies, tribe and genus in addition to the presence in each environment.

Richness estimates by sample coverage were performed using the rarefaction and extrapolation curve based on the Chao 1 estimator with 40 nodes and 500 randomizations. The analysis was run with the iNEXT software (Chao et al. 2016).

Sampling adequacy was verified from the Jackknife 1 species richness estimator for all sampled areas using the EstimateS 9.1 software (Colwell 2013), as suggested by Toti et al. (2000). We used EstimateS with 500 randomizations.

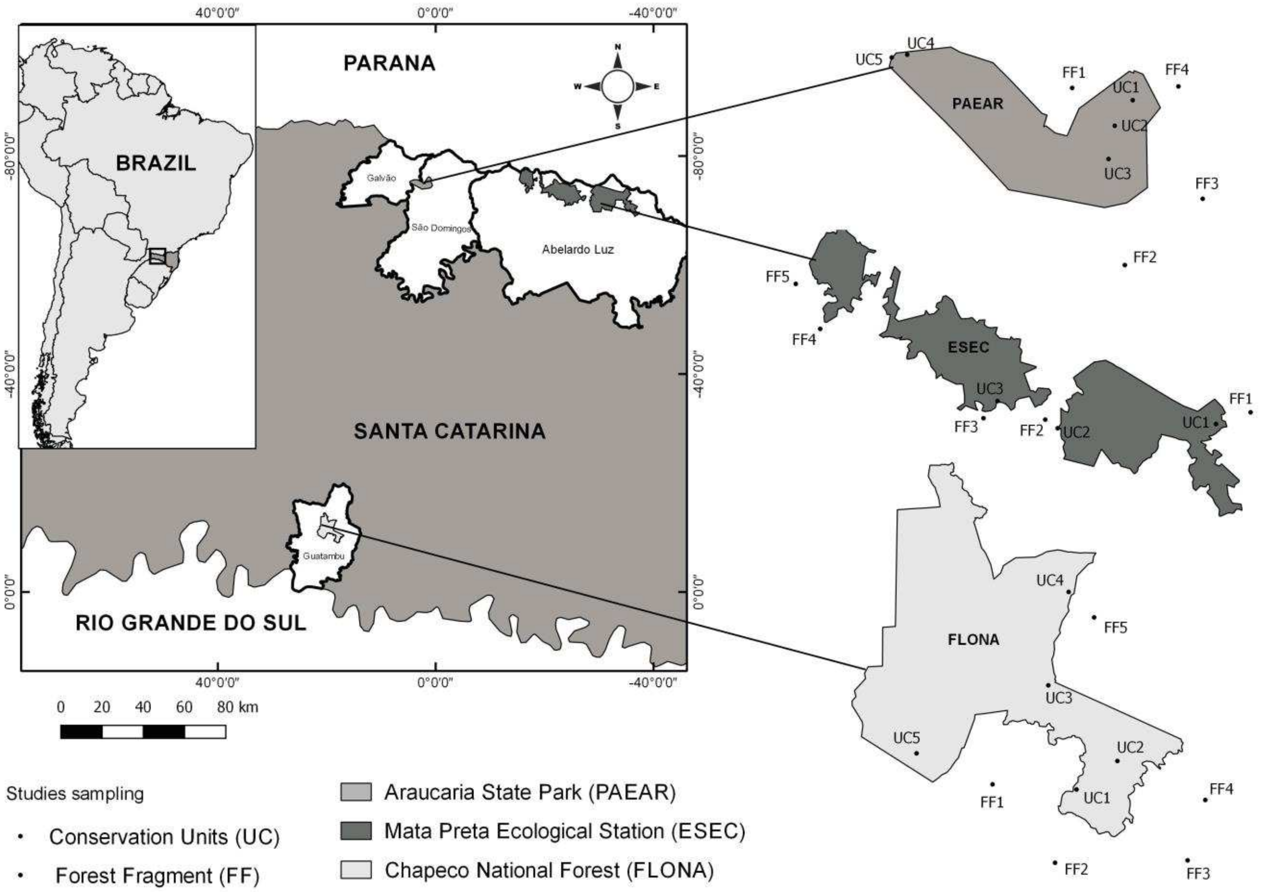


Figure 1 Map of the study areas and sample units for collections of frugivorous butterflies in the municipalities of Guatambú, Abelardo Luz and São Domingos, Santa Catarina, from December 2017 to March 2018.

To illustrate butterflies species composition comparisons two ordenations were plotted (Non-metric MultiDimensional Scaling - nMDS) using a qualitative similarity index (Simpson). Qualitative analysis was performed using a species presence-absence matrix, using the Simpson index to build a dissimilarity matrix among sample units. To test for statistical differences among butterflies assemblage composition for the above similarity indexes, we applied two one-way ANOSIM (Analysis of Similarities) with Bonferroni correction, one for each factor. We also performed an analysis of similarity percentage (SIMPER) (Clarke & Warwick 1994), based on Bray-Curtis distance, in order to identify those taxa responsible for observed differences in species composition among forest classes, also quantifying their relative contribution for such differences. Composition analyses were developed using PASt (Paleontological Statistics 2.17c, Hammer & Harper 2009).

Results

There were registered 4,231 frugivorous butterflies belonging to four subfamilies, 12 tribes and 49 species (Table 1). In total, 49 species of frugivorous butterflies (2,418 individuals) were sampled in FLONA (N=670, S=37) and adjacent forest fragments (N=1,748, S=29); 37 species (1,234 individuals) in ESEC (N=547, S=29) and adjacent forest fragments (N=687, S=33) and 35 species (579 individuals) in PAEAR (N=368, S=33) and adjacent forest fragments (N=211, S=28) (Table 1).

Of the total richness in FLONA and adjacent forest fragments, 25 species occurred in all sampled areas. In all, 12 species were sampled exclusively in the areas of CU and four in the adjacent forest fragments. In ESEC, 25 species were common to the areas sampled, four species were sampled exclusively in the areas of CU and eight occurred exclusively in the adjacent forest fragments. In turn, in PAEAR, 26 species were common to the sampled areas, another seven species were sampled exclusively in the CU areas and two occurred in the adjacent forest fragments (Table 1).

From the total of species, 15 species of frugivorous butterflies are new records for the state of Santa Catarina, namely 12 Satyrinae, two Biblidinae and one Charaxinae (Table 1). New species records for the state: *Zaretis strigosus* (Gmelin, [1790]), *Cissia eous* (Butler, 1867), *Moneuptychia soter* (Butler, 1877) recorded in all sampled areas. *Forsterinaria necys* (Godart, [1824]) was not recorded in the adjacent forest fragments of FLONA. *Carminda paeon* (Godart, 1824) was not sampled in PAEAR and adjacent forest fragments. *Callicore hydaspes* (Drury, 1782) was recorded only in FLONA and adjacent forest fragments; *Paryphthimoides poltys* (Prittwitz, 1865) was not sampled in ESEC, PAEAR and adjacent forest fragments. *Eunica tatila* (Herrich-Schäffer, 1855) and *Splendeuptychia libitina* (Butler, 1870), singleton species, occurring only in FLONA. *Catoblepia amphirhoe* (Hübner, 1825) was recorded in FLONA and adjacent forest fragments of PAEAR (doubleton) and *Pseudodebis euptychidia* (Butler, 1868) was sampled in FLONA, PAEAR and adjacent forest fragments. *Splendeuptychia ambra* (Weymer, [1911]) registered in PAEAR. *Taygetis laches* (Fabricius, 1793) was not sampled in the adjacent forest fragments of PAEAR, FLONA and their adjacent forest fragments. *Yphthimoides straminea* (Butler, 1867) in the ESEC, FLONA and adjacent forest fragments of PAEAR. *Yphthimoides celmis* (Godart, [1824]) did not occur in the FLONA and adjacent forest fragments of the ESEC (Table 1).

The study added 11 new records of frugivorous butterflies to the Western region of the state of Santa Catarina, with eight Satyrinae, one Charaxinae and Nymphalinae (Table 1). *Hermeuptychia* sp., *Pareuptychia ocirrhoe* (Fabricius, 1776) and *Smyrna blomfildia* (Fabricius, 1781) recorded in all areas sampled. *Archaeoprepona demophon* (Linnaeus, 1758) recorded in all areas sampled with the exception of the adjacent forest fragments of FLONA. *Blepolenis catharinae* (Stichel, 1902) sampled in ESEC. *Opoptera sulcius* (Staudinger, 1887) was not recorded in FLONA and adjacent forest fragments. *Euptychoides castrensis* (Schaus, 1902) did not occur in the adjacent forest fragments of PAEAR. *Godartiana muscosa* (Butler, 1870) was not registered in FLONA. *Taygetis acuta* Weymer, 1910 was not recorded in ESEC and adjacent forest fragments of FLONA. *Taygetis yptima* (Hübner, 1821) was not recorded in the adjacent forest fragments of ESEC and FLONA and *Zischkaia pacarus* (Godart, [1824]) was only sampled in FLONA (singleton) (Table 1).

The most abundant species in FLONA were *Manataria hercyna* (Hübner, [1821]) with 164 individuals (24.48%), *P. ocirrhoe* (Fabricius, 1776) with 147 (21.94%) and *Hermeuptychia* sp. with 114 (17.01%) (Table 1, Figure 2a). On the other hand, in the CU, 27 species of frugivorous butterflies totaled less than 10 individuals, being generally restricted to a single area sampled. Among the total fauna of frugivorous butterflies in the CU, 12 singletons were recorded: *A. demophon* (Linnaeus, 1758), *Archaeoprepona chalciope* (Hübner, [1823]), *C. hydaspes* (Drury, 1782), *C. paeon* (Godart, 1824), *C. amphirhoe* (Hübner, 1825), *Cybdelis phaesyla* (Hübner, 1825), *E. tatila* (Herrich-Schäffer, 1855), *Hamadryas epinome* (Felder & Felder, 1867), *Morpho aega* (Hübner, [1822]), *S. libitina* (Butler, 1870), *Temenis laothoe* (Cramer, 1777) and *Z. pacarus* (Godart, [1824]) and five doubletons: *Epiphile hubneri* (Hewitson, 1861), *F. necys* (Godart, [1824]), *Memphis acidalia victoria* (H. Druce, 1877), *Opsiphanes invirae* (Hübner, [1808]) and *T. acuta* Weymer, 1910 (Table 1, Table 2). In the adjacent forest fragments of FLONA, it was verified that the most abundant species were *Hermeuptychia* sp. with 494 individuals (28.26%), *M. soter* (Butler 1877) with 369 (21.11%) and *Y. ordinaria* Freitas, Kaminski & Mielke 2012 with 203 (11.61%) (Table 1, Figure 2a). In these forest fragments, 15 species of frugivorous butterflies numbered less than 10 individuals and four singletons were recorded: *C. phaesyla* (Hübner, 1825), *G. muscosa* (Butler, 1870), *Hamadryas amphinome* (Linnaeus, 1767) and *P. euptychidia* (Butler, 1868) and two doubletons: *C. hydaspes* (Drury, 1782) and *Caligo illioneus* (Cramer, 1775) (Table 1, Table 2).

In ESEC, *Hermeuptychia* sp. with 189 individuals (34.55%), *Y. ordinaria* Freitas, Kaminski & Mielke, 2012 with 78 (14.26%) and *Eryphanes reevesii* (Doubleday, 1849) with 65 (11.88%) were the most abundant species (Table 1, Figure 2b). In the CU, it was observed that 18 species of frugivorous butterflies totaled less than 10 individuals. Five species of singleton frugivorous butterflies were recorded: *C. phronius* (Godart, [1824]), *C. phaesyla* (Hübner, 1825), *G. muscosa* (Butler, 1870), *M. acidalia victoria* (Druce, 1877) and *Yphthimoides celmis* (Godart, [1824]), and six doubletons *A. chalciope* (Hübner, [1823]), *Morpho helenor* (Cramer, 1776), *O. invirae* (Hübner, [1808]), *S. bomfildia* (Fabricius, 1781), *T. laches* (Fabricius, 1793) and *Z. strigosus* (Gmelin, [1790]) (Table 1, Table 2).

Hermeuptychia sp. with 141 individuals (20.52%), *M. soter* (Butler, 1877) with 100 (14.55%) and *Morpho epistrophus* (Fabricius, 1796) with 93 (13.53%) presented greater abundance in the adjacent forest fragments of ESEC (Table 1, Figure 2b). In these forest fragments, there were 18 species of frugivorous butterflies with less than 10 species, four singletons: *A. demophon* (Linnaeus, 1758), *Blepolenis bassus* (Felder & Felder, 1867), *F. necys* (Godart, [1824]) and *O. invirae* (Hübner, [1808]) and two doubletons: *S. bomfildia* (Fabricius, 1781) and *T. acuta* Weymer, 1910 (Table 1, Table 2). In PAEAR, there was a greater abundance of *Forsterinaria quantius* (Godart, [1824]) with 65 individuals (17.66%), *E. reevesii* (Doubleday, 1849) with 56 (15.22%) and *T. acuta* Weymer, 1910 with 31 individuals (8.42%) (Table 1, Figure 2c). It was observed that in the CU, 22 species of frugivorous butterflies with less than 10 individuals were sampled. Also, nine species of singleton frugivorous butterflies were found: *Caligo martia* (Godart, 1824), *E. hubneri* (Hewitson, 1861), *Epiphile orea orea* (Hübner, [1823]), *E. castrensis* (Schaus, 1902), *H. epinome* (Felder & Felder, 1867), *O. invirae* (Hübner, [1808]), *P. euptychidia* (Butler, 1868), *Splendeuptychia ambra* (Weymer, [1911]) and *Z. pacarus* (Godart, [1824]) and three doubletons: *A. chalciope* (Hübner, [1823]), *M. helenor* (Cramer, 1776) and *Z. strigosus* (Gmelin, [1790]) (Table 1, Table 2).

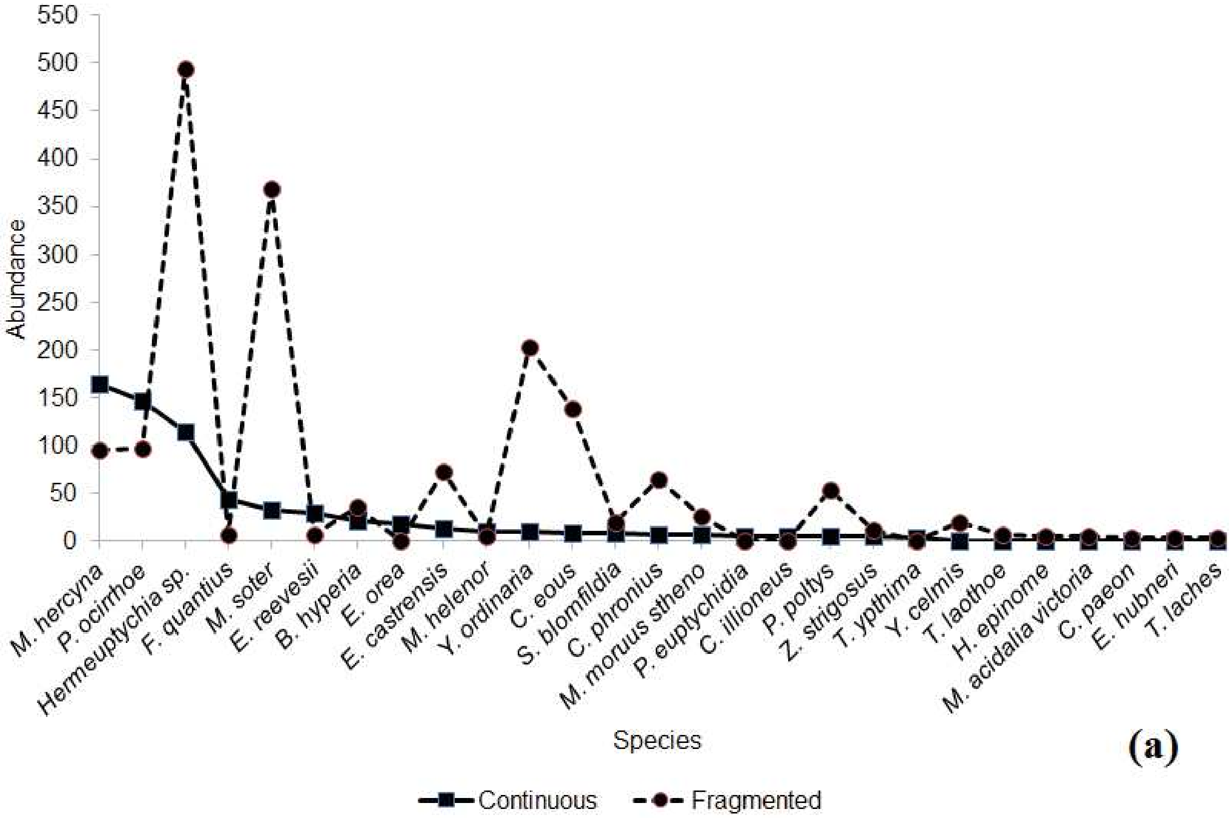
The most abundant species in the adjacent forest fragments of PAEAR were *F. quantius* (Godart, [1824]) com 23 individuals (10.90%), *Hermeuptychia* sp. and *M. soter* (Butler, 1877) with 22 (10.42%) (Table 1, Figure 2c). For the forest fragments, 19 species of frugivorous butterflies with less than 10 species, six singletons: *C. martia* (Godart, 1824), *C. amphirhoe* (Hübner, 1825), *O. invirae* (Hübner, [1808]), *P. euptychidia* (Butler, 1868), *Yphthimoides straminea* (Butler, 1867) e *Z. strigosus* (Gmelin, [1790]) and six doubletons: *A. demophon* (Linnaeus, 1758), *A. chalciope* (Hübner, [1823]), *E. orea orea* (Hübner, [1823]), *F. necys* (Godart, [1824]), *G. muscosa* (Butler, 1870) and *T. ypthima* (Hübner, 1821) (Table 1, Table 2).

The general distribution of abundance showed a pattern of high dominance (Table 1, Figure 2a, Figure 2b, Figure 2c). The five most abundant species make up more than 70% of the individuals sampled in FLONA (Figure 2a) and ESEC (Figure 2b). The five most abundant species in the adjacent forest fragments of FLONA also presented the same pattern of dominance (Figure 2a). The five most abundant species in the adjacent forest fragments of ESEC corresponded to more than 60% of the individuals sampled (Figure 2b). On the other hand, in PAEAR the five most abundant species totaled more than 50% of the individuals sampled and in the adjacent forest fragments of this CU, 46% dominance was observed in the five most abundant species (Figure 2c).

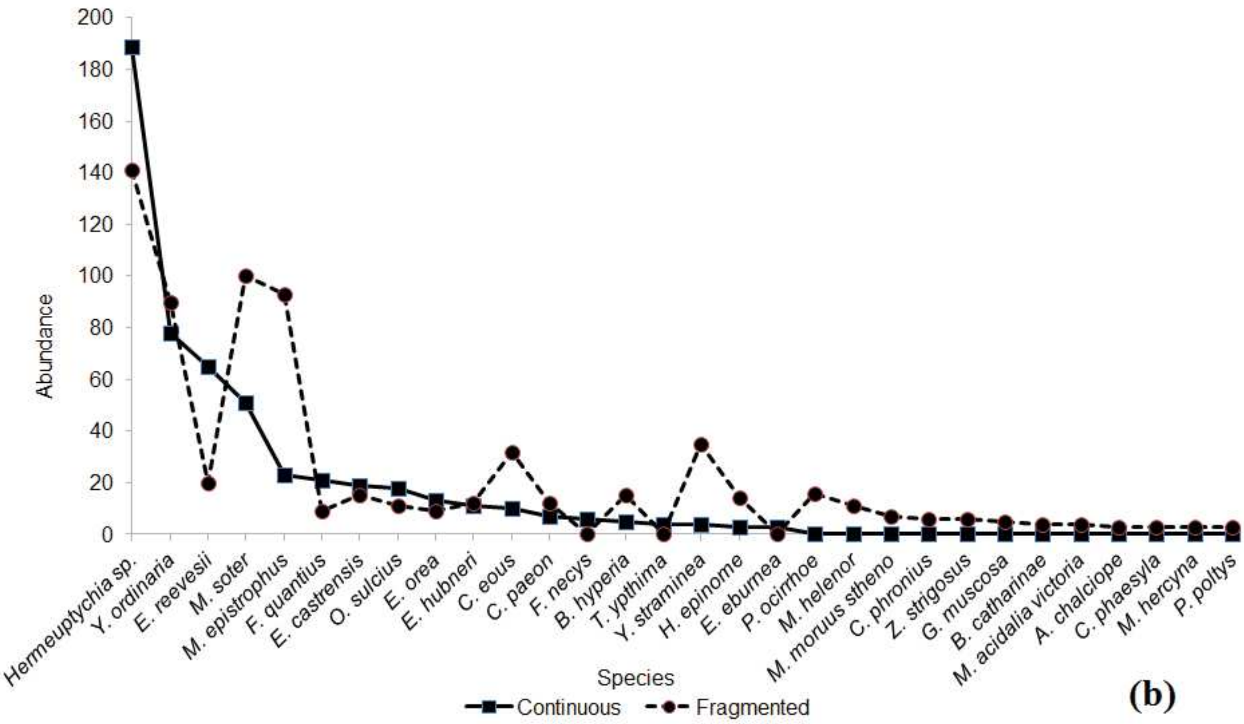
Table 1. List of species of frugivorous butterflies sampled with Van Someren-Rydon traps recorded in Conservation Units and adjacent forest fragments, Western region of the state of Santa Catarina, Brazil, between December 2017 and March 2018. (ES) ESEC; (FL) FLONE; (P) PAEAR; (T) Total butterflies in Conservation Units; (FES) ESEC Fragments; (FF) FLONA Fragments; (FP) PAEAR Fragments; (FT) Total butterflies in forest fragments; (S) Riqueza; (N) Abundância; *New records for Santa Catarina; **New Records for the Western region of state of Santa Catarina.

	CONSERVATION UNITS				FOREST FRAGMENTS			
TAXON	**ES**	**F**	**P**	**T**	**FES**	**FF**	**FP**	**FT**
Charaxinae (S=5)								
Preponini (S=2)								
Archaeoprepona chalciope (Hübner, [1823])	-	1	8	9	1	-	2	3
Archaeoprepona demophon (Linnaeus, 1758)**	2	1	2	5	3	-	2	5
Anaeini (S=3)								
Memphis acidalia victoria (Druce, 1877)	1	2	4	7	4	5	-	9
Memphis moruus stheno (Prittwitz, 1865)	-	6	12	18	7	26	10	43
Zaretis strigosus (Gmelin, [1790])*	2	4	2	8	6	11	1	18
Biblidinae (S=10)								
Biblidini (S=1)								
Biblis hyperia (Cramer, 1779)	5	21	6	32	15	35	9	59
Callicorini (S=1)								
Callicore hydaspes (Drury, 1782)*	-	1	-	1	-	2	-	2
Epicaliini (S=3)								
Cybdelis phaesyla (Hübner, 1825)	1	1	-	2	3	1	-	4
Eunica eburnea Fruhstorfer, 1907	3	-	-	3	-	-	-	-
Eunica tatila (Herrich-Schäffer, 1855)*	-	1	-	1	-	-	-	-
Epiphilini (S=3)								
Epiphile hubneri (Hewitson, 1861)	11	2	1	14	12	3	-	15
Epiphile orea orea (Hübner, [1823])	13	18	1	32	9	-	2	11
Temenis laothoe (Cramer, 1777)	-	1	-	1	-	6	-	6
Ageroniini (S=2)								
Hamadryas amphinome (Linnaeus, 1767)	-	-	-	-	-	1	-	1
Hamadryas epinome (Felder & Felder, 1867)	3	1	1	5	14	5	7	26
Satyrinae (S=33)								
Brassolini (S=8)								
Blepolenis bassus (Felder & Felder, 1867)	-	-	-	-	1	-	-	1
Blepolenis catharinae (Stichel, 1902)**	-	-	-	-	4	-	-	4
Caligo illioneus (Cramer, 1775)	-	4	-	4	-	2	-	2
Caligo martia (Godart, 1824)	-	-	1	1	-	-	1	1
Catoblepia amphirhoe (Hübner, 1825)*	-	1	-	1	-	-	1	1
Eryphanis reevesii (Doubleday, 1849)	65	29	56	150	20	7	9	36
Opoptera sulcius (Staudinger, 1887)**	18	-	15	33	11	-	10	21
Opsiphanes invirae (Hübner, [1808])	2	2	1	5	1	-	1	2
Satyrini (S=21)								
Carminda paeon (Godart, 1824)*	7	1	-	8	12	3	-	15
Cissia eous (Butler, 1867)*	10	8	18	36	32	139	11	182
Cissia phronius (Godart, [1824])	1	6	7	14	6	64	8	78
Euptychoides castrensis (Schaus, 1902)**	19	13	1	33	15	72	-	87

Forsterinaria necys (Godart, [1824])*	6	2	20	28	1	-	2	3
Forsterinaria quantius (Godart, [1824])	21	43	65	129	9	6	23	38
Godartiana muscosa (Butler, 1870)**	1	-	6	7	5	1	2	8
Hermeuptychia sp.**	189	114	28	331	141	494	22	657
Moneuptychia soter (Butler, 1877)*	51	32	15	98	100	369	22	491
Pareuptychia ocirrhoe (Fabricius, 1776)**	-	147	4	151	16	97	5	118
Paryphthimoides poltys (Prittwitz, 1865)*	-	4	-	4	3	53	-	56
Pseudodebis euptychidia (Butler, 1868)*	-	5	1	6	-	1	1	2
Splendeuptychia ambra (Weymer, [1911])*	-	-	1	1	-	-	-	-
Splendeuptychia libitina (Butler, 1870)*	-	1	-	1	-	-	-	-
Taygetis acuta Weymer, 1910**	-	2	31	33	2	-	7	9
Taygetis laches (Fabricius, 1793)*	2	-	4	6	-	3	-	3
Taygetis ypthima Hübner, 1821**	4	3	7	14	-	-	2	2
Yphthimoides celmis (Godart, [1824])*	1	-	11	12	-	19	6	25
Yphthimoides ordinaria Freitas, Kaminski & Mielke, 2012	78	9	9	96	90	203	18	311
Yphthimoides straminea (Butler, 1867)*	4	-	-	4	35	-	1	36
Zischkaia pacarus (Godart, [1824])**	-	1	1	2	-	-	-	-
Melanitini (S=1)								
Manataria hercyna (Hübner, [1821])	-	164	21	185	3	95	11	109
Morphini (S=3)								
Morpho aega (Hübner, [1822])	-	1	-	1	-	-	-	-
Morpho epistrophus (Fabricius, 1796)	23	-	-	23	93	-	-	93
Morpho helenor (Cramer, 1776)	2	10	2	14	11	5	-	16
Nymphalinae (S=1)								
Coeini (S=1)								
Smyrna blomfildia (Fabricius, 1781)**	2	8	6	16	2	20	15	37
N Total	547	670	368	1585	687	1748	211	2646


550
500
450
400
350
300
250
200
150
100
50
0
Abundance
M. hercyna
P. ocirrhoe
Hermeuptychia sp.
F. quantius
M. soter
E. reevesii
B. hyperia
E. orea
E. castrensis
M. helenor
Y. ordinaria
C. eous
S. blomfildia
C. phronius
M. moruus stheno
P. euptychidia
C. illioneus
P. poltys
Z. strigosus
T. ypthima
Y. celmis
T. laothoe
H. epinome
M. acidalia victoria
C. paeon
E. hubneri
T. laches
Species
Continuous
Fragmented

(a)


200
180
160
140
120
100
80
60
40
20
0
Abundance
Hermeuptychia sp.
Y. ordinaria
E. reevesii
M. soter
M. epistrophus
F. quantius
E. castrensis
O. sulcius
E. orea
E. hubneri
C. eous
C. paeon
F. necys
B. hyperia
T. ypthima
Y. straminea
H. epinome
E. eburnea
P. ocirrhoe
M. helenor
M. moruus stheno
C. phronius
Z. strigosus
G. muscosa
B. catharinae
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A. chalciope
C. phaesyla
M. hercyna
P. poltys
Species
Continuous
Fragmented

(b)

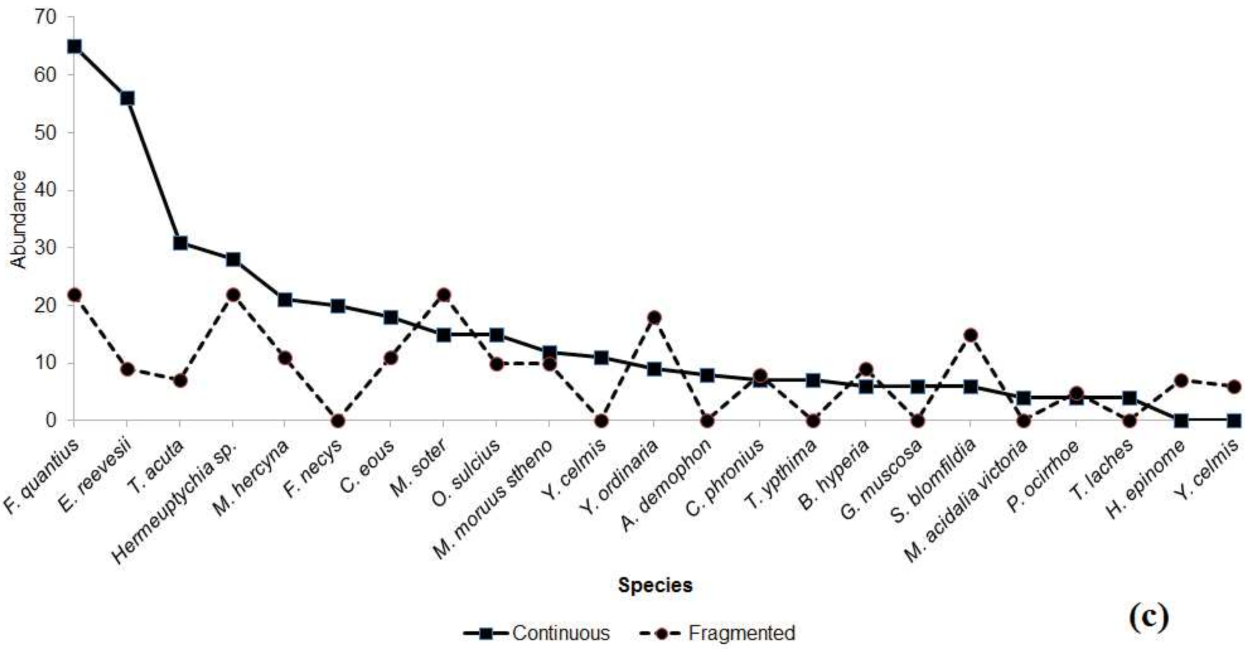

Figure 2. Distribution of abundance of frugivorous butterflies species sampled with Van Someren-Rydon traps in Conservation Units and adjacent forest fragments, from December 2017 to March 2018, in the Western region of Santa Catarina, Brazil. a = FLONA; b = ESEC; c = PAEAR. Linha continua = Unidade de Conservação; Linha tracejada = fragmentos florestais adjacentes;

Table 2. Species richness, abundance and Jackknife 1 species richness estimator for the guild of frugivorous butterflies sampled with Van Someren-Rydon traps, recorded in Conservation Units (CU) and adjacent forest fragments (FF), in the Western region of the state of Santa Catarina, between December 2017 and March 2018.

Sampling areas	FLONA/CU	FLONA/FF	ESEC/CU	ESEC/FF	PAEAR/CU	PAEAR/FF
Species richness	37	29	29	33	33	28
Abundance	670	1748	547	687	368	211
Singletons	12	4	5	4	9	6
Doubletons	5	2	6	2	3	6
Jackknife 1	50.75±4.09	34.58±2.12	36.36±2.43	37.52±1.63	43.08±2.12	37.09±3.14

Table 3. Percentage of individuals of the subfamilies of frugivorous butterflies sampled with Van Someren-Rydon traps, recorded in Conservation Units and adjacent forest fragments in the Western region of the state of Santa Catarina, Brazil, between December 2017 and March 2018. (F) FLONA; (ES) ESEC; (P)PAEAR; (T) Total butterflies in Conservation Units; (FF) FLONA Fragments; (FES) ESEC Fragments; (FP) PAEAR Fragments; (FT) Total butterflies in adjacent forest fragments.

Subfamilies	F	ES	P	T	FF	FES	FP	FT
Satyrinae	14.22	11.91	7.68	33.81	38.6	14.32	3.85	56.77
Biblidinae	1.09	0.85	0.21	2.15	1.25	1.37	0.42	3.04
Charaxinae	0.33	0.12	0.66	1.11	0.99	0.5	0.35	1.84
Nymphalinae	0.19	0.04	0.14	0.37	0.47	0.04	0.35	0.86

Satyrinae presented higher species richness (69.38%) and abundance (90.58%) of frugivorous butterflies in all sampled areas (Table 1, Table 3), followed by Biblidinae (5.19%). Most of the captured frugivorous butterflies belong to the tribe Satyrini, being associated with all forest areas sampled (Table 1). It was found that in the adjacent forest fragments there was a higher percentage of Satyrinae when compared to CU (Table 3).

From the rarefaction and extrapolation curve, for the CU and respective forest fragments, based on the Chao 1 estimator (Figure 3), a total richness estimate was generated for the CU and adjacent forest fragments. The estimated sampling coverage for frugivorous butterflies in the CU and adjacent forest fragments was above 97%. Figure 3 shows that the richness approached an asymptote, indicating a greater rise in the sampling areas of FLONA, and the PAEAR and adjacent forest fragments. It can be seen in the graphs that the richness of frugivorous butterflies species was the same in UC and FF.

The parameters of richness and abundance of frugivorous butterflies showed variations, mainly between the areas in the CU and their respective forest fragments. The number of species of frugivorous butterflies varied between 28 (PAEAR/FF) and 37 (FLONA/CU). The abundance in turn ranged from 211 (PAEAR/FF) to 1748 (FLONA/ FF) butterflies (Table 2).

The Jackknife 1 richness estimator indicated that 72.9% of the frugivorous butterflies were sampled in FLONA and 83.7% for the adjacent forest fragments. In ESEC, the estimator indicated a sampling of 79.8% and 87.9% for the adjacent forest fragments. In PAEAR, the analysis indicated that 76.6% of the frugivorous butterflies were sampled and in the adjacent forest fragments, 75.5% (Table 2). The expected richness, calculated through the Jackknife 1 estimator, was higher than the richness obtained in the samplings, and for the FLONA and PAEAR samplings, the estimator presented a high value (50.75 and 37.09) (Table 2).

Qualitative ANOSIM analyses indicated different species composition among Conservations Units (ANOSIM: $R = 0.43$, $p = 0.001$, Figure 4a) and by forest fragments vs Conservation Units (ANOSIM: $R = 0.10$, $p = 0.001$, Figure 4a). There is apparent founder effect in terms of species composition, since difference among sites (CU and FF) and between Conservation Units was found for Simpson index. Figure 4 illustrates a visual inspection of the nMDS scatterplots by species composition differences among Conservations Units (Figure 4a) and by forest fragments vs Conservation Units (Figure 4b).

The contribution of the most representative species in each environment to dissimilarity (SIMPER) between Conservation Units is presented in Table 4, and for different enviroments (CU vs FF) in Table 5. The most dominant species was *Hermeuptychia* sp. (overall contribution: 15.9%, for Conservation Units, Table 4; overall contribution: 15.5%, for CU vs FF, Table 5). The species of greatest contribution to the dissimilarity among the CU belong to Satyrinae: *Hermeuptychia* sp.

(15.9%), *M. hercyna* (9.4%) and *M. soter* (9%) (Table 4). These same species presented dissimilarity when analyzed between different environments, only *M. soter* (9.27%) contributed more than *M. hercyna* (8.53%) (Table 5).

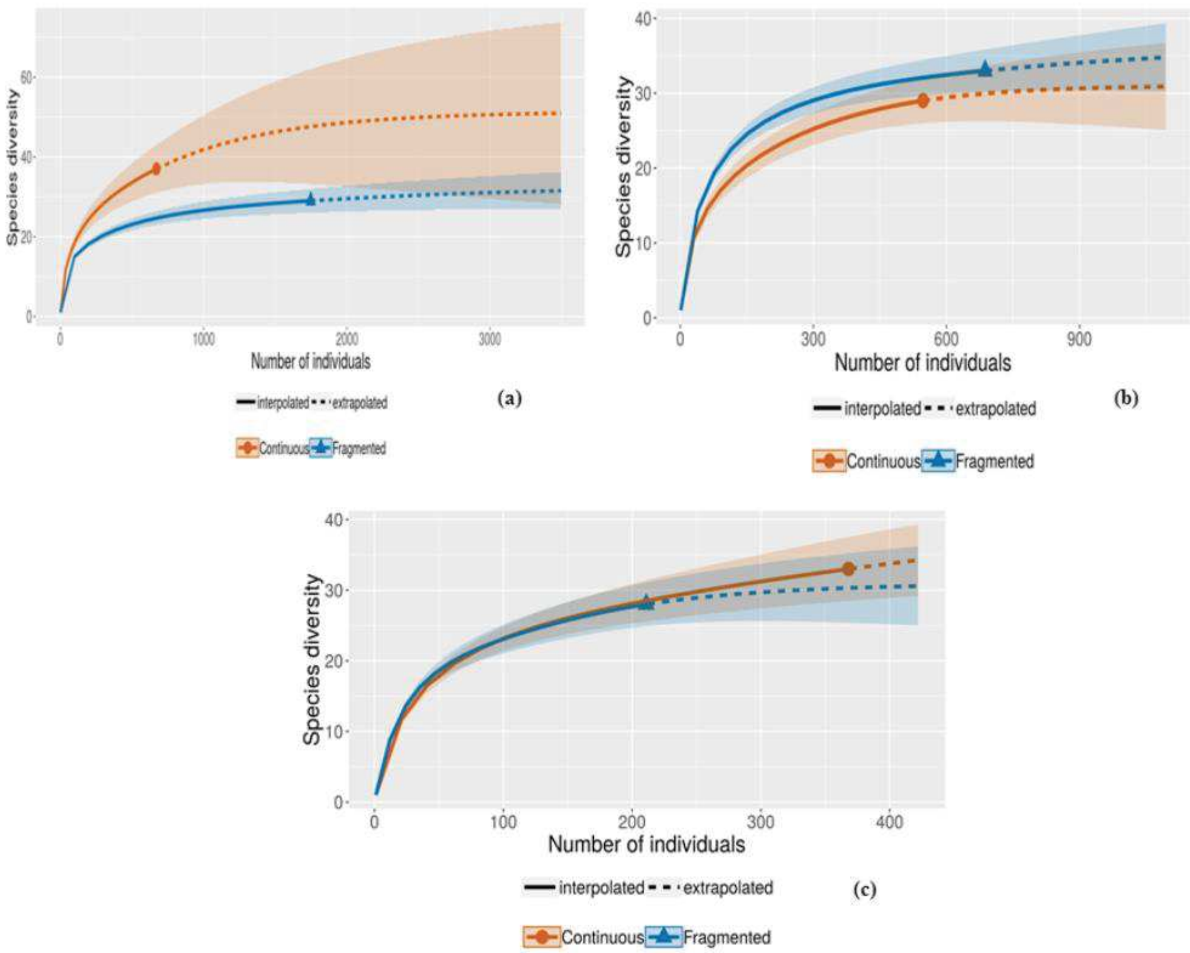

Figure 3. Richness estimates for rarefied and extrapolated sample for frugivorous butterflies sampled with Van Someren-Rydon traps in Conservation Units and adjacent forest fragments, Western region of Santa Catarina, Brazil. 3a = FLONA; 3b = ESEC; 3c = PAEAR.

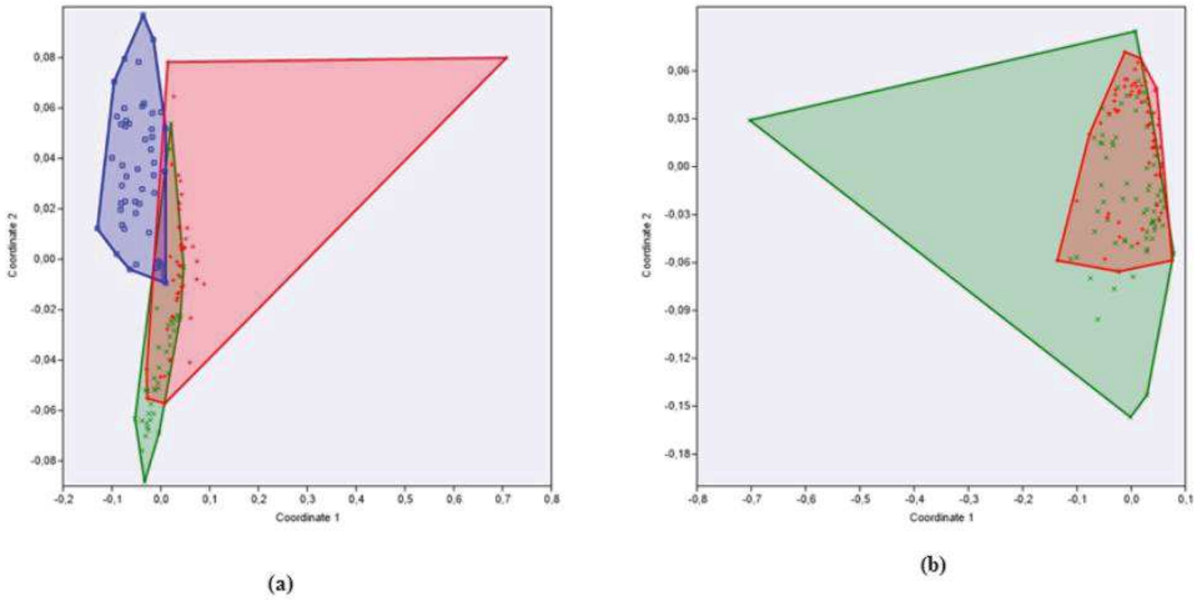

Figure 4. Ordination of butterflies fauna composition for Conservation Units (ESEC, FLONA, PAEAR), and for Conservation Units (CU) and adjacent forest fragments (FF) by Non-Metric MultiDimensional Scaling (nMDS), using qualitative similarity index in Southern Brazil. (a) Conservation Units, ESEC, green; FLONA, blue; PAEAR, red. Simpson index. Stress = 0.439. (b) Environments, CU, red; and FF, green Simpson index. Stress = 0.478.

Table 4. SIMPER analysis for ten butterflyes species contributing more to dissimilarities between the Conservation Units (ESEC, FLONA, PAEAR) in Brazil (*species percentage contribution to dissimilarity; # cumulative dissimilarity among three CU; † average species abundance in each CU).

Species	Contribution*	Cumulative %#	Mean abund.† ESEC	Mean abund.† FLONA	Mean abund·† PAEAR
Hermeuptychia sp.	15.89	15.89	8.25	12.2	1.11
Manataria hercyna	9.4	25.28	0.08	5.18	0.71
Moneuptychia soter	9.07	34.35	3.77	8.02	0.82
Pareuptychia ocirrhoe	8.82	43.17	0.4	4.88	0.2
Yphthimoides ordinaria	7.57	50.74	4.2	4.24	0.6
Eryphanes reevesii	5.82	56.56	2.13	0.72	1.44
Forsterinaria quantius	5.3	61.86	0.75	0.98	1.96
Morpho epistrophus	5.2	67.06	2.9	0	0
Cissia eous	3.82	70.87	1.05	2.94	0.64
Biblis hyperia	2.32	73.19	0.5	1.12	0.3
Overal average dissimilarity: 83.2					

Table 5. SIMPER analysis for ten butterflieses species contributing more to dissimilarities between forest fragments (FF) and Conservation Unit (CU) in Brazil (*species percentage contribution to dissimilarity; # cumulative dissimilarity among FF and CU; † average species abundance in each).

Species	**Contribution***	**Cumulative%#**	**Mean abund.† FF**	**Mean abund.† CU**
Hermeuptychia sp.	15.54	15.54	9.39	5.09
Moneuptychia soter	9.27	24.81	7.01	1.51
Manataria hercyna	8.53	33.34	1.57	2.83
Pareuptychia ocirrhoe	7.69	41.03	1.69	2.32
Yphthimoides ordinaria	7.58	48.6	4.44	1.48
Eryphanes reevesii	6.65	55.26	0.51	2.31
Forsterinaria quantius	6.14	61.39	0.54	1.98
Morpho epistrophus	4.34	65.74	1.26	0.43
Cissia eous	4	69.73	2.6	0.55
Biblis hyperia	2.38	72.11	0.84	0.49
Overal average dissimilarity: 84.06				

Discussion

The total richness of frugivorous butterflies recorded in the present study was superior to what has been found for the state and Western region of Santa Catarina [Corso & Hernandez (2012), with 20 species; Schmidt et al. (2012) with two, Piovesan et al. (2014) with 43, Fanton (2014) with 14, Favretto et al. (2015), with 9, Silva (2015) with 16 and Colpani (2018) with 26]. The recent increase in the biodiversity studies on Lepidoptera is in the state of Santa Catarina highluminosityed, with surveys carried out in the municipalities of the Florianopolis, Joinvile and Joaçaba (Orlandin et al. 2016).

Although the studies were carried out with different sampling efforts and prevailing the use of entomological nets, and in certain cases in restricted and smaller areas, such comparisons indicate that the environmental heterogeneity of the sampling areas favors the maintenance of the frugivorous butterflies diversity.

In addition, surveys conducted using exclusively traps in fragments of Mixed Ombrophilous Forest in the state of Rio Grande do Sul, also disregarding differences in relation to sampling effort, identified a lower richness of frugivorous butterflies compared to the present study [Graciotim & Morais (2016) with 31 species; Pedrotti et al. (2011) with 30 and Giovenardi et al. (2008) with 32].

Satyrinae concentrated the greatest richness and abundance of species in the 27 sampling units, a representativeness that was also found in other studies with butterflies in the state (Corso & Hernandez 2012, Carneiro et al. 2008, Schmidt et al. 2012, Piovesan et al. 2014, Fanton 2014, Favretto et al. 2015, Silva 2015 and Colpani 2018). These results corroborate the observations of DE VRIES (1987) that the diversity of habitats in the Neotropics would make the southern and

Southeastern regions of the Atlantic Forest of Brazil the largest in Satyrinae richness in the world, being considered the largest group within Nymphalidae (Lamas 2004).

The Neotropical Region is home to the greatest richness of satyrines of the world (D'abrera 1987). Satyrinae is a subfamily of wide diversity, biology and distribution, making up a third of all species of Nymphalidae (Peña & Wahlberg 2008). Its main host plants are monocotyledons (DE VRIES 1987; Peña & Wahlberg 2008), abundant in clearings. The forest fragments sampled had trails and clearings, so it is believed that these spaces become conducive to the development and maintenance of this group, generating resources for both juveniles and adults.

Composing most of Satyrinae stands out the tribe Satyrini with more than 1,000 representatives among the almost 1,600 species of frugivorous butterflies in the Neotropical Region (Lamas 2004). In view of this representativeness, the high richness and abundance of Satyrini evidenced in the present study is not surprising. The high abundance of individuals obtained for the representatives of this tribe must be associated with the areas that presented clearings. Bossart and Opuni-Frimpong (2009) point out that Satyrinae dynamics with grasses, which may become more numerous in environments with greater luminosity penetration (for example, disturbed environments), can make this group an important biological indicator under the conditions of forest. According to Beccaloni et al. (2008), the host plants of Satyrini are composed mainly of grasses, host plants of caterpillars, thus the propagation of the tribe (Peña & Wahlberg 2008). In this way, high population densities could be expected for this group in the areas sampled.

An important Satyrinae species is *M. hercyna* (Hübner, [1821]) because of its high abundance in FLONA (164 individuals). This species is considered rare in the northwest region of the state of Rio Grande do Sul (Biezanko 1960; Giovenardi et al. 2008) and Argentina (Núñez-Bustos 2010). *Manataria hercyna* (Hübner, [1821]) has crepuscular habitats, being found in dark and humid places (Nuñez-Bustos 2010) and is considered an indicator of an environment preserved in Atlantic Forest areas in Southeastern Brazil (Brown Jr. & Freitas 2000). Other abundant Satyrinae in the sampled areas were *Hermeuptychia* sp., *M. soter* (Butler, 1877), *F. quantius* (Godart, [1824]), *Y. ordinaria* (Freitas, Kaminski & Mielke, 2012) with generalist habitats (Brown Jr. 1992) and being commonly found (Morais et al. 2007; Nuñez-Bustos 2010). *Hermeuptychia sp.* is among the ten most abundant species in the state of Rio Grande do Sul (Morais et al. 2007).

Butterflies *Hermeuptychia* are widely distributed from the Southeastern United States to northern Argentina and present a large number of individuals and almost ubiquitous in most butterflies lists to sites in the Neotropics (Seraphim et al. 2014). All eight species recognized within *Hermeuptychia* are small and brown, with very similar interspecific species (Lamas 2004). Seraphim et al. (2014) indicate that external morphologies and *Hermeuptychia* ocelli patterns are intraspecific variables making taxonomic identification difficult. Part of this biodiversity is hidden in the form of cryptic species, which can be defined as a group of morphologically similar species usually identified under a single name (Bickford et al. 2007).

Although the characteristics of the surroundings of all the areas sampled were equivalent, it was verified in the sampling period the presence of extensive agricultural areas, being able to influence the composition of the fauna and favor the high dominance of some species of frugivorous butterflies. For Marín et al. (2009), the intensification of agriculture can affect the quality of the matrix and the persistence of species inhabiting the fragments of forest inserted in it, favoring the dominance of some species. Considering that lepidopterans are affected mainly by the impacts of agricultural activities (Bonebracke et al. 2010), for butterflies in particular, the way the matrix influences the fauna can vary between different species or assemblages, so in general, the disturbances favor the generalist species and negatively affect specialists (Littlewood et al. 2011).

The fact that more than 60% of the fauna sampled is composed of some species of frugivorous butterflies more abundant, characterizes the community with a high degree of dominance. Fragmentation and modification of environments tends to alter the natural balance in the diversity of different groups. Not all species respond in the same way and there may be different responses up to the level of specimens (Samways 2005). Nevertheless, what tend to happen is the decline of specialist species and the increase of populations of generalist species. Species more abundant in forest remnants could be considered resistant to fragmentation dynamics, while species that show a remarkable decrease in abundance could presumably suffer the negative effects in relation to fragmentation (Uehara-Prado et al. 2005).

The rarefaction and extrapolation curves for the CU and their forest fragments provide reliable responses, since there was a large sampling effort in the study. The estimated sampling coverage, above 97%, shows a good representation of the community of frugivorous butterflies in the region. Species richness was equal in UC and FF, in accordance with known standards. For FLONA and PAEAR, it is observed that the richness approached an asymptote, indicating that a sample increase would contribute with few additional species. According to Brown Jr. & Freitas (2000), in tropical environments, the curve rarely stabilizes. Some studies show that richness of frugivorous species is higher in environments under stronger disturbances (Uehara-Prado et al. 2005), while others show that richness is lower in these environments and higher in more preserved environments (DE VRIES et al. 1997).

According to Bonebrake et al. (2010), butterflies communities are very variable between sites and between years, and are affected in the short term by differences in environmental/temporal conditions. Besides that, butterflies go out in search of host plants, food resources for adults, mating and overnight sites, reaching what is recognized as functional habitat (Marin et al. 2009). Therefore, it is important to establish relationships between the butterflies community and the vegetation structure, since both are closely related.

Studies emphasize how frugivorous butterflies are an excellent model for landscape characterization (Kremen 1992; Brown Jr. & Freitas 2000, Uehara et al. 2007), which corroborates, with the results of our study, where we can detect differences between the composition between different CU and between different environments.

Uehara et al. (2007) showed differences in the composition of butterflies species and in the distribution along different habitats in landscapes. Other studies have revealed differences in composition in response to habitat structural variables and associations of species of butterflies and their subfamilies to habitats with varying degrees of disturbance (Kremen 1992, Brown Jr. & Freitas 2000).

With the increasing reduction and modification of natural environments and the increasingly imminent threats to biodiversity, up-to-date studies on the ecology of species occupying a region, such as frugivorous butterflies, insects that can be very sensitive to environmental changes, are essential. Thus, the importance of surveys with a sampling methodology directed to the frugivorous butterflies is emphasized, allowing the adoption of actions contributing to the conservation of species.

The information generated through the present study contributes to the knowledge and characterization of the guild of frugivorous butterflies of the state. The fauna of frugivorous butterflies from the Western region of the state of Santa Catarina, first investigated in areas of CU, has shown to be quite expressive and well represented in the Atlantic Forest Biome, indicating it’s potential as a refuge for biodiversity.

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Author Contributions

Sandra Mara Sabedot Bordin: Contribution in data acquisition and identification of biological material; Contribution in the analysis and interpretation of data; Contribution in the preparation of the manuscript; Contribution in critical review, adding intellectual content.

Marcelo Monteiro: Contribution in data acquisition and identification of biological material.

Valéria Wesner Ferreira: Contribution in data acquisition and identification of biological material.

Junir Antonio Lutinski: Contribution in the analysis and interpretation of data; contribution in the critical review, adding intellectual content.

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Conflict of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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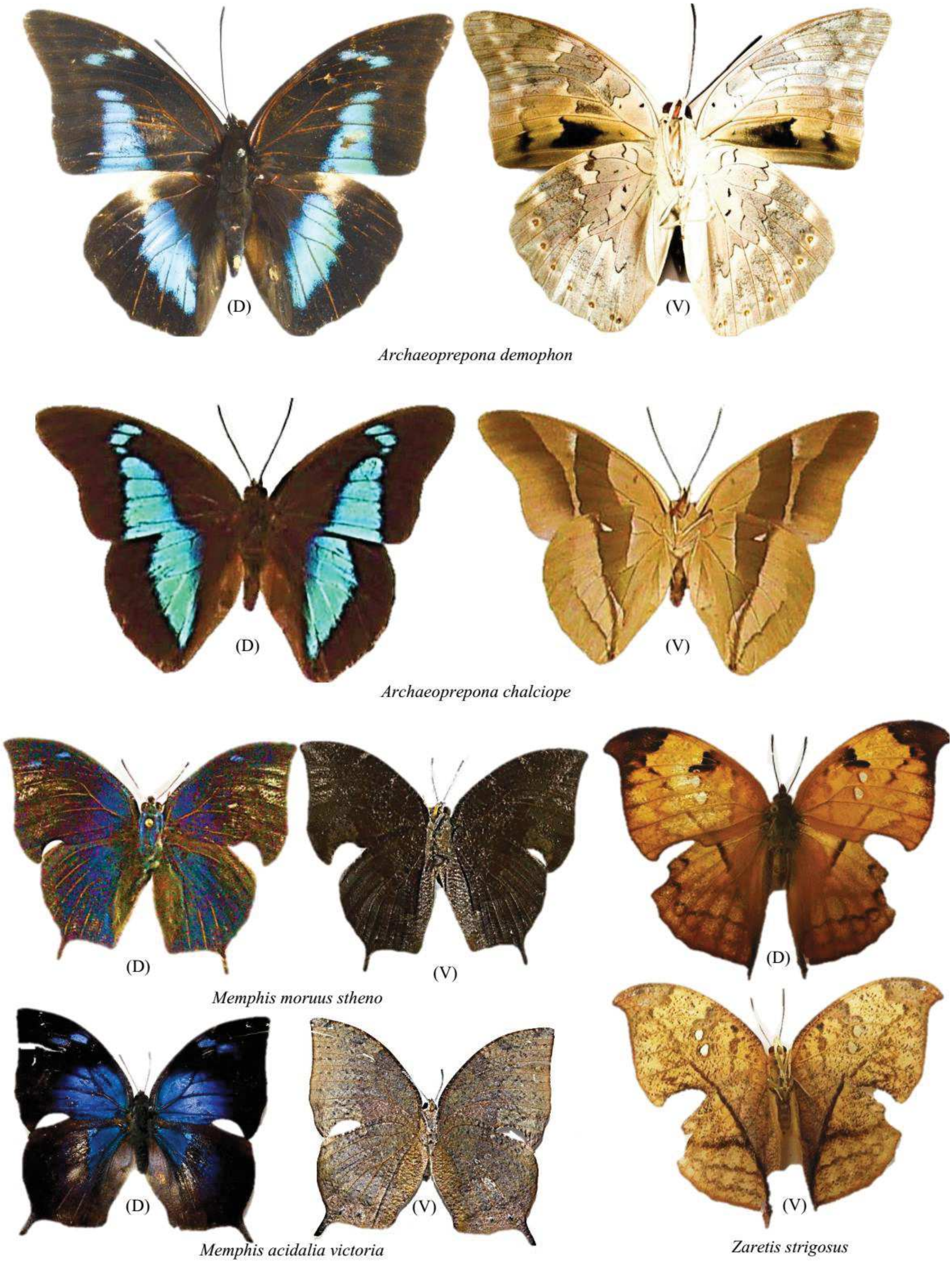
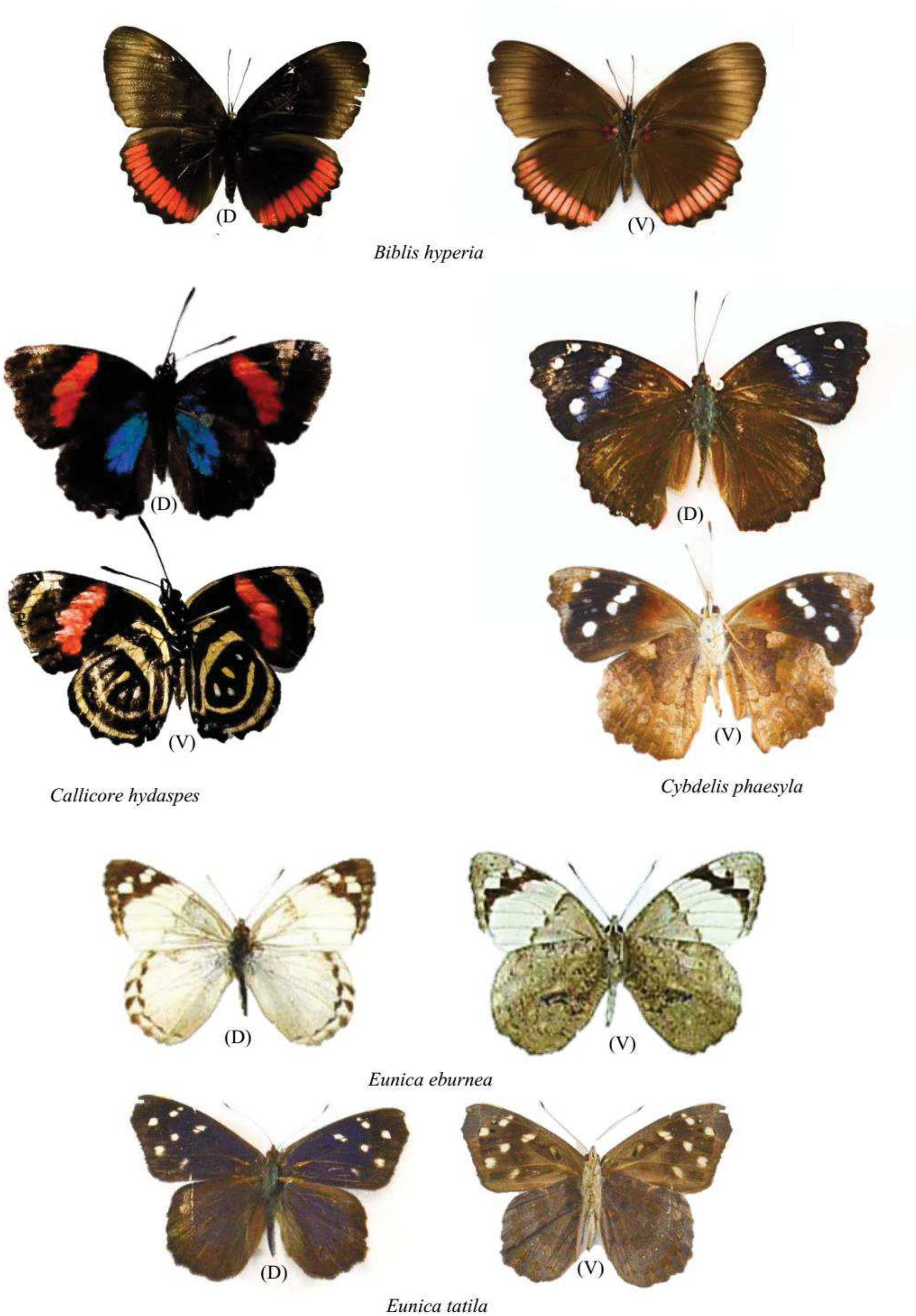
Supplementary Material

Plank 1. Fruit-feeding butterflies Charaxinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil



Plank 2. Fruit-feeding butterflies Biblidinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.



Plank 3. Fruit-feeding butterflies Biblidinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.

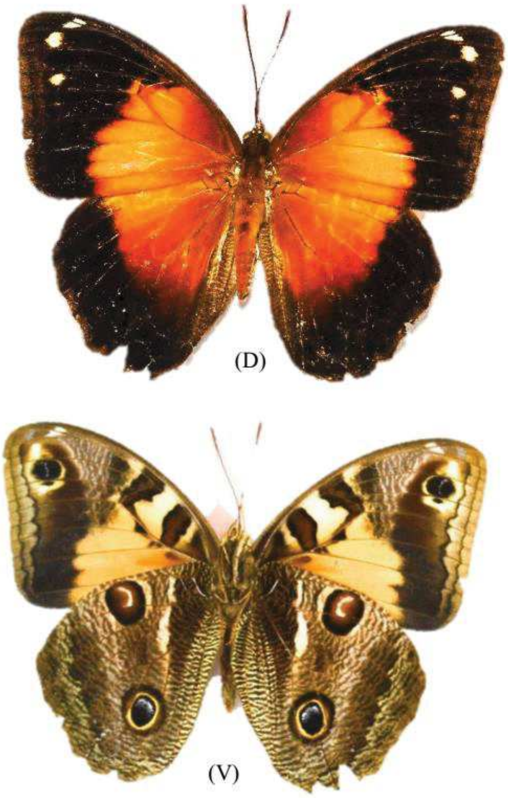
Epiphile orea orea *Epiphile hubneri*

Temenis laothoe

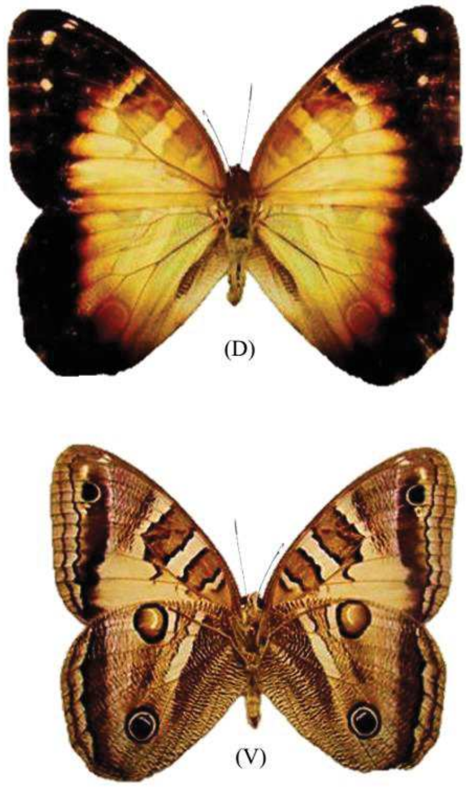
Hamadryas epinome

Hamadryas amphinome

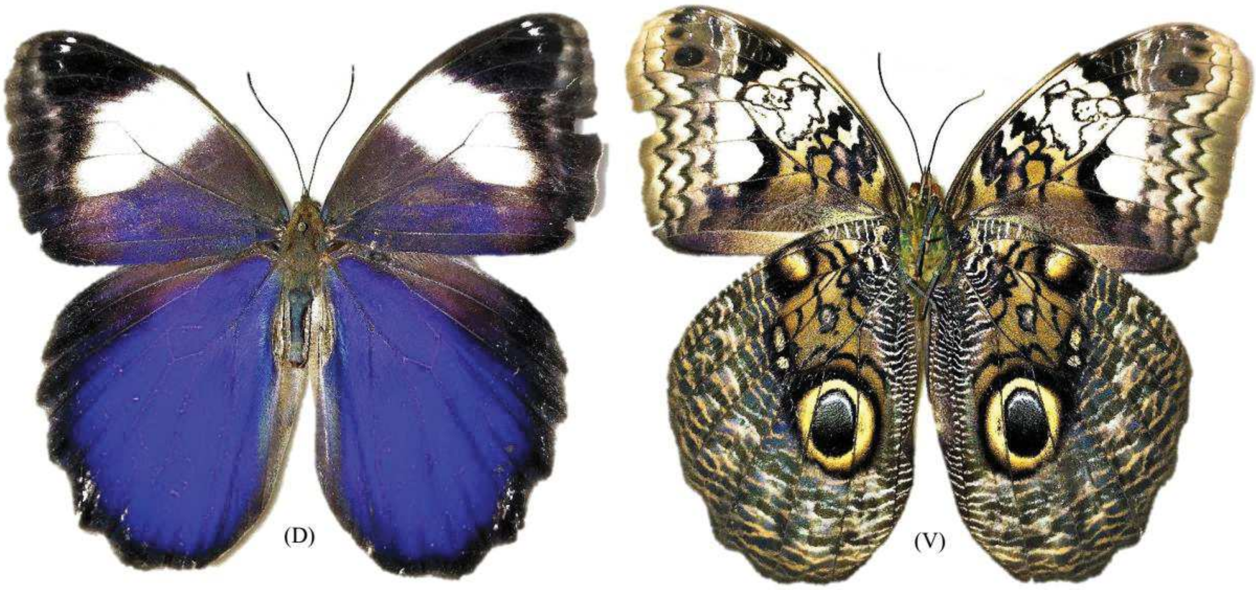
Plank 4. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.



Blepolenis catharinae



Blepolenis bassus



Caligo martia

Plank 5. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest of the Western region of Santa CatarinaBrazil

Caligo illioneus

Eryphanis reevesii

Catoblepia amphirhoe

Plank 6. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.

Opoptera sulcius

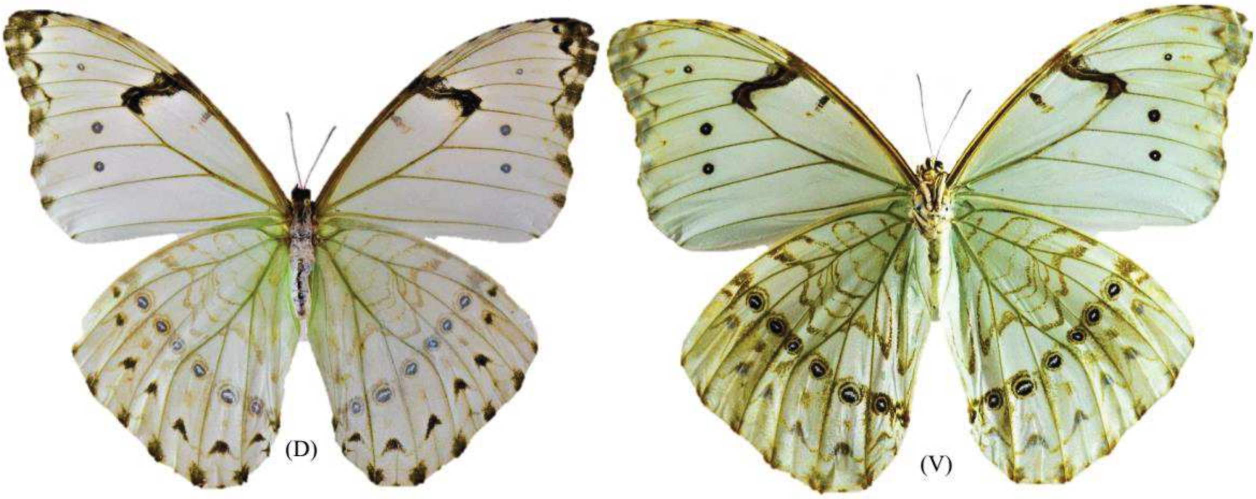
Opsiphanes invirae

Manataria hercyna

Plank 7. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.

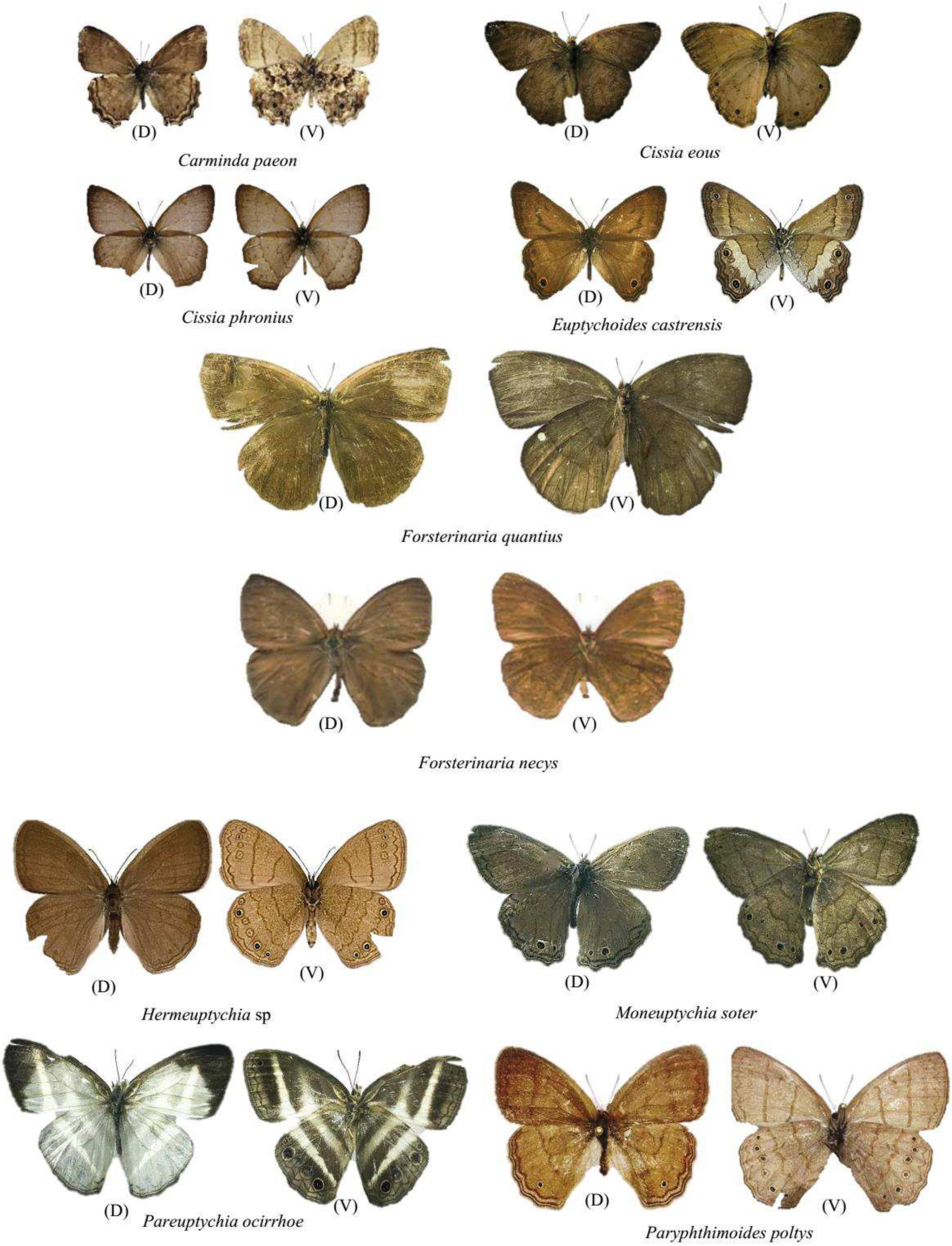
Morpho aega

Morpho helenor

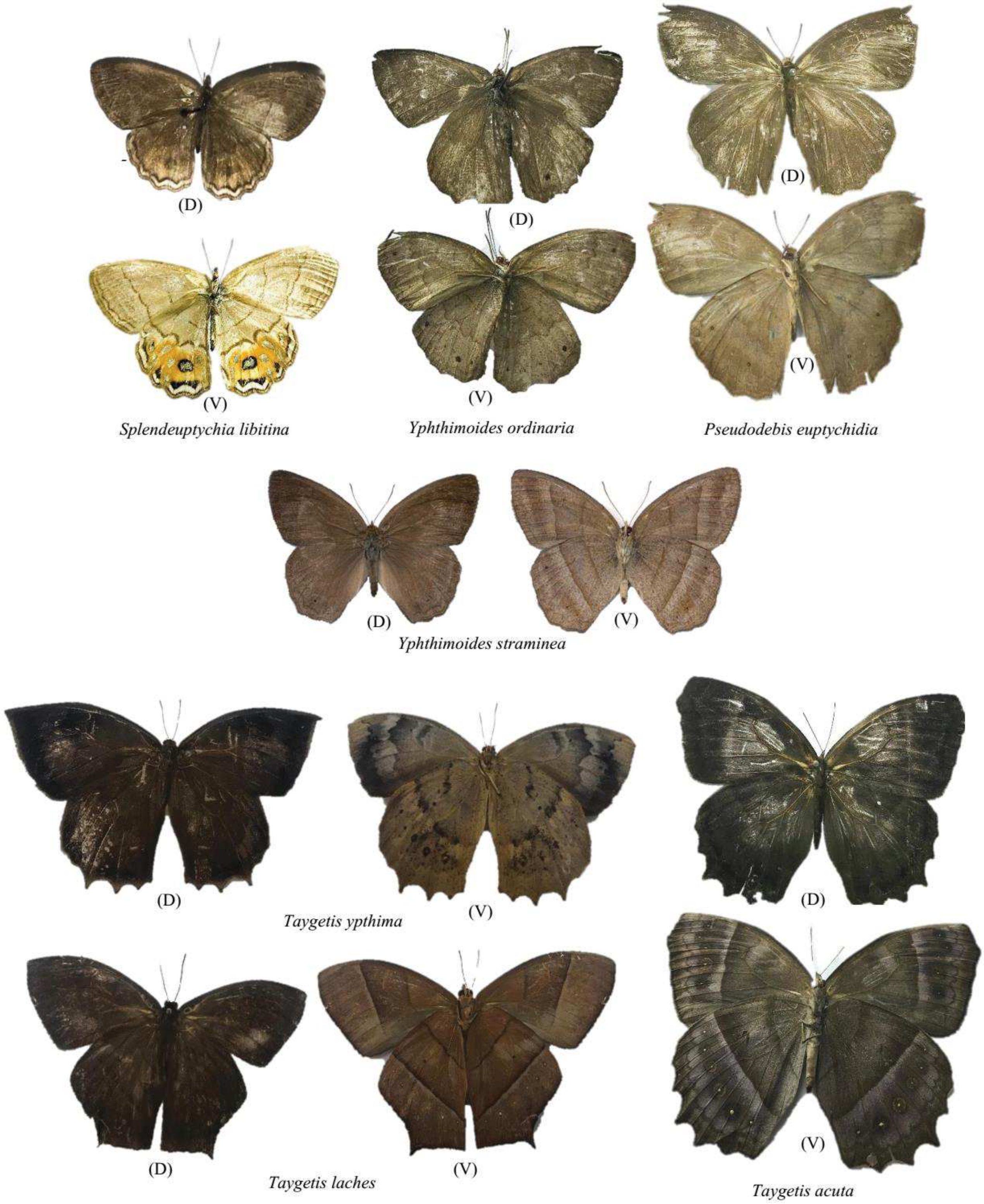


Morpho epistrophus

Plank 8. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.



Plank 9. Fruit-feeding butterflies Satyrinae in Mixed Ombrophilous Florest lof the Western region of Santa Catarina, Brazil.



Plank 10. Fruit-feeding butterflies Nymphalinae in Mixed Ombrophilous Florest of the Western region of Santa Catarina, Brazil.

(D) *Smyrna blomfildia* (V)

CAPÍTULO 2

How Do Fragmented Landscapes Affect the Composition and Diversity of Fruit-Feeding Butterflies?[2]

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Abstract

Fragmentation is a major threat to the Atlantic Forest Biome and the biodiversity of Lepidoptera. The study aimed to: a) analyze the composition and diversity (abundance and species richness) of fruit-feeding butterflies in Conservation Units and in adjacent fragments of Mixed Rainforest and; b) analyze whether Conservation Units maintain the biodiversity of fruit-feeding butterflies in adjacent forest fragments, in Southern Brazil. From December 2017 to March 2018, in a total of 24 sampling days, fruit-feeding butterflies were captured with Van Someren-Rydon bait traps. The species richness and abundance of fruit-feeding butterflies differed between the Conservation Units and the adjacent forest fragments, and the composition was altered, with a turnover of species from one environment to another. There was a clustering pattern, separating the fruit-feeding butterflies samples according to the sampled areas. The similarity in terms of abundance and species composition ranged from 50 to 55% among samples. The species of fruit-feeding butterflies showed a variation of occurrence of 85.23% in the National Forest of Chapecó, 75.92% in the Ecological Station of Mata Preta and 66.28% in the State Park of Araucárias. Assemblages in the National Forest of Chapecó and State Park of Araucárias were nested with their adjacent fragments. The study reinforces the role of Conservation Units in maintaining the biodiversity of fruit-feeding butterflies in adjacent forest fragments. There is a need for the conservation of adjacent forest fragments in highly fragmented landscapes, very common in the Atlantic Forest, avoiding the loss of fruit-feeding butterflies diversity.

Keywords

Atlantic Forest, Mixed Ombrophilous Forest, fragmentation, Lepidoptera, Conservation Units.

[2] O capítulo segue as normas da Revista Biodiversity Data Journal.

Introduction

Originally, the Atlantic Forest Biome covered an area equivalent to 131,546.000 hectares, however, due to agriculture and farming, exploitation of natural resources, industrialization, disorderly urban expansion, today only 12.4% forest remain (Fundação SOS Mata Atlântica 2019). Consequently, the original area of this biome is being reduced for five centuries, causing an increase in fragmentation (Tabarelli et al. 2004, 2005, Ribeiro et al. 2009, Tabarelli et al. 2012). In the last years, in the Brazilian Atlantic Forest, there has been a decrease in deforestation, but the degradation of ecosystems and threats to species persist (Silva et al. 2016).

The current state of conservation of the remnants of the Brazilian Atlantic Forest is critical since they are fragmented (smaller than 100 hectares) and isolated in the midst of highly anthropized landscapes (Ribeiro et al. 2012, SOS Mata Atlântica 2015). Only 14% of the remnants of the Atlantic Forest are within protected areas (Conservation Units) (Ribeiro et al. 2012), where legislation has been shown to be more efficient in preserving natural vegetation (Sparovek et al. 2012). However, many remnants of the Atlantic Forest are found in private areas (Rodrigues et al. 2011, Sparovek et al. 2012, Silva et al. 2016), and deficiencies in the management and inspection system do not ensure the conservation of the biome (Tabarelli et al. 2005, Tabarelli et al. 2012, Silva et al. 2016).

The acceleration in the fragmentation process of the Atlantic Forest causes changes in the dynamics of ecosystems and in the arrangement of natural resources in landscapes, threatening local biodiversity (Bond-Buckup and Dreier 2008; Tabarelli et al. 2012; Silva et al. 2016). Therefore, the conservation of biodiversity in fragmented tropical landscapes has become a major concern in Conservation Biology in recent decades (Metzger 2006; Newbold et al. 2015). The Atlantic Forest is a habitat to a greater number of threatened animal species, both in absolute numbers and in proportion to the richness of the biomes (ICMBio 2018). Of the total endangered species in Brazil, 50.5% are found in the Atlantic Forest, and 38.5% are endemic to this biome (ICMBio 2018).

Although fragmentation is a threat to several groups of Lepidoptera (Bonebrake et al. 2010), in the Brazilian Atlantic Forest many species of butterflies are found in fragments smaller than 1,000 hectares, are adapted to the fragmented landscape, thus some populations become more abundant (Brown Júnior and Freitas 2002; Uehara-Prado et al. 2007). In these fragments, the local instability of populations is very high, causing the butterflies communities to migrate, surviving in altered environments (Brown Júnior and Freitas 2002). On the other hand, the process of reducing forests facilitates the invasion of generalist/opportunistic species and a decrease in the diversity of native species (Shahabuddin and Ponte 2005; Uehara-Prado et al. 2005).

In Brazil there are 13,985 species of Lepidoptera (Casagrande and Duarte 2020), of which 3,834 are butterflies, distributed in the following families: Nymphalidae with 1,869 species (Casagrande and Duarte 2020), Hesperiidae com 1.692 espécies (Mielke *et al.*, 2020), Riodinidae with 1,170 (Dolibaina et al. 2020), Lycaenidae with 428 (Duarte and Robbins 2020), Papilionidae with 185 (Carneiro 2020) and Pieridae with 182 (Leviski and Casagrande 2020).

In Brazil, the guild of fruit-feeding butterflies is represented by four Nymphalidae subfamilies: Satyrinae, Charaxinae, Biblidinae and some Nymphalinae (Wahlberg et al. 2009; Freitas et al. 2014). This guild comprises 50-75% of the Neotropical Nymphalidae fauna (Brown Júnior 2005), and because they are taxonomically and ecologically diverse in tropical environments, they occur in all Brazilian biomes (Freitas et al. 2003; Freitas et al. 2014).

There is a lack of researchers in lepidopterofauna in Brazil and adequate knowledge about the biodiversity of butterflies is still far from being reached (Santos et al. 2016). They also report that for the coming decades, there remains the enormous task of studying the biodiversity of Brazilian butterflies, aiming to generate and make available information to support decision-making by the institutions responsible for environmental management, promoting strategies for preventing and mitigating impacts on biodiversity. In this way, it is crucial to concentrate efforts, both for the systematization of data in regional biological collections, and for gathering new information, thus making it possible to set priorities for conservation (Freitas and Marini-Filho 2011). Studies with Lepidoptera in fragmented landscapes have provided important results regarding species resilience to fragmentation (Daily and Ehrlich 1995, Shahabuddin and Terborgh 1999, Brown and Freitas 2002, Uehara-Prado et al. 2005, 2007, Ribeiro et al. 2008).

Thus, considering that the main threat to all endangered species of Lepidoptera of the Brazilian fauna is fragmentation and loss of their original habitats (Machado et al. 2018) and considering that fragmentation alters the composition (Shahabuddin and Terborgh 1999; Uehara-Prado et al. 2007; Filgueiras et al. 2016; Lourenço 2019) and diversity of fruit-feeding butterflies (Shahabuddin and Terborgh 1999; Hill and Hamer 2004; Uehara-Prado et al. 2005), the present study had the following hypotheses: 1) There are differences in composition, abundance and species richness of fruit-feeding butterflies between the Conservation Units and the adjacent forest fragments; 2) The assemblages of fruit-feeding butterflies in adjacent forest fragments are maintained by the Conservation Units, because these sites function as refuges for different species (Brown Júnior and Freitas 2000).

Considering the above, the objectives of the study were: a) to describe the composition and diversity (species richness and abundance) of fruit-feeding butterflies in Conservation Units and in adjacent forest fragments of Mixed Ombrophilous Forest and; b) to analyze whether Conservation Units maintain the biodiversity of fruit-feeding butterflies in adjacent forest fragments, in Southern Brazil.

Material and Methods

Study areas

The study was carried out in two Federal Conservation Units (protected areas in Brazil): National Forest of Chapecó (FLONA) (27°06'24.8" S and 52°46'59,3" W) and Ecological Station of Mata Preta (ESEC) (26°30'57.31" S and 52°7'59.69" W) and a State Conservation Unit, State Park of Araucárias (PAEAR) (26º27'08" S and 52º33'56" W). All Conservation Units are fully protected, located in the Western region of the state of Santa Catarina, Southern Brazil (Figure 1) and inserted in the Atlantic Forest Biome with forest phytophysiognomies classified as Mixed Ombrophilous Rainforest with different succession stages (Dick et al. 2013).

FLONA is located in the municipalities of Chapecó and Guatambú, and it was established in 1968, with an area of 1,590 hectares. Samples of fruit-feeding butterflies were taken in fragment I of FLONA with an area of 1,287.54 hectares, in Guatambú (ICMBio 2013). Mata Preta ESEC was established in 2005, with an area of 6,536 hectares, in the municipality of Abelardo Luz (Apremavi 2009). PAEAR was created in 2003 and covers an area of 612.5 hectares. PAEAR is between the municipalities of São Domingos and Galvão (Fatma 2016) (Figura 1).

The climate of the Western region of the state of Santa Catarina is *cfa*, humid subtropical, with abundant and well distributed rainfall throughout the year. The annual average temperature is less than 18ºC and average temperatures range from 13ºC to 25ºC (Alvares et al. 2014).

Sampling design

Sampling units for collection of fruit-feeding butterflies were defined (five for FLONA and PAEAR, three for ESEC) within the Conservation Units (CU) and a single sampling unit in each of the adjacent forest fragments (FF) of each CU. Five FF were defined for FLONA and ESEC, and four for PAEAR (Figure 1). The FF had different sizes and distances from the CU. Among the FF there was a minimum distance of 250 meters (Santos et al. 2014). The sampling unit was formed by a linear transect, the first trap was placed at a distance of at least 50 meters from the edge (Freitas et al. 2014). In each transect, five traps were used (Freitas *et al* 2014), 30 to 50 meters apart (Santos et al. 2014), depending on the availability of places to hang them on trees. The other transects of the sampling units with a minimum distance of 250 meters between them (Freitas et al. 2014). A total of 135 traps were installed, 50 of which were in FLONA/FF (25/25); 40 traps in ESEC/FF (15/25) and 45 in PAEAR/FF (25/20).

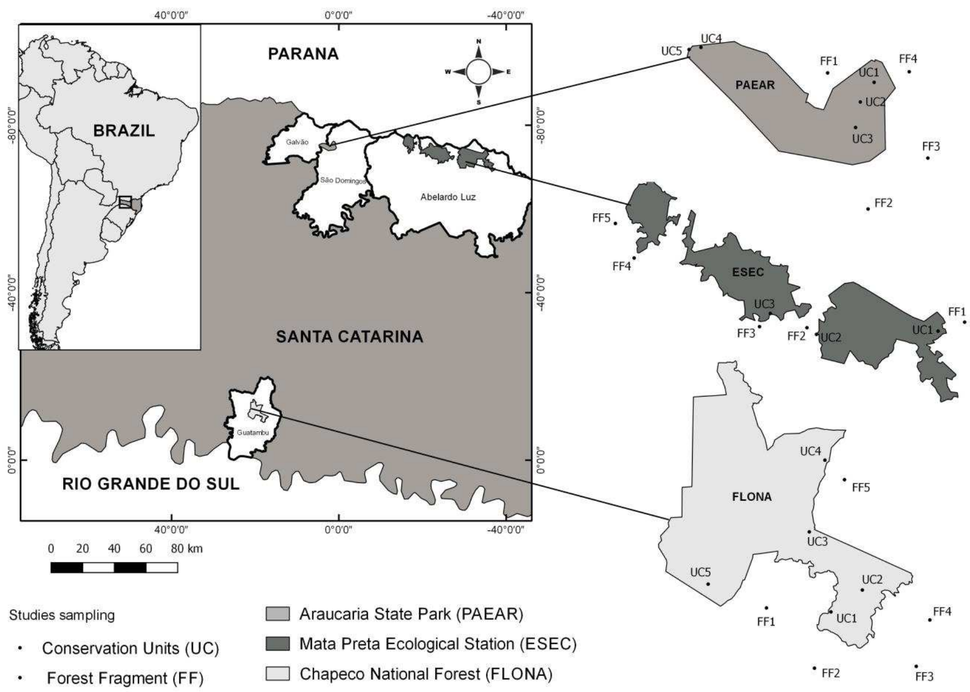


Figure 1. Map of the study areas and sample units for collections of frugivorous butterflies in the municipalities of Guatambú, Abelardo Luz and São Domingos, Santa Catarina, from December 2017 to March 2018.

Three samplings were conducted in each CU and in the respective FF, from December 2017 to March 2018, totaling 21 days of collections in each sampling area. The traps were left active in the field for seven consecutive days in each sampling, inspected every 48 hours to collect the specimens and to replace baits (Freitas et al. 2014).

The sampling procedure followed the protocol established by the National Lepidoptera Research and Conservation Network (RedeLep) using Van Someren-Rydon traps. The traps were hung on trees using ropes, at a height of approximately 1.5 meter above the ground level (Uehara-Prado et al. 2005). Each trap was provided with a 50 mL plastic cup containing an attractive bait based on a mixture of sugarcane juice with ripe bananas, in 1/3 proportion, prepared 48 hours before the start of sampling, which is the time necessary for fermentation (Uehara-Prado et al. 2005).

Storage and identification of fruit-feeding butterflies

The sampled specimens were killed by pressing the thorax at the base of the wings and packed in properly identified entomological envelopes (Almeida et al. 1998). The collected butterflies were taken to the Laboratory of Ecological Entomology (LABENT-Eco) of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ) in the state of Santa Catarina, Brazil, for freezer storage and later identification of the species. The identification was based on specialized literature (Canals 2003, Lamas 2004, Wahlberg 2009) and the online identification guide (http://butterfliesofamerica.com). The identification was also confirmed by experts from the Universidade Estadual de Campinas (UNICAMP) and the Universidade Federal do Paraná (UFPR).

Voucher specimens of each of the sampled species were deposited in the reference collection of the Laboratory of Ecological Entomology (LABENT-Eco) of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ), Chapecó, Santa Catarina and in the

Zoological Collection of the Universidade do Vale do Rio dos Sinos (MZ UNISINOS), São Leopoldo, State of Rio Grande do Sul, Brazil. Samples were authorized by ICMBio (Collection License ICMBio/SISBio 60789-1).

Data analysis

The richness of each CU and the corresponding FF was compared using individual-based rarefaction (Gotelli and Graves 1996), with 1,000 randomizations, in the Past software (Hammer and Harper 2009). This analysis eliminates the influence of the sample size when comparing species richness from different environments or different methods (Gotelli and Graves 1996).

To analyze the abundance based composition of the assemblages of the sampling units, the non-metric multidimensional scaling ordination (NMDS) was applied. The Bray-Curtis dissimilarity matrix was used, and the data were log-transformed with log (x + 1). The ordinations were generated using the statistical software PRIMER (Clarke and Gorley 2006).

The SIMPROF method was used to support the interpretation of NMDS analyses and to identify significant groups in the cluster analysis. The UPGMA method was used, in which the linkage of clusters is based on unweighted arithmetic means. Clarke et al. (2008) suggested the use of a combination of SIMPROF with hierarchical cluster analysis to indicate which clusters are significantly different from each other from randomization.

Principal component analysis (PCA) was applied to check the association of species with the sampling units in the CU and in the respective adjacent FF. Previously data were log transformed [Log(x+1)] to reduce the influence of very abundant species. Species sampled with one or two individuals were excluded from the analysis for the same reason. The analysis was run in the Past software (Hammer & Harper 2009).

To explore possible differences in species richness and abundance of fruit-feeding butterflies assemblages in the CU and FF and their interactions, as well as to verify the relative contribution of each sampling unit in the structure of the fruit-feeding butterflies assemblage, a multivariate permutational analysis of variance was applied, types of Sum of Squares for unbalanced designs (Type II SS) - PERMANOVA (Anderson 2001). Permutations were restricted using CU as blocks. The test provides the simultaneous response of one or more variables (species richness and abundance) for one or more sampling units (CU and FF) using a design of analysis of variance based on distance measurements, using permutational methods (Anderson 2005), generating significance values of *p*. Were generated 9,999 permutations, using the Bray-Curtis similarity index to measure the similarity between the sampling units, and the data were log-transformed [log(x+1)]. The adonis.II function of the RVAideMemoire package was used. The assumption of homogeneity of dispersions of the groups was tested with the betadisper and permutest functions and the paired test was performed with the pairwise.perm.manova function of the RVAideMemoire package. Analyses were performed using R software (R Development Core Team 2019).

For the nestedness analysis, it was calculated the NODF index ("Nestedness metric based on Overlap and Decreasing Fill"), based on 9,999 randomizations, proposed by Almeida-Neto et al. (2008) and Ulrich et al. (2009) using the software R (R Development Core Team 2019). This index was chosen because it contains a null model in its calculation, which compares the index values to the actual data observed with the probabilities of expected results if the distribution of the organisms occurred at random, providing a statistical confidence interval ($p<0.05$) to the results (Almeida-Neto et al. 2008).

The incidence matrix used for the nestedness analysis consists of a m X n matrix, where m is the number of recorded fruit-feeding butterflies species and n is the number of sampling sites (in this case, CU and FF areas). If species i was absent in environment j, cell a_i

$_j$ receives a value of 0 (zero), otherwise, it receives a value of 1. In addition, the matrix was ordered in a decreasing way for both columns and rows, ranking the species of fruit-feeding butterflies in the columns according to their "status" of richness and ordering the areas in the rows, from the most frequent to the rarest, as explained by Almeida-Neto et al. (2008) and Ulrich et al. (2009).

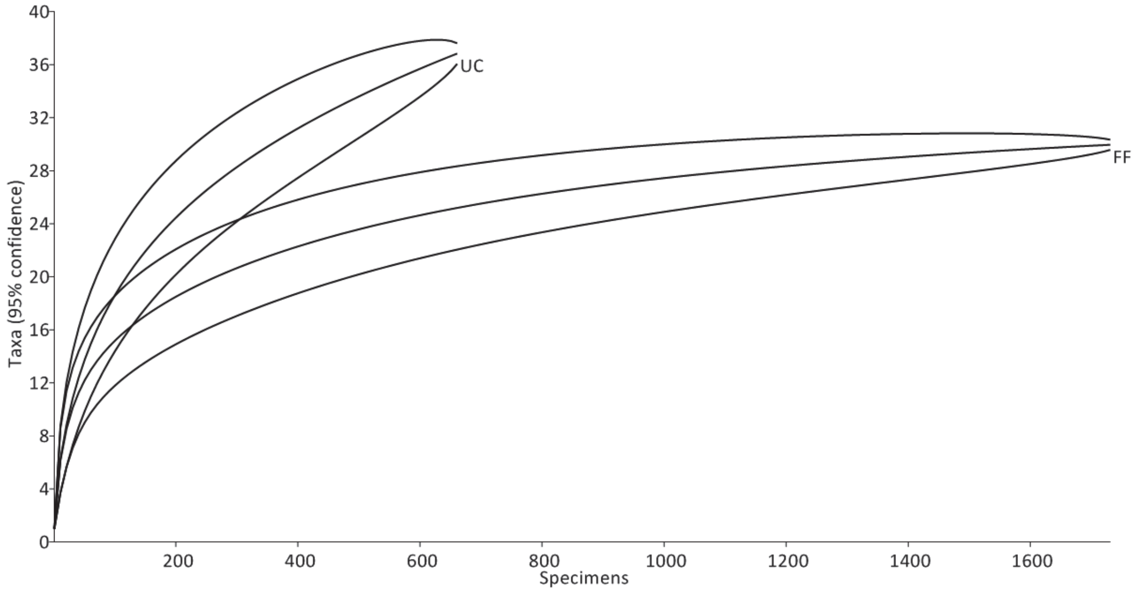
A matrix with perfect nestedness (NODF = 100) occurs when 50% columns are filled from left to right and from top to bottom in the rows or decreasing the marginal totals in all pairs of columns and all pairs of rows (Almeida-Neto et al. 2008).

Results

We sampled 4,231 fruit-feeding Nymphalidae butterflies, belonging to four subfamilies, 12 tribes and 49 species. In all, 37 species were sampled in FLONA and 29 in adjacent FF. In ESEC, 29 species were recorded, and in FF, 33. In PAEAR, 33 species were sampled, and 28 in FF. The complete species list can be found in Sabedot-Bordin et al. (2019).

The rarefaction analysis indicated differences in species richness between the CU and FF areas. In FLONA, higher species richness was found in relation to the respective FF (Fig 1a), lower species richness in ESEC in relation to the respective FF (Fig 1b) and that species richness is equal in PAEAR and in its FF (Fig

1c).



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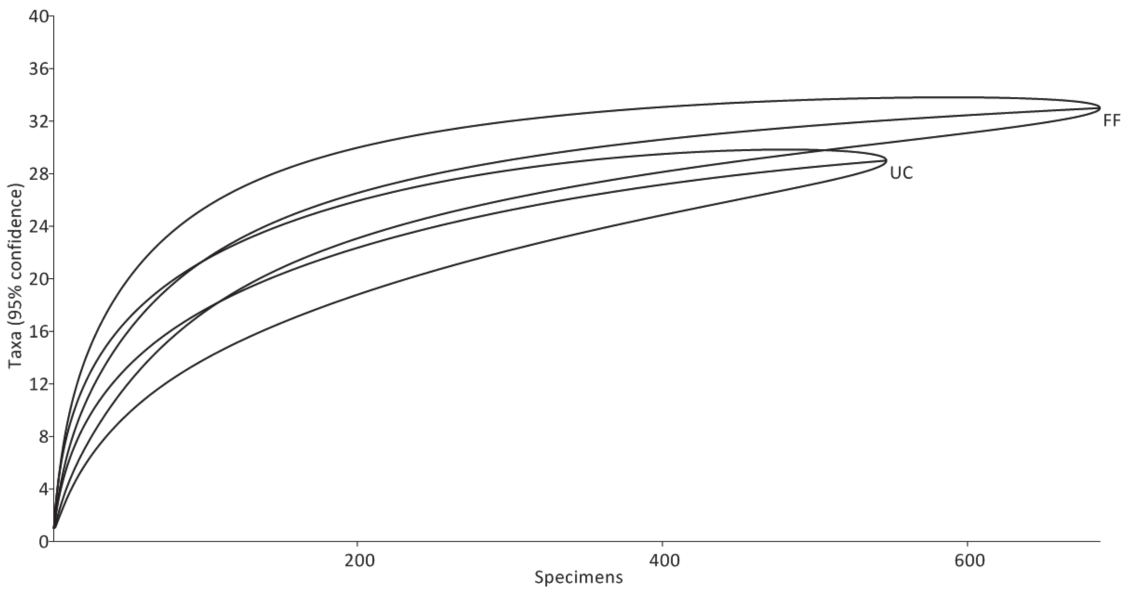

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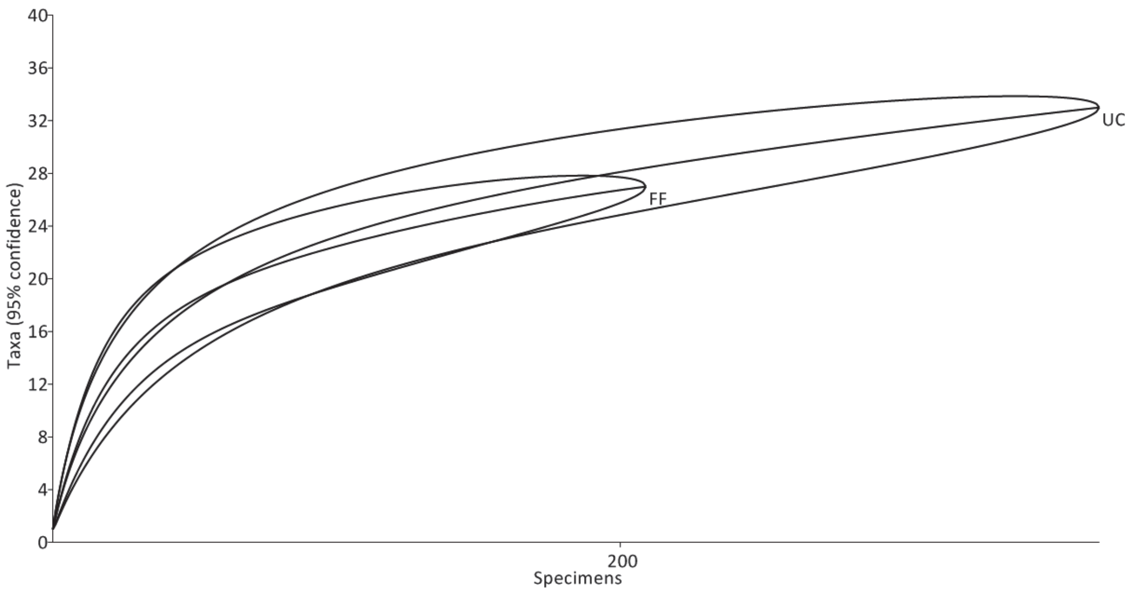

(c)

Figure 2. Individual-based rarefaction analysis for the richness of fruit-feeding butterflies species sampled with Van Someren-Rydon traps, in Conservation Units (CU) and adjacent forest fragments (FF), from December 2017 to March 2018, in the Western region of the state of Santa Catarina, Brazil. a: FLONA; b: ESEC; c: PAEAR

When the fruit-feeding butterflies species were analyzed individually, there was a distribution pattern where some species were more abundant in FF than in CU and vice versa. Exclusive species were sampled in the FF, being singletons in the sampling, such as *Hamadryas amphinome* (Linnaeus, 1767), *Blepolenis bassus* (Felder & Felder, 1867) and *Blepolenis catharinae* (Stichel, 1902). In CU areas: *Eunica eburnea* Fruhstorfer, 1907, *Eunica tatila* (Herrich-Schäffer, 1855), *Morpho aega* (Hübner, [1822]), *Splendeyptychia ambra* (Weymer, [1911]), *Splendeyptychia libitina* (Butler, 1870) and *Zischkaia pacarus* (Godart, [1824]).

Of the 12 tribes sampled in the study, 58.3% showed a reduction in the abundance of fruit-feeding butterflies in the CU areas in relation to the FF. Among the tribes, Morphini and Satyrini showed this pattern.

There was a greater abundance of Satyrinae species in the samples, with 28.5% of the species: *Cissia eous* (Butler, 1867), *Cissia phronius* (Godart, [1824]), *Forsterinaria* *quantius* (Godart, [1824]), *Moneuptychia soter* (Butler, 1877) and *Yphthimoides ordinaria* (Freitas, Kaminski & Mielke, 2012), besides *Hermeuptychia* sp. associated with all forest areas of the study.

The NMDS analysis showed separation of the samples, mainly of the CU in relation to the adjacent FF. The cluster significance test (SIMPROF) confirmed the results presented in the ordination analysis (NMDS) (Fig 2-4).

The sampling units in FLONA and FF showed a similarity of 50% (stress = 0.15) in terms of abundance and composition of fruit-feeding butterflies species. The sampling units 12UC and 5UC showed differences in relation to the other samples (Fig 2).

The ordination analysis (NMDS) for the abundance and composition of samples of the ESEC and adjacent FF showed a similarity of 55% (stress = 0.17). Only the 5UC sampling unit showed a difference in relation to the other samples (Fig 3). In PAEAR, there was a similarity of 55% (stress = 0.23) between the abundance and composition of fruit-feeding butterflies in the samples. In PAEAR, no sampling unit showed a difference in relation to the other samples.

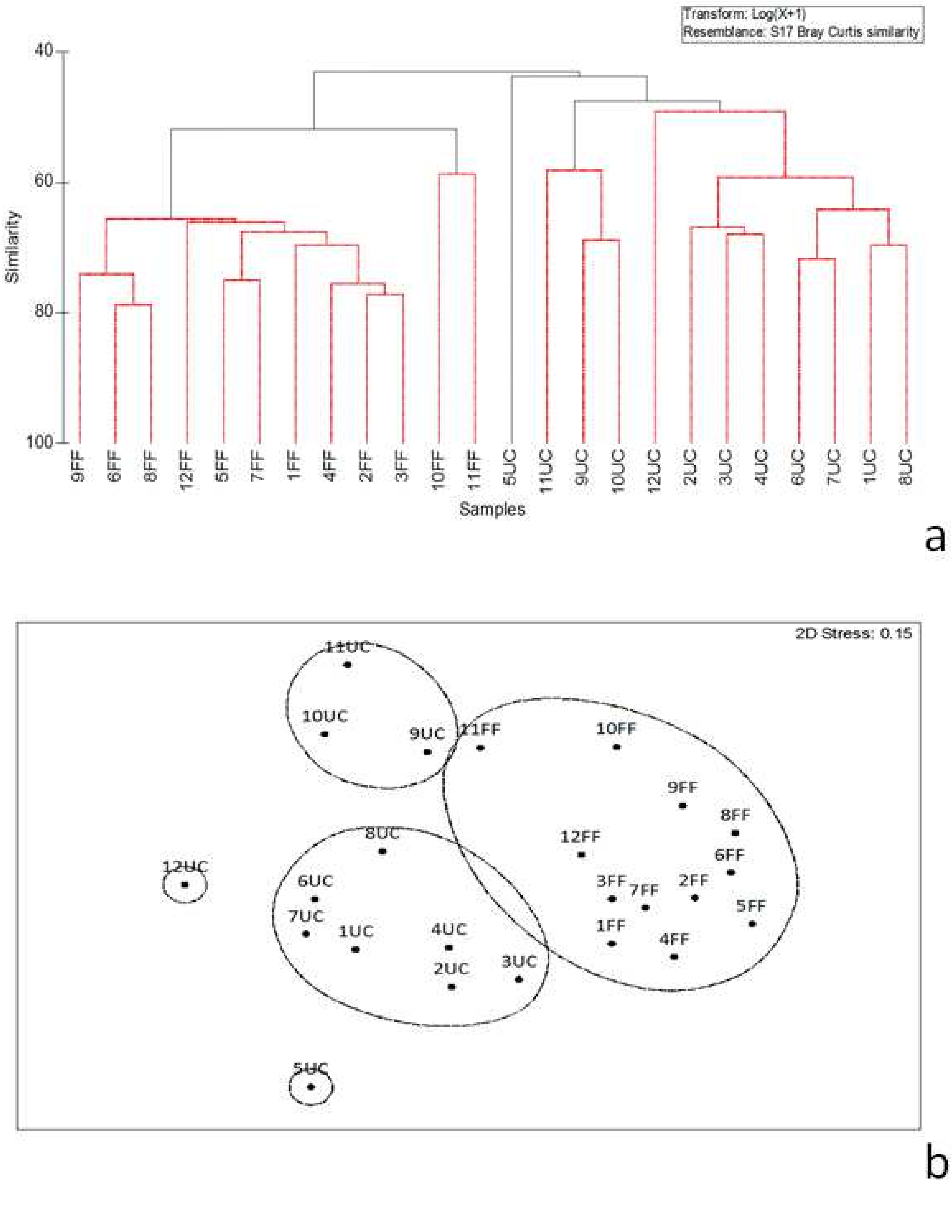

Figure 3. (a) Cluster analysis with SIMPROF test and (b) Non-Metric Multidimensional Scaling Ordination analysis (NMDS, stress = 0.15) dissimilarity (Bray-Curtis) showing similarities in the composition and abundance of fruit-feeding butterflies sampled in FLONA and FF, from December 2017 to March 2018. Similar groups by SIMPROF analysis are highluminosityed. Circles represent 50% similarity. The numbers identify the sampling periods; CU = Conservation Unit; FF = Adjacent Forest Fragment.

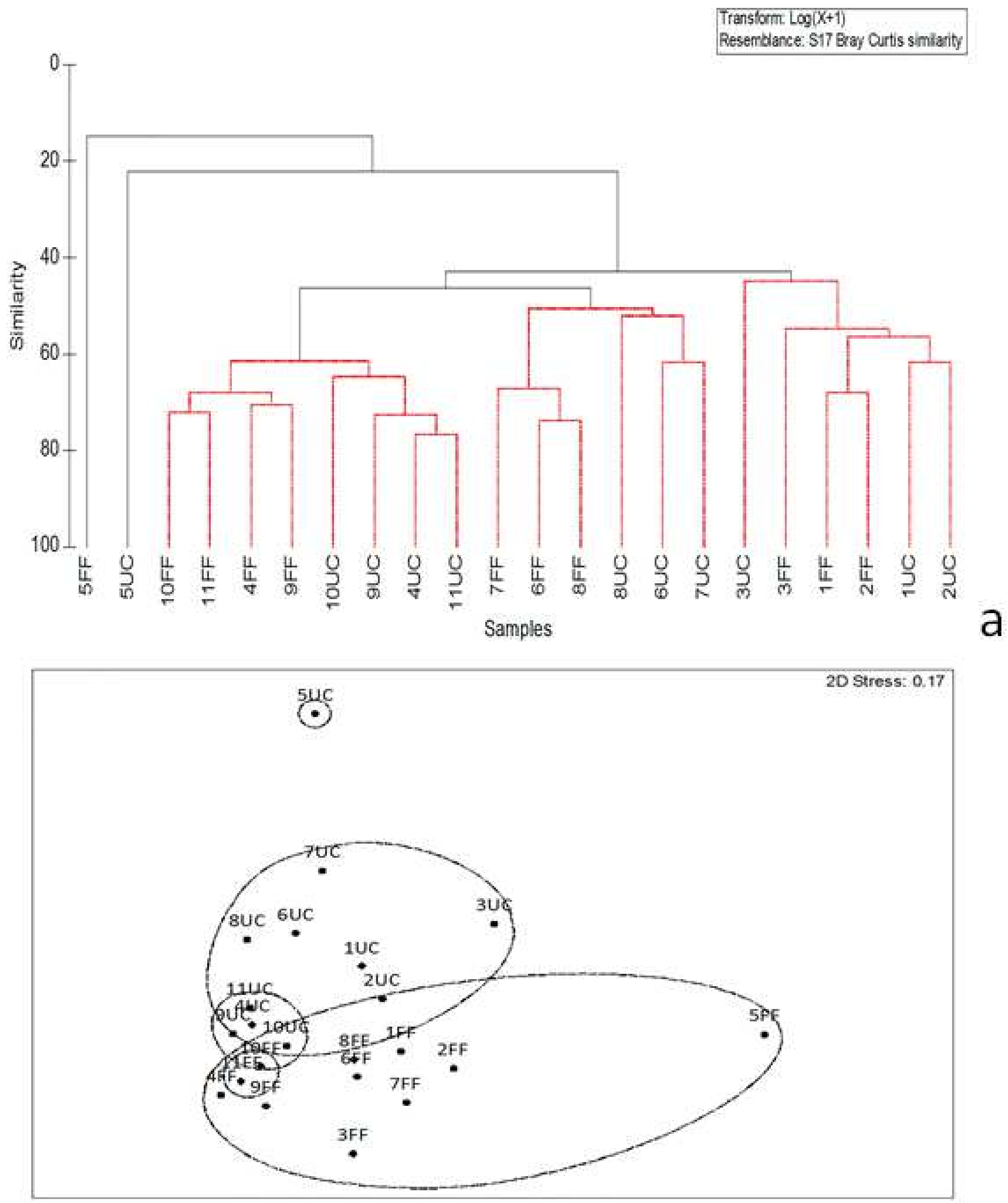

Figure 1. (a) Cluster analysis with SIMPROF test and (b) Non-Metric Multidimensional Scaling Ordination analysis (NMDS, stress = 0.15) dissimilarity (Bray-Curtis) showing similarities in the composition and abundance of fruit-feeding butterflies sampled in ESEC and FF, from December 2017 to March 2018. Similar groups by SIMPROF analysis are highluminosityed. Circles represent 50% similarity. The numbers identify the sampling periods; CU = Conservation Unit; FF = Adjacent Forest Fragment.

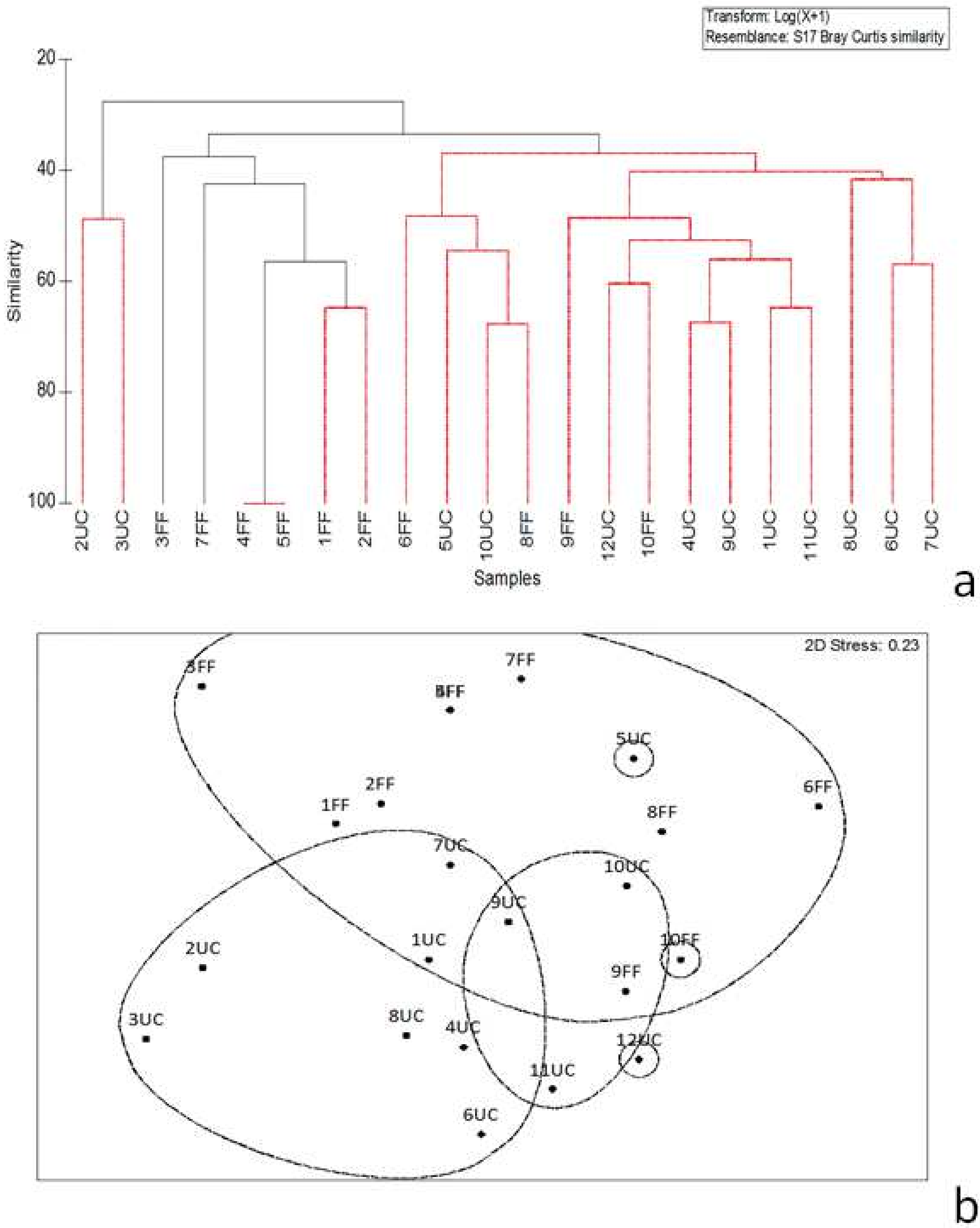

Figure 2. (a) Cluster analysis with SIMPROF test and (b) Non-Metric Multidimensional Scaling Ordination analysis (NMDS, stress = 0.15) dissimilarity (Bray-Curtis) showing similarities in the composition and abundance of fruit-feeding butterflies sampled in PAEAR and FF, from December 2017 to March 2018. Similar groups by SIMPROF analysis are highluminosityed. Circles represent 50% similarity. The numbers identify the sampling periods; CU = Conservation Unit; FF = Adjacent Forest Fragment.

The species *Biblis hyperia* (Cramer, 1779), *C. eous*, *C. phronius*, *Euptychoides castrensis* (Schaus, 1902), *Hermeuptychia* sp., *M. soter*, *Morpho moruus stheno* (Prittwitz, 1865), *Paryphthimoides poltys* (Prittwitz, 1865), *Smyrna blomfildia* (Fabricius, 1781), *Y. ordinaria* showed a positive association with the FF areas. *Epiphile orea* (Hübner, [1823]), *Eryphanis reevesii* (Doubleday, 1849), *Forsterinaria quantius*, *Manataria hercyna* (Hübner, [1821]) and *Pareuptychia ocirrhoe* (Fabricius, 1776) were associated with FLONA areas. The other species occurred independently of the sampled area (Fig 5). Axes 1 and 2 of the PCA explained 85.23% of the variation of occurrences in the samples.

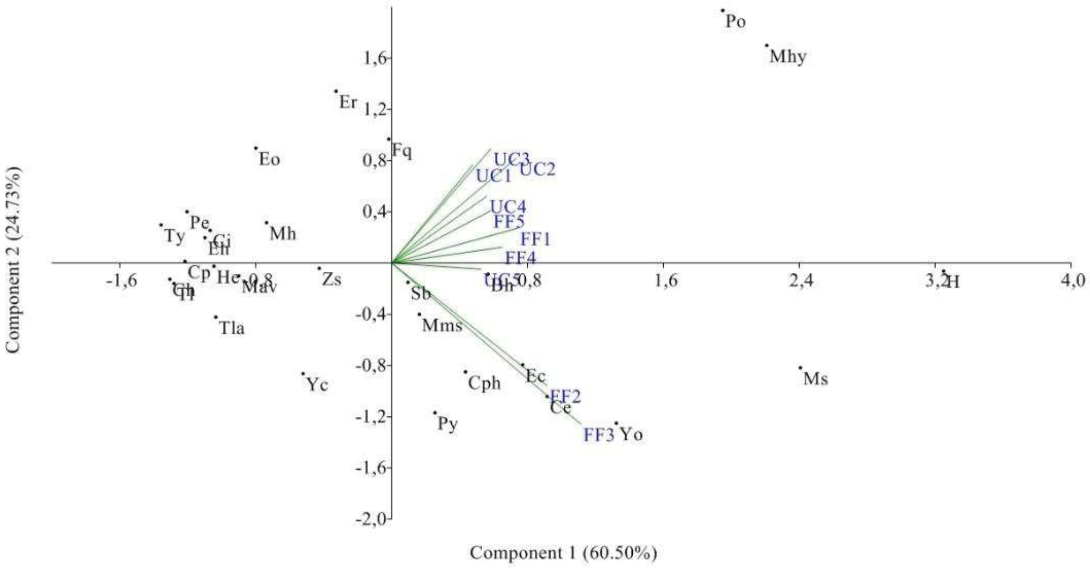

Figure 3. Principal Component Analysis of fruit-feeding butterflies species sampled in FLONA and FF in the Western region of the state of Santa Catarina, from December 2017 to March 2018. CU = Conservation Unit; FF = Adjacent Forest Fragments. Bh: *Biblis hyperia*; Ch: *Callicore hydaspes*; Ci: *Calligo illioneus*; Cp: *Carminda paeon*; Ce: *Cissia eous*; Cph: *Cissia phronius*; Eh: *Epiphile hubneri*; Eo: *Epiphile orea*; Er: *Eryphanes reevesii*; Ec: *Euptychoides castrenses*; Fq: *Forsterinaria quantius*; He: *Hamadryas epinome*; H: *Hermeuptychia sp.*; Mhy: *Manataria hercyna*; Mav: *Memphis acidalia victoria*; Mms: *Memphis moruus stheno*; Ms: *Moneuptychia soter*; Mh: *Morpho helenor*; Po: *Pareuptychia ocirrhoe*; Py: *Paryphthimoides poltys*; Pe: *Pseudodebis euptychidia*; Sb: *Smyrna blomfildia*; Tl: *Taygetis laches*; Ty: *Taygetis ypthima* Tla: *Temenis laothoe*; Yc: *Yphthimoides celmis*; Yo: *Yphthimoides ordinaria*; Zs: *Zaretis strigosus*.

In the ESEC, *E. castrenses*, *E. reevessii*, *F. necys*, *F. quantius* and *Opoptera sulcius* (Staudinger, 1887) showed a positive association with CU areas. In turn, *M. soter*, *Morpho epistrophus* (Fabricius, 1796), *Y. ordinaria* and *Yphthimoides straminea* (Butler, 1867) had a positive association with FF. The other species occurred independently of the sampled area (Fig. 6). PCA axes 1 and 2 explained 75.92% of the variation of occurrences in the samples.

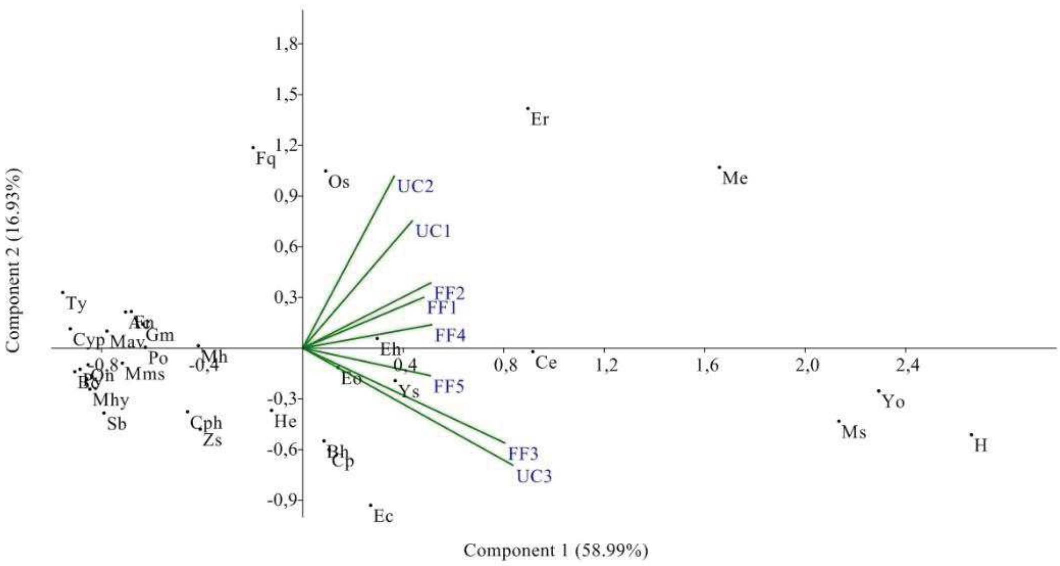

Figure 4. Principal Component Analysis of fruit-feeding butterflies species sampled in ESEC and FF in the Western region of the state of Santa Catarina, from December 2017 to March 2018. CU = Conservation Unit; FF = Adjacent Forest Fragments. Ac: *Archeoprepona chalciope*; Bh: *Biblis hyperia*; Bc: *Blepolenis catharinae*; Cp: *Carminda paeon*; Ce: *Cissia eous*; Cph: *Cissia phronius*; Cyp: *Cybdelis phaesyla*; Eh: *Epiphile hubneri*; Eo: *Epiphile orea*; Er: *Eryphanes reevesii*; Ec: *Euptychoides castrenses*; Fn: *Forsterinaria necys*; Fq: *Forsterinaria quantius*; Gm: *Godartiana muscosa*; He: *Hamadryas epinome*; H: *Hermeuptychia* sp.; Mhy: *Manataria hercyna*; Mv: *Memphis acidalia victoria*; Mms: *Memphis moruus stheno*; Ms: *Moneuptychia soter*; Me: *Morpho epistrophus*; Mh: *Morpho helenor*; Os: *Opoptera sulcius*; On: *Opsiphanes invirae*; Po: *Pareuptychia ocirrhoe*; Py: *Paryphthimoides poltys*; Sb: *Smyrna blomfildia*; Ty: *Taygetis ypthima*; Yo: *Yphthimoides ordinaria*; Ys: *Yphthimoides straminea*; Zs: *Zaretis strigosus*.

In the PAEAR, *E. reevesii* and *Taygetis acuta* Weymer, 1910 presented a positive association with CU areas. However, *Hermeuptychia* sp. and *M. soter* showed a positive association with FF areas. The other species occurred independently of the sampled area (Fig. 7). PCA axes 1 and 2 explained 66.28% of the variation of occurrences in the samples.

The results of PERMANOVA evidenced a difference in the CU factor (Pseudo-F = 16,3260; Df = 2; p = 0.0001) and local factor (Pseudo-F = 6,9841; Df = 1; p = 0.0001), separately, for richness and abundance of fruit-feeding butterflies. When the interaction between the two factors was evaluated, differences were also detected (Pseudo-F = 3,0764; Df = 2; p = 0.0001). The structure of the fruit-feeding butterflies community was influenced by factors separately and by the interaction between them (Table 1). PERMANOVA revealed that the factors analyzed, separately, or in interaction, present different communities.

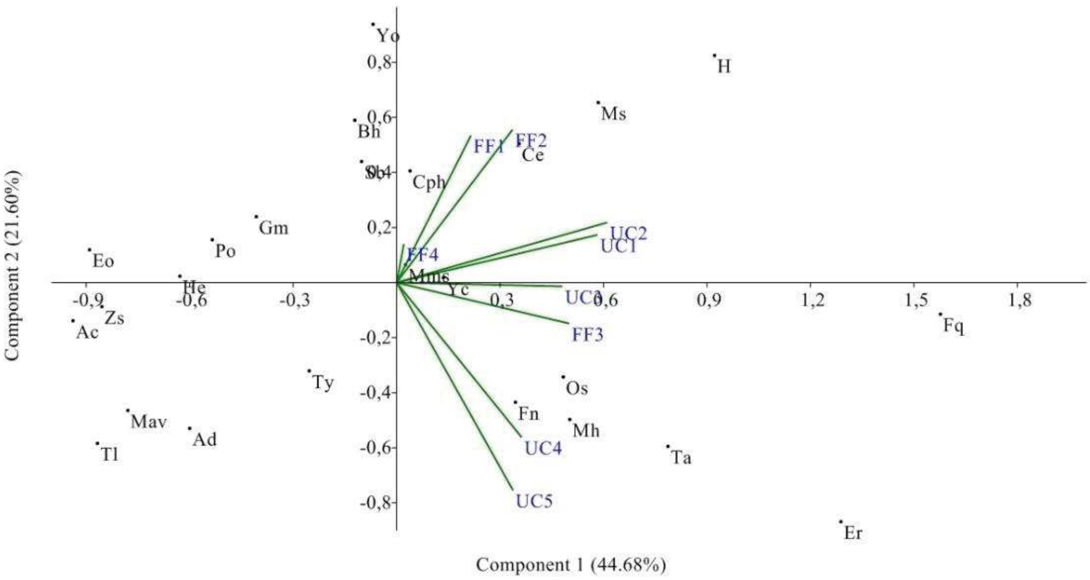

Figure 5. Principal Component Analysis of fruit-feeding butterflies species sampled in PAEAR and FF in the Western region of the state of Santa Catarina, from December 2017 to March 2018. CU = Conservation Unit; FF = Adjacent Forest Fragments. Ad: *Archaeoprepona demophon*; Ac: *Archeoprepona chalciope*; Bh: *Biblis hyperia*; Ce: *Cissia eous*; Cph: *Cissia phronius*; Eo: *Epiphile orea*; Er: *Eryphanes reevesii*; Fn: *Forsterinaria necys*; Fq: *Forsterinaria quantius*; Gm: *Godartiana muscosa*; He: *Hamadryas epinome*; H: *Hermeuptychia* sp.; Mhy: *Manataria hercyna*; Mv: *Memphis acidalia victoria*; Mms: *Memphis moruus stheno*; Ms: *Moneuptychia soter*; Os: *Opoptera sulcius*; Po: *Pareuptychia ocirrhoe*; Sb: *Smyrna blomfildia*; Ta: *Taygetis acuta*; Tl: *Taygetis laches*; Ty: *Taygetis ypthima*; Yc: *Yphthimoides celmis*; Yo: *Yphthimoides ordinaria*; Zs: *Zaretis strigosus*.

Table 1. PERMANOVA based on the Bray-Curtis Similarity Matrix, applied to the fruit-feeding butterflies community structure in FLONA, ESEC, PAEAR and their adjacent forest fragments, in the Western region of the state of Santa Catarina, Brazil, for the factors: sampled CU and sites (FF and CU), and interaction between factors. SS: sum of squares, df: degrees of freedom, MS: mean of squares, Pseudo-F: Proportion of Pseudo-F. P values indicate statistical significance (p <0.05).

Sources of variation	Df	SS	MS	Pseudo-F	p (perm)
Areas (CU)	02	8.015	4.0075	16.3260	0.0001
Sites (FF and CU)	01	1.714	1.7144	6.9841	0.0001
Areas X Sites	02	1.510	0.7552	3.0764	0.0001
Residuals	129	31.665	0.2455		
Total	134	43.237			

The nestedness analysis of FLONA and PAEAR with their respective adjacent FF was significant ($p < 0.001$), with an index of 71.36 and 73.60, and matrix fill of 0.53% and 0.55%, respectively (Table 2), indicating that the assemblages of fruit-feeding butterflies had a nested distribution with CU ($p < 0.05$). For ESEC, there was no statistically significant nestedness ($p > 0.05$) (Table 2).

Table 2. Results of the nestedness analysis for the fruit-feeding butterflies community in FLONA, ESEC, PAEAR and their adjacent forest fragments in the Western region of the state of Santa Catarina, Brazil. NODF = Nestedness Overlap and Decreasing Fill.

NODF Index							
FLONA							
	Statistics	**Z**	**0%**	**50%**	**95%**	**p**	**% fill.**
Number of columns	71.13	8.49	61.01	63.60	65.18	0.001	----
Number of rows	84.70	2.40	41.71	69.36	77.15	0.001	----
NODF	71.36	8.17	60.98	63.64	65.33	0.001	0.53
ESEC							
Number of columns	68.65	1.61	64.11	67.08	68.92	0.007	----
Number of rows	69.54	0.49	20.60	67.65	75.33	0.300	----
NODF	68.67	1.57	63.86	67.07	68.96	0.007	0.60
PAEAR							
Number of columns	73.50	10.84	57.95	61.28	63.30	0.001	----
Number of rows	79.93	2.54	24.21	61.19	70.20	0.001	----
NODF	73.60	10.56	57.97	61.26	63.34	0.001	0.55

Discussion

The present study investigated the differences in the composition, species richness and abundance of fruit butterflies in Conservation Units and in adjacent forest fragments of Mixed Rainforest. The results show that there is distribution pattern for the composition and abundance of fruit-feeding butterflies in the study areas, as there was a heterogeneous distribution of fruit-feeding butterflies in the sampling units. The species composition patterns in the study are similar to those found by Melo et al. (2019), and this explanatory variable responded to the type of habitat, fragment area and distance between the sample units. These findings illustrated that species composition and abundance are adequate parameters for accessing the responses of fruit-feeding butterflies to habitat loss and fragmentation.

The adjacent forest fragments studied are isolated sampling units, with a smaller area compared to the Conservation Units area. They also have more open areas, thus in the FF, it was observed that the composition of fruit-feeding butterflies was altered. This finding supports the prediction that small fragments shelter fruit-feeding butterflies species from more open areas, present at the edges of forests and clearings (Uehara-Prado et al. 2007).

The results demonstrated differences in the richness of fruit-feeding butterflies species between the different sampling areas. There may be an effect of butterfly resistance as the habitat is modified and fragmentation does not affect the richness of frugivorous butterfly species (Uehara-Prado et al. 2007). The results indicate that FFs are inhabited by more resilient species and CU, as they are larger, support a more diversified assemblage.

It can be inferred, based on the results obtained, that the FF of Mixed Rainforest studied have an adequate micro habitat for the maintenance of some fruit-feeding butterflies species. This inference is supported by Ribeiro et al. (2008), who adds that the greatest abundance of butterflies occurs nearby their host plants. According to Melo et al. (2019) the fragment area is negatively correlated with species richness and fruit-feeding butterflies abundance, while habitat type is correlated with butterflies richness and abundance. These findings illustrated the sensitivity of fruit-feeding butterflies to habitat loss and fragmentation and the relevance of a heterogeneous environment and connected landscape for butterflies conservation, where small fragments are important to generalist or open habitat specialists and large remnants are fundamental to disturbance-sensitive and threatened taxa.

The prevalence of Satyrinae species in the samples in all forest areas included in the study. This result corroborates the studies carried out in Santa Catarina by Corso and Hernandez (2012) who also counted this subfamily as the most abundant in all the sampled areas. Morphini and Satirini were not very representative in the UC areas, compared to the FF, can be because the Morphini species (especially *M. aega*) disappear quickly when there is strong disturbance, deforestation, or reduction in forest size (Brown 1992). Shahabuddin and Terborgh (1999) affirm that the species of Morphini can be vulnerable to local extinction after habitat fragmentation, while small Satirini can be relatively resilient.

The pattern shown in the PERMANOVA analysis occurred because there was variation in the abundance and richness of fruit-feeding butterflies species between the FF and CU. Our results corroborate the pattern found by Ribeiro et al. (2008), in which the most dominant species are the same in both landscapes, and the greatest differences between the butterflies assemblages are explained by the less abundant species. The authors also reported that these variations in pattern and differences in diversity are probably caused by the presence of rare species, a fact corroborated by this study.

For some species of fruit-feeding butterflies, FF are likely to maintain a different diversity, as the physical and environmental differences in the areas must be considered. This inference is supported by DeVries (1987) and Brown Júnior and Freitas (1999), who considered that the occurrence of host plants for caterpillars, specific habitats, mutualistic associations, food and water sources are determinant for fruit-feeding butterflies species. Marín et al. (2009) add food resources for adults, and mating and overnight sites, recognizing them as a functional habitat.

The study presented a nested pattern of assemblages of frugivorous butterflies from FLONA and PAEAR, showing that the species that occur in FF are a subset of UC species. Cook et al. (2004) described the nesting as a result of the set of species in the region, which is being selected due to the specific environmental restrictions of each one. Thus, the existence of distinct communities in the contexts explained is mainly due to the substitution of species. Environmental restrictions and availability of host plants are important in structuring communities, defining the distribution of frugivorous butterflies and shaping the biological diversity of the place.

It is necessary to consider that the species of frugivorous butterflies differ in their needs and physiological tolerances, certain conditions and environmental gradients can be characterized as extremes for some species. On the other hand, other species can tolerate these same conditions, being structured by both biotic and abiotic factors (Townsend et al. 2003).

Based on the nested distribution pattern obtained, it is suggested that, despite the existence of FF that sustain a part of the richness of fruit-feeding butterflies, considering the dispersal ability and environmental requirements of the species, there must be a strong interaction between the environments of the area. Therefore, areas with different patterns of composition and richness of fruit-feeding butterflies are essential to maintain the group's diversity, given the biological and environmental dynamics found.

The study highluminosityed the role of Conservation Units in maintaining the biodiversity of fruit-feeding butterflies in adjacent forest fragments. The FF can harbor a high richness of fruit-feeding butterflies species as the CU fragments, even if the species composition is different, acting at least as breeding and development grounds for fruit-feeding butterflies species. This demonstrates the importance that the FF can have in highly fragmented landscapes, very common in the Atlantic Forest, affecting the diversity of fruit-feeding butterflies. The study agrees Daily and Ehrlich (1995), who suggest that isolated fragments sustain debilitated assemblages of butterflies in relation to those supported by continuous fragments.

Considering the obtained results, it was verified the importance of the study for a region where the fragmentation effect is evident and growing. The results corroborate Ribeiro et al. (2008) who signaled that most efforts are aimed at the conservation of primitive areas of continuous forest, but one cannot neglect the importance of preserving fragmented local landscapes.

In conclusion, there were variations in composition, abundance and species richness of fruit-feeding butterflies in the different sampled environments. The assemblages of fruit-feeding butterflies have their composition changed, with a loss of species from one environment to another. Considering the ecological importance of fruit-feeding butterflies, the results point to studies on fruit-feeding butterflies as bioindicators, providing ecological analyses, for initiatives to monitor and preserve the Lepidoptera fauna in the State of Santa Catarina and Southern Brazil.

Author Contributions

All authors contributed to the study conception and design. All authors contributed in the preparation, data collection and analysis. The first draft of the manuscript was written by SM Sabedot-Bordin and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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CAPÍTULO 3

Environmental variables influence the diversity of fruit-feeding butterflies in forest fragments in southern Brazil [3]

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Abstract

Understanding the influence of regional environmental variables on the communities of fruit-feeding butterflies is extremely relevant in the face of the current scenario of increasing forest fragmentation and an increase in the number of secondary forests in the tropics. This study aimed to: 1) analyze the influence of abiotic (temperature, relative air humidity, luminosity and wind speed) and biotic variables (canopy height and openness) on composition, abundance and richness of fruit-feeding butterflies in Conservation Units and adjacent forest fragments (FFs); 2) analyze whether abundance and richness increase with size of forest fragments and decrease with isolation. The study was conducted in the Chapecó National Forest (FLONA), Mata Preta Ecological Station (ESEC) and Araucárias State Park (PAEAR) and their respective FFs, Western region of the state of Santa Catarina, Brazil. Butterflies were collected using Van Someren-Rydon traps between December 2017 and March 2018, totaling 24 sampling days. Our results show that: 1) abundance and richness in FLONA and PAEAR were positively related to relative air humidity, temperature and luminosity; 2) luminosity and relative air humidity were the most significant abiotic variables for species composition; 3) there was a positive relation of richness to canopy height and openness (only abundance for ESEC), and positive relation of abundance to canopy openness in areas of FLONA. The composition of fruit-feeding butterflies in FLONA varied with canopy height and openness (only openness in ESEC). Abundance showed a positive relation to isolation in FLONA. This knowledge can be useful to elaborate future management and conservation plans for the fauna of subtropical butterflies in Atlantic Forest in Brazil.

Keywords: Lepidoptera, Mixed Ombrophilous Forest, Atlantic Forest, Nymphalidae

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[3] O capítulo segue as normas do periódico Journal of Insect Conservation

Introduction

All animal species need an adequate environment to ensure survival, and this environment is mainly determined by the correlation between different abiotic variables such as temperature, wind speed, relative air humidity, luminosity and atmospheric pressure (Checa et al. 2014). These variables affect essential activities of species such as reproduction, growth, and feeding (Navarro-Cano et al. 2015), determining patterns of species distribution as well (Graae et al. 2011). Additionally, these abiotic variables regulate the development plants that serve as hosts for butterflies (Navarro-Cano et al. 2015).

Butterflies are ectothermic organisms and, therefore, respond quickly to climatic changes in their habitats (Bonebrake et al. 2010). Abiotic variables influence diversity patterns in butterflies communities (Bale et al. 2002) and climate may act on the community of fruit-feeding butterflies, increasing mortality levels or changing food availability (Checa et al. 2009). Biotic variables also influence diversity, being associated with vegetation structure (Koh and Sodhi 2004; Pardonnet et al. 2013) and canopy openness in forests (Barlow et al. 2007), which explain the composition, abundance and richness of fruit-feeding butterflies of a certain place (Bonebrake et al. 2010).

Understanding the influence of regional environmental variables on the communities of fruit-feeding butterflies is extremely relevant in the face of the current scenario of increasing forest fragmentation and an increase in the number of secondary forests in the tropics (Tabarelli et al. 2004). Size and isolation level of forest fragments are important metrics that can affect insect communities (Major et al. 2003; Veddeler et al. 2005). In this respect, the area of the forest fragment can influence the abundance of resources, as well as the complexity of the vegetation structure (Laurance et al. 2006). There is a positive relationship between the area of a forest fragment and its number of species, and a negative relationship between isolation and number of species (Tabarelli et al. 2008, 2010). For Rosch et al. (2013), the number of species can decrease with an increase in isolation in small fragments but not in complex landscapes with large fragments.

In this context, it is necessary to conduct studies that emphasize the influence of abiotic and biotic variables on the composition, abundance, and species richness in assemblages of fruit-feeding butterflies in Conservation Units and adjacent forest fragments, since it is fundamental to know the effects of these variables on the community of fruit-feeding butterflies in the face of the current rate of destruction of forest remains. Thus, this study aimed to answer the following question: which biotic and abiotic variables influence the composition, abundance and species richness of assemblages of fruit-feeding butterflies?

For this purpose, we tested the following hypotheses: 1) abiotic variables (temperature, relative air humidity, luminosity and wind speed) influence the composition, abundance and species richness of fruit-feeding butterflies in Conservation Units and adjacent forest fragments; 2) canopy height and cover have a positive effect on the composition, abundance and species richness of fruit-feeding butterflies; 3) abundance and species richness of fruit-feeding butterflies increase with an increasing area of the forest fragment and decrease with increasing isolation.

Methods

Study Areas

The study was conducted in two federal Conservation Units: National Forest of Chapecó (FLONA) (27°06'24.8" S and 52°46'59.3" W) and Ecological Station of Mata Preta (ESEC) (26°30'57.31" S and 52°7'59.69" W) and one state-level Conservation Unit, State Park of Araucárias (PAEAR) (26º27'08" S and 52º33'56" W). All Conservation Units are fully protected and located in the Western region of the state of Santa Catarina, Southern Brazil (Figure 1) and inserted in the Atlantic Forest biome with forest phytophysiognomies classified as Mixed Ombrophilous Forest (Araucaria Forest) with different stages of succession (Dick et al. 2013).

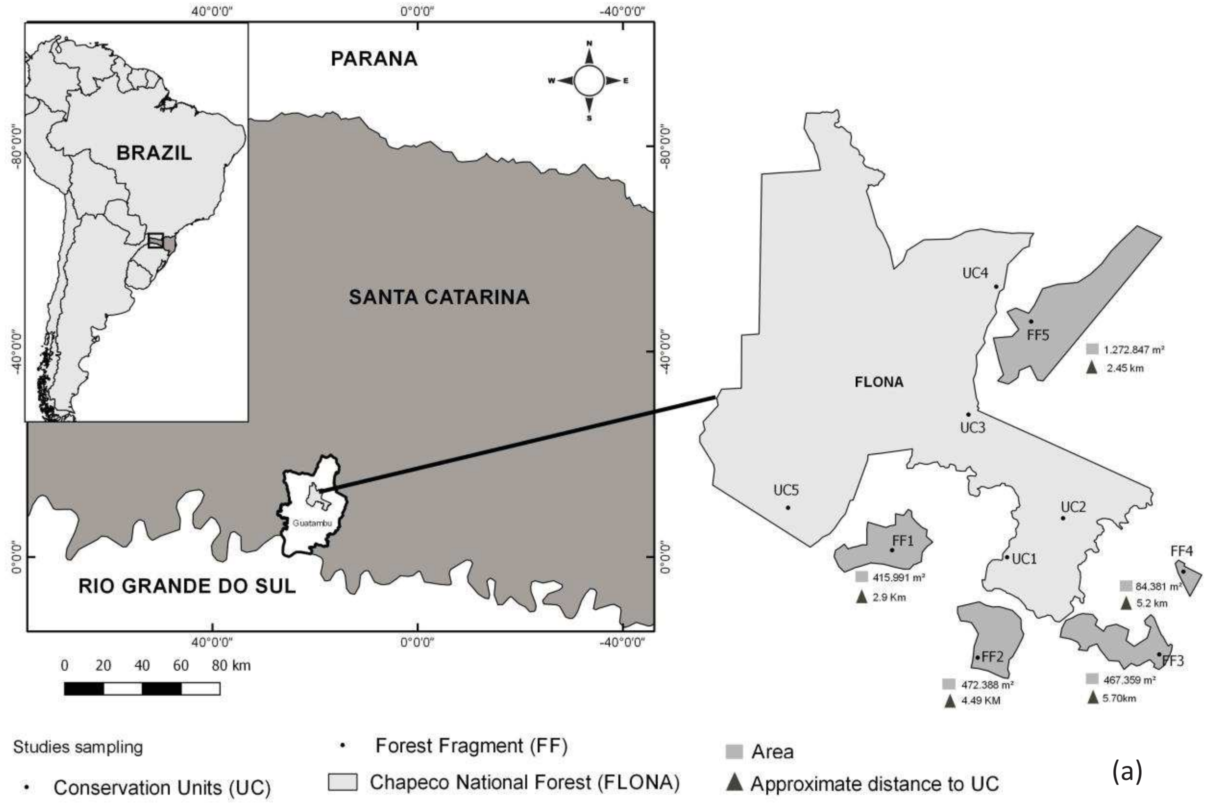
FLONA is located in the municipalities of Chapecó and Guatambú and was implemented in 1968 and has an area of 1590 ha. Sampling of fruit-feeding butterflies occurred in FLONA's fragment I, with an area of 1287.54 ha, located in Guatambú (ICMBio 2013) (Figura 1a). The ESEC of Mata Preta was established in 2005, has an area of 6536 ha and is located in the municipality of Abelardo Luz (Apremavi 2009) (Figura 1b). PAEAR was created in 2003 and covers an area of 612.5 ha between the municipalities of São Domingos and Galvão (FATMA 2016) (Figura 1c).

The climate of Western Santa Catarina is of the Cfa type, subtropical humid with abundant rainfall well distributed throughout the year. The average annual temperature is lower than 18 ºC and average temperatures vary from 13 ºC to 25 ºC (Alvares et al. 2014).

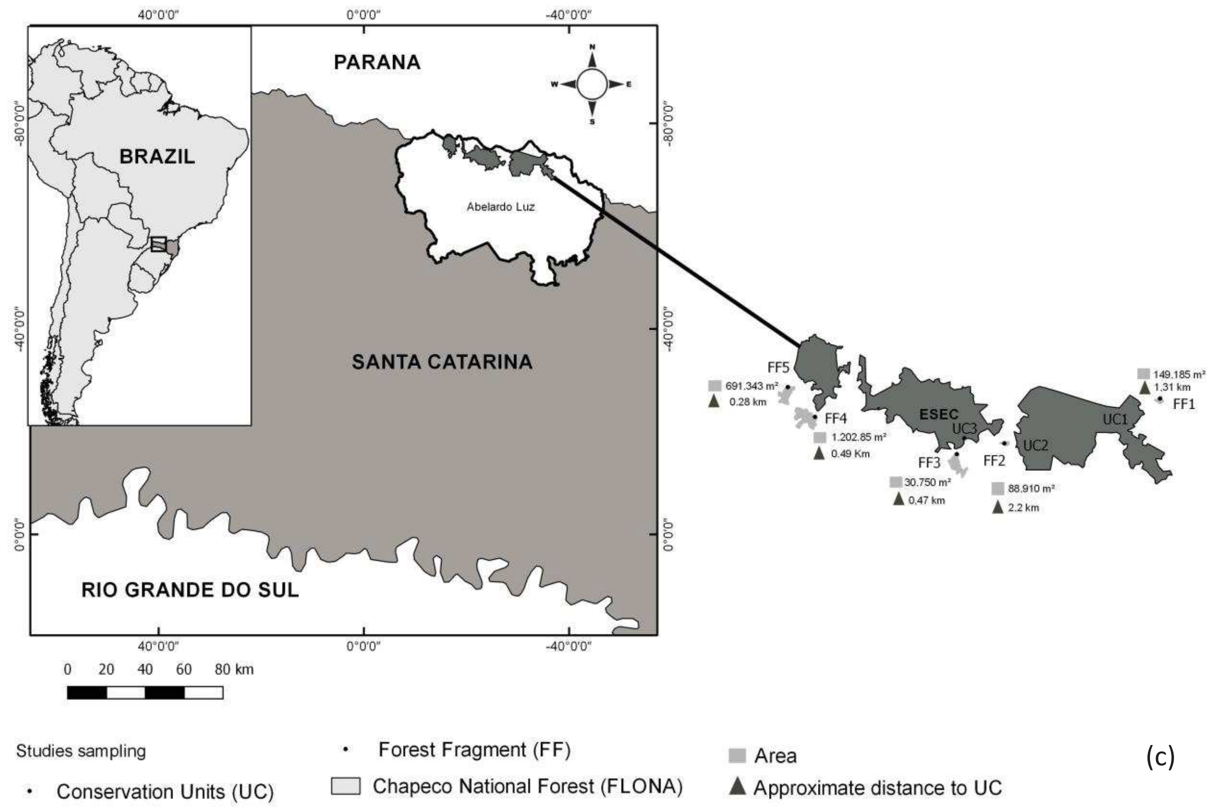
Sampling Design

For the sampling of fruit-feeding butterflies, we defined five sampling units for FLONA, five for PAEAR and three for ESEC inside the Conservation Units (CU) and a single sampling unit in each of the adjacent forest fragments (FF) of each CU. We defined five FF for FLONA

(FF1=27° 6'51.10" S; 52°46'21.11" W; FF2=27° 7'32.57" S; 52°45'43.97" W; FF3=27° 7'31.32" S; 52°44'25.14" W; FF4=27° 6'59.38" S; 52°44'14.62" W; FF5=27° 5'27.68" S; 52°45'21.10" W) and ESEC (FF1=26°28'30.03" S; 52° 9'11.14" W; FF2=26°29'51.83" S; 52°14'28.17" W; FF3=26°30'16.01" S; 52°16'21.44" W; FF4=26°28'55.85" S; 52°21'56.52" W; FF5=26°27'52.82" S; 52°23'01.03" W) and four for PAEAR (FF1=26°27'14.85" S; 52°34'30.77" W; FF2=26°28'36.15" S; 52°33'28.18" W; FF3=26°27'49.60" S; 52°32'56.19" W; FF4=26°26'56.54" S; 52°33'30.69" W) (Figura 1). FF had different sizes and distances from the CU. The area of the FF varied from 30.750 to 1272.847 m² and distances varied from 0.28 to 5.7 km (Figura 1). There was a minimum distance of 250 m between FF (Freitas et al. 2014).



(a)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PARANA
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SANTA CATARINA
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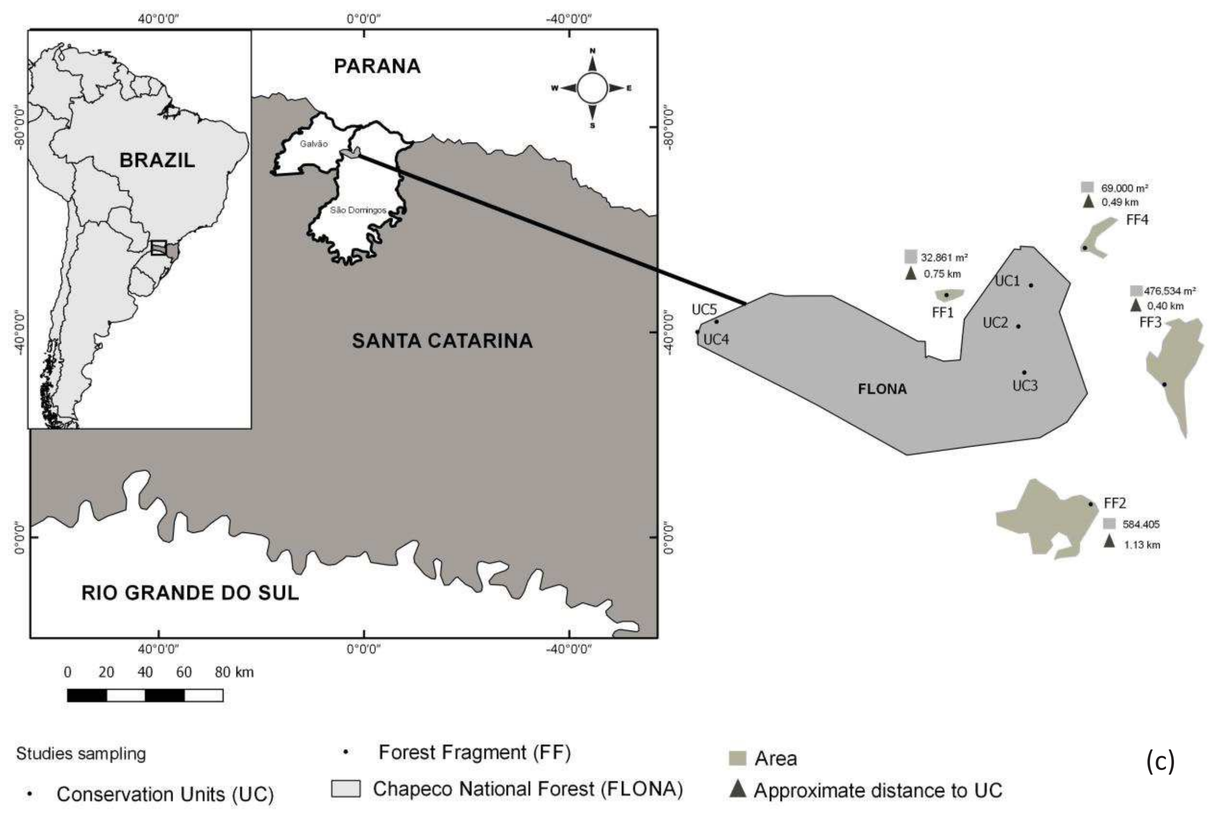
0 20 40 60 80 km
FF5
691.343 m²
0.28 km
FF4
1.202.85 m²
0.49 Km
ESEC
UC3
FF3
30.750 m²
0.47 km
FF2
UC2
88.910 m²
2.2 km
UC1
149.185 m²
1,31 km
FF1
Studies sampling
Conservation Units (UC)
Forest Fragment (FF)
Chapeco National Forest (FLONA)
Area
Approximate distance to UC

(c)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0 20 40 60 80 km
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FF4
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0,75 km
FF1
UC1
UC2
UC3
UC5
UC4
FLONA
476.534 m²
0,40 km
FF3
FF2
584.405
1.13 km
Studies sampling
Conservation Units (UC)
Forest Fragment (FF)
Chapeco National Forest (FLONA)
Area
Approximate distance to UC

(c)

Figure 1. Map of the study areas and sample units for collections of frugivorous butterflies in the municipalities of Guatambú, Abelardo Luz and São Domingos, Santa Catarina, from December 2017 to March 2018; a= FLONA; b= ESEC; c=PAEAR.

Each sampling unit consisted of a linear transect. In the transect, the first trap was placed at a distance of at least 50 m from the edge (DeVries 1997; Uehara-Prado 2003; Freitas et al. 2014). We used five traps in each transect (DeVries 1997) laced 30 to 50 m from each other (Santos et al. 2014) according to the availability of places to suspend them on the trees. Different transects in the sampling units were placed at least 250 m from each other (Freitas et al. 2014). We installed a total of 135 traps, of which 50 were in FLONA/FF (25/25); 40 in ESEC/FF (15/25) and 45 in PAEAR/FF (25/20).

We conducted three samplings in each CU and its respective FF from December 2017 to March 2018, totaling 21 sampling days. Traps were kept active in the field during seven consecutive days in each sampling and were checked every 48 hours to remove specimens and replace baits (Freitas et al. 2014).

The sampling procedure followed the protocol established by the National Lepidoptera Research and Conservation Network (RedeLep). We used Van Someren-Rydon traps. Traps were suspended on trees using ropes at a height of about 1.5 m above the ground (Uehara-Prado et al. 2005). Each trap received a 50-ml plastic bottle with an attractive bait consisting of a mixture of sugarcane juice with ripe bananas in the proportion of 1/3 prepared 48 hours before the beginning of the samplings to allow fermentation (Uehara-Prado et al. 2005).

Butterflies preservation

Sampled specimens were sacrificed by thoracic pressure at the base of the wings and placed in properly identified entomological envelopes (Almeida et al. 1998). Collected butterflies were taken to the Laboratory of Ecological Entomology (LABENT-Eco) of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ) in Santa Catarina, Brazil, for freezer storage and later determination of the species.

Butterflies species determination

Determination was based on specialized literature (Canals 2003, Lamas 2004, Wahlberg 2009) and the use of an online guide (http://butterfliesofamerica.com). Additionally, determination was conducted by experts of the Universidade Estadual de Campinas (UNICAMP) and the Universidade Federal do Paraná (UFPR).

Specimens of each sampled species were deposited in the reference collection of the Laboratory of Ecological Entomology (LABENT-Eco) of the Universidade Comunitária da Região de Chapecó (UNOCHAPECÓ), Chapecó, Santa Catarina and in the Zoological Collection of the Universidade do Vale do Rio dos Sinos (MZ UNISINOS), São Leopoldo, Brazil. Samplings were authorized by ICMBio (Collection License ICMBio/SISBio 60789-1).

Metrics of abiotic variables

During the samplings, we measured abiotic variables (temperature, relative air humidity, luminosity and wind speed) using a portable digital thermo-hygro-anemometer-luminosity meter Instrutherm, model Thal-300. The measurement of abiotic variables was performed in all samples. In each linear transect, we select traps 1, 3 and 5 to measure abiotic variables. The variables were measured at a height of 1.2 m above the ground and close to the trap. In each sampling unit and in each collection, we calculate the average of the abiotic measures of the traps.

Metrics of the biotic variables

To measure canopy openness, we used a convex spherical densiometer LEMMON (Lemmon 1956). The spherical densiometer consists of a convex reflective metal piece made up of 24 quadrants to reflect the incoming luminosity at an angle of 180 degrees. The equipment's mirror is attached to a wood piece with a bubble for leveling during the reading. The canopy image is reflected on the metal piece and each quadrant is divided into four parts, where each part has the value of one point, totaling 96 points (Lemmon 1957). After leveling the equipment (when the bubble is in the middle of the circle), it was placed at the height of the elbow, about 1 m above the ground and away from the body, forming a 90-degree angle and avoiding the reflection of parts of the measurer's body on the equipment. The sum of the number of illuminated dots in each of the four quadrants of the mirror was considered. This procedure was repeated for each of the four cardinal points (North, South, East and West) (Lemmon 1956). The measurement was always performed by the same person (Werneck et al. 2004). To obtain the measurement of canopy openness (%), we used the sum of the illuminated dots of the cardinal points and took the mean. This mean was multiplied by 1.04 (correction factor of the equipment) (Lemmon 1956).

To obtain the measurement of canopy height, we used a digital clinometer ECII HAGLOF. We defined a distance from the measurer to the tree (1 to 2 m). From the central point of the three, the measurement was conducted by looking in a horizontal line from the tree's base to the crown through the equipment's viewer, pressing the ON button. This way, the measurer covered the whole tree up to the top and released the button, obtaining the measure. The height of the canopy is recorded in the equipment's screen (Silva et al. 2012). Canopy height was measured in all traps.

The distance from the edge of each FF to the edge of the CU was used as an insulation measure (Metzger 2003). The area of each FF and the distance of the FF to the CU were obtained using Google Earth Pro (version 7.0).

Data Analysis

The relationship between abiotic variables and abundance and richness of fruit-feeding butterflies was assessed from an analysis of multiple linear regression of the stepwise type for each sampled area, separately. Abundance and species richness were considered as response variables and abiotic variables as predictors. Abiotic variables were tested for normality with the Shapiro-Wilk test and, if not reaching the assumption, were linearized. Analyses were conducted in the program Bioestat (Ayres et al. 2007).

We assessed the association between the composition of fruit-feeding butterflies of each CU with abiotic variables using Canonical Correspondence Analyses (CCA) through the program Canoco For Windows (Ter Braak and Smilauer 1998). For this analysis, we built two matrices, one containing the composition with the abundance of the fruit-feeding butterflies sampled in each environment and the other with the respective abiotic variables. The matrix of microclimatic variables was standardized by subtracting the corresponding value of each variable in each sample from the respective mean and dividing this difference by the respective standard deviation. Species of fruit-feeding butterflies with one or two occurrences were removed from the analysis. The statistical significance of the relationship between all the occurrences of species of fruit-feeding butterflies and the microclimatic variables was assessed through the Monte Carlo test with 499 permutations (Ter Braak and Smilauer 2002; Izhaki et al. 2009). The variables that did not show significance ($p < 0.05$) were removed from the analyses.

The hypothesis that canopy height and cover have a positive effect on richness and abundance of fruit-feeding butterflies was tested with Generalized Linear Models (GLMs) (Zuur et al. 2009). The response variables were inspected for the distribution of Poisson-type errors since they consist of discrete variables (positive integers). The models were initially built using Poisson distribution and were investigated regarding overdispersion (variation that is greater than the mean). The models with species richness as the response variable did not show overdispersion and the Poisson distribution was maintained. On the other hand, the models with abundance as the response variable showed overdispersion and were changed into a negative binomial distribution (Zuur et al. 2009) using the package 'MASS' (Venables and Ripley 2002). The models were validated with a visual inspection of the Pearson residuals versus the adjusted values.

To test the hypothesis that canopy height and cover had a positive effect on the composition of fruit-feeding butterflies, we applied multivariate generalized linear models (Warton et al. 2012) using the negative binomial distribution. The analysis was conducted with the package 'mvabund' (Wang et al. 2012, 2019).

The relation of the abundance and richness of fruit-feeding butterflies to the area of the forest fragment and its level of isolation was tested with GLMs (Zuur et al. 2009). The models were originally build using the distribution of Poisson-type errors and were investigated regarding overdispersion (variance higher than the mean). The models with species richness as the response variable did not show overdispersion and the Poisson-type dispersion was maintained. On the other hand, the models with abundance as the response variable showed overdispersion and were changed into a negative binomial distribution (Zuur et al. 2009) using the package 'MASS' (Venables and Ripley 2002). The models were validated with a visual inspection of the Pearson residuals versus the adjusted values. The GLMs were performed in the R software (R Core Team 2018).

Results

We sampled 4231 fruit-feeding butterflies of the family Nymphalidae belonging to four subfamilies, 12 tribes, 34 genera and 49 species. We sampled 37 species in FLONA and 29 in its respective FF. In ESEC, we recorded 29 species, with 33 in the FF. In PAEAR, we sampled 33 species, with 28 in the FF. The complete species-list can be found in Sabedot-Bordin et al. (2019).

For the dependent variables, abundance and richness of fruit-feeding species, the correlations obtained by the multiple regression analysis, when related to some abiotic (predictor) variables such as relative air humidity, temperature and luminosity, were significant. However, we highluminosity a negative correlation between the variables in the areas sampled in ESEC (Table 1).

Table 1 Values of multiple regression of abiotic factors (temperature, relative air humidity, luminosity and wind speed) in relation to abundance and species richness of frugivorous butterflies in FLONA, ESEC, PAEAR and their respective adjacent forest fragments in the Western Santa Catarina, Southern Brazil. Abundance was transformed into the log(N+1) scale. Factors with significant effects ($p < 0.05$) are highluminosityed in bold.

FLONA					
Abundance			Richness		
$F_{(4,115)} = 5.5688$	$R^2 = 0.1331$	$p = 0.0006$	$F_{(4,115)} = 6.844$	$R^2 = 0.1642$	$p = 0.0002$
Factors	R	p	Factors	R	p
Temperature	0.166	0.1069	Temperature	-0.0138	0.8908
Humidity	-0.0821	0.3951	**Humidity**	**-0.3263**	**0.0008**
Luminosity	**0.2172**	**0.0329**	Luminosity	0.1877	0.0600
Wind Speed	0.079	0.4181	Wind Speed	0.0784	0.4132
ESEC					
Abundance			Richness		
$F_{(4,91)} = 1.3241$	$R^2 = 0.0135$	$p = 0.2661$	$F_{(4,91)} = 1.2601$	$R^2 = 0.0108$	$p = 0.2908$
Factors	R	p	Factors	R	p
Temperature	0.2205	0.0904	Temperature	0.1522	0.2412
Humidity	0.1541	0.2177	Humidity	-0.0954	0.4447
Luminosity	0.1061	0.3338	Luminosity	-0.0867	0.4297
Wind Speed	0.0048	0.9630	Wind Speed	0.0845	0.4142
PAEAR					
Abundance			Richness		
$F_{(4,103)} = 10.9659$	$R^2 = 0.2714$	$p = 0.0001$	$F_{(4,103)} = 4.7953$	$R^2 = 0.1243$	$p = 0.0017$
Factors	R	p	Factors	R	p
Temperature	**0.5015**	**0.0001**	**Temperature**	**0.3738**	**0.0008**
Humidity	**0.5439**	**0.0001**	**Humidity**	**0.3636**	**0.0007**
Luminosity	-0.0225	0.8055	Luminosity	-0.0493	0.6224
Wind Speed	-0.1104	0.2092	Wind Speed	-0.1296	0.1790

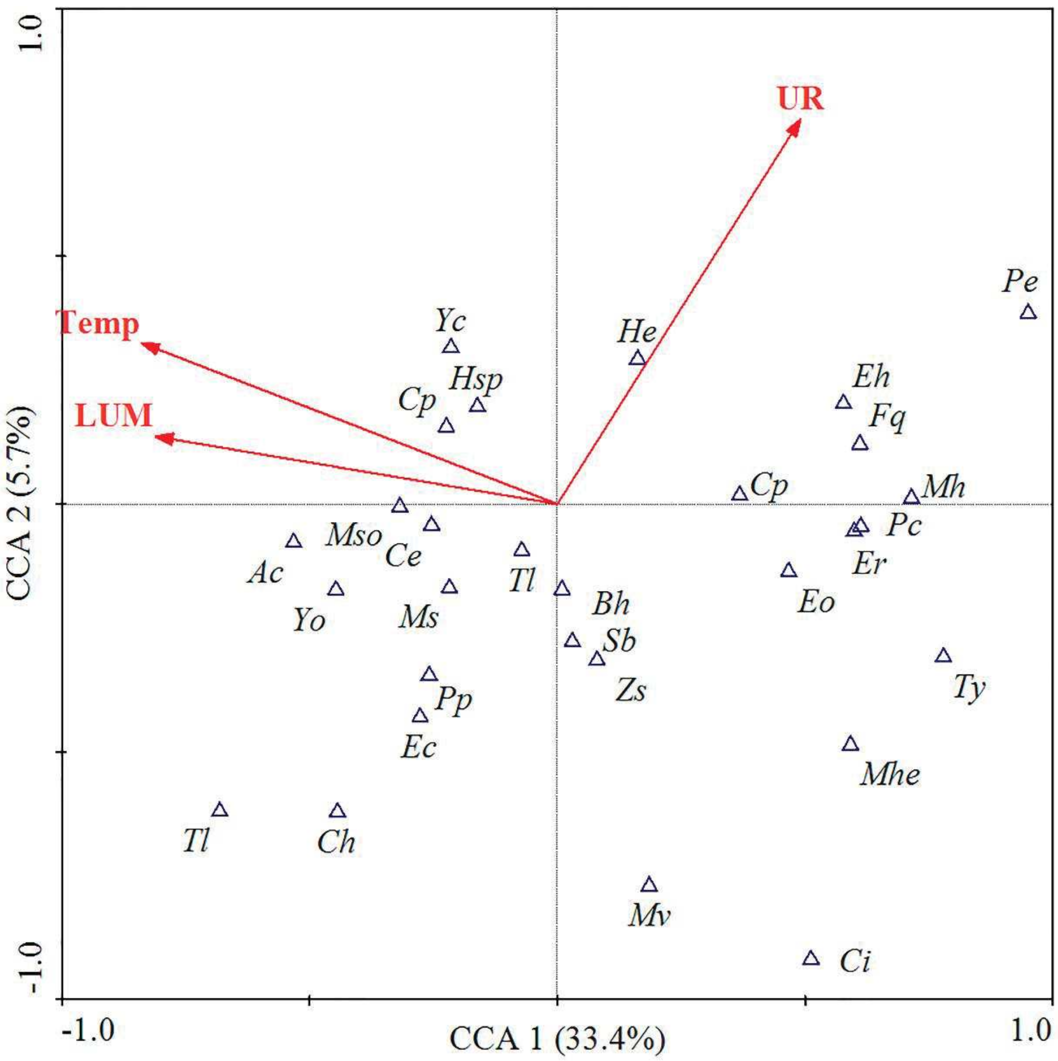

Fig. 1 Canonical correspondence analysis (CCA) comparing the matrix of abiotic (Temperature=Temp; relative air humidity=UR; luminosity=LUM; wind speed=VV) with the matrix of abundance of fruit-feeding butterflies (▲) of the forest fragments of FLONA sampled from December 2017 to March 2018 in Guatambú, Santa Catarina, Southern Brazil. Triangles represent taxa and arrows represent environmental variables. Species names are represented by the following abbreviations: *Archeoprepona chalciope*: Ac; *Biblis hyperia*: Bh; *Callicore hydaspes*: Ch; *Calligo illioneus*: Ci; *Carminda paeon*: cp; *Cissia eous*: Ce; *Cissia phronius*: Cp; *Epiphile hubneri*: Eh; *Epiphile orea*: Eo; *Eryphanes reevesii*: Er; *Euptychoides ordinaria*: Ec; *Forsterinaria quantius*: Fq; *Hamadryas epinome*: He; *Hermeuptychia* sp: Hsp; *Manataria hercyna*: Mh; *Memphis acidalia victoria*: Mv; *Memphis moruus stheno*: Ms; *Moneuptychia soter*: Mso; *Morpho helenor*: Mhe; *Pareuptychia ocirrhoe*: Pc; *Paryphthimoides poltys*: Pp; *Pseudodebis euptychidia*: Pe; *Smyrna blomfildia*: Sb; *Taygetis laches*: Tl; *Taygetis yptima*: Ty; *Temenis laothoe*: Tla; *Yphthimoides celmis*: Yc; *Yphthimoides ordinaria*: Yo; *Zaretis strigosus*: Zs;

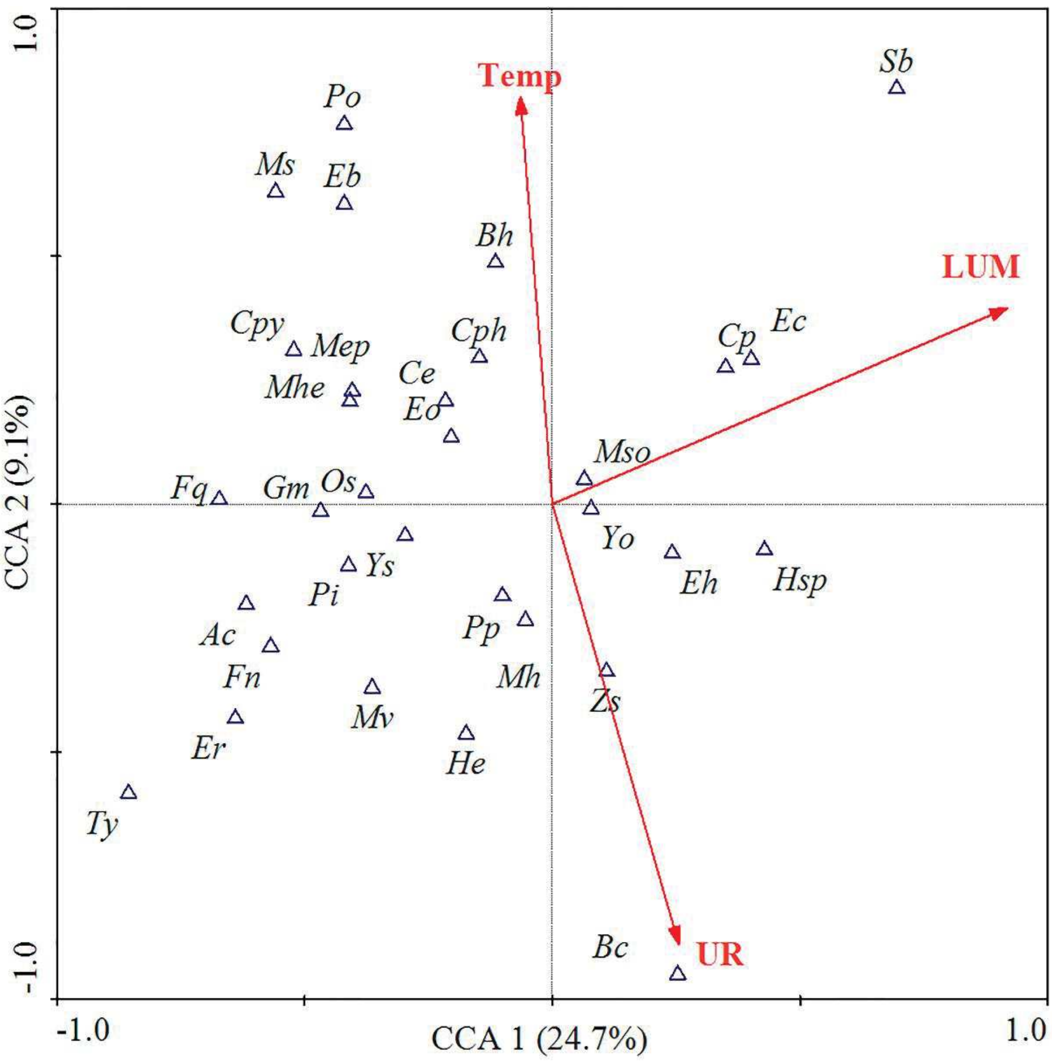

Fig. 2 Canonical correspondence analysis (CCA) comparing the matrix of abiotic (Temperature=Temp; relative air humidity=UR; luminosity=LUM; wind speed=VV) with the matrix of abundance of species of fruit-feeding butterflies (▲) of the forest fragments of ESEC sampled from December 2017 to March 2018 in Abelardo Luz, Santa Catarina, Southern Brazil. Triangles represent taxa and arrows represent environmental variables. Species names are represented by the following abbreviations: *Archeoprepona chalciope*: Ac; *Biblis hyperia*: Bh; *Blepolenis bassus*: Bb; *Blepolenis catharinae*: Bc; *Carminda paeon*: cp; *Cissia eous*: Ce; *Cissia phronius*: Cp; *Cybdelis phaesyla*: Cpy; *Epiphile hubneri*: Eh; *Epiphile orea*: Eo; *Eryphanes reevesii*: Er; *Eunica eburnea*: Eb; *Euptychoides castrensis*: Ec; *Forsterinaria necys*: Fn; *Forsterinaria quantius*: Fq; *Godartiana muscosa*: Gm; *Hamadryas epinome*: He; *Hermeuptychia* sp: Hsp; *Manataria hercyna*: Mh; *Memphis acidalia victoria*: Mv; *Memphis moruus stheno*: Ms; *Moneuptychia soter*: Mso; *Morpho epistrophus*: Mep; *Morpho helenor*: Mhe; *Opoptera sulcius*: Os; *Opsiphanes invirae*: Pi; *Pareuptychia ocirrhoe*: Po; *Paryphthimoides poltys*: Pp; *Pseudodebis euptychidia*: Pe; *Smyrna blomfildia*: Sb; *Taygetis yptima*: Ty; *Yphthimoides ordinaria*: Yo; *Yphthimoides straminea*: Ys; *Zaretis strigosus*: Zs.

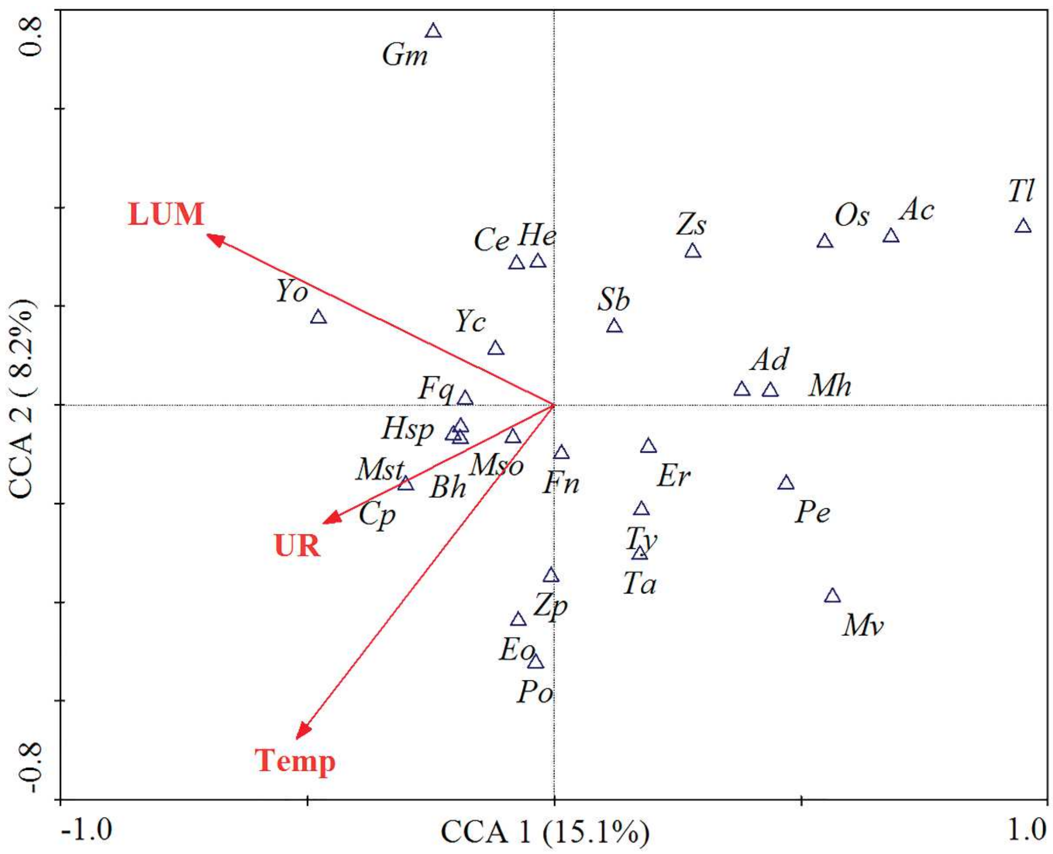

Fig. 3 Canonical correspondence analysis (CCA) comparing the matrix of abiotic (Temperature=Temp; relative air humidity=UR; luminosity=LUM; wind speed=VV) with the matrix of abundance of species of fruit-feeding butterflies (▲) of the forest fragments of PAEAR sampled from December 2017 to March 2018 in São Domingos, Santa Catarina, Southern Brazil. Triangles represent taxa and arrows represent environmental variables. Species names are represented by the following abbreviations: *Archaeoprepona demophon*: Ad; *Archeoprepona chalciope*: Ac; *Biblis hyperia*: Bh; *Cissia eous*: Ce; *Cissia phronius*: Cp; *Epiphile orea*: Eo; *Eryphanes reevesii*: Er; *Forsterinaria necys*: Fn; *Forsterinaria quantius*: Fq; *Godartiana muscosa*: Gm; *Hamadryas epinome*: He; *Hermeuptychia* sp: Hsp; *Manataria hercyna*: Mh; *Memphis acidalia victoria*: Mv; *Memphis moruus stheno*: Mst; *Moneuptychia soter*: Mso; *Opoptera sulcius*: Os; *Pareuptychia ocirrhoe*: Pc; *Pseudodebis euptychidia*: Pe; *Smyrna blomfildia*: Sb; *Taygetis acuta*: Ta; *Taygetis yptima*: Ty; *Yphthimoides celmis*: Yc; *Yphthimoides ordinaria*: Yo; *Zaretis strigosus*: Zs; *Zichkaia pacarus*: Zp

In the multiple regression analysis, for FLONA, we found that species richness was explained by 18% (F = 6.844, R2 = 0.1642, p = 0.0002), having a negative relation to relative air humidity (R2 = -0.3263 and p = 0.0008). Abundance was explainde by 13.3% of the variation (F = 5.5688, R2 = 0.1331, p = 0.0006) and had a positive relation to luminosity (R2 = 0.2172 and p = 0.0329). The multiple regression analysis did not find influence of abiotic variables on abundance (p = 0.2661) and species richness (p = 0.2908) ESEC and FF. In

PAEAR, abundance ($R2 = 0.2714$ and $p = 0.0001$) was influenced by temperature ($R2 = 0.5015$ and $p = 0.0001$) and relative air humidity ($R2 = 0.5439$ and $p = 0.0001$). Species richness ($R2 = 0.1243$ and $p = 0.0017$) also had a positive correlation with temperature ($R2 = 0.3738$ and $p = 0.0008$) and relative air humidity ($R2 = 0.3636$ and $p = 0.0007$) (Table 1).

The results of the CCA showed that the abiotic variables explain between 23.3% and 39.1% of the assemblage of fruit-feeding butterflies sampled in the CU and FF. Luminosity and relative air humidity were the most significant variables. We verified a heterogeneous distribution of the species in the CCA axes. Thus, one can notice that the species appear scattered in the figures.

In the CCA of the sampled areas of FLONA, the variables did not contribute to the formation of the axes. Axis 1 of the graph explained 33.4% of the relation between fruit-feeding butterflies and abiotic variables and axis 2 explained 5.7% of the variation (Fig. 1). The graphic representation of the CCA revealed that the species sampled in the forest fragments of FLONA did not present a positive relation to the analyzed abiotic variables. We observed a positive relation of *Hermeuptychia* sp. with relative air humidity.

For the sampled areas of ESEC, the percentage of variation explained by the abiotic variables in axes 1 and 2 was 24.7% and 9.1%, respectively. In Fig. 2, we can observe that relative air humidity and luminosity contributed to the formation of both axes. Temperature had a negative relation to the species sampled in ESEC.

We highluminosity, in Fig. 2, that the species sampled in ESEC did not show association with the analyzed variables. However, there was a positive association of the species *Zaretis strigosus* (Gmelin, [1790]) with relative air humidity and of the species *Moneuptychia soter* (Butler, 1877) with luminosity.

For the FF of PAEAR, we found that in axes 1 (15.1%) and 2 (8.2%) of the CCA, species were significantly related to luminosity and relative air humidity. We highluminosity the relation of the species *Cissia phronius* (Godart, [1824]), *M. soter* and *Memphis moruus stheno* (Prittwitz, 1865) to relative air humidity. Also, *Yphthimoides ordinaria* (Freitas, Kaminski & Mielke, 2012), *Yphthimoides celmis* (Godart, 1824) and *Forsterinaria quantius* (Godart, 1824) showed association with luminosity (Fig. 3).

In the exploratory analysis of the GLM, we verified that the adjustment of species richness (response variable) with the Poisson distribution and canopy height and openness (exploratory variables) for each CU and respective FFs did not indicate overdispersion since the points are located within the envelope of the confidence interval, with the highluminosityed points (red) being the ones with the more extreme values for richness

(Appendix, Fig. 4, 5). Regarding the abundance (response variable) of fruit-feeding butterflies in relation to canopy height and openness (explanatory variables), GLM analysis with Poisson-type error distribution for each CU and their respective FFs indicated overdispersion for FLONA and ESEC because many points are located outside of the envelope of the confidence interval (Appendix, Fig. 6, 7).

Table 2 Results of the generalized linear models (GLM) of the biotic variables (canopy height and openness) for abundance and species richness of fruit-feeding butterflies in FLONA, ESEC, PAEAR and their respective adjacent forest fragments from December 2017 to March 2018 in Western Santa Catarina, Southern Brazil. Factors with significant effects ($p < 0.05$) are highluminosityed in bold.

FLONA					
Abundance			Richness		
		$pR^2 = 0.1249$			$pR^2 = 0.1852$
Factors	Estimate	P	Factors	Estimate	p
Intercept	2.743547	7.95e-07	Intercept	1.601370	1.86e-10
Canopy height	0.002915	0.9253	**Canopy height**	**0.032790**	**0.0209**
Canopy openness	**0.087902**	**0.0114**	**Canopy openness**	**0.018400**	**0.0130**
ESEC					
Abundance			Richness		
		$pR^2 = 0.2675$			$pR^2 = 0.1617$
Factors	Estimate	P	Factors	Estimate	p
Intercept	1.94274	0.00174	Intercept	2.011810	6.08e-08
Canopy height	0.04332	0.23636	Canopy height	-0.002825	0.898
Canopy openness	**0.08213**	**0.00147**	**Canopy openness**	**0.030807**	**0.039**
PAEAR					
Abundance			Richness		
		$pR^2 = 0.0176$			$pR^2 = 0.0137$
Factors	Estimate	*P*	Factors	R	*p*
Intercept	2.65657	6.24e-08	Intercept	2.115935	6.57e-10
Canopy height	-0.01274	0.582	Canopy height	-0.09778	0.544
Canopy openness	0.01518	0.600	Canopy openness	0.010458	0.601

The result of the generalized linear models (GLM) indicated a positive relation of species richness to canopy height (estimate = 0.032, p = 0.020) and openness (estimate = 0.018, p = 0.013) for the areas of FLONA. However, there was also a positive relation of abundance (estimate = 0.087, p = 0.011) of fruit-feeding butterflies to canopy openness (Table 2). For areas of ESEC, we observed a positive relation of abundance (estimate = 0.082, p = 0.001) and species richness (estimate = 0.030, p = 0.039) to canopy openness. On the other hand, there was no relationship between the analyzed variables in PAEAR (Table 2).

We observed, in the validation of the GLM using a negative binomial distribution for the species composition of FLONA, that there is no pattern in the residuals in relation to the adjusted values and the theoretical quantiles were adjusted for a normal distribution

(Appendix, Fig. 8). For ESEC and PAEAR, the model did not show patterns in the residuals in relation to the adjusted values except for some points gathered at the predictor's minimum value, and the theoretical quantiles were adjusted for a normal distribution (Appendix, Fig. 9, 10).

The composition of fruit-feeding butterflies in FLONA and FF varied according to dossel openness (LR = 198.19, p = 0.0009). In ESEC, we verified that composition varied according to dossel openness (LR = 9195, p = 0.002). However, in PAEAR, we did not find influence of the variables in the composition of fruit-feeding butterflies (Table 3).

Table 3 Results of the multivariate negative binomial GLM for the composition of fruit-feeding butterflies sampled in the Conservation Units and adjacent forest fragments from December 2017 to March 2018 in Western Santa Catarina, Southern Brazil. Significant values highluminosityed with an asterisk and bold. LR = Likelihood Ratio Test (calculated and tested value equivalent to ANOVA's F).

	FLONA		ESEC		PAEAR	
	LR value	pr(>LR)	LR value	pr(>LR)	LR value	pr(>LR)
Intercept	163.17	0.000999 ***	53.40	0.101	45.54	0.133
Canopy height	88.95	0.06993	44.27	0.299	37.52	0.306
Canopy openness	**198.19**	**0.000999 *** **	**91.95**	**0.002 ** **	42.43	0.157

In the exploratory analysis of the GLM, we verified that the adjustment of species richness (response variable) with Poisson-type error distribution and area and isolation level (exploratory variables) for the FF of the respective CU did not indicate overdispersion (Appendix, Fig. 11). For the abundance of fruit-feeding butterflies, the adjustment of the variable was done using a negative binomial, so there was also no overdispersion (Appendix, Fig. 12). Thus, the validation of the models of abundance and species richness for each sampled area (CU and FF) did not show patterns in the residuals in relation to the adjusted values.

Abundance in the FFs had a positive relation (Estimate = 0.627, p < 0,001) to the isolation level from FLONA (Table 4). However, there was a negative relation to the area. We also noticed that species richness in the FFs of FLONA had a negative relation to area and isolation level. For the FFs of both ESEC and PEAR, there was no influence of area and isolation level on the abundance and species richness of fruit-feeding butterflies (Table 4).

Table 4 Results of the multivariate negative binomial GLM for abundance and species richness of fruit-feeding butterflies according to the area of adjacent forest fragments and their distance from the respective Conservation Units in Western Santa Catarina, Southern Brazil. Significant values in bold.

		FLONA			
	Abundance			Richness	
		$pR^2 = 0.4845$			$pR^2 = 0.2015$
Factors	Estimate	p	Factors	Estimate	P
Intercept	1.1937128	0.150	**Intercept**	**1.77600**	**< 0,001**
Area	0.0004115	0.393	Area	3.236e-05	0.8858
Isolation	**0.6270351**	**< 0,001**	Isolation	1.256e-01	0.0639
		ESEC			
	Abundance			Richness	
		$pR^2 = 0.1193$			$pR^2 = 0.0671$
Factors	Estimate	p	Factors	Estimate	P
Intercept	**3.528285**	**< 0,001**	**Intercept**	**2.30500**	**< 0,001**
Area	-0.0001410	0.5183	Area	< 0,001	0.952
Isolation	-0.2665026	0.0559	Isolation	-6.851e-02	0.459
		PAEAR			
	Abundance			Richness	
		$pR^2 = 0.0380$			$pR^2 = 0.1229$
Factors	Estimate	p	Factors	R	P
Intercept	**2.0087604**	**< 0,001**	**Intercept**	**1.533689**	**< 0,001**
Area	0.0003256	0.621	Area	0.00539	0.176
Isolation	0.3506688	0.531	Isolation	0.251206	0.435

Discussion

The data set analyzed in this study includes assemblages of fruit-feeding butterflies in 27 sampling units including CU and their respective FF in areas of Mixed Ombriphilous Forest of the Atlantic Forest in Southern Brazil. The results of the multivariate analyses indicated differences regarding the percentage of variation explained by the set of tested abiotic and biotic variables.

Of the analyzed abiotic variables, It was found that the abundance and richness of frugivorous butterfly species are higher in environments with higher relative humidity. This variable is important to define the behavioral pattern of butterflies (Sims 2007). The result is corroborated by the explanation that some frugivorous butterflies, such as Brassolini and few *Taygetis* have more twilight habits, flying close to the ground and the understory (Marín et al. 2011). Generally, the richness and abundance of frugivorous butterflies tends to increase in the wet season because at this time there is a greater availability of food resources (DeVries et al. 1997). Luminosity was also significant in the study, affecting the abundance of fruit-feeding butterflies in FLONA. This result is explained by considering that butterflies need heat to reach certain body temperature and, consequently, be able to fly, and this heat comes from sunluminosity (Van Dyck and Matthysen 1998). Another relevant aspect to understand the study's results, as pointed out by Stefanescu et al. (2011), is that many butterflies species fly into the forests during the dry season looking for shadow and humidity.

We found a negative relation of temperature to species richness in the sampled areas, corroborating the study of Brown & Freitas (2000). Environmental temperature is an essential variable for the biology and physiology of ectothermic organisms such as butterflies and is fundamental to define the pattern of species distribution as it also affects food resources (Ribeiro et al. 2010; Ribeiro and Freitas 2010). Moreover, if butterflies are exposed to high temperatures, they may be at risk of desiccation, but temperatures that are too low may make them unable to escape predators, seek partners and lay eggs (Berwaerts and Van Dyck 2004).

Ribeiro et al. (2008) suggest that the distribution of resources by immature and adult stages could explain the patterns of grouping of species within forest fragments, as well as the influence of temperature, humidity and luminosity on the composition of fruit butterflies. This statement sustains the positive relationship of the results obtained in this study regarding the composition of fruit-feeding butterflies in CU and FF. For Ricklefs (2011), organisms are adapted to the physical conditions of their ecosystems. Thus, we highluminosity from the results that many butterflies species are limited or favored by specific abiotic variables of the habitats that they occupy. This explains the greater relationship of some of the fruit-feeding butterflies sampled in the CU and FF than others to the analyzed variables.

Canopy openness had a positive influence on the abundance of fruit-feeding butterflies, revealing to be a structuring variable of the community. This result goes against the study by Basset et al. (2012), where there were no significant differences in the abundance of butterflies in relation to the opening of the canopy. We agree with Brito et al. (2014), who report that the butterflies in habitats with a more open canopy have a natural resistance to low humidity levels, high temperatures and strong solar incidence.

The results allow us to point out that the opening of the canopy influenced the composition of the fruit-feeding butterflies community in the sampled areas, indicating the need for light for the fruit-feeding butterflies. Studies have shown a positive relation of abundance and species richness to vegetation structure (Hammer et al. 1997; Ramos 2000). Also, one can infer that understory cover can difficult the dispersion of some fruit-feeding butterflies species, as recorded by Uehara-Prado et al. (2005), as many Satyrinae show a pattern of low fluminosity. The study indicates that microhabitat-tolerant species in the sampled forest fragments may have their abundance increased with a reduction in canopy openness, corroborating the study of Brito et al. (2014).

From the results of our study, we believe that the negative relation of canopy height for all studied areas and canopy openness for ESEC and PAEAR can be related to understory cover. Zellweger et al. (2016) highluminosity that, in more open areas, with a more open canopy, the understory density tends to increase, providing a more illuminated environment and, therefore, more resources for butterflies, such as host plants and fruits. They also report that an environment with more understory cover may not be heterogeneous since there may be a dominance of some plant species.

The results of our study indicate that the abundance and species richness of fruit-feeding butterflies have a positive relation to canopy height and openness. These results corroborate the study of Weerakoon et al. (2015) that indicates that the abundance and species richness of butterflies tends to be greater in areas with greater canopy openness, although there are also records of a negative relation to canopy openness (Houlihan et al. 2013).

The hypothesis that the abundance of fruit-feeding butterflies increases with an increase in the area of the FF and decreases with isolation (distance from the CU) was confirmed for FLONA but without effect on species richness. However, regarding abundance and species richness in the other FF and CU, the hypothesis was rejected. The results are corroborated by the study by Veddeler et al. (2005), who states that the degree of isolation and the size of the forest fragment affect the assemblages of frugivorous butterflies. Uehara-Prado et al. (2006), indicate that the richness of frugivorous butterfly species was not related to the fragmentation effect, suggesting that there is a resistance of the Atlantic Forest butterflies to habitat modification. However, Uehara-Prado et al. (2006) describe clear patterns of distribution, when frugivorous butterfly species are analyzed individually, with some species very abundant in the fragmented landscape and absent in continuous landscapes, and vice versa. On the other hand, Krauss et al. (2003) did not record differences in richness regarding isolation. In a study area with fragments of Atlantic Forest, Ribeiro (2006) also did not record a relation of abundance and species richness to the area, concluding that the surrounding matrix is more important to determine the butterflies fauna than the size of the fragment.

Our results aimed to show an influence of abiotic and biotic variables on the assemblages of fruit-feeding butterflies sampled in CU and their respective FF in areas of Atlantic Forest in the Western region of Santa Catarina, Southern Brazil. The obtained results showed the relevance of the environmental and regional variables on the butterflies community since most of them had some level of significance for these insects. There are no studies with this approach in Santa Catarina. However, they are essential since, from these results, it is possible to understand the important relationship between species and how they are influenced by environmental variations, mainly in a scenario of environmental degradation and global climate change.

We suggest a continuity of the studies with the investigation of the influence of other environmental variables on the structuring of assemblages of fruit-feeding butterflies, such as environmental connectivity and integrity, presence of host plants for the caterpillars, food resources for adults, among others. However, we hope that this knowledge may be useful to elaborate future management and conservation plans of the subtropical butterflies fauna in the Mixed Ombrophilous Forest in Southern Brazil.

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Appendix

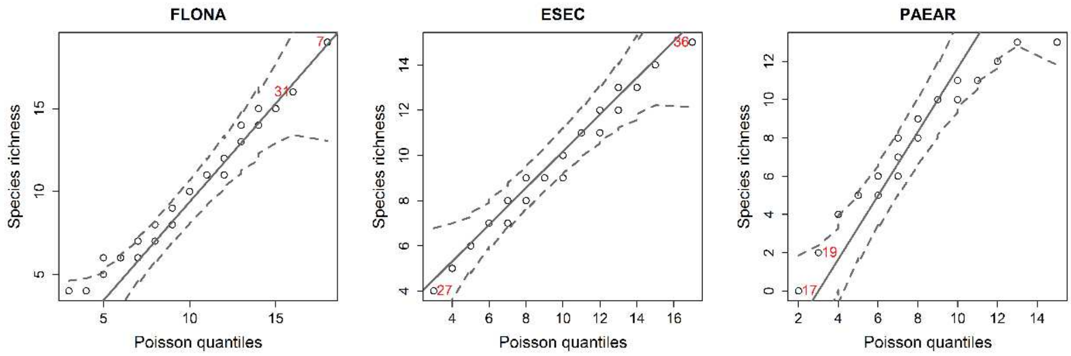

Fig. 4 Results of the analysis of the Generalized Linear Model (GLM) using the distribution of Poisson-type errors, indicating that there was no overdispersion in the model of species richness of fruit-feeding butterflies of each Conservation Unit and respective adjacent forest fragments sampled from December 2017 to March 2018 in the Western region of Santa Catarina, Southern Brazil. Red dots are points with the most extreme values for species richness.

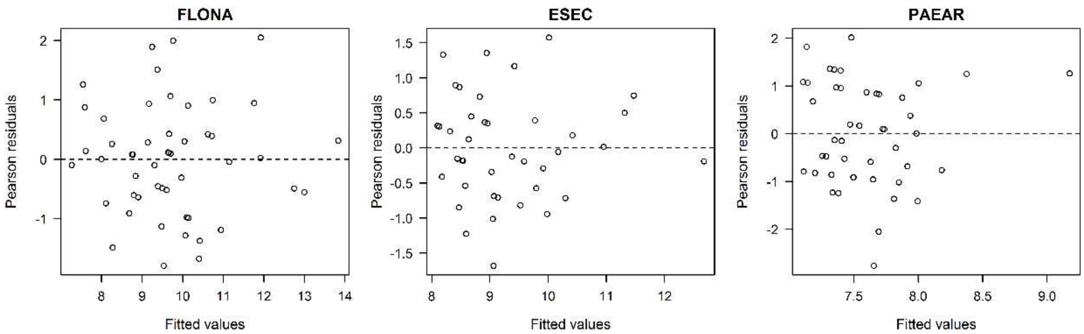

Fig. 5 Validation of the Generalized Linear Model (GLM) for species richness of fruit-feeding butterflies with dispersion of the Pearson residuals in relation to the adjusted values for each Conservation Unit and respective adjacent forest fragments.

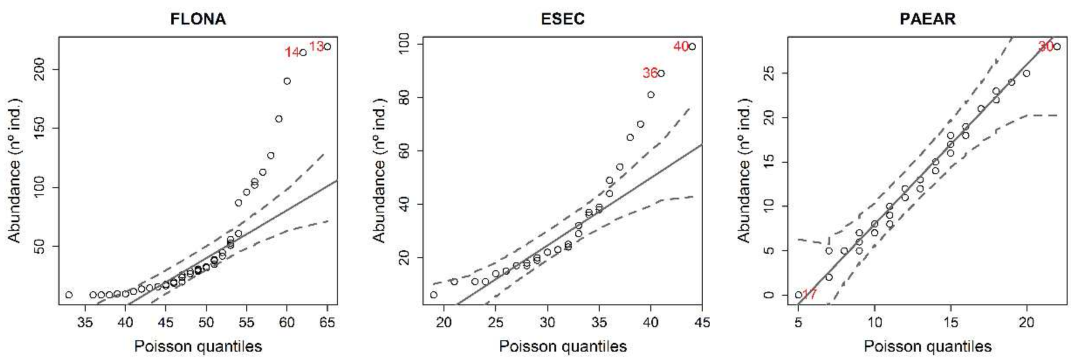

Fig. 6 Results of the analysis of the Generalized Linear Model (GLM) using the distribution of Poisson-type errors, indicating that there was no overdispersion in the model of the variable abundance of fruit-feeding butterflies of each Conservation Unit and respective adjacent forest fragments sampled from December 2017 to March 2018 in the Western region of Santa Catarina, Southern Brazil. Red dots are points with the most extreme values for species richness.

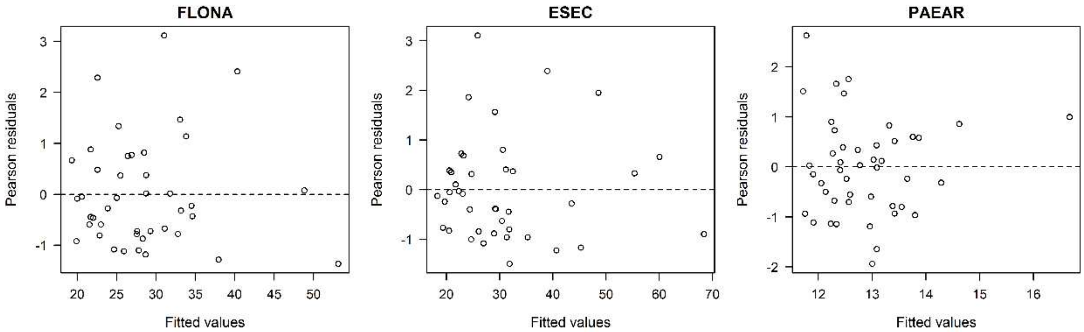

Fig. 7 Validation of the Generalized Linear Model (GLM) for the abundance of fruit-feeding butterflies with dispersion of the Pearson residuals in relation to the adjusted values for each Conservation Unit and respective adjacent forest fragments.

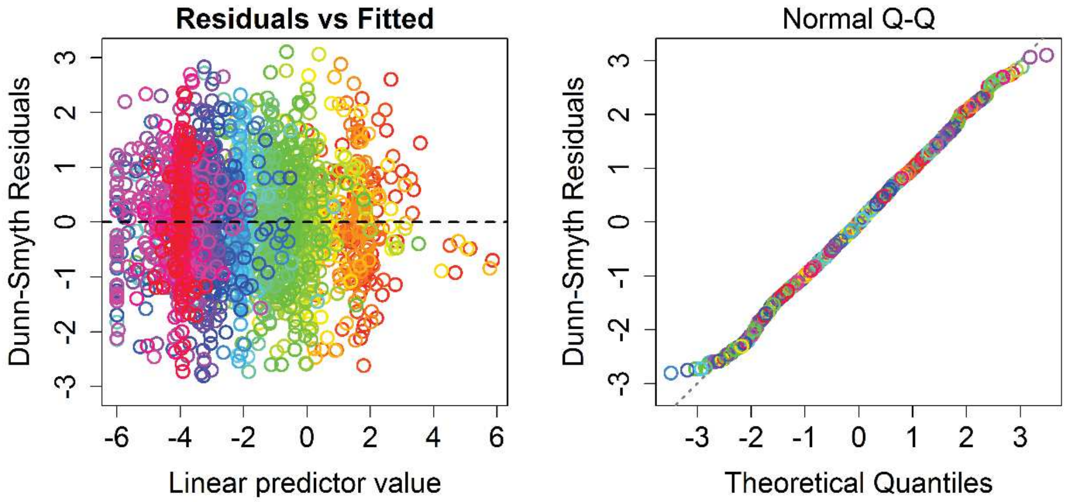

Fig. 8 Validation of the Generalized Linear Model (GLM) for the composition of fruit-feeding butterflies of FLONA and respective FF using the negative binomial distribution. Values adjusted for the Conservation Unit and respective adjacent forest fragments. Residuals in relation to the adjusted values (left); adjustment to the theoretical quantiles of a normal distribution (right).

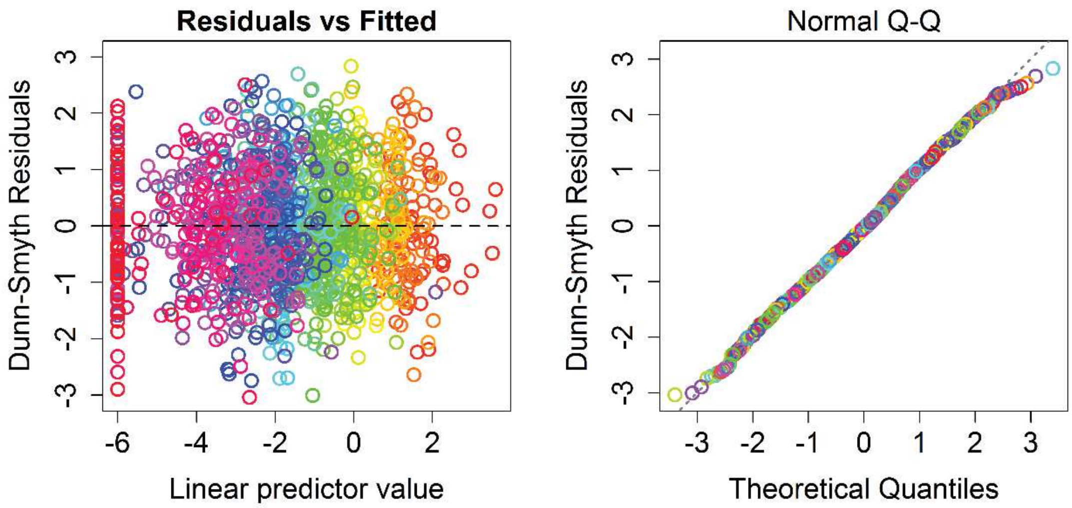

Fig. 9 Validation of the Generalized Linear Model (GLM) for the composition of fruit-feeding butterflies of ESEC and respective FF using the negative binomial distribution. Values adjusted for the Conservation Unit and its respective adjacent forest fragments. Residuals in relation to the adjusted values (left); adjustment to the theoretical quantiles of a normal distribution (right).

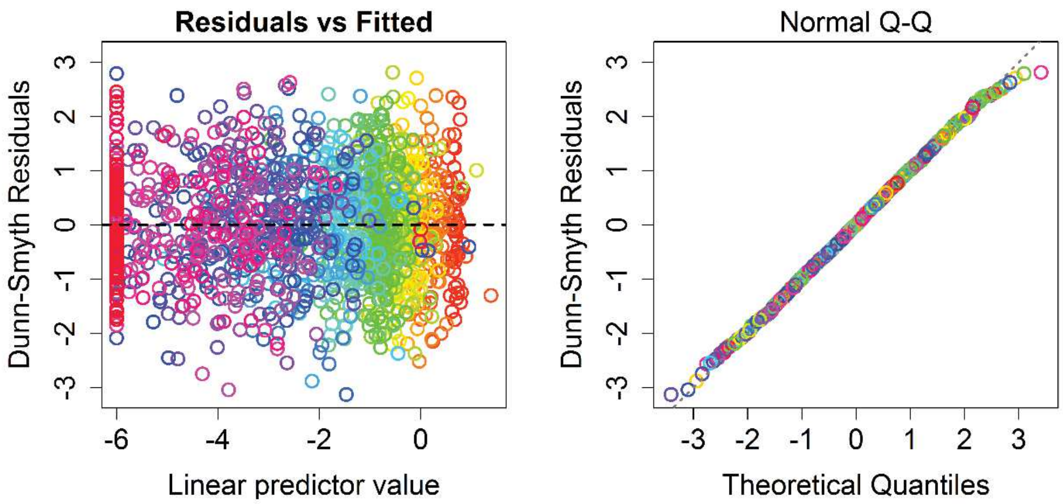

Fig. 10 Validation of the Generalized Linear Model (GLM) for the composition of fruit-feeding butterflies of PAEAR and respective FF using the negative binomial distribution. Values adjusted for the Conservation Unit and respective adjacent forest fragments. Residuals in relation to the adjusted values (left); adjustment to the theoretical quantiles of a normal distribution (right).

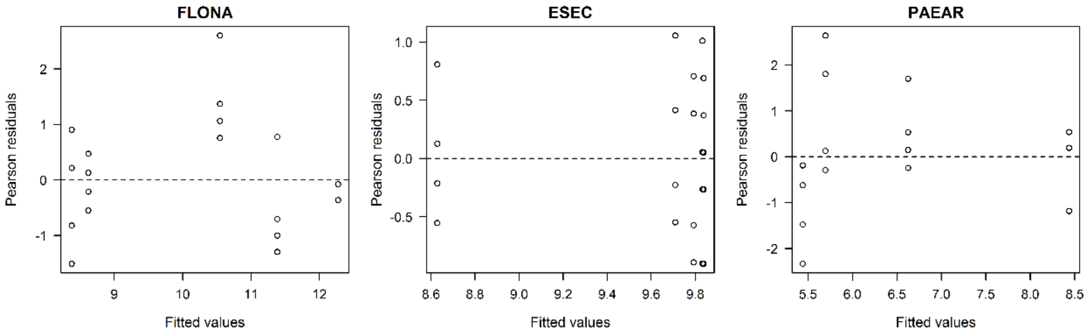

Fig. 11 Validation of the Generalized Linear Model (GLM) for species richness of fruit-feeding butterflies using the Poisson-type error distribution for each Conservation Unit and respective adjacent forest fragments, not showing patterns in the residuals in relation to the adjusted values.

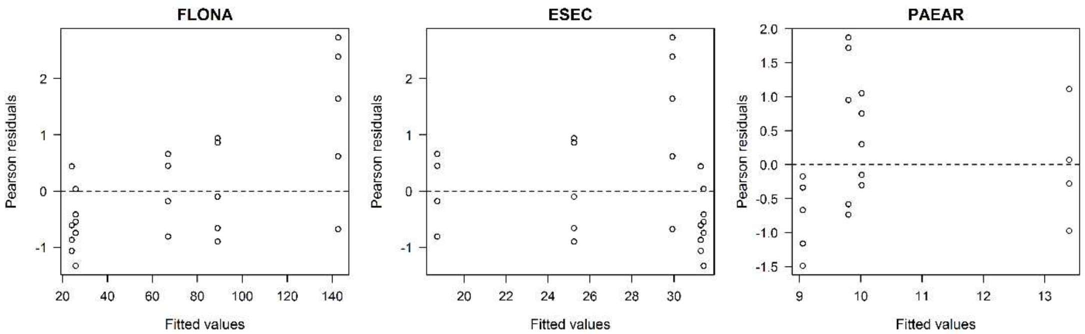

Fig. 12 Validation of the Generalized Linear Model (GLM) for the abundance of fruit-feeding butterflies using the Poisson-type error distribution for each Conservation Unit and respective adjacent forest fragments, not showing patterns in the residuals in relation to the adjusted values.

CONSIDERAÇÕES FINAIS

Este foi o primeiro estudo abordando as borboletas frugívoras ocorrentes em Unidades de Conservação e fragmentos florestais adjacentes da Região Oeste de Santa Catarina. Ficou evidenciado no estudo a existência de uma fauna de borboletas frugívoras bastante peculiar e assembleias com abundância e riqueza de espécies bastante representativas para as áreas de Floresta Ombrófila Mista da região.

O estudo destacou o papel das Unidades de Conservação para a manutenção da biodiversidade de borboletas frugívoras em fragmentos florestais adjacentes. Constatou-se que fragmentos florestais adjacentes mantem uma diversidade de borboletas frugívoras bem representativa, abrigando uma grande riqueza de espécies, como amostrado nas áreas das Unidades de Conservação, mesmo que a composição seja diferente. Isso demonstra a importância que os fragmentos florestais adjacentes têm em paisagens altamente fragmentadas, muito comuns na Mata Atlântica, afetando a diversidade de borboletas frugívoras. Assim, a conservação de muitos desses fragmentos estudados e o estabelecimento de corredores ecológicos entre eles e outros fragmentos locais poderiam auxiliar na conservação da fauna de borboletas frugívoras e na biodiversidade associada. Contudo, ficou comprovado que existe uma alta diversidade de espécies de borboletas frugívoras nas Unidades de Conservação. Esses fragmentos florestais necessitam de atenção urgente, sendo ambientes essenciais para os ecossistemas adjacentes.

É preciso destacar também a importância das variáveis ambientais visto terem sido preditoras significativas na estruturação das assembleias de borboletas frugívoras nas áreas amostradas. Destaca-se aqui a necessidade de outros estudos para uma melhor compreensão da influência dos fatores ambientais na estrutura das assembleias de borboletas. Também, tornam-se necessários estudos que determinem se as características biológicas (atributos funcionais) das borboletas frugívoras da Mata Atlântica diferem entre populações de florestas contínuas e adjacentes, como também o efeito de borda das áreas florestais sobre a composição e diversidade de borboletas frugívoras.

Estudos que investiguem os efeitos das variações sazonais sobre a composição, abundância e riqueza de espécies de borboletas frugívoras na região, também são necessários. Como também uma análise mais específica dos efeitos das variações sazonais sobre diferentes populações de espécies de borboletas frugívoras mais abundantes nos estudos.

Considerando-se a importância ecológica das borboletas frugívoras, os resultados sinalizam para a necessidade da análise do potencial de bioindicação da guilda de borboletas frugívoras, pois os padrões de composição, abundância e riqueza de espécies deste grupo estão associados com muitos parâmetros ambientais. A partir de análises ecológicas das espécies bioindicadoras, os resultados subsidiarão ações de monitoramento e conservação das espécies de borboletas frugívoras na região e no estado.

Contudo, outras pesquisas devem ser realizadas, dando continuidade para um melhor conhecimento desta fauna de borboletas frugívoras. Provavelmente, com o incremento de estudos sobre borboletas na região, em áreas ainda não inventariadas, mais espécies devem ser descobertas. Pesquisas direcionadas para os aspectos ecológicos da fauna de borboletas devem ser incentivadas, visando contribuir com resultados que subsidiem documentos legais, a fim de assegurar a conservação efetiva das espécies, em uma região que tão pouco conhece à sua biodiversidade.

Finalizo ressaltando a importância dos resultados obtidos nessa tese, demonstrando a urgente necessidade da ampliação do conhecimento sobre a biodiversidade regional, na perspectiva de que é preciso conhecer para conservar. Espera-se que com a publicação dos resultados, outras pesquisas possam ser incentivadas e realizadas nessas áreas florestais tão ameaçadas e pela divulgação científica por meio da Educação Ambiental, pessoas possam ser sensibilizadas para contribuir na proteção das espécies. Portanto, a criação e/ou implementação de programas de Educação Ambiental, tornam-se imprescindíveis.

ANEXOS

Anexo 1. Imagem da primeira página do artigo publicado (Capítulo 1) na Revista Biota Neotropica em 2019.

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Frugivorous butterflies from the Atlantic Forest in Southern Brazil (Lepidoptera: Nymphalidae)

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SABEDOT BORDIN, S.M. MONTEIRO, M., FERREIRA, V.W., LUTINSKI, J.A., RODRIGUES, E.N.L. **Frugivorous butterflies from the Atlantic Forest in Southern Brazil (Lepidoptera: Nymphalidae)**. Biota Neotropica. 19(4): e20180722. http://dx.doi.org/10.1590/1676-0611-BN-2018-0722

Abstract: This study aimed to present a list of the species of frugivorous butterflies occurring in Atlantic Forests, in the Conservation Units: National Forest of Chapecó (FLONA), Ecological Station of Mata Preta (ESEC) and State Park of Araucárias (PAEAR) and adjacent forest fragments, located in the western region of the state of Santa Catarina. Three samplings were conducted between December 2017 and March 2018, totaling 24 days of collection in each sampling area. Van Someren-Rydon traps were used to capture frugivorous butterflies. There were 4,231 frugivorous butterflies belonging to four subfamilies, 12 tribes and 49 species. In all, 37 species of frugivorous butterflies were sampled in FLONA and 29 in adjacent forest fragments. In ESEC, 29 species and 33 in adjacent forest fragments. In PAEAR, 33 species and 28 in adjacent forest fragments. Of the total species registered, 15 species are new records for the state of Santa Catarina and 11 are new records for the western region of the state. The most abundant species for FLONA were: *Manataria hercyna* (Hübner, 1821) and *Hermeuptychia* sp. In ESEC, were *Hermeuptychia* sp. and *Yphthimoides ordinaria* (Freitas, Kaminski & Mielke, 2012). In PAEAR, greater abundance of *Forsterinaria quantius* (Godart, 1824) and *Eryphanes reevesii* (Doubleday, 1849) were verified. For the adjacent forest fragments to Conservation Units, there was a greater abundance of *Hermeuptychia* sp., *Moneuptychia soter* (Butler, 1877), *Morpho epistrophus* (Fabricius, 1796) e *Forsterinaria quantius* (Godart, 1824). Satyrinae presented higher richness (S = 34) and abundance (90.58%) in all areas sampled. The rarefaction and extrapolation curves for the Conservation Units and adjacent forest fragments showed a greater rise in the FLONA and PAEAR sampling units and their adjacent forest fragments. The estimated sampling coverage for Conservation Unit and forest fragments was above 97%. The richness calculated through the Jackknife 1 estimator, for the FLONA and PAEAR samplings, presented a value of 50.75 and 37.09, respectively. The fauna of frugivorous butterflies from this region, first investigated in areas of Conservation Units, showed to be expressive and well represented in the Atlantic Forest Biome, indicating its potential as a refuge for biodiversity.
Keywords: *conservation, diversity, ecology, forest fragmentation, species richness.*

Borboletas frugívoras da Mata Atlântica no Sul do Brasil (Lepidoptera: Nymphalidae)

Resumo: O estudo teve como objetivo elaborar uma lista das espécies de borboletas frugívoras ocorrentes em florestas da Mata Atlântica, nas Unidades de Conservação: Floresta Nacional de Chapecó (FLONA), Estação Ecológica da Mata Preta (ESEC) e Parque Estadual das Araucárias (PAEAR) e fragmentos florestais adjacentes, localizados na Região Oeste de Santa Catarina. Foram realizadas três campanhas de coletas entre dezembro de 2017 e março de 2018, totalizando 24 dias de coletas em cada área amostral. Para a captura das borboletas frugívoras, foram utilizadas armadilhas Van Someren-Rydon. Foram registradas 4231 borboletas frugívoras pertencentes a quatro subfamílias, 12 tribos e 49 espécies. Foram amostradas 37 espécies de borboletas frugívoras na FLONA e 29 nos fragmentos florestais adjacentes. Na ESEC 29 espécies e 33 nos fragmentos florestais adjacentes. No PAEAR 33 espécies e 28 nos fragmentos florestais adjacentes. Do total de espécies registradas, 15 espécies de borboletas frugívoras são novos registros para o estado de Santa Catarina e 11 são novos registros para a região

https://www.scielo.br/scielo.php?script=sci_arttext&pid=S1676-06032019000400310&tlng=en

Anexo 2. Cópia da autorização do ICMBio/SISBio para a coleta das borboletas frugívoras em Unidades de Conservação e fragmentos florestais adjacentes na Região Oeste de Santa Catarina.

Ministério do Meio Ambiente - MMA
Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio
Sistema de Autorização e Informação em Biodiversidade - SISBIO

Autorização para atividades com finalidade científica

Número: 60789-1	Data da Emissão: 20/11/2017 15:05	Data para Revalidação*: 20/12/2018

* De acordo com o art. 28 da IN 03/2014, esta autorização tem prazo de validade equivalente ao previsto no cronograma de atividades do projeto, mas deverá ser revalidada anualmente mediante a apresentação do relatório de atividades a ser enviado por meio do Sisbio no prazo de até 30 dias a contar da data do aniversário de sua emissão.

Dados do titular

Nome: Sandra Mara Sabedot Bordin	CPF: 023.107.149-33
Título do Projeto: Composição e diversidade de borboletas frugívoras (Lepidoptera: Nymphalidae) em Unidades de Conservação e fragmentos de Floresta Ombrófila Mista	
Nome da Instituição : SOC ANTONIO VIEIRA	CNPJ: 92.959.006/0001-09

Cronograma de atividades

#	Descrição da atividade	Início (mês/ano)	Fim (mês/ano)
1	coleta das borboletas	11/2017	07/2018

Observações e ressalvas

1	As atividades de campo exercidas por pessoa natural ou jurídica estrangeira, em todo o território nacional, que impliquem o deslocamento de recursos humanos e materiais, tendo por objeto coletar dados, materiais, espécimes biológicos e minerais, peças integrantes da cultura nativa e cultura popular, presente e passada, obtidos por meio de recursos e técnicas que se destinem ao estudo, à difusão ou à pesquisa, estão sujeitas a autorização do Ministério de Ciência e Tecnologia.
2	Esta autorização NÃO exime o pesquisador titular e os membros de sua equipe da necessidade de obter as anuências previstas em outros instrumentos legais, bem como do consentimento do responsável pela área, pública ou privada, onde será realizada a atividade, inclusive do órgão gestor de terra indígena (FUNAI), da unidade de conservação estadual, distrital ou municipal, ou do proprietário, arrendatário, posseiro ou morador de área dentro dos limites de unidade de conservação federal cujo processo de regularização fundiária encontra-se em curso.

Anexo 3. Instalação das armadilhas Van Someren-Rydon para coleta das borboletas frugívoras em Unidades de Conservação e fragmentos florestais adjacentes na Região Oeste de Santa Catarina.

Anexo 4. Coleta, armazenamento e registros das borboletas frugívoras coletadas durante o período de amostragem. A= Armadilha Van Someren-Rydon com borboletas frugívoras amostradas; B= Retirada das borboletas frugívoras capturadas em armadilha Van Someren-Rydon nas áreas amostradas das Unidades de Conservação e fragmentos florestais adjacentes na Região Oeste de Santa Catarina; C= Armazenamento das borboletas frugívoras em envelopes entomológicos; D= Registro dos dados, número de indivíduos coletados, das variáveis abióticas e bióticas na planilha de campo.

A

B

C

D

Anexo 5. Divulgação da Pesquisa no facebook da Floresta Nacional de Chapecó.

Anexo 6. Atividade de apresentação do projeto de pesquisa e dos resultados da composição de borboletas frugívoras, para os estudantes do 1º período do curso de Ciências Biológicas da UNOCHAPECÓ, realizada na Floresta Nacional de Chapecó.

Anexo 7. Palestra sobre as borboletas frugívoras ministrada no dia 24 de outubro de 2018 no evento comemorativo aos 50 anos da FLONA.