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MARIA BEATRIZ DE ANDRADE SOUSA

ESTRUTURA DAS COMUNIDADES DE RÉPTEIS E ANFÍBIOS TERRESTRES EM AMBIENTES NATIVOS E ANTRÓPICOS NA FLORESTA NACIONAL DE NÍSIA FLORESTA, RIO GRANDE DO NORTE, BRASIL

João Pessoa

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Ata da 376ª Apresentação e Banca de Defesa de Mestrado de Maria Beatriz de Andrade Sousa

Ao(s) vinte e oito dias do mês de agosto de dois mil e vinte e quatro, às 14:00 horas, no(a) Ambiente Virtual, da Universidade Federal da Paraíba, reuniram-se, em caráter de solenidade pública, membros da banca examinadora para avaliar a dissertação de mestrado de **Maria Beatriz de Andrade Sousa**, candidato(a) ao grau de Mestre(a) em Ciências Biológicas. A banca examinadora foi composta pelos seguintes membros: **Dr. Adrian Antonio Garda (Orientador-UFRN/RN); Dr. Adriano Caliman Ferreira Da Silva (UFRN/RN); Dr. Daniel Oliveira Mesquita (UFPB/PB).** Compareceram à solenidade, além do(a) candidato(a) e membros da banca examinadora, alunos e professores do PPGCB. Dando início à sessão, a coordenação fez a abertura dos trabalhos, apresentando o(a) discente e os membros da banca. Foi passada a palavra ao(à) orientador(a), para que assumisse a posição de presidente da sessão. A partir de então, o(a) presidente, após declarar o objeto da solenidade, concedeu a palavra a **Maria Beatriz de Andrade Sousa**, para que dissertasse, oral e sucintamente, a respeito de seu trabalho intitulado **"DINÂMICA DAS COMUNIDADES DE RÉPTEIS E ANFÍBIOS TERRESTRES EM AMBIENTES NATIVOS E ANTRÓPICOS NA FLORESTA NACIONAL DE NÍSIA FLORESTA, RIO GRANDE DO NORTE, BRASIL".** Passando então a discorrer sobre o aludido tema, dentro do prazo legal, o(a) candidato(a) foi a seguir arguido(a) pelos examinadores na forma regimental. Em seguida, passou a Comissão, em caráter secreto, a proceder à avaliação e julgamento do trabalho, concluindo por atribuir-lhe o conceito Aprovada. Perante o resultado proclamado, os documentos da banca foram preparados para trâmites seguintes. Encerrados os trabalhos, nada mais havendo a tratar, eu, orientador(a), como presidente, lavrei a presente ata que, lida e aprovada, assino juntamente com os demais membros da banca examinadora.

João Pessoa, 28/08/2024.

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Orientador(a) e presidente da banca

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DANIEL OLIVEIRA MESQUITA
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Daniel Oliveira Mesquita
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Maria Beatriz de Andrade Sousa
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MARIA BEATRIZ DE ANDRADE SOUSA

ESTRUTURA DAS COMUNIDADES DE RÉPTEIS E ANFÍBIOS TERRESTRES EM AMBIENTES NATIVOS E ANTRÓPICOS NA FLORESTA NACIONAL DE NÍSIA FLORESTA, RIO GRANDE DO NORTE, BRASIL

Dissertação apresentada ao programa de Pós-graduação em Ciências Biológicas (Zoologia) da Universidade Federal da Paraíba, como parte das exigências para a obtenção do título de Mestre em Zoologia.

Orientador: Prof. Dr. Adrian Antonio Garda

Coorientadora: Profa. Dra. Marília Bruzzi Lion

João Pessoa

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Resumo

Um dos objetivos em ecologia de comunidades é entender que fatores são responsáveis pela diversidade biológica. Parâmetros da paisagem fornecem respostas fundamentais sobre os padrões de distribuição, riqueza e abundância de espécies. Anfíbios e répteis são grupos modelo em estudos que relacionam as comunidades com alterações da paisagem e estrutura do habitat. A Floresta Atlântica é um *hotspot* de biodiversidade mundial e há anos sofre com alta pressão antropogênica. A Floresta Nacional de Nísia Floresta é uma unidade de conservação que protege um remanescente de Floresta Atlântica no estado do Rio grande do Norte. A área é caracterizada por vegetação nativa (Mata Atlântica, ‘’Restinga ou Tabuleiros’’) assim como áreas abandonadas de plantio de espécies exóticas. Esse estudo está dividido em 2 capítulos. O primeiro capítulo teve como objetivos: 1- Realizar um levantamento da herpetofauna da Floresta Nacional de Nísia Floresta e a criação de uma lista oficial para a unidade. 2- Comparar a diversidade de répteis e anfíbios nas diferentes áreas considerando as variações nos tipos vegetais. O segundo capítulo teve como objetivo: 3- Investigar a relação da diversidade de répteis e anfíbios com as variáveis da paisagem e micro-habitat, identificando quais fatores melhor explicam a diversidade destes grupos. Para alcançarmos os objetivos do primeiro capítulo nós utilizamos uma amostragem padronizada e de longo prazo, juntamente com encontros visuais e ocasionais. Realizamos levantamentos mensais em toda área utilizando 84 armadilhas de interceptação e queda distribuídas aleatoriamente em 21 conjuntos ao longo das três zonas fitogeográficas (restinga, mata e regeneração). Coletamos um total de 39 espécies de repteis (entre lagartos, serpentes, quelônios, crocodilianos e anfisbênios) e 24 espécies de anfíbios. A família mais numerosa de répteis foi Dipsadidae, seguida por Colubridae. Para Anfíbios a mais numerosa foi Leptodactylidae seguida de Hylidae. A diversidade da herpetofauna em áreas de regeneração é menor do que em florestas que por sua vez são marginalmente menos diversas do que a Restinga. Embora menor, a diversidade em áreas de regeneração é semelhante às áreas naturais. Para o segundo capítulo, nós utilizamos os dados de riqueza e abundância obtidos somente por meio das armadilhas. Nós medimos 10 parâmetros de micro-habitat em cada conjunto de armadilha de queda, além disso nós usamos duas métricas da paisagem para testar o efeito nas comunidades, usando o QGIS. Para identificar quais variáveis melhor explicaram a riqueza e a diversidade da herpetofauna nós empregamos uma GLM com a abordagem do modelo mínimo adequado. A distância até a lagoa explicou a riqueza total. A distância até a lagoa e a densidade da vegetação explicou a diversidade total. Da mesma forma, distância até a lagoa e a densidade vegetal influenciaram a riqueza e a diversidade de anfíbios, enquanto cobertura do dossel afetou a riqueza de répteis.

Palavras-chave: Conservação; Estrutura da comunidade; Unidade de conservação; Floresta Atlantica.

Abstract

One of the objectives in community ecology is to understand which factors are responsible for biological diversity. Landscape parameters provide fundamental answers about the patterns of distribution, species richness, and abundance. Amphibians and reptiles are model groups in studies that relate communities to landscape alterations and habitat structure. The Atlantic Forest is a global biodiversity hotspot and has been subjected to high anthropogenic pressure for years. The Nísia Floresta National Forest is a protected area that protects a remnant of the Atlantic Forest in the state of Rio Grande do Norte. The area is characterized by native vegetation (Atlantic Forest, "Restinga or Tabuleiros") as well as abandoned exotic plantation areas. This study is divided into two chapters. The first chapter had the following objectives: 1- Conduct a survey of the herpetofauna of the Nísia Floresta National Forest and create an official list for the unit. 2- Compare the diversity of reptiles and amphibians in different areas considering variations in vegetation types. The second chapter aimed to: 3- Investigate the relationship between the diversity of reptiles and amphibians with landscape and microhabitat variables, identifying which factors best explain diversity. To achieve the objectives of the first chapter, we used standardized and long-term sampling, along with visual and occasional encounters. We conducted monthly surveys throughout the area using 84 pitfall traps randomly distributed in 21 arrays across the three phytogeographic zones (restinga, forest, and regeneration). We collected a total of 39 species of reptiles (including lizards, snakes, turtles, crocodilians, and amphisbaenians) and 24 species of amphibians. The most numerous reptile family was Dipsadidae, followed by Colubridae. For amphibians, the most numerous was Leptodactylidae, followed by Hylidae. The diversity of herpetofauna in regeneration areas is lower than in forests, which in turn are marginally less diverse than Restinga. Although diversity in regeneration areas is lower, it is similar to natural areas. For the second chapter, we used richness and abundance data obtained only from the traps. We measured 10 microhabitat parameters at each pitfall trap array, and we used two landscape metrics to test the effect on communities, using QGIS. To identify which variables best explained the richness and diversity of the herpetofauna, we employed a GLM with the minimal adequate model approach. Distance to the pond explained total richness. Distance to the pond and vegetation density explained total diversity. Also, distance to the pond and vegetation density explained amphibian richness and diversity, while canopy cover explained reptile richness.

Keywords: Landscape ecology; Atlantic Forest; Diversity; Microhabitat.

Sumário

1.INTRODUÇÃO GERAL

Um dos objetivos em ecologia de comunidades é entender que fatores são responsáveis pela diversidade biológica (Morin, 2011). Parâmetros da paisagem e inerentes a ela por muito tempo vêm sendo foco de diversos estudos em ecologia, porque fornecem respostas fundamentais sobre os padrões de distribuição, riqueza e abundância de espécies (Bell et al., 2012; Miller et al., 1997). Relacionar parâmetros da paisagem, como a distância até a borda, e de micro-habitat, como número de troncos caídos, serrapilheira e dossel nos permite entender a dinâmica de funcionamento das comunidades biológicas especialmente em ambientes perturbados (Turner, 2010; Garda et al., 2013).

A ecologia de paisagem tem dois focos principais: um geográfico, que estuda a influência do homem sobre a paisagem e a gestão do território; e outro ecológico, que enfatiza a importância do contexto espacial sobre processos ecológicos e a relevância desses processos para conservação biológica (Metzger, 2001). Ainda do ponto de vista ecológico, é possível observar como características da paisagem podem exercer efeitos sobre os organismos seja em ambientes naturais, agriculturas ou sistemas urbanos, e esses efeitos podem vir das mais diversas formas dentro das relações entre espécies, populações ou comunidades biológicas (Turner & Gardner, 2015).

Uma das abordagens mais comuns em ecologia de paisagem é relacionar as características do ambiente com a diversidade de espécies (MacArthur & MacArthur, 1961; Price et al., 2010; Tuanmu & Jetz, 2015). A organização de habitats no espaço permite variações na cobertura vegetal, tipos de solo, presença de corpos d’água e estrutura topográfica, cada uma contribuindo unicamente na composição das comunidades locais (Bazzaz, 1975). Esses parâmetros compreendem características relacionadas aos nichos das espécies e suas diferentes combinações podem influenciar a diversidade de espécies de um local (Hansson et al., 1995).

Compreender os mecanismos que regulam as interações entre a paisagem e a estrutura das comunidades é essencial para desenvolver estratégias eficientes de conservação e manejo da biodiversidade (Barahona-Segovia et al., 2023; Wintle et al., 2019). Tais mecanismos envolvem a conectividade entre habitats, os efeitos de borda e variações climáticas que influenciam diretamente a distribuição e a abundância das espécies (Turner & Gardner, 2015; Willmer et al., 2022). A fragmentação, por exemplo, pode levar ao isolamento de populações, dificultando o fluxo gênico e aumentando o risco de extinção devido a eventos aleatórios (Hansson et al., 1995).

A manutenção da conectividade entre os fragmentos pode ser uma estratégia crucial para permitir o movimento das espécies entre essas áreas (Coulon et al., 2004). Além disso, características de micro-habitats, como a profundidade da camada de serrapilheira ou a cobertura florestal, desempenham um papel significativo na oferta de recursos e abrigo para as espécies (Keppel et al., 2017; Olson, 1994). Ao entender essas relações, é possível que os conservacionistas criem áreas protegidas, recuperem paisagens degradadas e adotem práticas de uso da terra que promovam a preservação da biodiversidade (Ockermüller et al., 2023; Rija, 2022).

As respostas as variações do ambiente podem ser diferentes de acordo com o grupo taxonômico (Fahrig, 2003; Tews et al., 2003). Por exemplo, a heterogeneidade da paisagem influencia mais na distribuição e riqueza de aves e lepidópteros em ambientes mediterrâneos, porque a promove a diversidade de habitats e, consequentemente, mais recursos, dessa forma acumulando mais espécies com diferentes necessidades (Atauri & Lucio, 2001). Por outro lado, anfíbios e répteis parecem responder melhor a certos tipos de uso da terra, sendo mais sensíveis as alterações no meio (Atauri & Lucio, 2001).

Anfíbios e répteis são importantes modelos para pesquisas que envolvem ecologia, genética, comportamento, filogeografia, biologia do desenvolvimento e biologia evolutiva (Vitt

& Caldwell, 2013). Do mesmo modo, podem explicar a percepção que as comunidades biológicas têm com a modificação da paisagem e estrutura do hábitat (Cordier et al., 2021; Doherty et al., 2020). Isso se deve às características fisiológicas particulares do grupo que lhes confere certa sensibilidade as alterações no ambiente (Hopkins, 2007; Vitt & Caldwell, 2013).

Esses grupos podem ter baixa capacidade de deslocamento e alta especificidade de habitat, tornando-os particularmente sensíveis às alterações ambientais (Haddad & Prado, 2005; Sinsch, 1990). Os anuros de maneira geral, são fortemente influenciados pela disponibilidade de corpos d'água, devido ao seu ciclo de vida complexo, que pode incluir fases aquáticas (Nunes-de-Almeida et al., 2021). Já para répteis, além da presença de corpos d'água, a estrutura da vegetação como a abertura do dossel, densidade do sub-bosque, circunferência da árvore, têm se mostrado crucial para a diversidade de espécies especialmente em ambientes fragmentados (Vitt et al., 1999; Vallan, 2000; Jellinek et al 2004; Vitt et al., 2007; Garda et al., 2013).

No Brasil, importantes estudos destacam a relação da paisagem e estrutura do habitat para anfíbios e répteis. Por exemplo, a área e a forma do fragmento podem explicar a abundância e riqueza de répteis em fragmentos de Floresta Atlântica no nordeste do Brasil (Lion et al., 2016). A distância de desconexão, por sua vez, é uma medida chave que explica a distribuição e abundância de anfíbios na Floresta Atlântica brasileira (Becker et al., 2007; Lion et al., 2014). A desconexão de habitat é a desconexão induzida pela ação humana entre diferentes hábitats necessários para diferentes estágios de vida utilizados por uma espécie, em anfíbios, por exemplo, que possuem uma fase aquática (larval) e outra terrestre (adulto) esse conceito é mais fácil de ser relacionado (Becker et al., 2007).

Historicamente, as florestas tropicais passaram por um longo processo de exploração de suas terras e foram sistematicamente convertidas em paisagens parcial ou totalmente modificadas (Melo et al., 2013; Wright, 2005). Isso resultou principalmente da atividade humana, que através dos avanços com a urbanização e desenvolvimento da agricultura contribuíram significativamente para redução das paisagens naturais e, consequentemente, para perda da biodiversidade (Allan et al., 2015; Souza et al., 2015).

A Floresta Atlântica é considerada a segunda maior floresta da região neotropical, sendo conhecida mundialmente como um *hotspot* de biodiversidade e por possuir elevados graus de endemismos (Mittermeier et al., 2004). Características como clima, heterogeneidade de fitofisionomias e topografia podem explicar tamanha diversidade na região (Moura et al., 2016). A combinação desses fatores confere à floresta atlântica considerável variação de temperatura, precipitação e umidade em toda sua extensão, corroborando para diversificação da biota na região Neotropical (Alvares et al., 2013).

A Mata Atlântica compreendia uma área de aproximadamente 1,5 milhão de km², com uma faixa contínua de terra ao longo da costa atlântica brasileira, ocorrendo também no Paraguai e Argentina (Galindo-Leal & Camara, 2003). A alta pressão antropogênica no bioma, com desenvolvimento de atividades de extração de madeira, plantações de monoculturas, além de uso das terras para a criação de gado, reduziram fortemente a área original da Floresta Atlântica. Atualmente, estima-se que há de 12% a 28% de sua cobertura original em fragmentos pequenos e isolados, aproximadamente 80% deles com menos de 50 hectares (Rezende et al., 2018; Ribeiro et al., 2009).

A Floresta Atlântica brasileira está dividida em 8 sub-regiões biogeográficas com base nas principais áreas de endemismo e transição (Ribeiro et al., 2011). Dentre elas, o centro de endemismo de Pernambuco, que está localizado mais ao norte do Rio São Francisco, e vai desde o extremo norte do estado do Rio Grande Norte, até Alagoas (França et al., 2023). A área apresenta elevados índices de diversidade biológica, é muito antropizada e caracterizada por pequenos fragmentos florestais imersos em uma matriz urbana e agrícola (Filho et al., 2023; Silva & Tabarelli, 2001). Consequentemente, é considerada por muitos a área mais ameaçada e menos protegida da Floresta Atlântica (França et al., 2023; Porto et al., 2006).

A Floresta Nacional de Nísia Floresta é uma unidade de conservação localizada no munícipio de Nísia Floresta e foi estabelecida em 2001 para preservar um remanescente de Mata Atlântica no estado do Rio Grande do Norte. A unidade possui uma área aproximada de 174 hectares e acentuada fragmentação. A flora da floresta é composta por vegetação nativa (Mata Atlântica e "Restingas ou Tabuleiros"), bem como áreas experimentais abandonadas, usadas anteriormente para o plantio de árvores exóticas para produção de madeira, principalmente eucalipto (MMA, 2012). A área destinada à experimentação florestal, que ocorreu na Floresta Nacional de Nísia Floresta até o final dos anos 1970 (na época do IBDF, antes de ser incorporada ao SNUC), apresenta um processo bem avançado de regeneração natural da floresta nativa, onde certas áreas agora exibem variações florísticas que se assemelham às áreas de Mata Atlântica (MMA, 2012).

Considerando que este ambiente passou por impactos antropogênicos resultando na conversão vegetação ao longo dos anos (Lins-e-Silva et al., 2021), informações sobre as comunidades de répteis e anfíbios nas diferentes fisionomias da área são cruciais para avaliar o impacto da modificação florestal na diversidade desses organismos na Mata Atlântica. É urgente, portanto, avaliar a dinâmica das comunidades de anfíbios e répteis terrestres desse importante fragmento florestal para a manutenção do patrimônio ambiental da Mata Atlântica no Rio Grande do Norte.

1.2 PROBLEMA DE PESQUISA

As variáveis da paisagem e micro-habitat, afetam a diversidade de répteis e anfíbios na Floresta Nacional de Nísia Floresta? Quais variáveis são mais importantes para explicar a diversidade da herpetofauna na unidade de conservação?

1.3 PRINCIPAIS HIPÓTESES

- Parâmetros da paisagem e do micro-habitat explicarão a diversidade local de répteis e anfíbios na unidade

- A diversidade local de anfíbios deverá ser maior próximo da lagoa devido a necessidade de água para reprodução e desenvolvimento das larvas
- A diversidade local de répteis deverá ser maior em áreas abertas (menos cobertura do dossel) na unidade de conservação

1.4 OBJETIVOS:

- Realizar um levantamento da herpetofauna da Floresta Nacional de Nísia Floresta e criar uma lista oficial de répteis e anfíbios.
- Avaliar e comparar a riqueza e a diversidade de répteis e anfíbios nas diferentes áreas da unidade de conservação, considerando as variações nas fisionomias vegetais.
- Investigar a relação entre a riqueza de répteis e anfíbios e as variáveis da paisagem e micro-habitat, identificando quais preditores são mais importantes para explicar a diversidade.

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CAPÍTULO 1

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Herpetofauna of Nísia Floresta National Forest, Rio Grande do Norte, Brazil: Richness and abundance differences among natural and secondary forests.

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Herpetofauna of Nísia Floresta National Forest, Rio Grande do Norte, Brazil: Richness and abundance differences among natural and secondary forests.

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Lista de autor(es) com ORCID validados no ScholarOne:

Daniel Victor Morais Marcos https://orcid.org/0009-0003-0481-1927

Felipe de Medeiros Magalhães https://orcid.org/0000-0001-5327-4337

Igor Peres Puertas https://orcid.org/0000-0001-5916-5369

Daniel Oliveira Mesquita https://orcid.org/0000-0002-8174-6837

Adrian Antonio Garda https://orcid.org/0000-0002-1178-1207

Marília Bruzzi Lion: https://orcid.org/0000-0002-3680-5463

Maria Beatriz de Andrade Sousa[1,2], Marília Bruzzi Lion[2,3], Winícius Mateus Magalhães Costa[2], Bryan André de Lima Egli[2], Fabiany Herica Figueiredo[2], Nicolas Vinicius A. A. Leite[2], Daniel Victor Morais Marcos[2], Felipe de Medeiros Magalhães[1], Cícera Silvilene Leite Matias[2], Aldenir Ferreira da Silva Neta[2], José Eduardo Gomes de Oliveira[2], Igor Peres Puertas[2], Vitória Godeiro de Queiroz[2], Daniel da Costa Silva[2], Willianilson Pessoa da Silva[2], Ricardo Rodrigues da Silveira-Filho[2,5], Matheus Lucas Azevedo Soares[2], Daniel Oliveira Mesquita[4] & Adrian Antonio Garda[2]*

[1]Universidade Federal da Paraíba, Programa de Pós-graduação em Ciências Biológicas (Zoologia), Castelo Branco, 58059-900, João Pessoa, PB, Brasil.

[2]Universidade Federal do Rio Grande do Norte, Centro de Biociências, Laboratório de Anfíbios e Répteis, Av. Senador Salgado Filho, 3000, 59078-900, Natal, RN, Brasil.

[3]*Universidade Federal do Rio Grande do Norte, Departamento de Ecologia, Av. Senador Salgado Filho, 3000, 59078-900, Natal, RN, Brasil.*

[4]*Universidade Federal da Paraíba, Centro de Ciências Exatas e da Natureza, Departamento de Sistemática e Ecologia, Castelo Branco, 58059-900, João Pessoa, PB, Brasil.*

[5]*Knowledge Center for Biodiversity, 31270-901, Belo Horizonte, MG, Brasil.*

**Corresponding author: pseudis@gmail.com*

SOUSA, M.B.A., LION, M.B., COSTA, W.M.M., EGLI, B.A.L., et al. **Herpetofauna of Nísia Floresta National Forest, Rio Grande do Norte, Brazil: Richness and abundance differences among natural and secondary forests.** Biota Neotropica 24(3): e20241643. https://doi.org/10.1590/1676-0611-BN-2024-1643

Abstract: In the Atlantic Forest, species distributions are not uniform. The biome has been divided into 8 biogeographic sub-regions, such as the Pernambuco Center of Endemism (PCE), in northeastern Brazil. Nísia Floresta National Forest (Flona) is a protected area situated in the municipality of Nísia Floresta, Rio Grande do Norte state, harboring native vegetation (Atlantic Forest and "Restingas or Tabuleiros") as well regenerating areas, with experimental plots of exotic plants for timber production. Herein, we present, for the first time, a species list of the herpetofauna surveyed at Flona over the past 10 years, using a standardize, long-term sampling design along with visual encounter surveys. We conducted monthly surveys across the area using 84 pitfall traps randomly distributed in 21 arrays throughout the forest's three phytogeographic zones (Restinga, Atlantic Forest, and Regeneration). In addition, we characterized ground-dwelling herpetofauna community diversity across these three zones over the course of an entire year. We collected a total of 39 species of reptiles (among lizards, snakes, chelonians, alligators, and amphisbaenians) and 24 species of frogs. The most frequent family found for reptiles was Dipsadidae, followed by Colubridae. In frogs, Leptodactylidae was the most common, followed by Hylidae. Herpetofaunal diversity in regeneration areas is smaller than forests, which in turn are marginally less diverse than the Restinga. Community descriptors such as equity, presence of exclusive species, and differences in abundances and composition indicate that distinct management strategies for each area are needed for this protected area. At last, albeit smaller, diversity in regenerating areas is similar to natural areas, a reassuring result considering the significant deforestation the Atlantic Forest has suffered and the urgent need for restoration initiatives.

Keywords: Conservation; Community Structure; Protected Areas; Atlantic Rain Forest.

Herpetofauna da Floresta Nacional de Nísia Floresta, Rio Grande do Norte, Brasil: Diferenças na riqueza e abundância entre florestas naturais e secundarias.

Resumo: Na Mata Atlântica, as distribuições de espécies não são uniformes. O bioma foi dividido em 8 sub-regiões biogeográficas, como o Centro de Endemismo de Pernambuco (CEP), no nordeste do Brasil. A Floresta Nacional de Nísia Floresta (Flona) é uma área protegida situada no município de Nísia Floresta, no Estado do Rio Grande do Norte, abrigando vegetação nativa (Mata Atlântica e "Restingas ou Tabuleiros"), bem como áreas em regeneração, com parcelas experimentais de plantas exóticas para produção de madeira. Aqui, apresentamos, pela primeira vez, uma lista de espécies da herpetofauna levantada na Flona ao longo dos últimos 10 anos, utilizando uma amostragem padronizada e de longo prazo, juntamente encontros visuais e ocasionais. Realizamos levantamentos mensais em toda a área utilizando 84 armadilhas de queda distribuídas aleatoriamente em 21 conjuntos ao longo das três zonas fitogeográficas da floresta (Restinga, Mata Atlântica e Regeneração). Além disso, caracterizamos a diversidade da herpetofauna terrestre nessas três zonas ao longo de um ano inteiro. Coletamos um total de 39 espécies de répteis (entre lagartos, serpentes, quelônios, crocodilianos e anfisbênios) e 24 espécies de anfíbios. A família mais frequente encontrada para os répteis foi a família Dipsadidae, seguida por Colubridae. Para anfíbios, Leptodactylidae foi a mais comum, seguida por Hylidae. A diversidade da herpetofauna em áreas de regeneração é menor do que em florestas, que por sua vez são marginalmente menos diversas do que a Restinga. Descritores da comunidade, como equidade, presença de espécies exclusivas e diferenças em abundâncias e composição indicam que estratégias de manejo distintas para cada área são necessárias para esta área protegida. Por fim, embora menor, a diversidade em áreas de regeneração é semelhante às áreas naturais, um resultado animador considerando o significativo desmatamento que a Mata Atlântica sofreu e a urgente necessidade de iniciativas de restauração.

Palavras-chave: Conservação; Estrutura de Comunidades; Unidades de Conservação; Floresta Atlântica.

Introduction

The Atlantic Forest is considered the second-largest forest in the Neotropical region, globally known as a biodiversity hotspot due to its high levels of threat and endemism (Mittermeier et al., 2004). Characteristics such as climate, heterogeneous phytogeographic patterns, and topography may explain the extensive diversity in the region (Moura et al., 2016). The combination of these factors bestows the Atlantic Forest with considerable temperature, precipitation, and humidity variation across its expanse, contributing to the diversification of the Neotropical biota (Alvares et al., 2013).

This biome once encompassed an area of approximately 1.5 million km², spanning Paraguay, Argentina, and with the largest portion situated in Brazil (Galindo-Leal & Camara, 2003). Intense anthropogenic pressure, driven by activities such as timber extraction, monoculture plantations (especially sugarcane and coffee), and land use for cattle ranching has significantly reduced the original extent of the Atlantic Forest. Today, estimates of the original coverage remaining range from 12% (Ribeiro et al., 2009) to 28% (Rezende et al., 2018). Most of these are comprised of small and isolated fragments, approximately 80% of which are less than 50 hectares in size (Ribeiro et al., 2009). The environment harbors around 2600 species of terrestrial vertebrates, with 954 of them being endemic (Figueiredo et al., 2021).

In the Atlantic Forest, species distributions are not uniform. The biome has been divided into eight biogeographic sub-regions based on primary areas of endemism and transition (Ribeiro et al., 2011). Among these, the Pernambuco Center of Endemism (PCE), located north of the São Francisco River, lays between northern of Rio Grande Norte state and Alagoas states. This region boasts high levels of biological diversity and consists of small forest fragments embedded in urban and agricultural matrices (Silva & Tabarelli, 2001; Filho et al., 2023). Consequently, it is considered the most threatened and least protected area within the Atlantic Forest hotspot (Porto et al., 2006; França et al., 2023). Furthermore, PCE's biodiversity was influenced by Pleistocene connections among the Atlantic and Amazon Forests, with species or closely-related species pairs occurring in both biomes, including mammals (Machado et al., 2024) birds (Batalha-Filho et al., 2013), and amphibians (Coelho et al., 2022) and reptiles (Zamudio & Greene, 1997).

Several herpetofauna surveys have been conducted in PCE (Oitaven et al., 2021; Roberto et al., 2017; Santana et al., 2008). A study in Parque Estadual de Dois Irmãos, Pernambuco state, for example, found 61 species of reptiles (Melo et al., 2018), while another study in Matas de Água Azul (also in Pernambuco state) recorded 83 species (Oliveira et al., 2021). Such studies have significantly improved our understanding of species richness and distribution along this region, uncovering richness up to 106 reptile species in a single locality (Mesquita et al., 2018). Likewise, in Rebio Serra Talhada, researchers identified 42 species of amphibians and 72 species of reptiles (Studer et al., 2015), while in Murici Ecological Station researchers recorded 89 species of reptiles (Dubeux et al., 2022). Nevertheless, considering the area of the Atlantic Forest in the PCE, works of this type remain scarce and relatively short-term in duration, hampering a proper ecological comparison of richness among areas. Even so, there are currently 97 species of amphibians and 143 species of reptiles known for this region (Filho et al., 2023).

Encompassing an area of approximately 174 hectares, Nísia Floresta National Forest is situated in the municipality of Nísia Floresta and was established in 2001 to preserve remnants of the Atlantic Forest in the state of Rio Grande do Norte. The forest's flora comprises native vegetation (Atlantic Forest and "Restingas or Tabuleiros") as well as abandoned areas where experimental plots with exotic plants for timber production, primarily eucalyptus. The area allocated for forest experimentation, which took place in Nísia Floresta National Forest until the late 1970s, features a well-advanced process of natural regeneration of native forest, where certain areas now exhibit floristic variations resembling those of Atlantic Forest areas (MMA, 2012). However, Nísia Floresta National Forest only possesses a preliminary list of reptile species and lacks a list for amphibians (MMA, 2012). Considering that this environment has undergone anthropogenic impacts resulting in vegetation conversion over the years (Lins-e-Silva et al., 2021), information on richness and abundances in the different physiognomies of the area is crucial for assessing the impact of forest modification on the diversity of these organisms in the Atlantic Forest.

Herein, we present a species list of the herpetofauna surveyed at Flona over the past 10 years, along with species abundances, using a standardize, long-term sampling design along with visual encounter surveys. To achieve this, we conducted monthly surveys across the area using 84 pitfall traps randomly distributed in 21 arrays throughout the forest's three phytogeographic zones (Restinga, Atlantic Forest, and Regeneration). In addition, we characterized ground-dwelling herpetofauna diversity across these three zones over the course of an entire year. We compared species richness among areas using rarefaction curves, diversity estimators, and exploratory statistical analyses (non-metric multidimensional scaling).

Material and Methods

1. *Study Area*

We conducted field surveys in Nísia Floresta National Forest (Flona, from now on), located in the municipality of Nísia Floresta, Rio Grande do Norte State, Brazil (06º05'11" S; 35º11'03" W). This protected area is managed by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). Flona has three well-defined vegetation types: Atlantic Forest, Regeneration (Atlantic Forest secondary succession growth with exotic trees like Pinus and Eucalyptus), and Restinga (Figure 1). The biome is the Atlantic Forest which, originally, spanned more than 1.3 million km² in Brazil. However, currently the coverage area represents 29% of the original territory (Rezende et al., 2018), which leads to major impacts, with approximately 3000 species facing extinction in Brazil, most of them in the Atlantic Forest (IBGE, 2022). The Atlantic Forest is composed of native rainforests, which can be dense, open, or mixed rainforests, and associated with other ecosystems, such as mangroves, rocky outcrops ("*Campos Rupestres*"), and Restingas, which are costal sand forests from eastern Brazil and northern Uruguay, characterized by areas of open shrubby vegetation, formed by ridges of beaches and sandy dunes that have a strong marine influence (Marques & Grelle, 2021).

2. *Data collection*

Two different sampling methods were used, Visual encounter surveys and pitfalls traps (see tables 1-3) (Heyer et al., 1994). Visual encounter surveys were conducted by a small group of researchers from 07:00 am to 12:00 pm, and from 05:00 pm to 10:00 pm in the survey of 2012-2013 when traps were open. For the 2022-2024 survey, visual encounters were conducted while walking the trails to check pitfall traps. We conducted pitfall trap field surveys during two periods, ten years apart. Firstly in 2012 and 2013, and secondly between June 2022 and August 2023.We used twenty-one pitfall trap arrays, distributed across three different physiognomies: Atlantic Forest, Regenerating forest, and Restinga (Figure 1-2). We selected sites to install pitfall trap arrays through a random search using ArcGIS, with the following conditions: arrays should be at least 50 meters apart and 100 meters or less to one of the access roads of the protected area. Each array contained four 30 liters buckets distributed in a Y-shape with one central bucket linked to three peripheral ones by six meters plastic drift fences (Cechin & Martins, 2000). In each bucket we left a piece of Styrofoam™ to help reduce mortality rates in case of flooding and covered exposed buckets with their lids 30cm above ground to protect animals against sun exposure.

Each pitfall array was sampled for a total of seven consecutive days each month from June 2022 to August 2023, and for varying periods of time during the period of 2012 to 2013. Traps were checked every morning by four observers. Each amphibian and reptile captured was identified and measured. The measurements (snout-vent length, tail length, tail base) were taken with a ruler and the weight was taken using a dynamometer scale, after all measures they were released back into the environment at least 100m away from pitfall trap arrays. We conducted this sampling in the protected area with permits from ICMBio (#82300-1) and the ethics committee at UFRN (#283.013/2022 and # 017/2011).

3. *Specimens*

We collected up to three voucher specimens per species, especially during the 2012–2013 survey. To reduce the likelihood of recapturing the same individual in a single field campaign. Specimens were given a unique field number (AAGARDA Field Series) and latter deposited in the Coleção Herpetológica da Universidade Federal da Paraíba (CHUFPB). Specimens were killed by rubbing benzocaine cream onto frogs' bellies or by injection of a lethal dose of barbiturate into the body cavity of lizards and snakes. We removed tissue samples and preserved specimens in formalin 10%, later storing them in ethanol 70%. We followed the taxonomic arrangements of Uetz et al. (2024) and Burbrink et al. (2020) for reptiles and Frost (2024) for amphibians.

4. *Data Analyses*

Species data obtained exclusively through visual encounter surveys were used solely to compile a complete species list. Consequently, these data were not utilized for comparing diversity across different Flona vegetation types. Instead, only data from the pitfall sampling survey were used for this comparison. We generated rarefaction curves for the three areas of the Flona: restinga, forest and regeneration, to compare diversity within and among the environments using *"iNext"* package (Gotelli & Colwell, 2001; Hsieh et al., 2016). To quantify species diversity across different vegetation types, we used observed species richness, rarefied species richness, and rarefied effective number of species (Hill numbers order q=1; Jost, 2006). The effective number of species for q=1 is a transformation of the Shannon diversity index which weighs all species by their frequencies, without favoring either common or rare species (Chao et al., 2014). To observe the proportion of abundances among the areas, we created species rank curves using the *"BiodiversityR"* package

(Kindt & Kindt, 2019). Multivariate patterns were inspected with a non-metric multidimensional scaling (nMDS) ordination to check for similarity in species composition within and between groups in the *"vegan"* package (Dixon, 2003). We conducted all statistical analysis using the R 4.3.1 (R Core Team, 2023).

Results

We collected a total of 17 species of lizards (11 families and 17 genera), 15 species of snakes (4 families and 12 genera), three species of chelonians (3 families and 3 genera), two species of amphisbaenians (1 family and 1 genera), one species of alligator, and 24 species of frogs (5 families and 11 genera) (Tables 1-3; Figures 3-6).

Amphibians – the family Leptodactylidae was the richest with 11 species, followed by Hylidae (9 spp.), Bufonidae (2 spp.) and Strabomantidae and Microhylidae one species each.

Reptiles – the richest lizard family was Teiidae with 4 species followed by Gymnophthalmidae (3 spp.), Mabuyidae (2 spp.) and Anolidae, Gekkonidae, Iguanidae, Leiosauridae, Phyllodactylidae, Polychrotidae, Sphaerodactylidae and Tropiduridae with a singles species each. For snakes, Dipsadidae family was the richest with 9 species, followed by Colubridae (4 spp.), Elapidae (2 spp.) and Typhlopidae with a single species.

Considering solely pitfall trapped animals, we sampled 31 species, 12 amphibians, and 19 reptiles. The Venn diagram illustrates species compositions across the three environments within the Flona, revealing that 12 species occur in all three areas, three species exclusively inhabit the forest, four species are exclusive to the restinga, and the regeneration area harbors no species unique to it (Figure 7A). Among these species, we identified *Ameivula ocellifera*, *Pleurodema diplolister*, and *Pseudopaludicola mystacalis* as dominant species in the restinga environment, while *Kentropyx calcarata* and *Physalaemus cuvieri* were noted as the most abundant species in the forest and regeneration areas.

On the other hand, we observed species restricted to only one environment within the Flona. Specifically, *Oxyrhopus trigeminus*, *Gymnodactylus geckoides*, *Vanzosaura multiscutata*, and *Leptodactylus natalensis* occur exclusively in the restinga, while *Norops fuscoauratus*, *Adelphostigma occipitalis, Pithecopus gonzagai* and *Micrurus corallinus* are found solely in the forest. Regarding species evenness, we observe a subtle difference among the areas when examining the rank curve, with Restinga exhibiting the highest number of species and greater species evenness (Figure 7B).

Pitfall trap species richness was highest in the Restinga (518 individuals; richness = 27; 95% CI [23.99, 30.01]), followed by Atlantic Forest (240 individuals; richness = 22; 95% CI [19.02, 24.98]), and Regeneration areas (203 individuals; richness = 18; 95% CI [15.37, 20.63]). These results indicate that the overall richness of amphibians and reptiles do not differ between Restinga and the Atlantic Forest, as their confidence intervals overlap. Still, Regeneration areas exhibit significantly lower richness than Restinga, but do not differ from the Atlantic Forest.

To compare richness among the three areas, we used rarefaction curves for trap-sampled species based on the smallest sample size of 203 individuals, which was observed in the regeneration area (Figure 7D). This analysis indicates that richness is lowest in Regeneration areas (observed richness = 18; 95% CI [15.37, 20.63]), followed by Atlantic Forest areas (rarefied richness = 21.28; 95% CI [18.52, 24.04]) and Restinga (rarefied richness = 22.18; 95% CI [20.36, 24.00]). However, since these confidence intervals overlap, the rarefied richness cannot be considered significantly different between the vegetation types, particularly between Restinga and Forest areas.

When comparting richness among areas based on Hill numbers (q=1) we recover similar results. Diversity was highest in Restinga (rarefied diversity = 11.38; 95% CI [10.40, 12.37]), followed by the Atlantic Forest (rarefied diversity = 10.20; 95% CI [8.91, 11.50]), and Regeneration areas (diversity = 8.33; 95% CI [6.94, 9.71]).The rarefaction curve for amphibians showed that the Forest and the Restinga are not significantly different, but both present significant differences from the Regeneration sites (Figure 7E). Meanwhile, for reptiles, results are similar to total richness, with no significant differences between the areas (Figure 7F).

Discussion

Nísia Floresta National Forest presents a moderate diversity of amphibians and reptiles compared to other areas of Atlantic Forest within the PCE, but significant considering is small size and insertion in a human disturbed matrix. In fact, there are important herpetofauna surveys in PCE, as well as studies that assessed taxonomy, ecology, and conservation status of individual species and communities (Dubeux et al., 2020; Filho et al., 2021; Oliveira et al., 2021). However, when it comes to comparing richness between areas, the lack of standardization in studies and the absence of details regarding sampling effort hinder the possible comparisons, limiting our ability to assess the true parameters responsible for the differences in richness between areas (França et al., 2023).

Nevertheless, we know that richness can vary depending on the size of the region, position in relation to ecotones, and diversity of microhabitats (Garda et al., 2013; MacArthur & Wilson, 2001; Ramanamanjato et al., 2002). In Guaribas Biological Reserve, Paraíba State, for example, 106 of reptiles and amphibians have been reported, a large number likely related to the protected area's size (4,000 hectares, or 23 times larger than Flona), and the presence of Tabuleiros (Vegetation type related to Restingas but geologically older), which enable richer communities associated to such environments (Mesquita et al., 2018). Additionally, there is a decrease in humidity and extension of the Atlantic Forest in the east-west direction as we enter Rio Grande do Norte; due to these characteristics, the state is sometimes excluded from studies involving the northeastern portion of the Atlantic Forest in Brazil (Ribeiro et al., 2011; Tabarelli et al., 2005). Despite the smaller area of the National Forest, proximity to the Caatinga may be contributing to the increase in richness. Here, Flona lacks flowing water, which limits or prevents the presence of some amphibian species such as *Proceratophrys renalis*, typical of the Atlantic Forest, and *P. cristiceps*, typical of the Caatinga. But ecotones may harbor species absent from adjacent environments. A study conducted in a transition zone between Caatinga and Atlantic Forest in Rio Grande do Norte revealed a remarkable diversity of amphibians (Magalhães et al., 2013). Similarly, we were able to observe species typical of the Caatinga at Flona, such as the lizard *Vanzosaura multiscutata* and the frog *Pseudopaludicola pocoto* (Magalhães et al., 2014; Recoder et al., 2014).

Some notable absences from our list of amphibians for Flona include Atlantic Forest species such as *Dendropsophus oliveirai*, *Lithobates palmipes*, and *Scinax cretatus*, which have been recorded north of this site in areas at the transition with the Caatinga Biome (Escola Agrícola de Jundiaí – EAJ, Magalhães et al., 2013). Likewise, species usually more associated to the Caatinga, like *Dermatonotus muelleri* and *Proceratophrys cristiceps*, were found at EAJ and in fragments to the south of Flona. At last, even some species common to both biomes were not found in Flona.

Such absences are likely linked to the ecological idiosyncrasies of these species. Ecologically, species like *P. cristiceps* and *L. palmipes* are associated to flowing streams, in which they call and where their tadpoles develop (in small ponds associated with flowing streams) (Nunes et al., 2015; Volpe & Harvey, 1958). The temporary and permanent water bodies at Flona are large and rest on sandy soils, possibly precluding the use of such areas by Atlantic Forest species that use smaller and more permanent ponds like *D. oliveirai* and *S. cretatus*. These water bodies at Flona are associated with Restinga areas with no nearby streams, which likely makes them less stable, exposed to high temperatures and very unpredictable, making such environments hostile for species where tadpoles take time to develop like *P. gonzagai* (Brasileiro et al., 2022). Indeed, we recorded *P.*

gonzagai for the first time in July 2024, after three consecutive years of significant rain that filled a temporary pond that had been dry for almost a decade. Diversity of reproductive sites has been shown to significantly determine amphibian species richness (Bickford et al., 2010)

For squamates, species recorded correspond to the diversity reported to other Atlantic Forest sites in the Atlantic Forest of Rio Grande do Norte (Freire, 1996; Lion et al., 2016). Compared to coastal sites near the Capital of the state – Natal, where similar habitats are found and long-term work has been conducted, the absence of Caatinga gecko *Hemidactylus brasilianus*, recorded at Parque das Dunas (Freire, 1996) and Centro de Lançamento da Barreira do Inferno (Adrian Garda, unpub. data), indicates a stochastic occurrence of Caatinga species within Atlantic Forest and Restinga sites in this northernmost portion of the Atlantic Forest. This is expected given climatic oscillations during the Pleistocene, with expansion and retraction of Forests and Caatinga areas, possibly leaving populations of caatinga species trapped within Atlantic Forest matrices (Guillory et al., 2024). Other examples of Caatinga species include *Lygodactylus klugei*, found in a forest fragment south of Flona, and *Vanzosaura multiscutata*, first recorded at Flona after 3 years of intense sampling.

Species diversity was only marginally higher in restinga compared to forest areas, but both were richer than regeneration sites. These results may be related to the fact that the Flona has been the subject of forest experiments with exotic species for many years ago (MMA, 2012). Lezzi et al. (2018) observed that mammal and bird diversity was higher in natural environments than in plantations. Just like for these groups, reptiles and amphibians can also be affected and, depending on the dynamics of the environment, may exhibit different patterns of species richness, abundance, and composition, whether in natural areas, secondary forests, or plantations (Gardner et al., 2007). This indicates that anthropogenic factors (such as deforestation, timber harvesting, monoculture plantations) may be linked to the distribution of these species in this fragment, as habitat modification is a crucial factor in the changes of biological diversity. The alteration of natural landscapes due to human action can affect the diversity of microhabitats, resource availability, hiding places, and cause changes in plant physiognomy (Cordier et al., 2021).

Our results show that regenerating areas contain a significant and diverse but depauperate community of amphibians and reptiles compared to natural areas. The regions near the pond and in the restinga areas have the highest diversity, yet they are the smallest in extent within Flona. The natural substitution of exotic plants and the subsequent regeneration of the Atlantic Forest is expected to contribute to an increase in the occurrence area for endemic species of the Atlantic Forest biome. The disparity in species richness between disturbed and natural sites within the studied fragment underscores the need for future investigations into the underlying ecological mechanisms. Further research could explore the specific factors driving these differences, assess long-term effects of disturbance on populations, consider landscape connectivity, and collaborate with conservation efforts to translate findings into effective management strategies, ultimately enhancing our understanding of reptile and amphibian ecology in fragmented landscapes.

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Associate Editor

Pedro Nunes

Author Contributions

Maria Beatriz de Andrade Sousa: Conceived the research; conducted sampling; analyzed the data; wrote the first draft of the paper; contributed to discussing and editing the manuscript.

Marília Bruzzi Lion: Conceived the research; analyzed the data; supervised the study; contributed to discussing and editing the manuscript.

Winícius Mateus Magalhães Costa: Conducted sampling; analyzed the data; contributed to discussing and editing the manuscript.

Bryan André de Lima Egli: Conducted sampling; contributed to discussing and editing the manuscript.

Fabiany Herica Figueiredo: Conducted sampling; analyzed the data; contributed to discussing and editing the manuscript.

Nicolas Vinicius A. A. Leite: Conducted sampling; contributed to discussing and editing the manuscript.

Daniel Victor Morais Marcos: Conducted sampling; contributed to discussing and editing the manuscript.

Felipe de Medeiros Magalhães: Conceived the research; obtained funding for sampling and analysis; supervised the study; contributed to discussing and editing the manuscript.

Cícera Silvilene Leite Matias: Conducted sampling; contributed to discussing and editing the manuscript.

Aldenir Ferreira da Silva Neta: Conducted sampling; contributed to discussing and editing the manuscript.

Igor Peres Puertas: Conducted sampling; contributed to discussing and editing the manuscript.

Vitória Godeiro de Queiroz: Conducted sampling; contributed to discussing and editing the manuscript.

Daniel da Costa Silva: Conducted sampling; contributed to discussing and editing the manuscript.

Willianilson Pessoa da Silva: Conducted sampling; contributed to discussing and editing the manuscript.

Ricardo Rodrigues da Silveira-Filho: Conducted sampling; analyzed the data; contributed to discussing and editing the manuscript.

Matheus Lucas Azevedo Soares: Conducted sampling; contributed to discussing and editing the manuscript.

Daniel Oliveira Mesquita: Conceived the research; obtained funding for sampling and analysis; supervised the study; contributed to discussing and editing the manuscript.

Adrian Antonio Garda: Conceived the research; conducted sampling; obtained funding for sampling and analysis; analyzed the data; supervised the study; wrote the first draft of the paper; contributed to discussing and editing the manuscript.

Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

Data Availability

The data and scripts used in this study are available at https://data.scielo.org/dataset.xhtml?persistentId=doi:10.48331/scielodata.HGMNQ5

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FIGURES

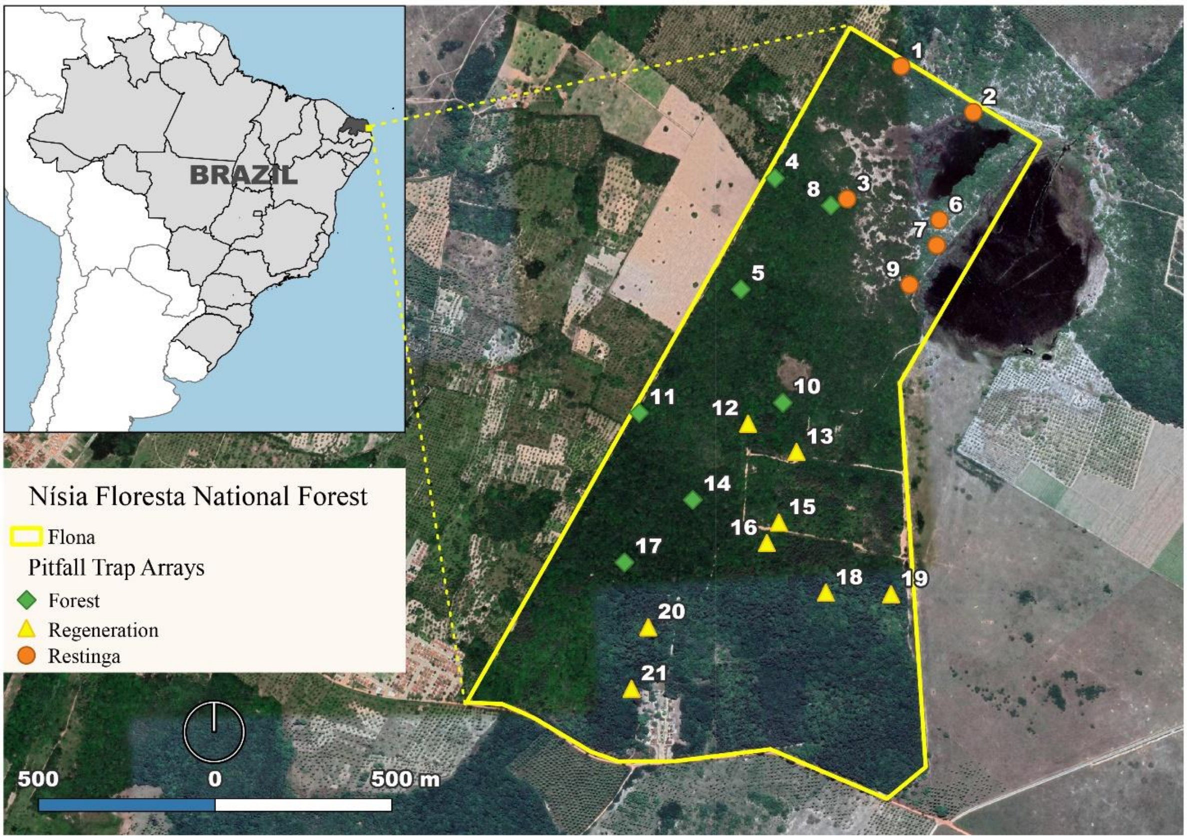

Figure 1. Location of the study area — Floresta Nacional de Nísia Floresta, in South America, Brazil, Rio Grande do Norte State. Symbols represent our pitfalls traps arrays, which are colored according to vegetation type.

Figure 2. Collecting Sites at Flona: A) Lagoa Seca, B) Lagoa da Coruja, C) Pitfall trap array 11 in the Forest, D) Pitfall trap array 6 in Restinga, E) Pitfall trap array 18 in Regeneration. Photo credits: Photo B Maria Beatriz, all others by Adrian Garda.

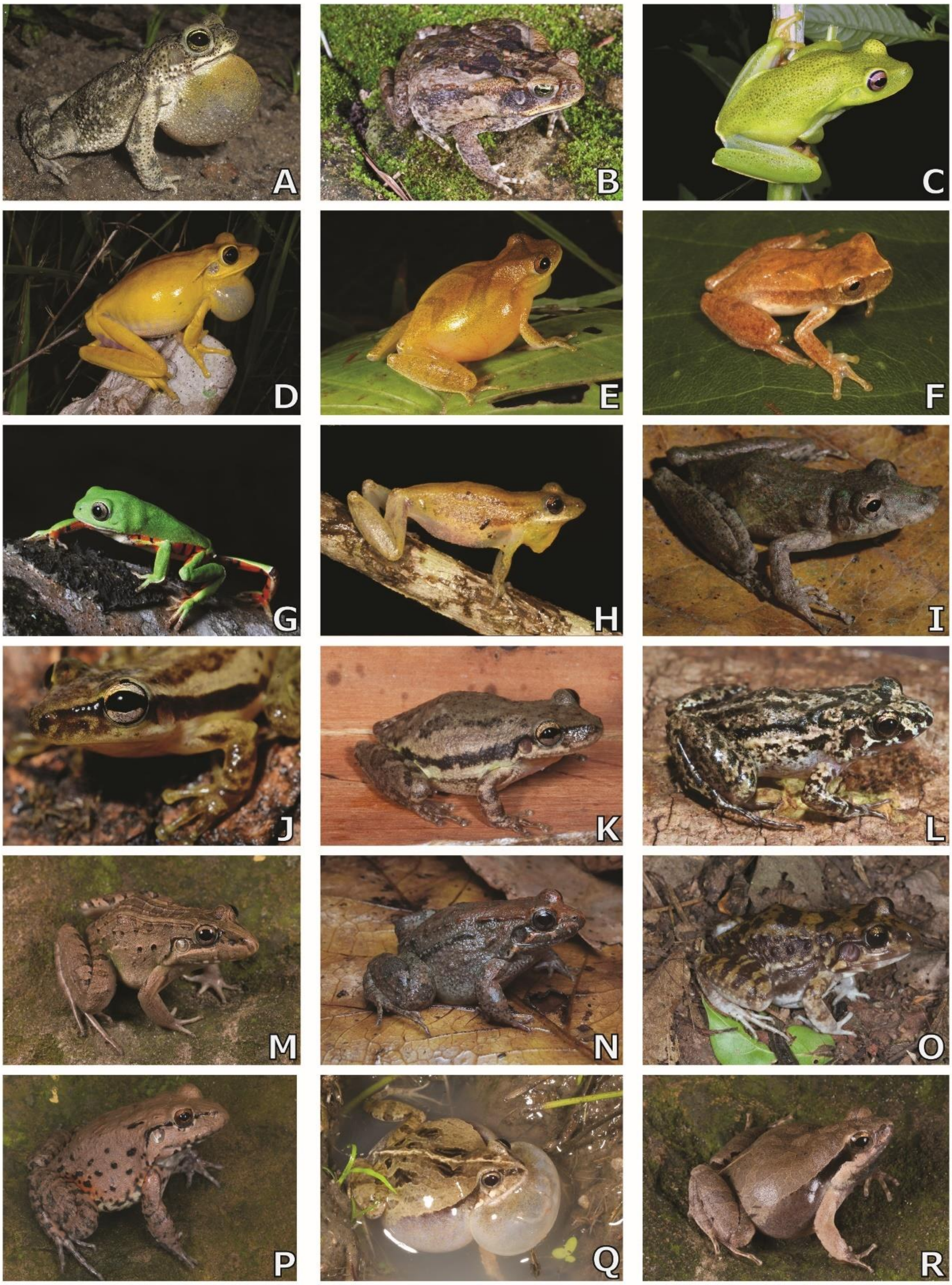

Figure 3. Reptiles and Amphibians of Floresta Nacional de Nísia Floresta, Rio Grande do Norte State, Brazil. AMPHIBIANS: **Bufonidae**: A) *Rhinella granulosa*, B) *R. diptycha*. **Hylidae**: C) *Boana albomarginata*, D) *B. raniceps,* E) *Dendropsophus minutus*, F) *D. nanus*, G) *Pithecopus gonzagai*, H) *Scinax fuscomarginatus*, I) *S. rostratus*, J) *S. pachycrus*, K) *S. x-signatus*. **Leptodactylidae**: L) *Adenomera hylaedactyla*, M) *Leptodactylus macrosternum*, N) *L. natalensis*, O) *L. troglodytes*, P) *L. vastus*, Q) *Physalaemus albifrons*, R) *P. cuvieri*. Photo credits: I, J, and N by Diego J. Santana; all other pictures by Adrian A. Garda.

Figure 4. Reptiles and Amphibians of Floresta Nacional de Nísia Floresta, Rio Grande do Norte State, Brazil. AMPHIBIANS: **Leptodactylidae (cont.)**: A) *Pleurodema diplolister*, B) *Pseudopaludicola mystacalis,* C) *P. pocoto*, D) *P. jaredi*. **Microhylidae**: E) *Elachistocleis cesarii*. **Strabomantidae**: F) *Pristimantis ramagii*.

SQUAMATA (LIZARDS): **Anolidae**: G) *Norops fuscoauratus*. **Gymnophthalmidae**: H) *Dryadosaura nordestina*, I) *Micrablepharus maximiliani*, J) *Vanzosaura multiscutata*. **Iguanidae**: K) *Iguana iguana*. **Leiosauridae**: L) *Enyalius bibronii*. **Phyllodactylidae**: M) *Gymnodactylus geckoides*. **Polychrotidae**: N) *Polychrus acutirostris*. **Scincidae**: O) *Brasiliscincus heathi*, P) *Psychosaura macrorhyncha*. **Sphaerodactylidae**: Q) *Coleodactylus meridionalis*. **Teiidae**: R) *Ameiva ameiva*. Photo credits: K and P by Willianilson Pessoa; all other pictures by Adrian A. Garda.

Figure 5. Reptiles and Amphibians of Floresta Nacional de Nísia Floresta, Rio Grande do Norte State, Brazil. SQUAMATA (LIZARDS): **Teiidae**: A) *Ameivula ocellifera* B) *Kentropyx calcarata*, C) *Salvator merianae*. **Tropiduridae**: D) *Tropidurus hispidus*. **Amphisbaenidae**: E) *Amphisbaena alba*, F) *A. vermicularis*.

SQUAMATA (SNAKES): **Colubridae:** G) *Chironius flavolineatus*, H) *Leptophis dibernardoi*, I) *Oxybelis aeneus*, J) *Tantilla melanocephala*. **Dipsadidae:** K) *Adelphostigma occipitalis*, L) *Apostolepis cearensis*, M) *A. longicaudata*, N) *Dipsas mikanii*, O) *Hydrodynastes gigas*, P) *Oxyrhopus trigeminus*, Q) *Philodryas olfersii*, R) *P. nattereri*. Photo credits: C, E, F, I, O, Q, R by Willianilson Pessoa; L by Maria Beatriz Sousa; all other pictures by Adrian A. Garda.

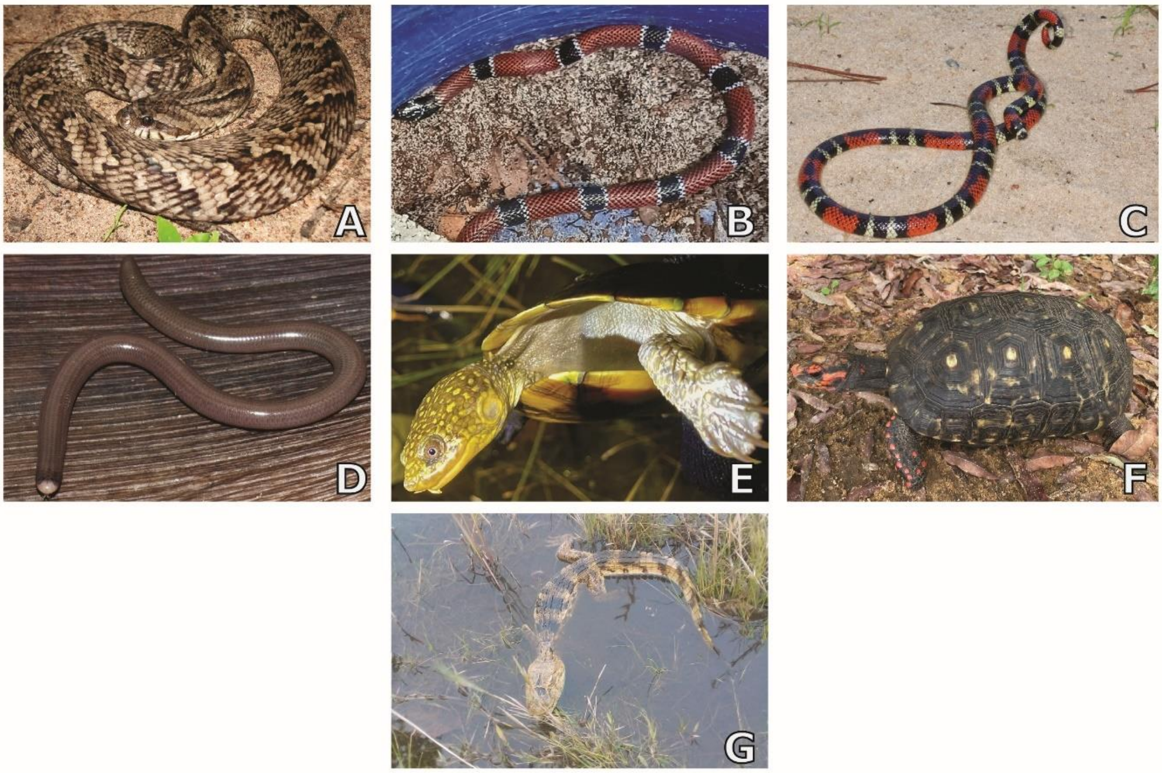

Figure 6. Reptiles and Amphibians of Floresta Nacional de Nísia Floresta, Rio Grande do Norte State, Brazil. Specimens registered but otherwise not collected. SQUAMATA (SNAKES): **Dipsadidae:** A) *Xenodon merremii* **Elapidae** B) *Micrurus corallinus*, C) *M. potyguara*. **Typhlopidae**: D) *Amerotyphlops pauscisquamus*. **Chelidae**: E) *Mesoclemmys tuberculata*. **Testudinoidea**: F) *Chelonoidis carbonarius*. **Alligatoridae:** G) *Caiman latirostris.* Photo credits: A by Willianilson Pessoa; B by Maria Beatriz Sousa; all other pictures by Adrian A. Garda

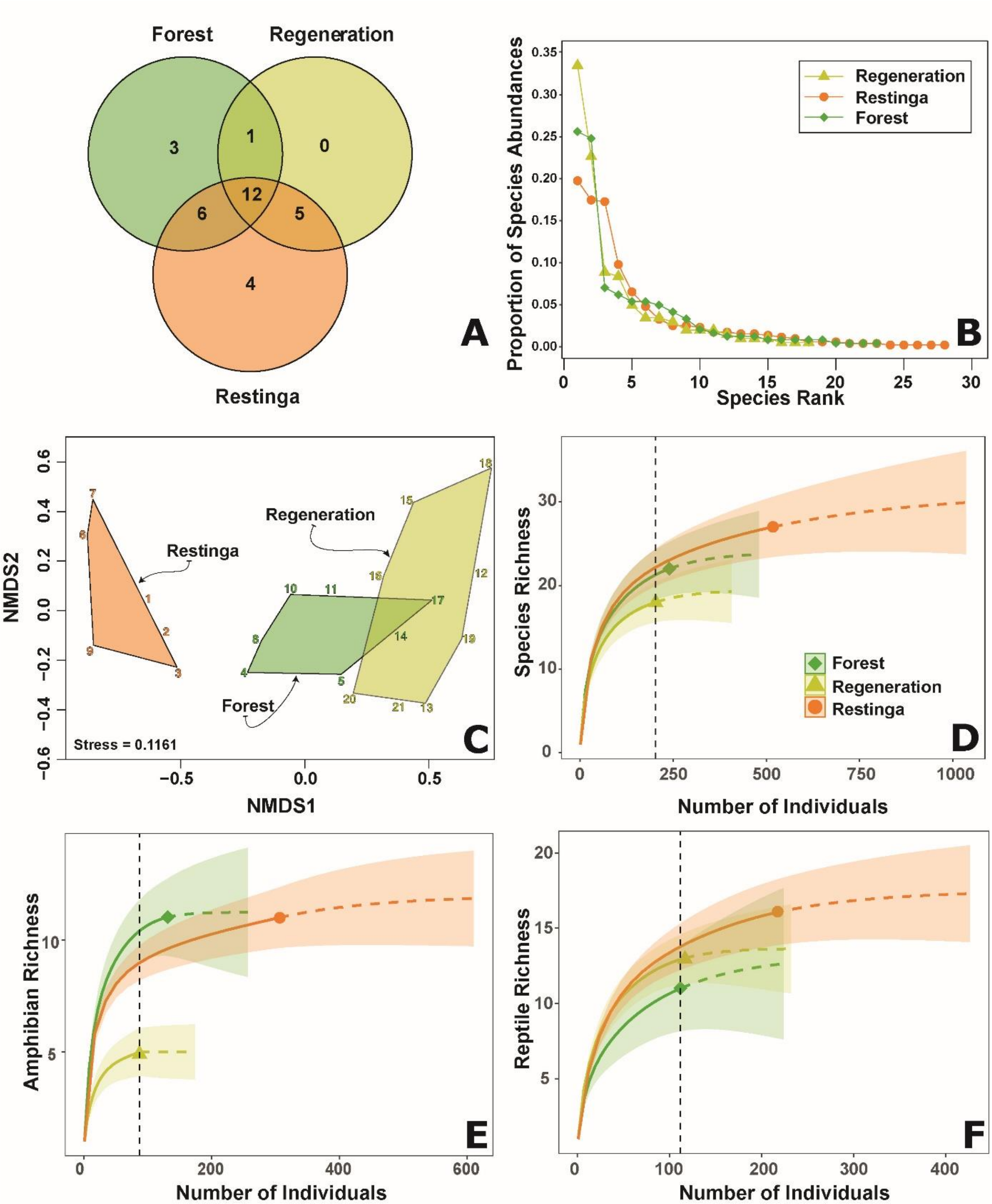

Figure 7. Descriptive statistics of the herpetofauna found in the Floresta Nacional de Nísia Floresta. A) Veen Diagram showing the distribution of the number of species among different vegetation types. B) Rank Curve presenting species proportions in a decrescent order of species abundance, within each vegetation type of the present study; C) NMDS graphic presenting similarity species composition in and among different vegetation types; D) Rarefaction curves with standard deviations presenting diversity of species in each vegetation type; y

axis shows species richness and x axis number of individuals; E) Rarefaction curves with standard deviations presenting amphibian species diversity in each vegetation type; F) Rarefaction curves with standard deviations presenting species reptile diversity in each vegetation type.

TABLE LEGENDS

Table 1. Amphibians recorded at Floresta Nacional de Nísia Floresta grouped by family, followed by genus and then species, the area where it was found and sampling method. Rs: Restinga; Rg: Regeneration; F: Forest; AS: Active Survey; and PT: Pitfall Trap. Vouchers with AAGARDA tag numbers are in the process of being incorporated into CHUFPB collection.

Table 2. Squamates (lizards) recorded at Floresta Nacional de Nísia Floresta grouped by family, followed by genus and then species, the area where it was found and the sampling method. Rs: Restinga; Rg: Regeneration; F: Forest; AS: Active Survey; and PT: Pitfall Trap. Vouchers with AAGARDA tag numbers are in the process of being incorporated into CHUFPB collection.

Table 3. Squamates (Snakes) and Chelonians recorded at Floresta Nacional de Nísia Floresta grouped by family, followed by genus and then species, the area where it was found and the sampling method. Rs: Restinga; Rg: Regeneration; F: Forest; AS: Active Survey; and PT: Pitfall Trap. Vouchers with AAGARDA tag numbers are in the process of being incorporated into CHUFPB collection.

Family		Species	Voucher	Area	Sampling methods
Bufonidae	1	*Rhinella granulosa* (Spix, 1824)	CHUFPB0023287	Rs	AS/PT
	2	*Rhinella diptycha* (Cope, 1862)	AAGARDA6210	F/Rs	AS/PT
Hylidae	3	*Boana albomarginata* (Spix, 1824)	AAGARDA13654	Rs	AS
	4	*Boana raniceps* (Cope, 1862)	AAGARDA13656	Rs	AS
	5	*Dendropsophus minutus* (Peters, 1872)	AAGARDA13657	Rs	AS
	6	*Dendropsophus nanus* (Boulenger, 1889)	CHUFPB0026593	Rs	AS
	7	*Pithecopus gonzagai* Andrade, Haga, Ferreira, Recco-Pimentel, Toledo, and Bruschi, 2020	AAGARDA13666	F	AS
	8	*Scinax fuscomarginatus* (Lutz, 1925)	CHUFPB0020398	Rs	AS
	9	*Scinax nebulosus* (Spix, 1824)	AAGARDA6251	Rs	AS
	10	*Scinax pachycrus* (Miranda-Ribeiro, 1937)	AAGARDA13616	Rs	AS
	11	*Scinax x-signatus* (Spix, 1824)	AAGARDA13655	Rs	AS
Leptodactylidae	12	*Adenomera hylaedactyla*	AAGARDA13571	F/Rs	AS/PT
	13	*Leptodactylus macrosternum* Miranda-Ribeiro, 1926	AAGARDA13659	Rs/F	AS/PT
	14	*Leptodactylus natalensis* Lutz, 1930	AAGARDA13614	Rs	AS/PT
	15	*Leptodactylus troglodytes* (Lutz, 1926)	CHUFPB0020873	Rs/Rg/F	AS/PT
	16	*Leptodactylus vastus* Lutz, 1930	Unvouchered	Rs/Rg/F	AS/PT
	17	*Physalaemus albifrons* (Spix, 1824)	CHUFPB0021089	F/Rs	AS/PT
	18	*Physalaemus cuvieri* Fitzinger, 1826	CHUFPB0023793	Rs/F/Rg	AS/PT
	19	*Pleurodema diplolister* (Peters, 1870)	AAGARDA13605	Rs/F/Rg	AS/PT
	20	*Pseudopaludicola mystacalis* (Cope, 1887)	CHUFPB0020049	Rs/F	AS/PT
	21	*Pseudopaludicola pocoto* Magalhães, Loebmann, Kokubum, Haddad & Garda, 2014	Unvouchered	Pond	AS/PT
	22	*Pseudopaludicola jaredi* Andrade, Magalhães, Nunes-de-Almeida, Veiga-Menoncello, Santana, Garda, Loebmann, Recco-Pimentel, Giaretta, and Toledo, 2016	AAGARDA9197	Rs	AS

Microhylidae	23	*Elachistocleis cesarii* (Miranda-Ribeiro, 1920)	CHUFPB0023477	F/Rs	AS/PT
Strabomantidae	24	*Pristimantis ramagii* (Boulenger, 1888)	AAGARDA13404	F	AS/PT

Family		Species	Voucher	Area	Sampling methods
Anolidae	1	*Norops fuscoauratus* (D'Orbigny, 1837)	AAGARDA13611	F	AS/PT
Gekkonidae	2	*Hemidactylus mabouia* (Moreau de Jonnès, 1818)	AAGARDA6232	Rg	
Gymnophthalmidae	3	*Dryadosaura nordestina* Rodrigues et al., 2005	AAGARDA8787	F/Rg	PT
	4	*Micrablepharus maximiliani* (Reinhardt & Lütken, 1862)	AAGARDA7318	Rs	PT
	5	*Vanzosaura multiscutata* (Amaral, 1933)	AAGARDA13602	Rs	PT
Iguanidae	6	*Iguana iguana* (Linnaeus, 1758)	AAGARDA8887	Rs	AS
Leiosauridae	7	*Enyalius bibronii* Boulenger, 1885	AAGARDA13610	F/Rg	PT
Phyllodactylidae	8	*Gymnodactylus geckoides* Spix, 1825	AAGARDA9442	Rs	PT
Polychrotidae	9	*Polychrus acutirostris* Spix, 1825	AAGARDA10415	Rs/Rg	AS
Scincidae	10	*Brasiliscincus heathi* (Schmidt & Inger, 1951)	AAGARDA8748	Rg/Rs	PT
	11	*Psychosaura macrorhyncha* (Hoge, 1946)	AAGARDA9805	F/Rg	PT
Sphaerodactylidae	12	*Coleodactylus meridionalis* (Boulenger, 1888)	AAGARDA8768	F/Rg/Rs	PT
Teiidae	13	*Ameiva ameiva* Linnaeus 1758	AAGARDA9823	Rg/Rs	PT
	14	*Ameivula ocellifera* (Spix, 1825)	AAGARDA13604	Rs/Rg	PT
	15	*Kentropyx calcarata* Spix, 1825	AAGARDA13606	F/Rg	PT
	16	*Salvator merianae* Duméril & Bibron, 1839	AAGARDA7313	Rg/Rs	PT
Tropiduridae	17	*Tropidurus hispidus* (Spix, 1825)	AAGARDA7362	Rg/Rs/F	PT
Amphisbaenidae	18	*Amphisbaena alba* Linnaeus, 1758	AAGARDA8788	F	AS
	19	*Amphisbaena vermicularis* Wagler, 1824	AAGARDA9814	Rg	AS

Family		Species	Voucher	Area	Sampling methods
Squamata (snakes)					
Colubridae	1	*Chironius flavolineatus* (Boettger, 1885)	AAGARDA8888	Rs	AS
	2	*Leptophis dibernardoi* Albuquerque, Santos, Borges-Nojosa & Ávila, 2022	AAGARDA9813	RS	AS
	3	*Oxybelis aeneus* (Wagler, 1824)	AAGARDA5866	RS	AS
	4	*Tantilla melanocephala* (Linnaeus, 1758)	AAGARDA10418	Rs/Rg	PT
Dipsadidae	5	*Adelphostigma occipitalis* (Jan, 1863)	AAGARDA13573	F	AS
	6	*Apostolepis cearensis* Gomes, 1915	Unvouchered	Rs	PT
	7	*Apostolepis longicaudata* Gomes, 1921	AAGARDA13505	Rs/Rg	PT
	8	*Dipsas mikanii* Schlegel, 1837	AAGARDA9441	F	PT
	9	*Hydrodynastes gigas* (Duméril, Bibron & Duméril, 1854)	AAGARDA8745	Rs	AS
	10	*Oxyrhopus trigeminus* Duméril, Bibron & Duméril, 1854	AAGARDA10417	Rs	PT
	11	*Philodryas olfersii* (Lichtenstein, 1823)	AAGARDA10436	Rs	AS
	12	*Philodryas nattereri* (Steindachner, 1870)	AAGARDA9372	Rs	AS
	13	*Xenodon merremii* (Wagler, 1824)	AAGARDA8826	F	AS
Elapidae	14	*Micrurus corallinus* (Merrem, 1820)	Unvouchered	F	PT
	15	*Micrurus potyguara* Pires, Silva Junior, Feitosa, Prudente, Pereira-Filho & Zaher, 2014	AAGARDA8890	Rs	PT
Typhlopidae	16	*Amerotyphlops paucisquamus* (Dixon & Hendricks, 1979)	AAGARDA13603	Rs/Rg	PT
Testudines					
Kinosternidae	17	*Kinosternon scorpioides* (Linnaeus, 1766)	Unvouchered	Rs	AS
Chelidae	18	*Mesoclemmys tuberculata* (Luederwaldt, 1926)	Unvouchered	Rs	AS
Testudinidae	19	*Chelonoides carbonarius* (Spix, 1824)	Unvouchered	Rs	AS
Crocodylia					
Alligatoridae	20	*Caiman latirostris* (Daudin, 1801)	Unvouchered	Rs	AS

CAPÍTULO II

(Esse artigo está sendo redigido nas normas da revista Perspectives in Ecology and Conservation)

Landscape and microhabitat factors shape herpetofauna species diversity in disturbed and natural habitats at an Atlantic Forest protected in northeast Brazil.

Landscape and microhabitat factors shape herpetofauna species diversity in disturbed and natural habitats at an Atlantic Forest protected in northeast Brazil.

Maria Beatriz de Andrade Sousa[1,2], Marília Bruzzi Lion[2,4,*], Ricardo Rodrigues da Silveira-Filho[2,3], Adrian Antonio Garda[1,2,3]

[1]Programa de Pós-graduação em Ciências Biológicas (Zoologia), Universidade Federal da Paraíba, Cidade Universitária, Castelo Branco, 58059-900, João Pessoa, PB - Brazil

[2]Laboratório de Anfíbios e Répteis, DBEZ, Centro de Biociências, Universidade Federal do Rio Grande do Norte, Av. Senador Salgado Filho, 3000, 59078-900 - Natal, RN - Brazil

[3]Knowledge Center for Biodiversity, 31270-901, Belo Horizonte, Minas Gerais, Brazil

[4]Departamento de Ecologia, Universidade Federal do Rio Grande do Norte, Av. Senador Salgado Filho, 3000, 59078-900 - Natal, RN – Brazil

*Correspondent author

Highlights

- Human-induced landscape alteration affects biological diversity.
- Study focuses on landscape and microhabitat impacts on reptile and amphibian communities in Atlantic Forest, Brazil.
- Key factors for species richness and diversity include distance to the pond, vegetation density, and canopy cover.
- Research highlights the importance of integrated conservation strategies for preserving amphibian and reptile populations.

Abstract

The alteration of natural landscapes due to human action is a crucial factor that can compromise biological diversity. Studying landscape parameters and those intrinsic to it, such as microhabitat characteristics, is an important step in understanding the dynamics of how biological communities' function, especially in disturbed environments. The aim of this study is to evaluate how landscape and microhabitat characteristics affect the richness and abundance of reptile and amphibian communities in a fragment of Atlantic Forest in northeastern of Brazil. Using 21 pitfall trap arrays, we sampled 961 individuals of 31 species: 12 amphibians species with 520 individuals and 19 squamate species with 441 individuals. Generalized linear models (GLMs) found that Distance to the pond, vegetation density, and canopy cover were the main factors explaining species richness and diversity, underscoring the significant impact of landscape and microhabitat characteristics on reptile and amphibian communities. Our study contributes valuable insights for conservation efforts by identifying specific habitat features that are critical for amphibians and reptiles populations. This research emphasizes the need for integrated conservation approaches that consider both microhabitat and landscape-level factors to enhance the resilience of amphibian and reptile communities in fragmented landscapes.

Keywords: Conservation; Atlantic Rain Forest; Communities; Generalized linear models.

Introduction

The alteration of natural landscapes due to human action is a crucial factor that can compromise biological diversity (Turner 2010). Such changes can directly affect species by interfering in resource availability and ultimately even changing the physiognomy of a given area (Scanes 2018). Evaluating the relationships of these changes with local diversity has been a focus of study in ecology (Bell et al., 2012). Studying landscape parameters and those intrinsic to it, such as microhabitat characteristics, is an important step in understanding the dynamics of how biological communities' function, especially in disturbed environments (Turner 2005; Morin 2011).

One of the most common approaches it is to relate patterns of diversity to habitat heterogeneity (MacArthur and MacArthur 1961; Price et al., 2010; Tuanmu and Jetz 2015). The arrangement of the environment allows variations in vegetation cover, soil types, the presence of water bodies, and topographical structures, each contributing uniquely to the composition of local communities (Bazzaz 1975). These parameters encompass characteristics related to species niches, and their different combinations allow higher species diversities (Hansson et al., 1995).

The response to landscape parameters varies significantly between different taxa (Fahrig 2003) (Tews et al., 2003). For instance, a study found that landscape heterogeneity may play a crucial role in influencing the distribution and richness of birds and lepidopterans in Mediterranean landscapes, because heterogeneity provides diverse habitats and resource availability, accommodating species with different ecological requirements (Atauri and Lucio 2001). The relationship between the grain of heterogeneity at the scale at which heterogeneity is expressed and how species of a particular group explore and use space is fundamental to this interaction. This highlights the importance of considering species-specific responses to landscape structure when evaluating biodiversity patterns (Kaspari et al., 2003; Hortal et al., 2006). In contrast, for reptiles and amphibians, specific types of land-use, such as irrigated and non-irrigated crops, were found to better explain the observed richness (Atauri and Lucio 2001). This suggests that while landscape heterogeneity benefits some taxa by offering a variety of habitats, other taxa may be more influenced by particular land-use practices that directly affect their habitat suitability and resource access.

In tropical environments, reptiles and amphibians also play fundamental roles in animal communities, for example These groups may have low dispersal capacity and high habitat specificity, making them particularly sensitive to environmental changes (Haddad & Prado, 2005; Rossa-Feres et al., 2008). Anurans, in general, are strongly influenced by the availability of water bodies due to their complex life cycle, which can include aquatic phases (Becker, 2007; Rossa-Feres, 2008). For reptiles, in addition to the presence of water bodies, vegetation structure—such as canopy openness, understory density, and tree circumference—has proven crucial for species diversity, especially in fragmented environments (Vitt, 1999; Vallan, 2000; Jellinek et al., 2004; Vitt et al., 2007; Garda et al., 2013). Forest fragment area and shape can explain the abundance and richness of reptiles in small fragments of Atlantic rain Forest in northeastern Brazil (Lion et al., 2016), while Split Distance was shown to be a critical variable explaining amphibians' richness and abundances (Lion et al., 2014). Habitat disconnection refers to the human-induced separation between different habitats required for various life stages used by a species. In amphibians, for example, which have an aquatic (larval) phase and a terrestrial (adult) phase, this concept is more easily understood (Becker et al., 2007).

Studying the mechanisms that permeate the relationships between landscape and habitat structure can contribute to the creation of proposals for conservation and management of biota (Wintle et al., 2019; Barahona-Segovia et al., 2023).These mechanisms can include Microhabitat features such as fallen logs and termite nests which can serve as refuge or protection from the sun. Additionally, canopy cover contributes to maintaining a more heterogeneous forest structure and allows for the presence of more reptile species, as it helps regulate humidity and temperature levels (Olson 1994; Keppel et al., 2017). . By understanding these relationships, conservationists can develop effective strategies to prioritize the maintenance of the habitat structure to support the persistence of species in disturbed landscapes, ensuring that critical resources remain available and contribute to species survival.(Rija 2022; Ockermüller et al., 2023).

Historically, tropical forests have undergone extensive land exploitation and systematic conversion into partially or completely modified landscapes, making them globally threatened environments (Wright 2005; Taubert et al., 2018).The Atlantic Forest is a global biodiversity hotspot, but due to anthropogenic pressures, particularly in the past, much of its territory has been reduced and is now highly fragmented (Mittermeier et al., 2004).

The Nísia Floresta National Forest, a protected area of approximately 174 hectares, is in the city of Nísia Floresta and conserves a remnant of the Atlantic Forest in Rio Grande do Norte. Before becoming a protected area, it was subject to forestry experiments involving the introduction of exotic species such as pine and eucalyptus (MMA 2012). Currently, the forest's flora comprises native vegetation (Atlantic Forest and ‘’Restinga’’, as well as areas of abandoned plantations, especially eucalyptus (MMA 2012). A recent study conducted in this protected area documented 39 reptile and 24 amphibian species, revealing that areas of regeneration are characterized by a depauperate herpetofaunal community compared to natural habitats (Sousa et al., 2024). Considering the characteristics of the Nísia Floresta National Forest as an altered landscape, it is important to test the effects of landscape and microhabitat variables on reptile and amphibian communities.

The aim of this study is to evaluate how landscape and microhabitat characteristics affect the richness and abundance of reptile and amphibian communities in a fragment of Atlantic Forest in northeastern of Brazil. We expect that the landscape metrics, along with the microhabitat variables, will influence the richness and diversity of herpetofauna in the Nísia Floresta National Forest.

Material and Methods

Study area

The research was conducted from June 2022 to August 2023, in the National Forest of Nísia Floresta (FLONA, from now on), located in the municipality of Nísia Floresta, Rio Grande do Norte state, Brazil (06°05’11’’S;35°11’03’’W). FLONA is located inside the Atlantic Forest biome, a biodiversity hotspot (Mittermeier et al., 1999; Mittermeier et al., 2011). Originally, the Atlantic Forest covered an area of more than 1.3 million km², but currently its extent is estimated to range from 11 to 28% of this original coverage (Ribeiro et al., 2009; Rezende et al., 2018). Among Brazilian biomes, the Atlantic

Forest has the highest number of threatened species, with approximately 3000 species at risk in 2022 (IBGE 2022). Of the total threatened species in Brazil, 50.5% are found in the Atlantic Forest, with 38.5% of them endemic to this biome (ICMBio/MMA 2018).

The Atlantic Forest is composed of native forests, which can be dense, open, mixed rainforests and associated with other ecosystems, such as mangroves, rocky outcrops and Restingas, which is characterized by coastal dune environments with herbaceous and shrub vegetation that extends along the Brazilian coast (Marques and Grelle 2021). The FLONA has three well-defined vegetation types: Atlantic Forest dense rainforest, a secondary growth mixed rainforest with exotic tress Pinus and Eucalyptus, and Restinga (MMA 2012).

Sampling of community

We used twenty-one pitfall trap arrays, distributed across three different physiognomies: Atlantic Forest, regenerating forest, and Restinga (Figure 1). We selected the sites to install pitfall trap arrays generating random points in ArcGIS program, with the following conditions: arrays should be at least 50 meters apart and 100 meters or less to one of the access roads of the protected area. Each array contained four 30l buckets distributed in a Y-shape with one central bucket linked to three peripheral ones by 6m plastic drift fences (Cechin and Martins 2000). Each pitfall array was sampled for a total of 7 consecutive days each month from June 2022 to August 2023.

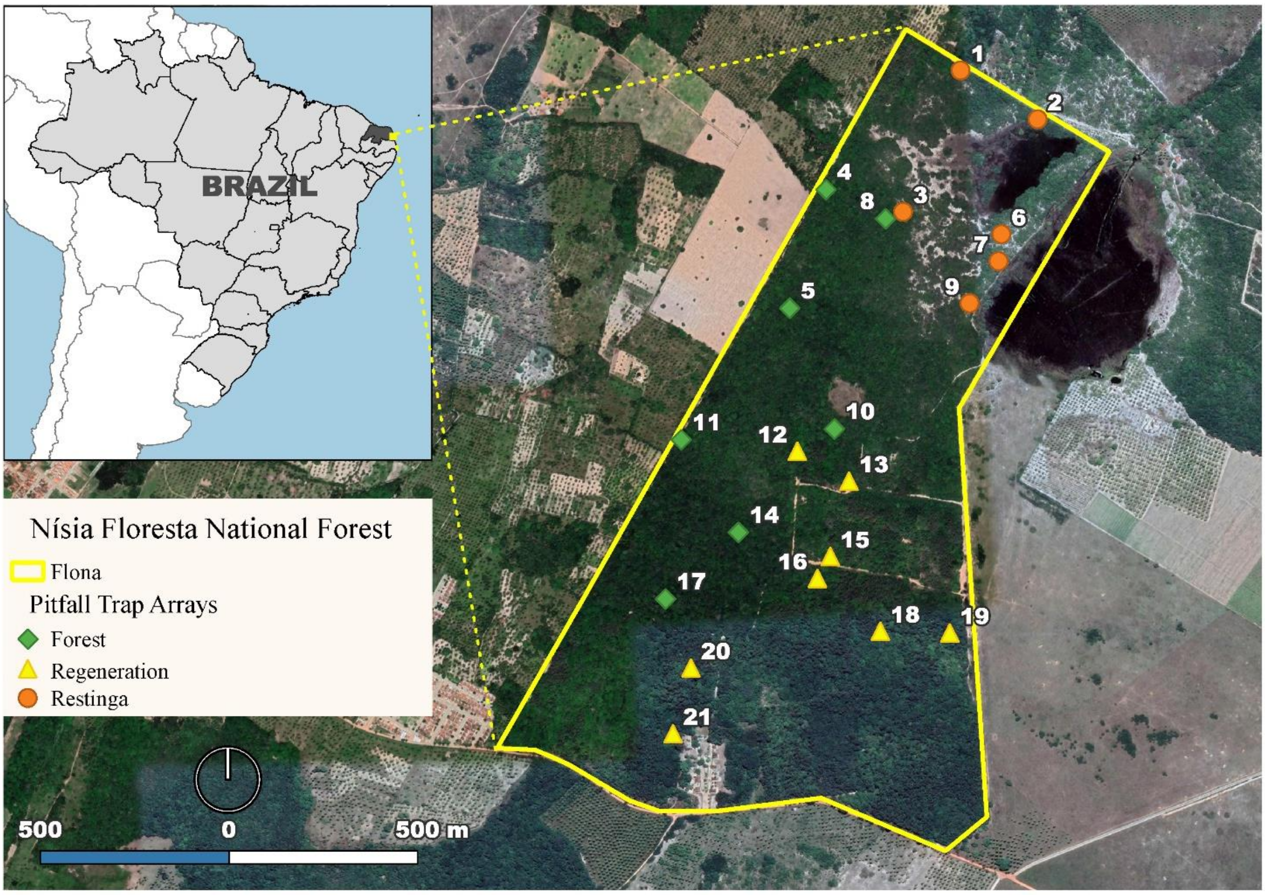

Figure 1. Location of the study area – Floresta Nacional de Nísia Floresta, in South America, Brazil, Rio Grande do Norte State. Symbols represent our pitfalls traps arrays, which are colored according to vegetation type. (map from first manuscript, we must make another map for the second paper).

Microhabitat variables

We measured the following 10 microhabitat parameters at each pitfall trap array, in July, at the end of the rainy season (Garda et al., 2013): (1) nearest tree distance, from the central bucket to the nearest tree with diameter greater than 10 cm at 120 cm above ground; (2) nearest tree circumference, at 120 cm aboveground; (3) circumference of the largest tree closest to the central bucket. (4) number of aboveground termite nests; (5) number of logs; (6) number of burrows; (7) number of bromeliads, for values smaller than 100, we counted all individual plants. However, as there was a very high number of bromeliads at some locations, we standardized it to >100. (8) leaf litter weight, in grams, with a spring scale, within three randomly selected 50 cm by 50 cm (9) To measure canopy cover, we used a mobile phone camera (Samsung SM-A135M) with an aperture of *f*/1.8, positioning it directly above each Y-bucket. This procedure was repeated for all 21 trap arrays to obtain values for the mean percentage of canopy cover. The images were then processed using the coverR package (Chianucci et al., 2022) in R software. The coveR package estimates canopy cover and leaf area index using digital cover photography, allowing us to calculate an average percentage of foliar cover for each site. (10) vegetation density measured as the number of stems, at the same locations as leaf litter weight, considering all plant individuals less than 10 cm in circumference at 120 cm above ground, counted at 40 cm in height in a 90 cm radius area.

Parameters 4, 5, 6 and 7 above were quantitated within a 6 m radius from the center of each pitfall trap array. The three measurements of parameters 8 and 10 at each array were later summed to obtain an average for each point to yield a single measurement for each parameter at each array. We used two landscape metrics to test the effect on the communities, which were distance of the trap array from FLONA’s edge and distance to the pond, using QGIS 3.34 software.

Statistical analyses

To assess which variables best explained species richness and diversity, we employed generalized linear models (GLMs). Because most of our predictors were correlated, we initially performed a principal component analysis (PCA) considering all 12 predictors, plus latitude and longitude of the trap arrays. From the PCA we selected the three predictors with the stronger correlations to the first three axis respectively: distance to the pond, vegetation density and number of termite nests. Additionally, distance to the forest edge, leaf litter weight, and canopy cover were selected due to their biological significance. Therefore, we considered these six predictors in all subsequent linear models. The greater correlation between the selected predictor was between canopy cover and leaflitter ($r_{Pearson} = 0.64$), followed by canopy cover and distance to the pond ($r_{Pearson} = 0.59$; Supplemental Table 1).

To evaluate the relative strength of the predictors in models we z-transformed them prior to running the models, using the R function 'scale'. We then constructed six separated models predicting species richness and diversity (Hill number, orders $q = 0$ and $q = 1$ respectively). Accordingly, dependent variables in models were: (1) overall species richness, (2) overall diversity, (3) amphibian richness, (4) amphibian diversity, (5) reptile richness and (6) reptile diversity. We used the "hillR" R package to generate Hill numbers (Li 2018).

Initially, models predicting species richness considered Poisson error distributions, while models predicting species diversity considered normal error distribution. However, we detected heteroskedasticity in residuals of selected model predicting reptile species richness. Therefore, we log-transformed reptile richness and considered normal residuals in these models. We used the function 'simulateResiduals' in "DHARMa" R package to confirm residuals normality and homoskedasticity (Hartig 2018)

In order to select the minimal adequate model (Crawley 2015), we used the function 'step' in the 'stats' R package (R Core Team 2023). When this automatic model simplification included nonsignificant predictors, we performed a manual model simplification removing variables and contrasting the models with ANOVA tests. If the reduced model was statistically different from the relatively more complex model ($p < 0.05$), then we retained the complex model as the minimal adequate. When the reduced model was not different from the more complex model ($p > 0.05$), we accepted the simplified model as the minimal adequate model (Crawley 2015). To extract coefficients of determination from the simplified models we used the default function from the 'rsq' R package (Zhang 2023).

We evaluated spatial autocorrelation in minimal adequate models using Moran's I test in the package 'ape' (Paradis and Schliep 2019) and confirmed that residuals from all retained models were spatially uncorrelated (Moran's I: 0.05 to 0.02; p > 0.22). All analyses were performed using R environment.

Results

In total, we sampled 961 individuals of 31 species: 12 amphibians species with 520 individuals and 19 squamate species with 441 individuals. The most abundant amphibian species was *Physalaemus cuvieri* with 143 individuals, followed by *Pleurodema diplolister* with 109 individuals. For reptiles, the most common captures were from *Kentropyx calcarata* (113 individuals), followed by *Ameivula ocellifera* (107 individuals). The physiognomy which we captured more species and individuals of herpetofauna was the Restinga, followed by Forest and secondary growth forest. Details from the species list and the contrast between physiognomies can be found in *Sousa et al submitted*.

The minimal adequate model explaining overall species richness contained only the distance to the pond (β = -0.270 ± 0.070, *z value* = -3.831, P = 0.0001). The relation was negative, consequently, overall richness decreased with distance to the pond (Table 1, Figure 2). For overall species diversity (Hill number order q = 1), the minimal adequate model retained the distance to the pond (β = -1.737 ± 0.416, *t value*= -4.177, P < 0.0006) and vegetation density (β = -0.838 ± 0.416, t = -2.016, P = 0.058). Both had negative coefficients, indicating that an increase in the distance to the pond and in the amount of surrounding vegetation density are associated with a decrease in overall species richness (Table 1, Figure 2).

Table 1. Table with the models that were accepted in the minimum adequate model approach, relating to overall richness and diversity, amphibian richness and diversity, and reptile richness.

	Pond Distance	Vegetation Density	Canopy Cover	Adjusted R^2
Overall				
Richness	-0.270 ± 0.070 (P < 0.001)	-	-	0.56

Diversity	-1.737 ± 0.416 (P < 0.001)	-0.838 ± 0.416 (P = 0.058)	-	0.45
Amphibians				
Richness	-0.437 ± 0.111 (P < 0.001)	-0.266 ± 0.107 (P = 0.013)	-	0.52
Diversity	-1.517 ± 0.327 (P < 0.001)	-0.866 ± 0.327 (P = 0.016)	-	0.52
Reptiles				
Richness	-	-	-0.171 ± 0.046 (P = 0.001)	0.39

For amphibians, predictors retained to explain species richness were distance to the pond (β = -0.437 ± 0.111, *z value* = -3.930, *P* <0.0001) and vegetation density (β = -0.266 ± 0.107, *z value* = -2.477, *P* = 0.0132; Table 1, Figure 3). The same predictors were selected to explain amphibian's diversity, distance to the pond (β = -1.517 ± 0.327, *t value* = -4.643, *P* = 0.0002) and vegetation density (β = -0.866 ± 0.327, *t value* = -2.651, *P* = 0.016; Table 1, Figure3) Therefore, our results suggests that as the distance to the pond increases and the density of surrounding understory vegetation increases, both richness and diversity of amphibians decrease.

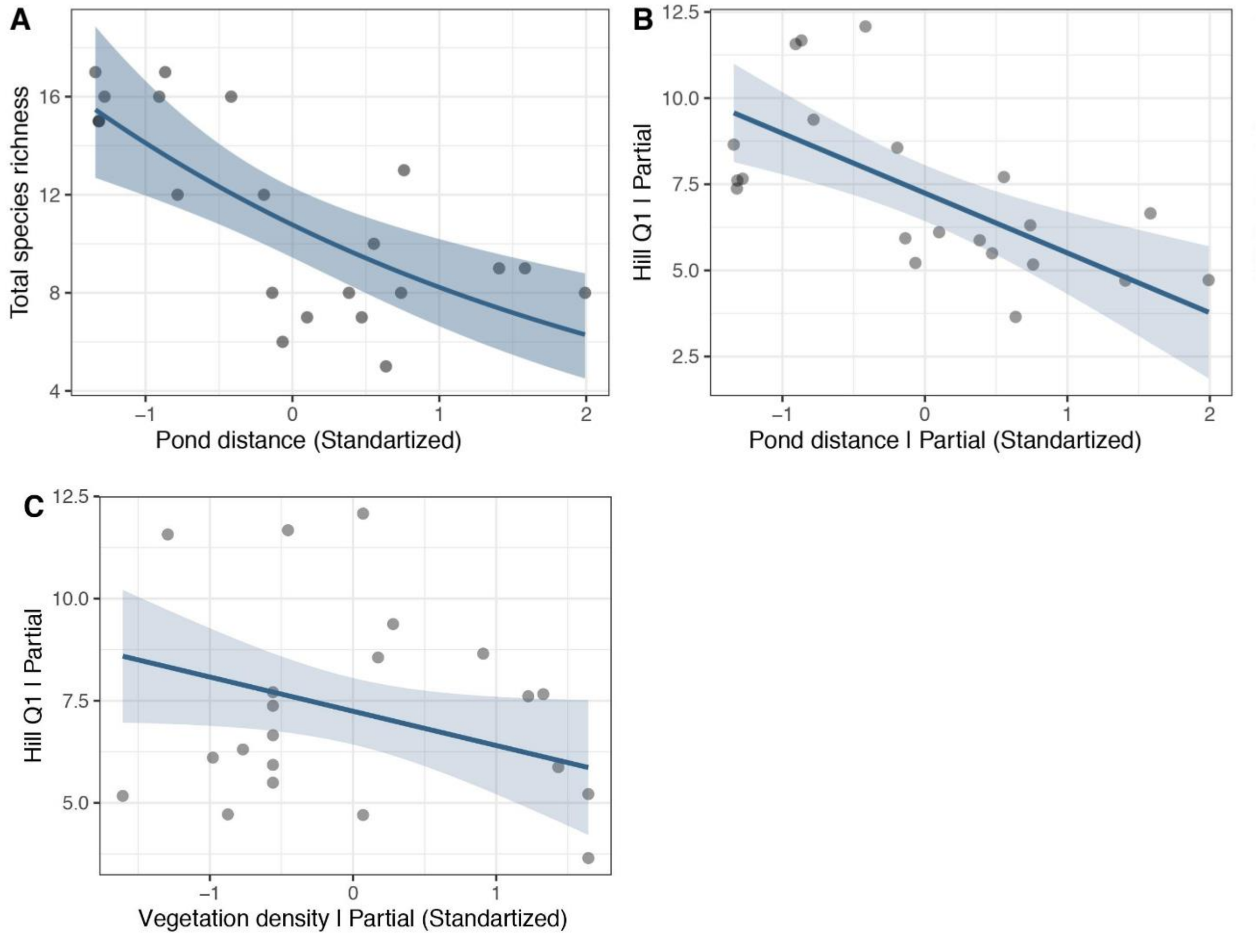

Figure 2. Effect of Pond distance and Vegetation density on the overall species richness and overall species diversity in Flona. The shaded parts indicate 95% confidence interval of the estimated effect size

For reptiles, only canopy cover explained richness (β = -0.171 ± 0.046, *t value* = -3.739, *P* = 0.0014; Table 1, Figure 4). The relationship was negative, with more canopy cover reducing reptile species diversity. For reptile diversity, no predictor performed better than the null model in the stepwise model simplification. Therefore, no variable was retained in the minimal adequate model predicting reptile species diversity.

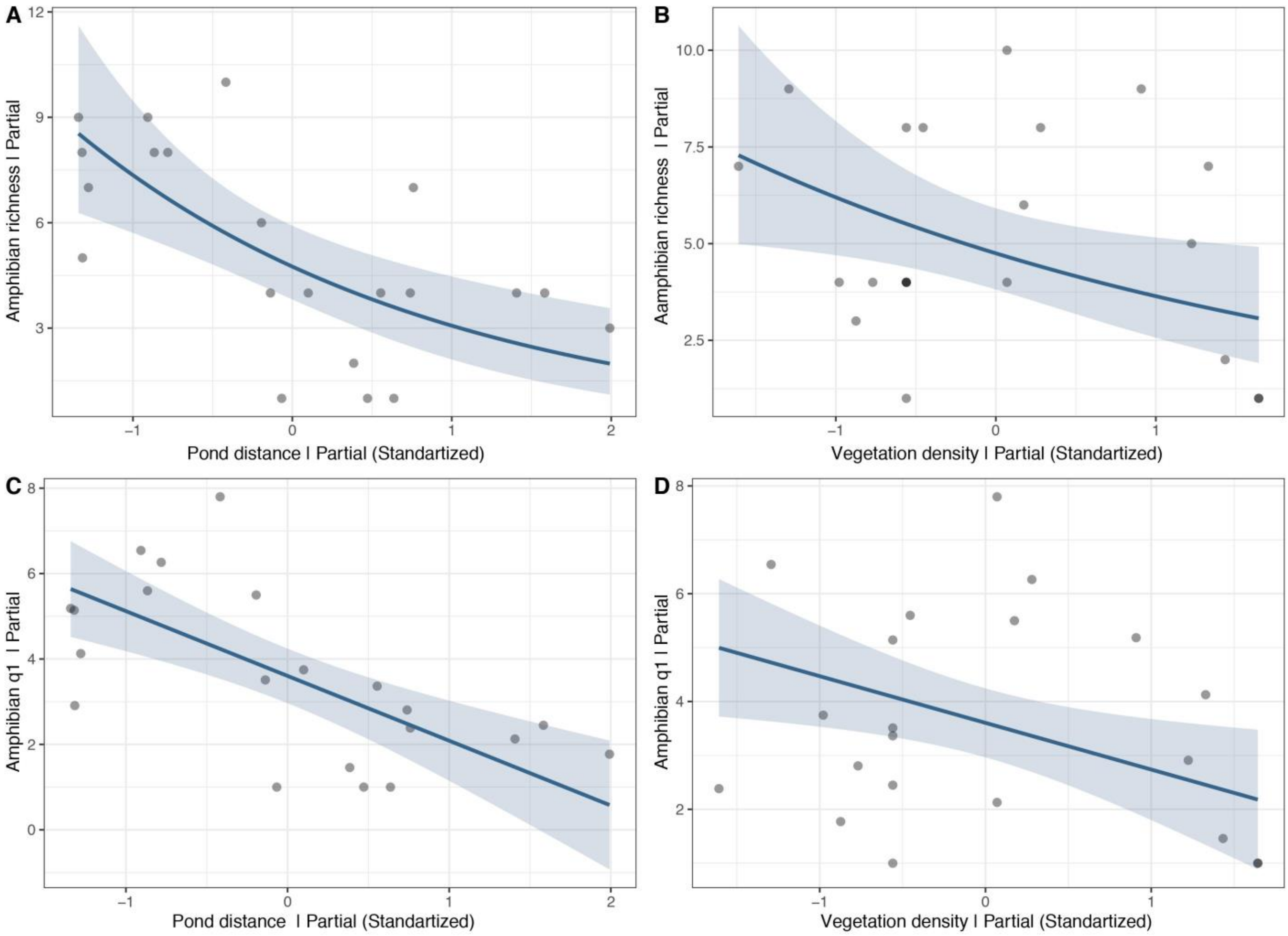

Figure 3. Effect of Pond distance and Vegetation density on the amphibian richness and diversity in Flona. The shaded parts indicate 95% confidence interval of the estimated effect size

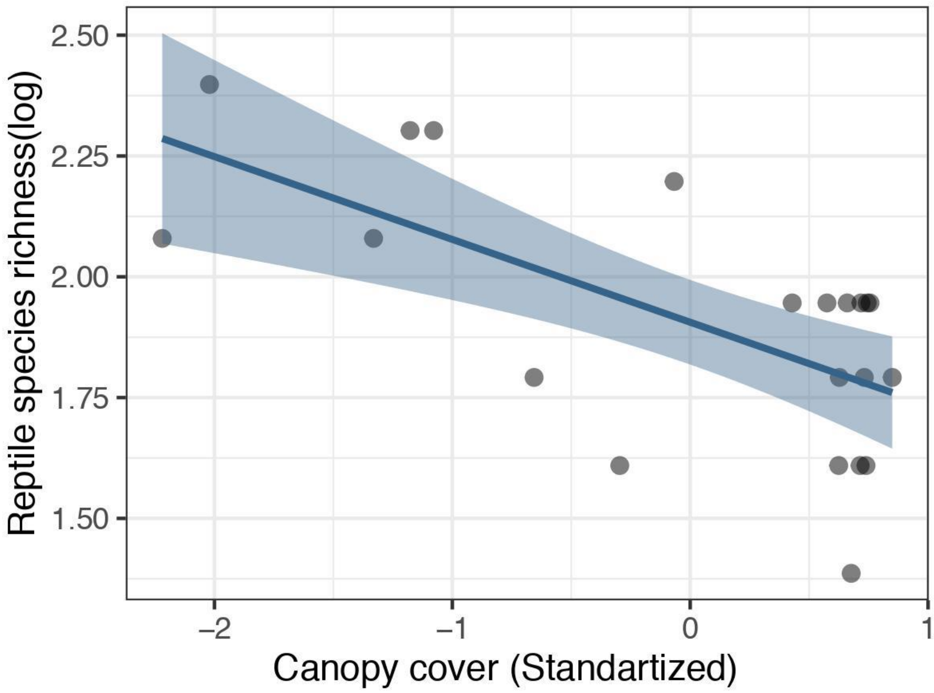

Figure 4. Effect of canopy cover on the reptile's richness in Flona. The shaded parts indicate 95% confidence interval of the estimated effect size

Discussion

Distance to the pond, vegetation density, and canopy cover were the main factors explaining species richness and diversity, underscoring the significant impact of landscape and microhabitat characteristics on reptile and amphibian communities. Our research found that the distance to the pond was negatively related to species richness and diversity of amphibians. This relationship is likely due to the dependence of many amphibian species on water bodies, especially for reproduction, as water is essential for the development of their larvae (Wells 2007).

Our results may be related to metapopulation dynamics, as many amphibian species depend on a mosaic of habitats to perform essential activities beyond reproduction (Smith and Green 2005). In this context, they may disperse to other areas for breeding, foraging, or avoiding predators. However, with increasing distance from breeding sites, there may be a decrease in species richness and diversity as local populations become less connected (Smith and Green 2005). Studies conducted in the Amazon, found that amphibian richness in riparian and non-riparian areas was related to the distance to streams, with richness increasing closer to the water sources (Ribeiro et al., 2012; Rojas-Ahumada et al., 2012). The consistent pattern observed highlights the importance of proximity to water bodies for maintaining amphibian diversity.

In addition to the distance to the pond, vegetation density was also an important variable explaining amphibian richness and diversity, and it was also negatively related. This finding contrasts with the literature, which often reports a positive relationship between vegetation density and amphibians diversity (Burrow and Maerz 2022). A potential explanation for this discrepancy is the presence of a significant number of exotic plants, such as pines and eucalyptus, in the study area (MMA 2012).

These plants are interspersed among the forested sites and may create less favorable conditions for native amphibian species, leading to lower richness. Additionally, few studies have focused on the terrestrial ecology of amphibians, with most research concentrating on wetland environments and agricultural or silvicultural settings, which often report negative responses to such conditions (Silva et al., 2011; Prado and Rossa-Feres 2014). The findings reported in the literature suggest that amphibian richness changes according to the dynamic of the habitat (Burrow and Maerz 2022). Therefore, the unique vegetational composition and habitat structure in our study area may contribute to the observed negative relationship between vegetation density and amphibian diversity.

Our results showed that canopy cover explained reptile richness. This may be related to the physiological characteristics of the group, as in open areas, solar incidence is higher, allowing many species take advantage for thermoregulation, reptiles could efficiently regulate their body temperature by moving between sun and shade (Sartorius et al., 1999; J. Vitt et al., 2007). Canopy cover contributes to a diverse environment by creating varied microclimates and resource availability, which in turn supports many of reptile species (Pike et al., 2011)

Garda et al. (2013) found that canopy cover, along with other microhabitat variables, better explained the occurrence of lizards than phylogeny in the Amazon rainforest. Mesquita et al. (2015) also found that canopy cover was one of the best predictors of lizard abundance in an ecotone area between the Cerrado and Amazon reinforcing the importance of canopy cover in different ecosystems.

We expected the "distance to the edge" to significantly explain amphibians and reptiles richness and diversity due to their sensitivity to environmental changes; however, this variable was not a strong predictor. Similar results in the literature suggest that the quality of the surrounding matrix might have a stronger influence, diminishing edge effects (Dixo and Martins 2008). Additionally, besides matrix quality, factors such as fragment size, habitat loss and habitat degradation are also reported as key indicators in the variation of herpetofauna diversity in Brazil (Teixido et al., 2021).

Conclusions

In this study, we tested whether landscape and microhabitat factors would explain the local diversity of reptiles and amphibians in a protected fragment of the Atlantic Forest in northeastern Brazil. Our analyses revealed that distance to the pond and vegetation density were the factors that contributed most to amphibian diversity in the fragment. On the other hand, for reptiles, only canopy cover was important for explaining species richness. Our findings are consistent with other studies and highlight the importance of access to water bodies for maintaining amphibian diversity, as well as the conservation of native vegetation to increase amphibian diversity. Maintaining areas with varying canopy cover may be more beneficial for increasing reptile diversity. Our results suggest the need for different management and conservation strategies for these groups, as they respond differently to structural landscape and habitat variables. Thus, this study significantly contributes to the understanding of the main factors shaping the diversity of reptiles and amphibians in fragmented environments, offering valuable insights for management and conservation actions in the Atlantic Forest.

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Supplementary material

Graph showing the correlation between variables

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Pitfall trap used to sample reptile and amphibian communities