UNIVERSIDADE FEDERAL DA PARAÍBA

CENTRO DE CIÊNCIAS AGRÁRIAS

PROGRAMA DE POS-GRADUAÇAO EM BIODIVERSIDADE

MATHEUS LEONYDAS BORBA FEITOSA

DINÂMICAS URBANAS NO USO DA TERRA INFLUENCIAM A DIVERSIDADE TAXONÔMICA, CONDIÇÃO CORPORAL E TRAÇOS FUNCIONAIS DA ASSEMBLEIA DE ESCORPIÕES EM BREJOS DE ALTITUDES PARAIBANOS

AREIA

2024

MATHEUS LEONYDAS BORBA FEITOSA

DINÂMICAS URBANAS NO USO DA TERRA INFLUENCIAM A DIVERSIDADE TAXONÔMICA, CONDIÇÃO CORPORAL E TRAÇOS FUNCIONAIS DA ASSEMBLEIA DE ESCORPIÕES EM BREJOS DE ALTITUDES PARAIBANOS

Dissertação apresentada ao Programa de Pós-Graduação em Biodiversidade da Universidade Federal da Paraíba, como requisito parcial à obtenção do título de Mestre em Biodiversidade

Orientador: Prof. (a) Dr. (a) Fredy Alvarado Roberto.

Coorientador: Prof. (a) Dr. (a) André Felipe de Araujo Lira.

AREIA

2024

Catalogação na publicação
Seção de Catalogação e Classificação

F311d Feitosa, Matheus Leonydas Borba.
Dinâmicas urbanas no uso da terra influenciam a diversidade taxonômica, condição corporal e traços funcionais da assembleia de escorpiões em Brejos de altitudes Paraibanos / Matheus Leonydas Borba Feitosa. - Areia:UFPB/CCA, 2024.
60 f. : il.

Orientação: Fredy Alvarado Roberto.
Coorientação: André Felipe de Araujo Lira.
Dissertação (Mestrado) - UFPB/CCA.

1. Biodiversidade. 2. Aracnídeos. 3. Ecologia de Paisagem. 4. Florestas tropicais. 5. Uso e cobertura da terra. I. Roberto, Fredy Alvarado. II. Lira, André Felipe de Araujo. III. Título.

UFPB/CCA-AREIA CDU 574.1(043.3)

Elaborado por LUCIANNA SILVESTRE DE CASTRO AZEVÊDO - CRB-15/973

MATHEUS LEONYDAS BORBA FEITOSA

DINÂMICAS URBANAS NO USO DA TERRA INFLUENCIAM A DIVERSIDADE TAXONÔMICA, CONDIÇÃO CORPORAL E TRAÇOS FUNCIONAIS DA ASSEMBLEIA DE ESCORPIÕES EM BREJOS DE ALTITUDES PARAIBANOS

Dissertação apresentada ao Programa de Pós-Graduação em Biodiversidade da Universidade Federal da Paraíba, como requisito parcial à obtenção do título de Mestre em Biodiversidade

Aprovado em: _27_/_08_/_2024_

BANCA EXAMINADORA

Prof. Dr. Fredy Alvarado Roberto – (Orientador)

Departamento de ciências ambientais, Instituto Potosino de Investigación Científica y Tecnológica

Prof. Dr. César Murilo de Albuquerque Correa – (Titular - Membro externo)

Laboratório de Bioecologia de Scarabaeoidea, Universidade Estadual de Mato Grosso do Sul

Prof. Dr. Edmundo González-Santillán – (Titular - Membro externo)

Instituto de Biologia, Universidad Nacional Autónoma de México

MINISTÉRIO DA EDUCAÇÃO
UNIVERSIDADE FEDERAL DA PARAÍBA
CENTRO DE CIÊNCIAS AGRÁRIA
PROGRAMA DE PÓS-GRADUAÇÃO EM BIODIVERSIDADE
CAMPUS II - AREIA

ATA DE DEFESA DE DISSERTAÇÃO

Ao vigésimo sétimo dia de fevereiro de 2024, às 16h, no Programa de Pós-Graduação em Biodiversidade - PPGBio, do Centro de Ciências Agrárias da Universidade Federal da Paraíba, estiveram presentes os membros da Comissão Examinadora sugerida pelo orientador e aprovada pelo Colegiado do PPGBio, para participação na Defesa Pública do Trabalho de Dissertação da discente **MATHEUS LEONYDAS BORBA FEITOSA**, aluno regularmente matriculado neste Programa de Pós-Graduação. O trabalho defendido pelo aluno intitulou-se: "***DINÂMICAS URBANAS NO USO DA TERRA INFLUENCIAM A DIVERSIDADE TAXONÔMICA, CONDIÇÃO CORPORAL E TRAÇOS FUNCIONAIS DA ASSEMBLEIA DE ESCORPIÕES EM BREJOS DE ALTITUDES PARAIBANO***". Os examinadores conferiram o conceito ao candidato em formulário que foi anexado à presente ata. Na ocasião, foi estabelecido o conceito **APROVADO**, e o aluno terá que entregar à Coordenação do Programa e ao sistema de Bibliotecas da UFPB os exemplares definitivos da dissertação de acordo com Regulamento Geral dos Programas de Pós-Graduação *Stricto Sensu* da Universidade Federal da Paraíba. E para constar, eu, José Domingos Ribeiro Neto, atuando como Coordenador, lavrei a presente ata que vai assinada por mim, pelo presidente e demais membros da Comissão Examinadora.

Documento assinado digitalmente
gov.br JOSE DOMINGOS RIBEIRO NETO
Data: 11/09/2024 15:08:24-0300
Verifique em https://validar.iti.gov.br

Areia - PB, 27 de agosto de 2024.

Coordenação do PPGBio

Dr. Fredy Alexander Alvarado Roberto
Presidente da comissão examinadora

César Murilo de A Correa

Dr. César Murilo de Albuquerque Correa
Examinador externo

Dr. Edmundo González-Santillán
Examinador externo

DADOS CURRICULARES DO AUTOR

MATHEUS LEONYDAS BORBA FEITOSA, nascido em Recife-PE, no dia 12 de março de 2001, filho de Isaac Tenório Feitosa e Tereza Cristina Silva Borba. Ingressou no Curso de Ciência Biológicas Bacharelado na Universidade Federal de Pernambuco, Cidade Universitária-Recife-PE, em fevereiro de 2018, e concluiu obtendo o título de Bacharel em Ciências Biológicas em Maio de 2022. Iniciou o curso de Mestrado no Programa de Pós-graduação em Biodiversidade da Universidade Federal da Paraíba, Campus II-Areia-PB, em setembro de 2022, e concluiu o curso obtendo o título de Mestre em Biodiversidade em Agosto de 2024 sob orientação do Prof.Dr Fredy Alvarado e Co-orienação do Prof.Dr André Lira.

AGRADECIMENTOS

Inicialmente, apresento meus agradecimentos a Deus, que permitiu o acontecimento de toda minha trajetória de vida, incluso o início e conclusão do mestrado. Deste modo, escrevo o salmo 91 “Aquele que habita no esconderijo do Altíssimo, à sombra do Onipotente descansará. Direi do senhor: Ele é meu Deus, o meu refúgio, a minha fortaleza, e nele confiarei”.

Agradeço a minha família que tem me apoiado desde o início da minha carreira acadêmica, em 2018 pela UFPE, que não fez diferente nesta caminhada em busca do título de mestre pela UFPB. Dentre meus familiares, agradeço principalmente a dona de casa Tereza Cristina e o caminhoneiro Isaac Feitosa, meus pais, que sempre com pouco muito fizeram. Agradeço a meus avós, Dona Zezé e Seu Moacir, que junto aos meus pais, nunca deixaram de me apoiar, aconselhar e mostrando o caminho certo a se seguir, sempre elucidando a seguinte frase para mim “Homem só vai pra frente de duas maneiras Matheus, estudando ou quando leva uma topada”. Agradeço a meus tios e tias, que apesar da minha escolha de estudar biologia e não seguir carreira militar, mantiveram seus apoios e acreditarem no meu potencial.

Aqui, agradeço novamente a Deus, porém, o agradecimento vai por ele ter permitido eu ter uma irmã, Marcielly. Deus permitiu que a primeira mulher que eu amasse fosse minha mãe, e logo em seguida, minha irmã. A vocês duas vai todo meu amor e carinho!

Agradeço a Rebeca, minha noiva, que vem acompanhando minha caminhada acadêmica desde metade da minha graduação. Gata, muito obrigado por ser quem você é e pelo bem que você me faz, te amo.

Nesse instante, agradeço a todas as pessoas que conheci durante minha passagem pela UFPB. Inicialmente, agradeço ao meu orientador, Prof. Fredy, que permitiu que tudo isto acontecesse, desde a aprovação, construção de um belo projeto de mestrado e a conclusão do curso. Agradeço aos demais professores da instituição, que juntos ao Fredy, forneceram bastantes conhecimentos que auxiliaram na minha formação, em novas pesquisas, novos questionamentos e principalmente por me fazer pensar um pouco mais fora da caixinha, vocês são SHOW!

Sobre as amizades que construí durante este período, tanto colegas de turma quantos professores, agradeço especialmente a Hidalgo e Igor por todo apoio, estádia, idas a campos diurnos e noturnos, juntos desbravamos bem partes dos brejos paraibanos. Agradeço ao grande Diegão, que com toda sua bagagem fora do âmbito acadêmico, no ICMBIO, promoveu bastantes pensamentos sobre a realidade que enfrentamos, experiencias reais de campo no âmbito da conservação brasileira, e além disso, bastantes risadas com suas histórias e boas músicas de sua banda. Agradeço aos demais companheiros de turma, por todos os conhecimentos e momentos durantes as aulas e nos momentos depois das aulas, adorei vocês.

Meus agradecimentos ao meu grupo de pesquisa pernambucano, ARACNO-PE, agradeço a todos integrantes por todo o apoio e momentos que vivemos em laboratório e em campo. Tratando do grupo, de forma especial, agradeço a equipe especial que tenho, composta por Hugo sem barba, Hugo com barba, André Junior e Thayna. Agradeço a um grande amigo que iniciou as pesquisas iniciais comigo, mas seguiu outra linha de pesquisa, mas neste pequeno tempo e até hoje é um grande amigo e irmão, Lauriano.

Agora, dedico esse paragráfo como uma pequena forma de agradecimento a Lira. Esse grande pesquisador tem me acompanhado desde 2019, e ao longo do tempo, atuou como orientador, coorientador e principalmente um grande amigo. Sinceramente, agradeço imensamente por tu ser um cara simples, conversa com seus alunos de forma que eles se sintam ouvidos e respeitados, fazendo com que a caminhada acadêmica (graduação, pós graduação) seja mais amigável. E quando falo de amigável, você realmente é um grande amigo de que a UFPE permitiu que eu conhecesse. Te agradeço pelo apoio, conselhos, puxões de orelhas, presença e oportunidades.

Agradeço de forma direta a Universidade Federal da Paraíba e ao Programa de Pós-graduação em Biodiversidade pela oportunidade. Além disso, agradeço e sinto-me lisonjeado pela banca examinadora, por aceitarem e estarem fazendo parte desta etapa.

Por fim, mas não menos importante, agradeço a minha pessoa! Para mim, deixo uma frase que levo para a vida “Lembre-se de quem você é”.

RESUMO

A urbanização, um fenômeno que transforma continuamente ambientes naturais em áreas industriais, residenciais e agrícolas, leva a altas taxas de desmatamento, fragmentação e mudanças no uso do solo. Esse processo gera fragmentos florestais imersos em matrizes urbanas, forçando a biodiversidade a se adaptar a ambientes alterados. A cobertura da terra e a heterogeneidade ambiental moldadas pela urbanização impactam a distribuição e a diversidade genética das espécies, além de aumentar as ilhas de calor e as pressões climáticas. O crescimento urbano vem promovendo decréscimos nas condições corporais e alterações em características morfométricas dos organismos que conseguem permear esses habitats. Além disso, a urbanização promove a homogeneização biótica e funcional, nesse sentido, os ecossistemas são formados por um número reduzido de espécies e com menor variabilidade, desempenhando funcionalidades similares no ambiente. Nos trópicos, especialmente nos brejos de altitude, caracterizados por serem enclaves altitudinais de florestas úmidas, a urbanização e atividades humanas como agricultura intensiva e exploração florestal resultam em perda de habitat e fragmentação. Esses ecossistemas, ricos em biodiversidade, são particularmente vulneráveis devido à sua localização em áreas de caatinga e limitações socioeconômicas. Apesar disso, algumas espécies, como escorpiões, apresentam plasticidade ecológica, ocupando diversos habitats, inclusive urbanos. Escorpiões, devido à sua sensibilidade a alterações ambientais, emergem como potenciais bioindicadores para monitorar impactos da urbanização na biodiversidade. Estudos indicam que a complexidade ambiental é crucial para a sobrevivência desses organismos, com habitats mais heterogêneos oferecendo maior disponibilidade de micro habitats e presas. Assim, é essencial que ecossistemas modificados ofereçam condições mínimas para a sobrevivência e manutenção das populações, destacando a importância da complexidade ambiental na qualidade do habitat.

Palavras chaves: aracnídeos; ecologia de paisagem; florestas tropicais; uso e cobertura da terra.

ABSTRACT

Urbanization, a phenomenon that continuously transforms natural environments into industrial, residential, and agricultural areas, leads to high rates of deforestation, fragmentation, and land-use changes. This process creates forest fragments embedded within urban matrices, forcing biodiversity to adapt to altered environments. Land cover and environmental heterogeneity shaped by urbanization impact the distribution and genetic diversity of species, while also increasing heat islands and climatic pressures. Urban growth has been associated with declines in body conditions and changes in the morphometric traits of organisms that manage to permeate these habitats. Furthermore, urbanization promotes biotic and functional homogenization, where ecosystems are composed of a reduced number of species with lower variability, performing similar functions in the environment. In the tropics, particularly in montane forest enclaves characterized by their humid forests at high altitudes, urbanization and human activities such as intensive agriculture and logging result in habitat loss and fragmentation. These ecosystems, rich in biodiversity, are particularly vulnerable due to their location within caatinga regions and socioeconomic limitations. Despite this, some species, such as scorpions, exhibit ecological plasticity, occupying various habitats, including urban areas. Scorpions, due to their sensitivity to environmental changes, emerge as potential bioindicators for monitoring the impacts of urbanization on biodiversity. Studies indicate that environmental complexity is crucial for the survival of these organisms, with more heterogeneous habitats offering greater availability of microhabitats and prey. Therefore, it is essential that modified ecosystems provide the minimum conditions for the survival and maintenance of populations, highlighting the importance of environmental complexity in habitat quality.

Keywords: arachnids; landscape ecology; tropical forest; land use and cover.

LISTA DE ILUSTRAÇÕES

Supplementary material

LISTA DE TABELAS

SUMÁRIO

1. INTRODUÇÃO GERAL

1.1 URBANIZAÇÃO E USO DO SOLO: MODULANDO A PAISAGEM

Entre os muitos fatores que causam a perda de biodiversidade no Antropoceno, a alteração de habitats naturais para centros urbanos se encontra entre os mais alarmantes (Díaz *et al*. 2019). Essa conversão é resultado da urbanização, processo descrito como um fenômeno que implica na alteração e conversão contínua de ambientes físicos e comunidades ecológicas, bem como paisagens naturais em áreas destinadas a suprir as necessidades humanas (Forman e Godron, 1986). A caráter de exemplo, a urbanização vai promover a construção de ambientes industriais, residenciais, agrícolas e redes viárias (Filgueiras *et al*. 2021; Slattery e Fenner, 2021). Consequentemente, a estruturação e a composição do ambiente ficam sujeitas aos processos de fragmentação per se, nos quais os habitats naturais são divididos em pequenos fragmentos isolados (Fahrig, 2003), à perda de habitat, que implica na redução ou eliminação de áreas naturais, e à perda de conectividade entre as manchas florestais (Gopalan e Radhakrishna, 2022; Perrin *et al*. 2023). Nesse sentido, os remanescentes florestais atuais tendem a ser representados por fragmentos isolados inseridos em matrizes antrópicas, submetendo a biodiversidade a desenvolver seus papéis ecológicos nessas paisagens alteradas (Melo *et al*. 2013).

Ao longo dos anos, o aumento da urbanização tem sido consistentemente acompanhado pelo rápido aumento da densidade populacional (Elmqvist, 2013; Ritchie e Roser, 2018). Assim, tanto em escala global quanto regional, as áreas designadas para o crescimento urbano muitas vezes coincidem com pontos críticos de biodiversidade (Seto *et al*. 2012). Isso, por sua vez, leva a biodiversidade a viver próximas ou inseridas nas áreas urbanas (Gopalan e Radhakrishna, 2022), sendo desfavorável em decorrência da estrutura da paisagem ser amplamente caracterizada por aspectos negativos, como a proporção de superfícies impermeáveis, exposição a poluentes, perda de interações tróficas e reduções de micro habitats (Threlfall *et al*. 2012; Seibold *et al*. 2019; Du Toit *et al*. 2021). Diante disso, estudos anteriores sugerem que a construção de uma matriz urbana promove uma filtragem ambiental favorecendo traços ou espécies adaptadas (Tóth e Hornung, 2020; Sharma *et al*. 2023). Desta maneira, McKinney (2006), destaca a hipótese de que esse processo de filtragem decorrente as construções das cidades, podem levar as comunidades biológicas a serem mais semelhantes entre si ao longo do tempo e espaço.

Tratando-se de cenários urbanos, onde a configuração e a distribuição da cobertura da terra são moldadas principalmente pelas necessidades humanas (Forman e Godron, 1981), observam-se diferentes tipos e quantidades de cobertura da terra, como áreas de pastagem, agricultura, monoculturas e um misto de usos imersos na matriz urbana. Consequentemente, essas variações resultam em mudanças na heterogeneidade ambiental (Gardner *et al*. 2009) e atuam impactando na montagem da biodiversidade no ambiente (Galán-Acedo *et al*. 2018; Grimm *et al*. 2008). A caráter de exemplo, essas alterações no uso e cobertura da terra têm o potencial de diminuir a dispersão e a frequência de movimentação, podendo promover a deriva genética, que resultaria em reduções da diversidade genética dentro das áreas de habitat e em uma maior variabilidade nas frequências alélicas entre essas áreas (Johnson e Munshi-South 2017). Além do mais, em decorrências a efeitos em escala local, assentamentos urbanos enfrentam grande formação de ilhas de calor resultando em pressões climáticas crescentes (Taha 1987). Desta maneira, a superfície impermeável resultante da urbanização representa um limite para a manutenção da biodiversidade nativa (Alberti, 2005). Consequentemente, os organismos tendem a permanecer em locais que apresentem condições mínimas paras sua sobrevivência, como jardins, terrenos abandonados, cultivos intraurbanos e fragmentos florestais localizados nas cidades (Goddard *et al*. 2010; Lepczyk *et al*. 2017). Sendo assim, apesar de um organismo apresentar determinada plasticidade ecológica e sua capacidade de dispersão determinar seu alcance, barreiras urbanas podem limitar a dispersão e promover restrições a habitats adequados (Amundrud *et al*. 2018). Como consequência, a biodiversidade em cada tipo de ecossistema responderá de forma variada, refletindo suas necessidades ecológicas específicas (Ferraz *et al*. 2007; Gopalan e Radhakrishna, 2022).

Embora a urbanização seja desenvolvida para moldar a paisagem em favor dos humanos, é crucial reconhecê-la também como uma ameaça à saúde e ao bem-estar da população global (Cardinale *et al*. 2012). Conforme observado por Mace *et al*. (2012), a biodiversidade está declinando em uma taxa sem precedentes, resultando na perda das funções ecossistêmicas essenciais para a saúde e o bem-estar humano, que anteriormente eram mantidas por esses organismos. A organização da biodiversidade é influenciada por combinações de fatores ambientais, desde condições abióticas a interações intra e interespecíficas (Diez e Pulliam, 2007). Neste contexto, o desenvolvimento urbano gera pressões de seleção que impactam a estrutura das comunidades biológicas, implicando em sua montagem em ambientes urbanizados (Filgueiras *et al*. 2011; Pardini *et al*. 2010). Essas pressões resultam em mudanças nos traços relacionados à sobrevivência, sucesso reprodutivo e interações entre espécies, influenciando a dinâmica populacional e a composição da comunidade (Johnson e Munshi-South 2017). Em abelhas *Bombus terrestres* L. *autor e ano*, após serem inseridas em habitats urbanos produziram mais descendentes, atingiram um tamanho máximo da colônia e estocaram mais alimento para reserva energética (Samuelson *et al*. 2018). Similarmente, Hahs *et al*. (2023), visualizaram no parâmetro de diversidade funcional uma relação dependente do táxon estudado com a urbanização. Para os carabídeos, aves e répteis, foi observado uma predisposição a apresentar tamanhos corporais inferiores em áreas mais urbanizadas, enquanto para organismos como anfíbios e morcegos foi observado a presença de tamanhos maiores nessas regiões. De forma adicional, as alterações na biodiversidade local devido à urbanização afetam processos ecológicos e evolutivos em uma escala mais ampla, incluindo competição entre espécies, interações presa-predador e diversidade genética em habitats urbanos (Alberti *et al*. 2017). Neste sentido, Sumasgutner *et al*. (2019), constataram que populações de *Falco naumanni* Fleischer, 1818 em áreas urbanas só realizavam a postura de ovos e nidificação quando suas presas (ratazanas) eram abundantes, além de que, experimentaram decréscimos em sua abundância, diversidade genética e ocupação de nicho, correlacionados a baixa abundância de suas presas. De maneira semelhante, foi observado uma significativa homogeneização biótica nos parâmetros de diversidade funcional e filogenética de aves como resultado do aumento da urbanização (Morelli *et al*. 2016). Deste modo, atualmente para a ecologia e biologia da conservação, identificar e entender os principais condutores que alteram e regulam os padrões da biodiversidade é um tópico chave (Sachs *et al*. 2009).

1.2 BREJOS DE ALTITUDES

Inserido dentro da distribuição das florestas tropicais nordestinas, os brejos de altitude ou refúgios florestais úmidos, representam enclaves altitudinais de vegetação considerados como ilhas de floresta semidecídua atlântica (Rodal *et al*. 2005; De Queiroz *et al*. 2017). Esses ecossistemas situam-se em planaltos e chapadas, com altitudes variando entre 500 a 1.000 metros acima do nível do mar (De Queiroz *et al*. 2017), sendo descritos como florestas neotropicais sub-montana (altitude<600m) e montana (altitude>600m) (Veloso *et al*. 1991). Além do mais, esses ambientes são caracterizados por estarem circundados por vegetação de Caatinga e sujeitos a receber chuvas orográficas que asseguram níveis de precipitação superiores a 1.200 mm por ano (Andrade-Lima, 1982) e grande camada superficial do solo rica em matéria orgânica (rodrigues *et al*. 2008).

Esses ecossistemas são descritos por apresentar grande diversidade, abrigando não apenas a biodiversidade nativa da floresta atlântica, mas também fauna e flora de origem amazônica e de florestas serranas do sul e sudeste do Brasil (Tabarelli e Santos, 2004). No entanto, sua localização em regiões da Caatinga os torna expostos a intensa retirada de madeira contínua, exposição ao pastoreio livre de animais exóticos (bovinos, caprinos, aves) e atividades decorrentes das significativas limitações socioeconômicas e ambientais dessa região (Melo, 2018; Jamelli *et al*. 2021). Por exemplo, a expansão da agricultura familiar e a exploração intensiva de recursos florestais para subsistência resultam na perda de habitat, fragmentação, desmatamento, queimadas e conversão de áreas naturais para atividades agrícolas, o que altera drasticamente a paisagem (Leal *et al*. 2005; Araújo *et al*. 2021).

Atualmente, estima-se que cerca de 80% do domínio da Caatinga já tenha sido modificado com à retirada da vegetação natural para áreas de pastagens, monoculturas e construções de residências, com aproximadamente 94% de seu território sujeito à desertificação (MMA, 2021). Como remanescentes tropicais úmidos em meio a essa paisagem, os brejos de altitude são explorados para a produção de diversas culturas, como café, banana, cana-de-açúcar, milho, feijão e mandioca, além da exploração de produtos madeireiros (Barbosa *et al*. 2004). Portanto, essas atividades aceleram a fragmentação regional das florestas e contribuem para a defaunação da biodiversidade (Leal *et al*. 2005).

As florestas tropicais, que abrigam uma grande parte da biodiversidade global, têm sido reduzidas devido à urbanização (Brannstrom, 2002). Apesar disso, a compreensão atual dos impactos da urbanização sobre a biodiversidade no hemisfério sul ainda é insuficiente quando comparada aos estudos realizados no hemisfério norte (Hahs *et al*. 2023; McDonald *et al*. 2020). Nesse contexto, a aplicação de descobertas oriundas de regiões temperadas e boreais podem introduzir vieses na compreensão de como a biodiversidade em regiões tropicais responde ao processo e à intensificação da urbanização (Rega-Brodsky *et al*. 2022). As florestas tropicais são cruciais para a biodiversidade mundial, além de que, em regiões tropicais a diversidade de espécies é naturalmente maior e abrigando maior concentração de *hotspots* (Myers *et al*. 2000; Slik *et al*. 2015). No entanto, de acordo com Laurance *et al*. (2014), cerca de 50% da extensão original dessas florestas foi convertida em áreas antropogênicas devido ao processo de urbanização. Essa transformação resultou em uma redução drástica na distribuição da cobertura florestal, cobrindo apenas cerca de 2% da superfície terrestre do planeta (Castro, 2009).

Atualmente, apesar das pressões antropogênicas, os brejos de altitude continuam a apresentar uma alta incidência de espécies endêmicas e comunidades biológicas ainda pouco estudadas (Andrade-Lima, 1982; Silva *et al*. 2018). A elevada riqueza de espécies observada nesses ecossistemas pode estar associada à maior complexidade estrutural da vegetação (Souza e Martins, 2005), que, por sua vez, está ligada ao aumento da riqueza de espécies vegetais (Silveira *et al*. 2020). Esse fenômeno é influenciado pelas características das áreas montanhosas, como a elevação da altitude e o consequente aumento da pluviosidade (Prado, 2003). Por exemplo, Diehl et al. (2013) demonstraram que, em áreas de brejo, o aumento da complexidade estrutural da vegetação permitiu maior disponibilidade de recursos e suportando assembleias de aranhas mais diversificadas. De maneira similar, essas regiões atuam como refúgios para a diversidade de escorpiões, proporcionando condições favoráveis para a persistência de espécies fora de suas áreas de distribuição principal (Foerster *et al*. 2019).

1.3 ESCORPIÕES: DIVERSIDADE E POTENCIAL COMO BIOINDICADORES AMBIENTAIS

A ordem dos escorpiões, está inserida no grupo dos quelicerados que integra a classe Arachnida (Stockmann e Flay, 2010; Brazil e Porto, 2011), sendo a quinta maior ordem em termo de riqueza de espécies, apresentando cerca de 2.800 espécies (Rein, 2023), com estimativa de apresentar em torno de 7.000 espécies (Coddington e Colwell, 2001). Popularmente conhecidos como lacraus, esses organismos detêm uma linhagem que remonta à datação mais remota dentro da classe, sendo considerados os aracnídeos mais basais (Cruz, 1994; Ruppert e Barnes, 1996). Neste sentido, o plano corporal dos escorpiões pouco diferiu morfologicamente dos seus antepassados do Período Siluriano, o grupo extinto Gigantostráceos (Eurypterida) (Brownell e Polis, 2001). Assim, os escorpiões possuem uma estruturação anatômica singular, com subdivisão do opistossoma em mesossoma e metassoma, possuindo um apêndice ventral chamado de pente no prossoma e um apêndice pós-anal especializado na produção de peçonha com um aguilhão inoculador (Figura 1) (Polis, 1990). Além de que, majoritariamente os escorpiões possuem em suas cutículas corpóreas à presença das proteínas beta-carbolina e 4-methil-7-hidroxicumarina, permitindo a capacidade de fluorescência ao contato com a luz ultravioleta (Figura 2) (Gaffin, 2012; Yoshimoto *et al*. 2020).

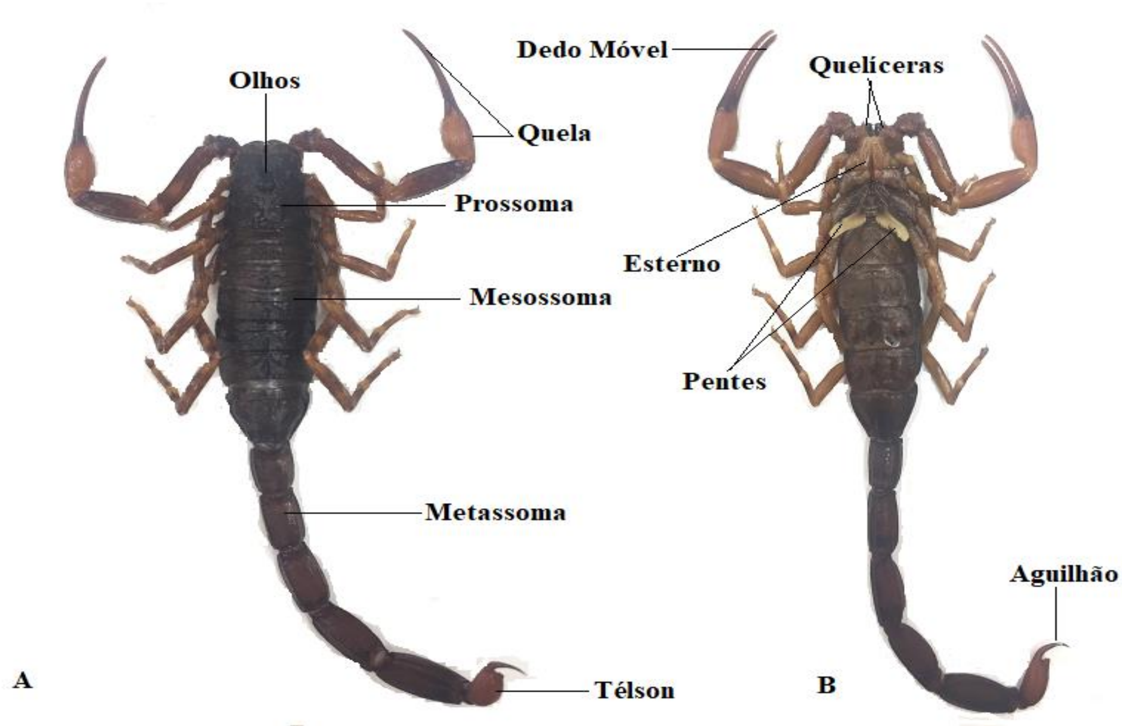

Figura 1. Morfologia do escorpião *Tityus brazilae* Lourenço e Eickstedt, 1984, em face dorsal (A) e face ventral (B). Fonte: Matheus Leonydas.

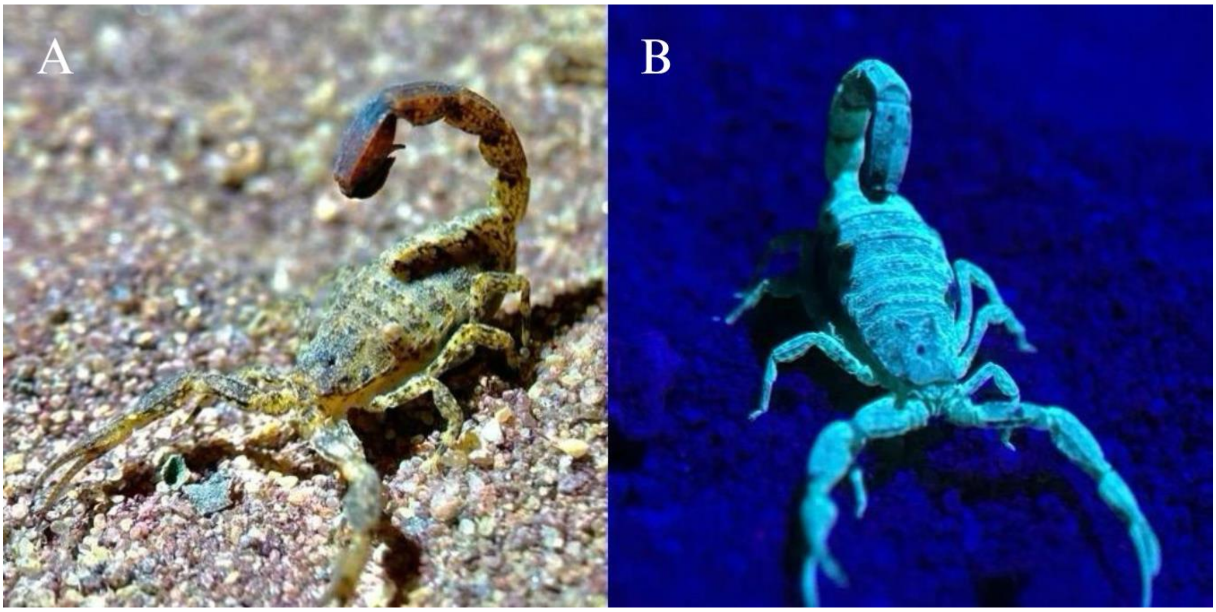

Figura 2. Fêmea de *Tityus mattogrossensis* Borelli, 1901 sob luz branca (A) e exposta ao espectro de luz ultravioleta. Fonte: Matheus Leonydas

Os escorpiões são frequentemente descritos como organismos sedentários, caracterizados por hábitos predatórios predominantemente noturnos e solitários, com pouca expressão de comportamento social (Lourenço, 2002). Apesar de sua natureza sedentária, adotando de forma frequente o comportamento de sentar-e-espera, desempenham um papel crucial no controle populacional de diversos organismos, como pequenos vertebrados (Silva-Júnior *et al*. 2023), outros aracnídeos (Albín *et al*. 2015; Silva-Júnior *et al*. 2021), grilos e baratas (Polis, 1990). Durante o dia, buscam abrigo em uma variedade de locais, como rochas, cascas de árvores, troncos em decomposição no solo, tocas, diferentes estratos da serrapilheira e cavernas, com as preferências específicas variando entre as espécies (Polis, 1990; Ruppert e Barnes, 1996; Brazil e Porto, 2011; Dehghani *et al*. 2016). Por outro lado, durante os períodos reprodutivos, as interações sociais tornam-se mais frequentes, pois os machos aumentam sua atividade de forrageio em direção às fêmeas, guiando-se por pistas químicas no substrato captadas por seus pentes (Mullen e Sissom, 2019). Embora a maioria das espécies se reproduza de forma sexuada, com o processo reprodutivo iniciando-se pelo comportamento de corte, algumas espécies apresentam a estratégia de partenogênese (Polis, 1990; Foerster *et al*. 2022).

Os escorpiões estão o entre os primeiros animais a conquistarem e dominarem o ambiente terrestre com ampla distribuição (Brandão e Françoso, 2010). Desde sua origem, estes aracnídeos se mostram como animais capazes de suportar e adaptar-se a diferentes situações e condições ambientais (Brazil e Porto, 2011). Como resultado, os escorpiões exibem uma ampla plasticidade ecológica, ocupando uma variedade de ecossistemas terrestres em todo o mundo, incluindo florestas tropicais, montanhas, desertos e cavernas (Polis, 1990), e até mesmo ambientes urbanos (Pucca *et al*. 2014; Amado *et al*. 2021). Sendo assim, são organismos que apresentam interações constantes com outros organismos e a situação atual da paisagem (Brownell e Polis, 2001). Entretanto, apesar de alta distribuição geográfica, não são caracterizados como animais ecologicamente generalistas, sendo na verdade espécies exigentes com relação ao hábitat e micro-hábitat, possuindo padrões ecológicos e biogeográficos específicos para cada espécie (Lourenço, 1994).

Os ecossistemas terrestres abrigam uma ampla diversidade de espécies de artrópodes, que são frequentemente utilizadas como modelos em estudos ecológicos (Schowalter, 2016). Estudos prévios indicam que a montagem das assembleias de escorpiões é influenciada por diversos fatores, tais como gradientes bioclimáticos (Lira *et al*. 2019), estrutura da vegetação do habitat (Foerster *et al*. 2020) e características da paisagem circundante (Feitosa *et al*. 2024). Portanto, por apresentarem relações direta com as condições ambientais dos variados ecossistemas em que vivem, os escorpiões mostram-se sensíveis as mudanças de cenários em diferentes escalas (Smith, 1995). Por exemplo, à medida que a serrapilheira das florestas tropicais fica mais profundas, e o aumento de árvores em áreas de Caatinga, juntamente com a presença de árvores lenhosas, promovem uma maior riqueza de espécies de escorpiões (Lira *et* *al*. 2016; Foerster *et al*. 2020). Essas associações estão relacionadas à ideia de que habitats mais heterogêneos, com uma estrutura vegetacional mais complexa, proporcione uma maior diversidade de micro habitats disponíveis (Habel *et al*. 2018). Nesse contexto, Lira *et al*. (2021) observaram em uma escala de paisagem que a perda de heterogeneidade ambiental, devido à conversão de áreas florestais em áreas de cultivo, resultou em uma redução significativa na abundância desses aracnídeos em florestas tropicais. Da mesma forma, Feitosa *et al*. (2024) destacaram a importância da cobertura florestal na composição da assembleia de escorpiões em ambientes urbanos, onde espécies florestais se beneficiaram do aumento da cobertura florestal nos arredores dos fragmentos. Por conseguinte, pode-se destacar que os escorpiões estão intimamente associados às condições ecológicas, sendo sensíveis a distúrbios ambientais, o que possibilita a obtenção de resultados confiáveis e replicáveis sobre as perturbações ocorridas em paisagens naturais (Uehara e Prado *et al*. 2009).

Portanto, fica evidente que alterações no cenário ambiental natural podem ter impactos significativos nas características das populações, comunidades e ecossistemas, afetando aspectos como diversidade, abundância e saúde dos organismos presentes (Godron e Forman, 1983). Diante disso, é crucial que os ecossistemas modificados ofereçam condições mínimas necessárias para a sobrevivência e manutenção das populações (Laurance *et al*. 2007). Nesse contexto, a complexidade ambiental emerge como um fator crucial para os escorpiões, pois influencia diretamente a disponibilidade de presas, tipos de habitat e qualidade dos micro-habitats (Druce, 2007; Ferraz, 2011; Dionisio *et al*. 2019). Por exemplo, observa-se que, em áreas urbanizadas, a dieta dos escorpiões é predominantemente composta por baratas e aranhas, enquanto em ambientes naturais, com maior complexidade ambiental, um amplo espectro de presas está disponível (Polis, 1990, Brasil, 2009). Além disso, estudos como o de Feitosa *et al*. (2024) evidenciam que a cobertura florestal desempenha um papel determinante na condição corporal das populações de *Tityus pusillus* em fragmentos urbanos, onde fêmeas apresentam maiores valores de massa seca e lipídica em áreas com maior cobertura florestal. Portanto, a obtenção de uma boa condição corporal, é essencial para a sobrevivência e reprodução, estando intrinsecamente ligada à qualidade ambiental do habitat (Møller *et al*. 1998). Dessa forma, é crucial reconhecer que habitats alterados pelo homem, aliados a mudanças na paisagem circundante, impõem estresses adicionais à biodiversidade em comparação com áreas preservadas (Macgregor-Fors *et al*. 2021).

2. OBJETIVOS

2.1 OBJETIVO GERAL

Analisar os impactos de diferentes tipos de habitat e da paisagem circundante sobre a assembleia de escorpiões na floresta submontana brasileira.

2.2 OBJETIVOS ESPECÍFICOS

1. Analisar os impactos dos diferentes habitats e da paisagem circundante sobre a abundância e riqueza de escorpiões na floresta submontana brasileira.
2. Analisar as influências dos diferentes usos da terra da paisagem circundante sobre a composição de espécies de escorpiões na floresta submontana brasileira
3. Mensurar os efeitos dos diferentes tipos de habitat e da paisagem sob a condição corporal da assembleia de escorpiões na floresta submontana brasileira
4. Avaliar os impactos dos diferentes tipos de habitat sob os traços funcionais da assembleia de escorpiões na floresta submontana brasileira.

3. HIPÓTESES

i. Habitats dentro do núcleo da cidade e com menor cobertura florestal na escala da paisagem apresentam menor diversidade taxonômica
ii. A expansão das áreas urbanas na escala da paisagem afetará a composição das espécies
iii. A condição corporal será impactada pelos diferentes habitats e pela paisagem circundante
iv. Habitats urbanos irão alterar as características funcionais dos escorpiões, alinhando-se com a seleção de características funcionais mediadas pela paisagem

REFERÊNCIAS

ALBERTI, Marina *et al*. Urban driven phenotypic changes: empirical observations and theoretical implications for eco-evolutionary feedback. **Philosophical Transactions of the Royal Society B: Biological Sciences**, v. 372, n. 1712, p. 20160029, 2017.

ALBERTI, Marina. The effects of urban patterns on ecosystem function. **International regional science review**, v. 28, n. 2, p. 168-192, 2005.

ALBÍN, Andrea *et al*. Predation among armored arachnids: *Bothriurus bonariensis* (Scorpions, Bothriuridae) versus four species of harvestmen (Harvestmen, Gonyleptidae). **Behavioural processes**, v. 121, p. 1-7, 2015.

AMADO, Talita Ferreira et al. Vulnerable areas to accidents with scorpions in Brazil. **Tropical Medicine & International Health**, v. 26, n. 5, p. 591-601, 2021.

AMUNDRUD, Sarah L *et al*. Dispersal barriers and climate determine the geographic distribution of the helicopter damselfly Mecistogaster modesta. **Freshwater biology**, v. 63, n. 2, p. 214-223, 2018.

ANDRADE-LIMA, D. de. Present-day forest refuges in northeastern Brazil. **Biological diversification in the tropics**, v. 245, p. 251, 1982.

BARBOSA, MR de V. et al. Diversidade florística na Mata do Pau-Ferro, Areia, Paraíba. **Brejos de altitude em Pernambuco e Paraíba: história natural, ecologia e conservação. Brasília: Ministério do Meio Ambiente**, p. 111-122, 2004.

BRANDÃO, R. Albuquerque; FRANÇOSO, R. Dias. Acidente por Rhopalurus agamemnon (Koch, 1839)(Scorpiones, Buthidae). **Revista da Sociedade Brasileira de Medicina Tropical**, v. 43, p. 342-344, 2010.

BRANNSTROM, Christian. Rethinking the 'Atlantic Forest'of Brazil: new evidence for land cover and land value in western São Paulo, 1900–1930. **Journal of Historical Geography**, v. 28, n. 3, p. 420-439, 2002.

BRASIL. Ministério da Saúde. Secretaria de Vigilância em Saúde. **Manual de controle e manejo de escorpiões**. Brasília, 2009.

BRAZIL, T; and PORTO, T. **Os escorpiões**. Edufba, 2011.

BROWNELL, P; POLIS, G. **Scorpions Biology** and Research. Oxford University Press. 544p, 2001.

CARDINALE, Bradley J. et al. Biodiversity loss and its impact on humanity. **Nature**, v. 486, n. 7401, p. 59-67, 2012.

CASTRO, C. Florestas tropicais na arena mundial. **Série CEPPAC**, 2009.

CODDINGTON, J. A; COLWELL, R. K. Arachnida. In: LEVIN, S. C. (Org.). **Encyclopedia of biodiversity**. New York: Academic Press, p. 199-218, 2001

CRUZ, E.F.S. **Biologia dos escorpiões**. In: BARRAVIERA, B. Venenos animais - Uma visão integrada. Rio de Janeiro: Editora de Publicações Científicas Ltda. p. 135-150, 1994.

DE ARAUJO, Helder F.P et al. A sustainable agricultural landscape model for tropical drylands. **Land use policy**, v. 100, p. 104913, 2021.

DE QUEIROZ, L Paganucci et al. Diversity and evolution of flowering plants of the Caatinga domain. **Caatinga: the largest tropical dry forest region in South America**, p. 23-63, 2017.

DEHGHANI, Rouhullah et al. Feeding behavior of the Iranian dangerous scorpion species in the laboratory. **J Entomol Zoology Studies**, v. 4, n. 4, p. 1156-1159, 2016.

DÍAZ, Sandra et al. Pervasive human-driven decline of life on Earth points to the need for transformative change. **Science**, v. 366, n. 6471, p. eaax3100, 2019.

DIEZ, Jeffrey M; PULLIAM, H. Ronald. Hierarchical analysis of species distributions and abundance across environmental gradients. **Ecology**, v. 88, n. 12, p. 3144-3152, 2007.

DIONISIO-DA-SILVA, Welton *et al*. Prey-predator interactions between two intraguild predators modulate their behavioral decisions. **acta ethologica**, v. 22, p. 195-201, 2019.

DIEHL, Eva et al. Management intensity and vegetation complexity affect web-building spiders and their prey. **Oecologia**, v. 173, p. 579-589, 2013.

DRUCE, Dave *et al*. Patterns of millipede (Diplopoda), centipede (Chilopoda) and scorpion (Scorpionida) diversity in savanna habitats within the Greater Makalali Conservancy, South Africa. **African Zoology**, v. 42, n. 2, p. 204-215, 2007.

DU TOIT, Marié J *et al*. The effect of landscape history on the urban environment: past landscapes, present patterns. **Urban Ecology in the Global South**, p. 51-78, 2021.

ELMQVIST, Thomas *et al*. Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment. **Springer Nature**, 2013.

FAHRIG, Lenore. Effects of habitat fragmentation on biodiversity. **Annual review of ecology, evolution, and systematics**. 34(1):487-515, 2003.

FAHRIG, Lenore; MERRIAM, Gray. Habitat patch connectivity and population survival: Ecological archives e066-008. **Ecology**, v. 66, n. 6, p. 1762-1768, 1985.

FEITOSA, Matheus L.B *et al*. Effects of landscape metrics on scorpion (Arachnida: Scorpiones) assemblage in a tropical urban ecosystem. **Ecology and Evolution**, v. 14, n. 2, p. e11026, 2024.

FERRAZ, Gonçalo *et al*. A large-scale deforestation experiment: effects of patch area and isolation on Amazon birds. **science**, v. 315, n. 5809, p. 238-241, 2007.

FERRAZ, Marcos Rochedo. **Manual de comportamento animal**. Editora Rubio, 2011.

FILGUEIRAS, Bruno KC *et al*. Habitat fragmentation alters the structure of dung beetle communities in the Atlantic Forest. **Biological Conservation**, v. 144, n. 1, p. 362-369, 2011.

FILGUEIRAS B *et al*. Winner–loser species replacements in human-modified landscapes. **Trends in Ecology & Evolution**. 36(6): 545-555, 2021.

FOERSTER, Stenio I.A *et al*. New records of the not-so-rare males of the parthenogenetic scorpion Tityus stigmurus (Thorell, 1876)(Scorpiones: Buthidae). **The Journal of Arachnology**, v. 50, n. 1, p. 27-29, 2022.

FOERSTER, Stenio I.A *et al*. Vegetation structure as the main source of variability in scorpion assemblages at small spatial scales and further considerations for the conservation of Caatinga landscapes. **Neotropical Biology and Conservation**, v. 15, n. 4, p. 533-550, 2020.

FOERSTER, Stenio I.A *et al*. Macroecological approach for scorpions (Arachnida, Scorpiones): β-diversity in Brazilian montane forests. **Canadian Journal of Zoology**, v. 97, n. 10, p. 914-921, 2019.

FORMAN, R; GODRON, M. **Landscape ecology**. New York: John Wiley, 1986

FORMAN, R; GODRON, M. Patches and structural components for a ladscape ecology. **BioScience**, v. 31, n. 10, p. 733-740, 1981.

GAFFIN D.D. *et al*. Scorpion fluorescence and reaction to light. **Animal Behaviour**, v. 83, n. 2, p. 429-436, 2012.

GALÁN-ACEDO, Carmen *et al*. Drivers of the spatial scale that best predict primate responses to landscape structure. **Ecography**, v. 41, n. 12, p. 2027-2037, 2018.

GARDNER, T.A. *et al*. Prospects for tropical forest biodiversity in a human-modified world. **Ecology letters**, v. 12, n. 6, p. 561-582, 2009.

GODDARD, Mark A.; DOUGILL, Andrew J.; BENTON, Tim G. Scaling up from gardens: biodiversity conservation in urban environments. **Trends in ecology & evolution**, v. 25, n. 2, p. 90-98, 2010

GODRON, M; FORMAN, R.T.T. Landscape modification and changing ecological characteristics. In: **Disturbance and ecosystems: components of response**. Berlin, Heidelberg: Springer Berlin Heidelberg, 1983. p. 12-28.

GOPALAN, RADHA; RADHAKRISHNA, SINDHU. Cities and biodiversity: Hidden connections between the built form and life. In: **Blue-Green Infrastructure Across Asian Countries: Improving Urban Resilience and Sustainability**. Singapore: Springer Singapore, 2022. p. 141-162.

GRIMM, Nancy B. *et al*. The changing landscape: ecosystem responses to urbanization and pollution across climatic and societal gradients. **Frontiers in Ecology and the Environment**, v. 6, n. 5, p. 264-272, 2008.

HABEL, Jan C *et al*. Mark-release-recapture meets Species Distribution Models: Identifying micro-habitats of grassland butterflies in agricultural landscapes. **PLoS One**, v. 13, n. 11, p. e0207052, 2018.

HAHS, Amy K. *et al*. Urbanisation generates multiple trait syndromes for terrestrial animal taxa worldwide. **Nature communications**, v. 14, n. 1, p. 4751, 2023.

JAMELLI, Davi *et al*. Habitat use and feeding behavior of domestic free-ranging goats in a seasonal tropical dry forest. **Journal of Arid Environments**, v. 190, p. 104532, 2021.

JOHNSON, Marc TJ; MUNSHI-SOUTH, Jason. Evolution of life in urban environments. **Science**, v. 358, n. 6363, p. eaam8327, 2017.

LAURANCE, William F. *et al*. Habitat fragmentation, variable edge effects, and the landscape-divergence hypothesis. **PLoS one**, v. 2, n. 10, p. e1017, 2007.

LAURANCE, William F *et al*. Agricultural expansion and its impacts on tropical nature. **Trends in ecology & evolution**, v. 29, n. 2, p. 107-116, 2014.

LEAL, Inara R. *et al*. Changing the course of biodiversity conservation in the Caatinga of northeastern Brazil. **Conservation biology**, v. 19, n. 3, p. 701-706, 2005.

LEPCZYK, Christopher A. et al. Biodiversity in the city: fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation. **BioScience**, v. 67, n. 9, p. 799-807, 2017.

LIRA, André F.A *et al*. Pattern of scorpion diversity across a bioclimatic dry-wet gradient in Neotropical forests. **Acta Oecologica**, v. 96, p. 10-17, 2019.

LIRA, André FA *et al*. The effect of habitat fragmentation on the scorpion assemblage of a Brazilian Atlantic Forest. **Journal of insect conservation**, v. 20, p. 457-466, 2016.

LIRA, Andre FA *et al*. Understanding the effects of human disturbance on scorpion diversity in Brazilian tropical forests. **Journal of Insect Conservation**, v. 25, n. 1, p. 147-158, 2021.

LOURENÇO, W. R. Diversity and endemism in tropical versus temperate scorpion communities. **Biogeographica**, v. 70, n. 3, p. 155-160, 1994.

LOURENÇO, WR. 2002. **Scorpions of Brazil**. Les editions de l'If, Paris.

MACE, Georgina M *et al*. Biodiversity and ecosystem services: a multilayered relationship. **Trends in ecology & evolution**, v. 27, n. 1, p. 19-26, 2012.

MACGREGOR-FORS, Ian *et al*. The urban contrast: A nationwide assessment of avian diversity in Mexican cities. **Science of the Total Environment**, v. 753, p. 141915, 2021.

MCDONALD, Robert I. et al. Research gaps in knowledge of the impact of urban growth on biodiversity. **Nature Sustainability**, v. 3, n. 1, p. 16-24, 2020.

MCKINNEY, Michael L. Urbanization as a major cause of biotic homogenization. **Biological conservation**, v. 127, n. 3, p. 247-260, 2006.

MELO, Felipe PL *et al*. On the hope for biodiversity-friendly tropical landscapes. **Trends in ecology & evolution**, v. 28, n. 8, p. 462-468, 2013.

MELO, F.P.L., 2018. The socio-ecology of the Caatinga: Understanding how natural resource use shapes an ecosystem, in: Silva, J.M.C., Barbosa, L.C.F., Leal, I.R., Tabarelli, M. (Eds.), Caatinga: the largest tropical dry forest region in South America, **Springer**. Cham, pp. 369–382.

MMA [Ministério do Meio Ambiente] (2014) Mapas de cobertura vegetal dos biomas brasileiros. http://mapas.mma.gov.br/mapas/aplic/probio/datadownload.htm?/. Acessado em 20 março 2023

MORELLI, Federico *et al*. Evidence of evolutionary homogenization of bird communities in urban environments across Europe. **Global Ecology and Biogeography**, v. 25, n. 11, p. 1284-1293, 2016.

MULLEN, Gary R; SISSOM, W. David. Scorpions (scorpiones). In: **Medical and veterinary entomology**. Academic Press, 2019. p. 489-504.

MYERS, Norman et al. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, n. 6772, p. 853-858, 2000.

PARDINI, Renata *et al*. The challenge of maintaining Atlantic Forest biodiversity: a multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. **Biological conservation**, v. 142, n. 6, p. 1178-1190, 2009.

PERRIN, Antoine *et al*. Relative effects of urbanisation, deforestation, and agricultural development on mosquito communities. **Landscape Ecology**, v. 38, n. 6, p. 1527-1536, 2023.

POLIS, G. A. The **Biology of Scorpions**.1990.

PUCCA, M. Berto *et al*. Scorpionism and dangerous species of Brazil. **Scorpion venoms**, v. 4, p. 299-324, 2015.

RITCHIE, Hannah; ROSER, Max. Urbanization. **Our world in data**, 2018.

REGA-BRODSKY, Christine C. et al. Urban biodiversity: State of the science and future directions. **Urban Ecosystems**, v. 25, n. 4, p. 1083-1096, 2022.

REIN, J. O. The scorpion files < https://www.ntnu.no/ub/scorpion-files/ > Acesso em 25 Março. 2024

RODAL, Maria J.Nogueira *et al*. Floristics of an upland forest in the oriental slope of the Borborema plateau, Pernambuco State, Brazil. **Acta Botanica Brasilica**, v. 19, p. 843-858, 2005.

RODRIGUES, Paulo C.Guimarães *et al*. Ecologia dos Brejos de Altitude do agreste pernambucano. **Revista de Geografia**, v. 25, n. 3, p. 20-34, 2008.

RUPPERT, E.E; BARNES, R.D. **Zoologia dos Invertebrados**. São Paulo, Editora Roca Ltda. 6.ed. 1029p, 1996.

SACHS, Jeffrey D. *et al*. Biodiversity conservation and the millennium development goals. **Science**, v. 325, n. 5947, p. 1502-1503, 2009.

SAMUELSON, Ash E. *et al*. Lower bumblebee colony reproductive success in agricultural compared with urban environments. **Proceedings of the Royal Society B**, v. 285, n. 1881, p. 20180807, 2018.

SCHOWALTER, T. D. Insect ecology: an ecosystem approach. Academic Press, 774 pp, 2016.

Seibold S *et al*. Microclimate and habitat heterogeneity as the major drivers of beetle diversity in dead wood. **Journal of Applied Ecology**. 2016; 53(3):934-943

SETO, Karen C *et al*. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. **Proceedings of the National Academy of Sciences**, v. 109, n. 40, p. 16083-16088, 2012.

SHARMA, Ankita *et al*. Impact of urbanization on the taxonomic and functional diversity of spider assemblages in Guwahati City, Assam, India. **bioRxiv**, p. 2023.01. 07.523076, 2023.

SILVA, José Maria Cardoso; LEAL, Inara R.; TABARELLI, Marcelo (Ed.). **Caatinga: the largest tropical dry forest region in South America**. Springer, 2018.

SILVA-JÚNIOR, André Otávio *et al.* Intraguild predation in Brazilian Atlantic Forest scorpions: Report of *Tityus brazilae* Lourenço & Eickstedt, 1984 preying on *Tityus pusillus* Pocock, 1893 (Scorpiones: Buthidae). **Austral Ecology**, v. 45, p. 215-228, 2021.

SILVA-JÚNIOR, André Otávio *et al*. Can size make a difference? Cross-predation occurrences between lizards and scorpions in the Brazilian seasonal dry tropical forest. **Zoologia Bespozvonocnyh**, v. 20, p. 343-347, 2023.

SILVERA, Andréa Pereira et al. Flora of Baturité, Ceará: a wet island in the Brazilian semiarid. **Floresta e ambiente**, v. 27, p. e20180320, 2020.

SLIK, J.W.F. *et al*. An estimate of the number of tropical tree species. **Proceedings of the National Academy of Sciences**, v. 112, n. 24, p. 7472-7477, 2015.

SLATTERY, Zoe; FENNER, Richard. Spatial analysis of the drivers, characteristics, and effects of forest fragmentation. **Sustainability**, v. 13, n. 6, p. 3246, 2021.

SOUZA, Andréa Lúcia Teixeira; MARTINS, Rogério Parentoni. Foliage Density of Branches and Distribution of Plant-Dwelling Spiders 1. **Biotropica: The Journal of Biology and Conservation**, v. 37, n. 3, p. 416-420, 2005.

STOCKMANN, R; FLAY, N. **Scorpions of the World**. NAP. 2010 (No. C/595.46 S8).

SUMASGUTNER, Petra *et al*. Landscape homogenization due to agricultural intensification disrupts the relationship between reproductive success and main prey abundance in an avian predator. **Frontiers in zoology**, v. 16, p. 1-14, 2019.

TAHA, Haider. Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. **Energy and buildings**, v. 25, n. 2, p. 99-103, 1997.

THOM, Dominik *et al*. Effects of disturbance patterns and deadwood on the microclimate in European beech forests. **Agricultural and Forest Meteorology**, v. 291, p. 108066, 2020.

THRELFALL, Caragh G *et al*. Influence of landscape structure and human modifications on insect biomass and bat foraging activity in an urban landscape. **PloS one**, v. 7, n. 6, p. e38800, 2012.

TABARELLI, Marcelo; SANTOS, André Mauricio Melo. Uma breve descrição sobre a história natural dos brejos nordestinos. **Brejos de Altitude em Pernambuco e Paraíba, História Natural, Ecologia e Conservação**, v. 9, p. 17-24, 2004.

TÓTH, Zsolt; HORNUNG, Elisabeth. Taxonomic and functional response of millipedes (Diplopoda) to urban soil disturbance in a metropolitan area. **Insects**, v. 11, n. 1, p. 25, 2019.

UEHARA-PRADO, Marcio *et al*. Selecting terrestrial arthropods as indicators of small-scale disturbance: A first approach in the Brazilian Atlantic Forest. **Biological Conservation**, v. 142, n. 6, p. 1220-1228, 2009.

VELOSO, Henrique Pimenta *et al.* **Classificação da vegetação brasileira, adaptada a um sistema universal**. Ibge, 1991.

YOSHIMOTO, Yusuke *et al*. A Fluorescent Compound from the Exuviae of the Scorpion, Liocheles australasiae. **Journal of natural products**, v. 83, n. 2, p. 542-546, 2020.

4. CAPÍTULO I – SCORPIONS IN URBANIZED LANDSCAPES: INFLUENCE OF HABITAT TYPE AND LANDSCAPE ON BODY CONDITIONS, DIVERSITY AND FUNCIONAL TRAITS IN NEOTROPICAL SUBMONTANE FOREST

Manuscrito submetido a revista Ecology and Evolution, Qualis A2, Fator de impacto 4.6

Matheus Leonydas Borba Feitosa [1,2], Fredy Alvarado[2], Hidalgo Valentim Gomes de Lima[1,2], Geraldo Jorge Barbosa de Moura[3], André Felipe de Araújo Lira[4]

[1]Programa de Pós-Graduação em Biodiversidade, Campus II Areia, Universidade Federal da Paraíba.

[2] Laboratorio de Paisajes Antrópicos Sostenibles (LPAS). Instituto Potosino de Investigación Científica y Tecnológica (IPICYT), División de Ciencias Ambientales, Camino a la Presa San José 2055, Lomas 4ta Sección, San Luis Potosí, CP 78216, SLP, México.

[3]Laboratório de Estudos Herpetológicos e Paleoherpetológicos, Departamento de Biologia, Universidade Federal Rural de Pernambuco, Recife, Brazil

[4]Colección Nacional de Arácnidos, Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, Ciudad de México, México.

Scorpions in urbanized landscapes: Influence of habitat type and landscape on body condition, diversity and functional traits in a Neotropical submontane forest.

Matheus Leonydas Borba Feitosa[1,2], Fredy Alvarado[2], Hidalgo Valentim Gomes de Lima[1,2], Geraldo Jorge Barbosa de Moura[3], André Felipe de Araújo Lira[4]*

[1]Programa de Pós-Graduação em Biodiversidade, Campus II Areia, Universidade Federal da Paraíba.

[2] Laboratorio de Paisajes Antrópicos Sostenibles (LPAS). Instituto Potosino de Investigación Científica y Tecnológica (IPICYT), División de Ciencias Ambientales, Camino a la Presa San José 2055, Lomas 4ta Sección, San Luis Potosí, CP 78216, SLP, México.

[3]Laboratório de Estudos Herpetológicos e Paleoherpetológicos, Departamento de Biologia, Programa de Pós-graduação em Biociência Animal, Departamento de Morfologia e Fisiologia Animal, Universidade Federal Rural de Pernambuco, Recife, Brazil

[4]Colección Nacional de Arácnidos, Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, Ciudad de México, México.

*Corresponding author: andre.lira@st.ib.unam.mx

Running title: Effects of habitat type and landscape in scorpions

ORCID
Matheus Leonydas Borba Feitosa: 0000-0003-1171-9689
Fredy Alvarado: 0000-0002-6724-4064
Hidalgo Valentim Gomes de Lima: 0000-0001-6891-6216
Geraldo Jorge Barbosa de Moura: 0000-0001-7241-7524
André Felipe de Araujo Lira: 0000-0002-8443-4126

Abstract

The local filtering process plays a role in shaping species traits, trait-based community assembly may also be influenced by the spatial arrangement of the landscape. Understanding how different habitats and land uses resulting from human actions in tropical forests affect the diversity, fitness, and functional characteristics of native fauna becomes fundamental to conservation biology. Here, we explore the effects of different habitats and different land use and cover on patterns of taxonomic diversity (abundance, species richness, and composition), body condition, and functional traits of the scorpion assemblage in a Neotropical submontane forest region. The scorpions were collected by active search in 60 sampling units evenly distributed among three habitat types: city core, urban green areas, and forests. We found 882 specimens distributed in five species within two families. Our results suggest that on a habitat scale, forests exhibited greater abundance and species richness, and these taxonomic patterns proved to be sensitive to the different surrounding land use. Additionally, the increase in urban areas in the landscape composition also promotes a change in species composition. Furthermore, forest habitats are crucial for maintaining higher body condition. On the other hand, habitats categorized as city core drove the emergence of traits adapted to urban conditions. We highlight the importance of urban green infrastructure even when it is immersed in highly urbanised environments may be important in maintaining scorpion biodiversity.

Keywords: Arachnids, community ecology, landscape ecology, urban ecology

4.1 INTRODUCTION

Rapid urban growth, coupled with an increase in population density in urban areas, had significant impacts on local biodiversity (Elmqvist, 2013; Ritchie and Roser, 2018). Deforestation, fragmentation, and loss of connectivity resulting from the rapid increase in urbanization have led many native species to live in close proximity to or even within urban areas (Gopalan and Radhakrishna, 2022). Thus, the conversion of natural forests into anthropized landscapes has been widely recognized as a significant factor in the disturbance of ecosystems (Fahrig, 1985; Thom *et al*. 2020). In these landscapes, the configuration and distribution of land cover are shaped mainly by human needs (Forman and Godron, 1981), resulting in different types and quantities of land cover and changes in environmental heterogeneity (Gardner *et al*. 2009). As a consequence, biodiversity in each type of ecosystem responds in a varied way, reflecting its specific ecological requirements (Ferraz *et al*. 2007; Gopalan and Radhakrishna, 2022).

Although there are positive responses associated with anthropogenic disturbances, such as a significant increase in the overall abundance and richness of some insect groups due to an increase in the amount and diversity of dead wood (Seibold *et al*. 2016). However, it is important to note that changes in vegetation structure may have negative diverse impacts for native communities. For example, these changes may lead to a deterioration in trophic interactions (Seibold *et al*. 2019), reductions in microhabitat provision and increased exposure to pollutants (Du Toit *et al*. 2021), resulting in significant reductions in the abundance and fitness (Salomão *et al*. 2018). According to Legendre *et al*. (2005), species composition can be modulated by environmental characteristics, since the landscape is characterized as a mosaic with its own set of environmental characteristics. This is exemplified by the landscape-moderated functional trait selection hypothesis (Tscharntke *et al*. 2012), as the pool of functionally important traits influences and modulates community assembly at different scales (Urban *et al*. 2008).Therefore, understanding the interactions that involve urban environments, such as environments originated through different land uses, is of growing relevance in urban ecology (e.g., Cressey, 2015; Le Provost *et al*. 2020; Fang *et al*. 2022). In this sense, different land uses may provide additional or alternative resources related to the spatial arrangement, heterogeneity, and capacity of the environment (Dunning *et al*. 1992; Villard and Metzger, 2014). As an example, Le Provost *et al*. (2020) observed that grassland areas inserted in former agricultural regions promoted a reduction in the diversity of traits related to mobility in (plants, grasshoppers, wild bees, hoverflies, carabid beetles, spiders and birds). On contrary, Salomão *et al*. (2023) found that in environments with greater forest cover, there was an increase in species richness, entropy, and functional dispersal of dung beetles. Therefore, in applied ecological research contexts, the analysis of the influence of cover, landscape surroundings, and land use on survival (Sala *et al*. 2000; Kéry *et al*. 2016), health status (Rulli *et al*. 2021) and functional traits related to animal fitness (Vandewalle *et al*. 2010), emerge as central topics of discussion.

About 50% of the original extent of tropical rainforests has been converted into anthropogenic areas because of the urbanization process (Laurance *et al*. 2014). As a result of the rapid conversion of landscapes, the risk of species extinction and the loss of associated ecosystem services is high (Hughes, 2017). This particularly truth for Neotropical submontane forest that represent altitudinal enclaves of vegetation considered to be islands of ombrophilous forests located on high-altitude plateaus and mountain ranges of up to 1,000 m a.s.l. (Queiroz *et al*. 2017, Magioli *et al*. 2021; Araújo *et al*. 2022) and surrounding by xerophytic vegetation (Andrade-Lima, 1982; Rodrigues *et al*. 2008). This ecological disjunction gives the marshes great relevance for research in terms of conservation in these areas. Thus, it is clear that the change in land use in these regions is a cause for concern, as it has been widely recognized as one of the main causes of the decline in the abundance and diversity of species and ecosystems (Davison *et al*. 2021). Therefore, in order to propose appropriate management plans, it is a priority to understand how biodiversity responds to variation in both anthropized habitats and their landscapes (Sachs *et al*. 2009).

Among the organisms that inhabit tropical forests, arthropods are an extremely representative group, accounting for around 75% of the total biomass and playing a fundamental role in many ecosystem services in these environments (Wilson, 1990; Laurance *et al*. 2002). In addition, arthropods have constantly been used as a model to measure human impacts on natural communities (e.g., Le Provost *et al*. 2020; Menta and Remelli 2020; Peng *et al*. 2020). In particular, predators are characterized by their high sensitivity to environmental changes (Morelli *et al*. 2017). For example, scorpions are considered to be primarily sedentary animals, with a low dispersal rate and demanding in terms of habitat quality, having specific ecological patterns for each species (Polis, 1990; Lira *et al*. 2018a; Feitosa *et al*. 2024). Thus, to examine the influence of habitat quality on biodiversity, scorpions have emerged as a bioindicator group of environment quality (Lira *et al*. 2021a, b). In this context, the aim of this study is to analyze the impacts of different habitat types and the surrounding landscape on the scorpion assemblage in Brazilian submontane forest. Specifically, we analyzed taxonomic diversity (abundance, species richness, and composition), body condition (dry mass, lipid mass, muscle mass), and functional traits response to three different habitat type (forest, city core and urban green infrastructure) and different land uses and land covers of the surrounding landscape. In this way, we test the following hypotheses: (i) Abundance and species richness of scorpions is reduced in habitats within city core and with less forest cover at the landscape scale, (ii) the expansion of the urban area will affect species composition, favoring the dominance of generalist species in areas with greater urban coverage (iii), the body condition of scorpions will be affected by urbanization, showing reduction in habitats within city core respect to landscapes with higher forest cover at the landscape scale. Finally, (iv) urban habitats are expected to reduced the functional traits of scorpions, aligning with landscape-mediated selection of functional characteristics.

4.2 MATERIALS AND METHODS

Study area

During the nineteenth century, most enclaves of Neotropical submontane forest in northeastern Brazil were converted to pasture and agriculture, overwhelmingly driven by a few commodities such as wood products, beef, coffee, banana, sugar cane, corn, beans, and cassava (Barbosa *et al.* 2004). These activities accelerated the regional forest fragmentation and defaunation in these enclaves (Leal *et al*. 2005). Thus, this study was carried out in three municipalities located in small mountain ranges known locally as 'brejos de altitude' (IBGE, 2022), which have remnants of ombrophilous forest vegetation in different stages of succession, area, and proximity to the city core in their periphery. The municipalities are located in the state of Paraíba, Northeastern Brazil (Figure 3). The municipalities of Areia (6º58'12.48 "S; 35º42'07.25 "W), Bananeiras (6º45'13.81 "S; 35º37'58.96 "W), and Solânea (6º45'29.06 "S; 35º39'32.93 "W) were selected due to their similar climatic conditions, characterized by average annual temperatures ranging from 23 to 24 °C and altitudes between 550 and 620 meters above sea level. The territorial areas of these municipalities are also comparable, with 270 km², 257 km², and 233 km² for Areia, Bananeiras, and Solânea, respectively. Additionally, the populations of these locations are similar, with Areia having 22,633 inhabitants, Bananeiras 23,134 inhabitants, and Solânea, the most populous, with 26,774 inhabitants. All municipalities have irregular shapes in terms of the perimeter of the urban core; however, all have a higher concentration of human residences in the urban core and less towards the periphery. In the three municipalities, most fragments of primary and secondary vegetation are currently under strong human pressure and have been continuously replaced by monocultures and pasture, along with local production of 'cachaça' (distilled alcohol made from fermented sugarcane juice) and beef, respectively (Barbosa *et al*. 2004).

Study design

Using Google Earth Pro software (Version 7.3.6.9345), we mapped 60 sampling units, equally distributed in three habitat types: city core (n=20), urban green areas (n=20) and forests (n=20), in the three municipalities previously mentioned (Figure 3). Each sampling unit consisted of one survey point spaced 400 m apart and located at each habitat type (city core, urban green areas, and forest). Habitat types were classified according to the following criteria proposed by MacGregor-Fors (2011): (i) cities core as urban settlements, wastelands, and square areas distributed within the intraurban perimeter; (ii) urban green areas were characterized by small forest patches distributed within the periurban perimeter; (iii) forests corresponded to native vegetation remmants outside the city and located in the exurban perimeter.

In order to identify land cover use for each sampling unit, we initially created a circular buffer of 200 meters centered on the sampling unit using QGIS 3.22 software (http://qgis.osgeo.org). The buffer size parameters are based on the work of Feitosa et al. (2024) and are related to the low dispersal capacity of scorpions, being sufficient to capture relationships with the surrounding landscape. Using the Zonal Tool in QGIS and through unsupervised classification, we obtained the land cover uses within the buffers. The identification of land cover use is derived from the land cover and use map for the year 2022, available in MapBiomas version 8 (https://mapbiomas.org). These maps are constructed from mosaics generated by Landsat, which uses a raster layer with a spatial resolution of 10 meters. Thus, we identified and utilized the following land uses and cover types: urban area, agriculture, pasture, river, and forest.

Scorpion sampling

At each sampling unit (n=60), scorpions were sampled by active search, during the night (19:00-22:00), throughout the month of January 2023, during the dry season. Each sampling unit was sampled once by two collectors equipped with tweezers and UV flashlights. Active search were made directly on potential microhabitats such as leaf litter, stones, and logs as suggested by Lira *et al*. (2018b). All scorpions were stored in vials with 70% ethanol and identified according to Lourenço (2002). The voucher specimens of each species were deposited in the Arachnological Collection of the Universidade Federal de Pernambuco, Brazil.

Measurements of body condition and functional traits

In order to determine scorpion body condition, we followed the methodology that has been proposed for scorpions in previous studies (Moreira *et al*. 2024, Feitosa *et al*. 2024). We employed measurements of dry mass, lipid content, and muscle mass. These parameters have been described as measure of size, energy reserves, and muscle mass as well to ecological indicators of environmental disturbances in arthropods (Wymann and Schneiter, 2008; Salomão *et al*. 2018; Feitosa *et al*. 2024). Only specimens of *Tityus pusillus* Pocock, 1893, and *Ananteris mauryi* Lourenço, 1982 had their body condition parameters measured, as they were the most abundant species within the collected species set (see results section). Thus, the individuals were put in an oven at 60° C for 48 hours to remove water and obtain the weight corresponding to the dry mass. Next, each individual was placed individually in chloroform-containing containers for 24 hours to degrade lipid reserves. After this period, the scorpions were placed again in an oven at 60° C for 48 hours and weighed. The difference between initial weight and final weight represented the lipid mass. To calculate muscle mass, the scorpions were individually exposed to potassium hydroxide (0.8 mol/L) for 48 hours. After exposure, they were washed in water, dried in an oven at 60° C for 48 hours, and again weighed. The difference between the weight corresponding to lipid mass and the final weight was considered a measure of muscle mass.

To analyze functional traits, we used 10 individuals of each sex (males and females) where possible or otherwise all individuals were included in species with less than 10 individuals. Therefore, we photographed 602 specimens in dorsal view and to visualize we used ImageJ software (Rasband, 2018) to obtain the following morphological components: (i) length of the movable finger; (ii) length and width of the pedipalp chela; (iii) length of the prosoma (corresponding to proxy of total size of the individual), and finally, (iv) length of the metasoma, which is the result of the sum of the metasomal segments, not including the telson. These morphological characteristics have been proposed as important traits related to fitness and ecological functions performed by scorpions within ecosystems. For example, van der Meijden *et al*. (2010) correlate the length and width of the chela with the force exerted by the pincers, implicating in the success of predation and reproduction of these animals. Additionally, the length of the movable finger also influences predation success, as it is correlated with the bending capacity of the chela (van der Meijden *et al*. 2012). Furthermore, Lira *et al*. (2021) categorize the length of the prosoma as a proxy for the total size of an individual, playing a crucial role in predation and reproduction capacity. The length of the metasoma is associated with the projection and reaches capacity of the telson, essential for predation actions and defense behaviors of scorpions (Simone and van der Meijden, 2021). Body condition and functional traits were obtained exclusively from collected adult individual and non-pregnant females.

Statistical analyses

We evaluated the sample completeness for each habitat type by generating a rarefaction curve, specifically using the Chao1 estimator to assess the expected species richness. This was accomplished using the iNEXT package in R (Chao, 2014, 2016).

To evaluate changes in the scorpion's assemblage between the three habitat types (forest, urban green area and city core), we assessed the dominance by plotting the species rank abundance for each habitat type. As the slope of the abundance distribution decreases and the range of this slope increases with respect to the x-axis, dominance within the assemblage decreases. This method is widely used to compare differences in structure among disparate communities (i.e., communities with different sizes and with few or no species in common) (Magurran and McGill 2011). To identify differences between response variables (scorpion abundance, species richness and body condition) on habitat categories, we employed an analysis of variance (ANOVA). When the ANOVA indicated significant overall differences between the groups (habitat type), we applied Tukey's test to identify which specific groups had statistically different (Tukey, 1955).

First, we determined the degree of collinearity between landscape metrics using the variance inflation factor (VIF) (Eisenlohr, 2014). VIF values greater than 5 indicate multicollinearity of the data and reduce the strength of the analysis (Zuur *et al*. 2010), thus, the forest was removed from our analysis (VIF > 5). In this way, we used all variables in our analysis (Table S1). To understand the relationship between abundance and species richness with land use/cover (urban area, agriculture, grassland, river) around the sampling points, we conducted statistical analyses using generalized linear mixed models (GLMMs) for each response variable. Specifically, we used a GLMM with a Poisson distribution to analyze both scorpion abundance and species richness, considering habitat type as a categorical variable and site ID as random intercepts to account for potential spatial dependencies in the data set. For the analyses, we utilized the lme4 package and the glmer (Bates *et al*. 2015) function in R. All analyses were conducted using the R software (R Core Team 2022). Additionally, for the analysis of body condition (dry mass, lipid mass, and muscle mass) in relation to the same land use/cover types, we performed statistical analyses using generalized linear models (GLM) with a Gaussian distribution, employing the stats package and the glm function (R Core Team 2022). Before modeling, we checked the normality and homoscedasticity of the data using the Shapiro-Wilk test with the shapiro.test function from the stats package and the check_heteroskedasticity function from the performance package (R Core Team 2022), respectively. We identified the need for data transformations to meet the assumptions of normality and homoscedasticity. Thus, only after applying the square root transformation to dry mass and lipid mass were the assumptions met. Specifically, in the case of the body condition analysis, separate analyses were conducted for each of the two species, including sex and habitat type as cofactors. To select the most appropriate model to represent the data, we reduced the models based on the Akaike Information Criterion (AIC) scores (Arnold, 2010).

To understand the relationship between species composition and different land uses and cover types, we initially explored the data using a Detrended Correspondence Analysis (DCA) with the decorana function from the vegan package (Hill, 1980). This analysis allowed us to assess the gradient of variation in species responses and identify whether the data followed a linear or unimodal structure. We observed that the length of the first axis of the DCA was less than 3, indicating that the data were suitable for constructing a Redundancy Analysis (RDA). Prior to the RDA, the species composition data were transformed using the Hellinger method. Based on these results, we employed the rda function from the vegan package to perform the RDA and analyze the relationship between species composition and different land uses and cover types. We then tested the significance of the RDA and its principal axes using the anova.cca function from the vegan package, with significance calculated using 999 Monte Carlo permutations (McCune *et al*. 2002; Legendre and Legendre, 2012). All analyses were conducted using the R software (R Core Team 2022).

Finally, we employed principal component analysis (PCA) to summarize the functional traits of the entire scorpion assemblage into a single axis, assuming that the first axis captures the overall size of the specimens (Foerster *et al*. 2024). Subsequently, generalized linear models (GLMs) with Gaussian distribution were constructed to evaluate the effect of land use and land cover on the functional traits. The models were fitted with all land use and land cover variables; additionally, different habitat types were included as cofactors to control for and identify the influence associated with the specific characteristics of each habitat.

4.3 RESULTS

In total, 882 individuals for five species belonging to the families Buthidae and Bothriuridae were recorded (Table 1). According to the sample coverage estimator, we sampled 100% of the species estimated for the three habitat types (Figure S1). The most abundant scorpion species was *T. pusillus* recorded in forest (72% of the total number of individuals collected) and urban green areas (57%) (Figure S2). The species *A. mauryi* was present in both urban green areas (43%) and forests (27%). *Tityus neglectus* Mello-Leitão, 1932, was only recorded in forest areas (n=2), and *Bothriurus asper* Pocock, 1893, were collected in urban green areas (n=1) and forests (n=2) (Figure S2). Finally, *Tityus stigmurus* (Thorell, 1876) representing 100% of individuals collected in city core habitat (n=6) (Figure S2).

Effects of habitat type in scorpion diversity and abundance

We found that, for scorpion abundance, different habitat types exhibited statistically significant differences (ANOVA: $F = 29.78$, $p < 0.01$). Scorpion abundance per sampling unit ranged from 5 to 63 individuals in forest habitats, from 0 to 58 in urban green areas, and from 0 to 1 in city core (Figure 4). According to the generalized linear mixed model (GLMM), scorpion abundance was significantly higher in forest habitats ($z = 4.748$, $p < 0.01$) and in urban green areas ($z = 4.599$, $p < 0.01$). Furthermore, GLMM revealed that scorpion abundance was negatively affected by land uses, specifically agriculture ($z=-2.839$, $p<0.01$) and urban area ($z=-2.054$, $p=0.03$) (Figure 5).

For species richness, we also observed that different habitat types exhibited statistically significant differences (ANOVA: $F = 66.50$, $p < 0.01$). Species richness per sampling unit ranged from 2 to 3 in forest habitats, from 0 to 3 in urban green areas, and from 0 to 1 in city core (Figure 4). According to the GLMM, species richness was significantly higher in forest habitats ($z = 2.349$; $p = 0.01$) and in urban green areas ($z = 2.552$; $p = 0.01$). Despite this, there was no relationship between species richness and land cover. In terms of species composition, we observed that land cover influenced 40.87% of the variation of species composition, with 37.81% explained by axis 1 and 3.06% by axis 2. Urban area cover was the only metric that significantly affected the composition of scorpion species (RDA: $F = 23.31$, $p<0.01$, $R^2 = 0.41$) (Figure 6).

Effects of habitat type in scorpions body condition

The different habitat types affected significantly the body condition parameters of *T. pusillus*, such as dry mass (ANOVA: $F=0.07$, $p<0.01$), lipid mass (ANOVA: $F=0.11$, $p<0.01$), and muscle mass (ANOVA: $F=0.01$, $p<0.01$). Furthermore, we found a sex-based response with significant relationships only for females and not males. Females of *T. pusillus* from forest habitats exhibited higher body conditions in terms of dry mass (GLM: Female: $t=15.30$, $p<0.01$; forest: $t=10.32$, $p<0.01$), lipid mass (GLM: Female: $t=13.24$, $p<0.01$; forest: $t=12.36$, $p<0.01$), and muscle mass (GLM: Female: $t=12.42$, $p<0.01$; forest: $t=7.28$, $p<0.01$) (Figure 5). Furthermore, we found a negative relationship with the increase in the percentage of urban settlements and grassland formed around the forests, negatively affecting female muscle mass (Urban area: $t=-1.99$, $p=0.04$; Grassland: $t=-2.00$, $p=0.04$). At the same time, with the increase of agricultural areas around the forests, we observed negative impacts on dry mass (Agriculture: $t=-2.67$, $p<0.01$) (Figure 8).

Similarly, habitat type was an important factor and showed significant differences for the dry mass (ANOVA: $F=0.07$, $p<0.01$), lipid mass (ANOVA: $F=0.11$, $p<0.01$), and muscle mass (ANOVA: $F=0.01$, $p<0.01$) parameters in *A. mauryi*. We observed significant relationships for *A. mauryi* females and not males. *Ananteris mauryi* females from forest areas showed higher dry mass values (GLM: Female: $t= 21.11$, $p<0.01$. forest: $t =4.88$, $p<0.01$), lipid (GLM: Female: 17.06, $p<0.01$; forest: $t = 5.75$, $p<0.01$) and muscle (GLM Female: $t=13.23$, $p<0.01$; forest: $t = 3.85$, $p<0.01$) masses compared to those in urban green areas (Figure 7).

Effects of landscape use in scorpion functional traits

A total of 602 scorpions were measured (table 2). The Principal Component Analysis (PCA) revealed that axis 1 accounted for 56.74% of the data variability (Figure S3). Consequently, we utilized the values of PCA axis 1 as the response variable in the GLM. We did not identify a statistically significant relationship between land use and the functional traits of scorpions. However, we observed that the functional traits of the scorpion assemblage showed significant relationships with forest (GLM: $t = -4.418$, $p < 0.01$) and urban green area (GLM: $t = -6.148$, $p < 0.01$), being lower in these habitats (Figure 9).

4.4 DISCUSSION

Our investigation focused on analyzing the impacts of different habitats and the effects of land cover on the scorpion assemblage in a submontane rainforest region. Our results revealed that different habitats types, together with the different land uses and land cover, exert significant effects on diversity parameters, species composition, as well as the physical condition and functional traits of these organisms. It is important to note that we observed remarkably different responses in *T. pusillus* and *A. mauryi* in terms of intraspecific variability, with implications for the females of these species in particular. Furthermore, our research identified the presence of a scorpion fauna that encompasses both species considered vulnerable to environmental disturbances (e.g. *T. pusillus*), as well as more resilient species, with eurytopic characteristics, such as *T. stigmurus* (Polis, 1990; Lira *et al*. 2020; Amado *et al*. 2021).

When we investigated the impact of different habitat type within a neotropical submontane forest on the abundance and species richness, we consistently found that forest habitats exhibited significantly higher values in all these parameters (Fig. 2). Therefore, in areas destined for forests possess greater environmental heterogeneity, which, in turn, may increase the availability of microhabitats at different scales, favoring the coexistence of a greater number of species and their individuals, resulting in greater local diversity (Oliver *et al*. 2010; Stein and Kreft, 2015). In this sense, we found that more preserved habitat types, such as forest habitats, present a better quality of maintenance of the diversity of the scorpion assemblage, with higher values of abundance and richness species than others habitat type sampled. Therefore, our analysis of the different land use and cover in each habitat type revealed that the increase in areas dedicated to agriculture and urban areas has a negative impact only on the abundance and not on the species richness of scorpions. In this sense, Dalle Laste *et al*. (2019), determine that changes at the level of habitat and natural microhabitat resulting from the expansion of agricultural areas and urban settlements reflect significant impacts on the abundance parameters and richness of communities. This trend is also observed in other arachnids, such as soil spiders, which suffer a significant reduction in abundance and species richness with increased intensification of agricultural management, often associated with the application of pesticides

(Lo-Man-Hung *et al*. 2011). Furthermore, the expansion of agricultural areas and urban settlements has the same negative impact on the abundance and richness of various arthropods groups (Dalle Laste *et al*. 2019; Latha *et al*. 2019; De Queiroz *et al*. 2020; Hahs *et al*. 2023). This shows that ecological processes that operate at spatial scales greater than the locality may exert additional influence on the diversity of local species, often manifesting a significant interaction with the intensity of landscape modification (Tscharntke *et al*. 2005). Consequently, supports the hypothesis that land use that preserve the main components of the species' natural ecological niche (e.g. areas of land designated as forests subject only to natural interference in their surroundings) will be more suitable for maintaining native species.

The species composition was influenced by the land use and cover metrics. Increase in the urban areas in favored the appearance and persistence of the opportunistic scorpion *T. stigmurus*. This species is considered synanthropic and is more abundant in urban than natural regions (Amado *et al*. 2021; Foerster *et al*. 2022). On the other hand, the increase in urban area coverage also disadvantaged species typically found in forested areas, such as *T. pusillus*, *A. mauryi*, and *T. neglectus* (Lira *et al*. 2020). In this way, we visualize the contrasting responses of scorpion species to anthropogenic land use, providing insight into the differential ecological plasticity of these taxa. Therefore, our findings corroborate previous studies reporting that other soil arthropods (e.g., coleoptera, chilopods, collembola, and isopods) respond in a similar way to changes in the landscape whose species composition changed as invasive woody plants were inserted into the landscape (McCary *et al*. 2018). In view of this, the conversion of landscape to a more uniform regions, consisting of intensive land use, such as urban areas, agricultural land, and fields (Robinson and Sutherland 2002), may result in impacts on species diversity parameters (Sharma *et al*. 2024; Millard *et al*. 2021). Therefore, habitat and microhabitat requirements arising from landscape structure may be key factors that act as an environmental filter that influences and determines the survival capacity of scorpions in anthropic environments.

The habitat forest also proved to be a determining factor for the body condition of *T. pusillus* and *A. mauryi* populations. In this habitat, females of both species showed higher values of dry mass, lipid content, and muscle mass. Lipid mass is recognized as a source of energy while dry mass represents the organism's biomass, and muscle mass originates from the stimulation of strength and protein synthesis; all of these components originate from the organism's nutrition (Goldspink *et al*. 1983; Drewnowski, 1992; Wymann and Schneiter, 2008). Therefore, organisms from stable and less altered environments, such as forests, may experience more regular and nutritive feeding (Chen and Wise, 1999). This, in turn, may increase the predatory efficiency of scorpions for both female *T. pusillus* and *A. mauryi*, allowing them to capture more nutritious prey in leaf litter layers. Therefore, considering that females of both species exhibit considerably less active foraging behaviors than males (Lira *et al*. 2018b), they are subject to lower energy expenditure and greater prey availability. Furthermore, according to Olivero *et al*. (2021) the body condition of scorpions is subject to landscape effects and is shaped during the individual's growth. In addition, our analysis revealed significant reductions in muscle mass correlated with increasing urban areas and grasslands in the surrounding habitats for both species. Similarly, we observed equally significant reductions in dry mass with increasing agriculture. Thus, the development of areas for agriculture, expansion of urban settlements, and creation of grasslands at the landscape scale appear to be generating an unfavorable matrix, imposing greater energy demands for foraging and survival.

Finally, we observed that scorpions from forest and urban green area habitats had smaller functional traits when compared to individuals from city core. The presence of larger functional traits may be related to the ability to deal with the challenges posed by the urban environment, including pollution, habitat fragmentation, distinct resources, and climate change (Oliveira Hagen *et al*. 2017; Du Toit *et al*. 2021). In this sense, groups of heteropterans subjected to intensive land use through grazing showed significant increases in some morphometric traits (legs, wings, and antennae), possibly to persist in these environments (Simons *et al*. 2016). In our study, we only observed the presence of *T. stigmurus* individuals in habitats located in the city core. This species is described as favorable to contrasting and challenging environmental conditions due to its strong synanthropic habits, facultative parthenogenesis, and high resistance to insecticides (Amado *et al*. 2021; Foerster *et al*. 2022). Therefore, urban areas promote environmental filtering of scorpions and their functional traits, favoring the persistence of opportunistic species with larger traits adapted to the imposed scenario.

4.5 CONCLUSIONS

In summary, our findings indicate that anthropogenic alterations at both habitat and landscape scales have adverse effects on the scorpion assemblage. Additionally, we found that habitats categorized as forests are crucial, consistently exhibiting higher abundance and richness of these arachnids, ensuring the maintenance of the higher body condition in *T. pusillus* and *A.*

mauryi compared to urban green areas. Conversely, the shift to city core induced greater functional traits, as exemplified by the synanthropic scorpion *T. stigmurus*. Furthermore, at the landscape scale, we observed the vulnerability of scorpions to the expansion of agriculture, urban areas, and grasslands, resulting in reductions in abundance and body condition, as well as alterations in species composition, leading to the favoring of synanthropic species in areas with greater urban coverage. Thus, our study contributes to understanding how habitat characteristics and landscape alterations shape the ecological patterns of scorpion assemblages. These findings not only enhance our knowledge of scorpion ecology but also emphasize the importance of preserving forest habitats. Importantly, we highlight to conservation authorities the urgent need to consider the surroundings of habitats to ensure ecological resilience of these arachnids and the entire biodiversity in the face of anthropogenic pressures.

AUTHOR CONTRIBUTIONS

Matheus Leonydas Borba Feitosa: Data curation (equal); investigation (equal); methodology (equal); formal analysis (equal); writing – original draf (equal). **Fredy Alvarado**: Conceptualization (equal); funding acquisition (equal); project administration (equal); resources (equal); writing – review and editing (equal). **Hidalgo Valentim Gomes de Lima**: formal analysis (equal); methodology (equal); writing – review and editing (equal). **Geraldo Jorge Barbosa de Moura**: Conceptualization (equal); funding acquisition (equal); resources (equal); writing – review and editing (equal). **André Felipe de Araujo Lira**: Conceptualization (equal); data curation (equal); formal analysis (equal); methodology (equal); supervision (equal); validation (equal); writing – review and editing (equal).

ACKNOWLEDGMENTS

We thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for a masters scholarship to MLBF and Dirección General de Asuntos del Personal Académico (DGAPA) postdoctoral fellowship from the Universidad Nacional Autónoma de México to AFAL.

FUNDING INFORMATION

AFAL was supported by Dirección General de Asuntos del Personal Académico (DGAPA) postdoctoral fellowship from the Universidad Nacional Autónoma de México. MLBF was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for a postgraduate scholarship.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

REFERENCES

AMADO, Talita Ferreira et al. Vulnerable areas to accidents with scorpions in Brazil. **Tropical Medicine & International Health**, v. 26, n. 5, p. 591-601, 2021.

ANDRADE-LIMA, D. de. Present-day forest refuges in northeastern Brazil. **Biological diversification in the tropics**, v. 245, p. 251, 1982.

ARAÚJO, F. M. S. et al. Altitudinal gradient drives regional and local diversity and composition patterns of epiphyllous bryophytes in ecological refuges. **Plant Biology**, v. 24, n. 2, p. 292-301, 2022.

ARNOLD, Todd W. Uninformative parameters and model selection using Akaike's Information Criterion. **The Journal of Wildlife Management**, v. 74, n. 6, p. 1175-1178, 2010.

BARBOSA, MR de V. et al. Diversidade florística na Mata do Pau-Ferro, Areia, Paraíba. **Brejos de altitude em Pernambuco e Paraíba: história natural, ecologia e conservação. Brasília: Ministério do Meio Ambiente**, p. 111-122, 2004.

BATES, Dougla. Fitting linear mixed-effects models using lme4. **arXiv preprint arXiv:1406.5823**, 2014.

CHAO, Anne et al. Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. **Ecological monographs**, v. 84, n. 1, p. 45-67, 2014.

CHAO. iNEXT Online: Software for Interpolation and Extrapolation of Species Diversity. Program and User’s Guide published at. 2016.

CHEN, Benrong; WISE, David H. Bottom-up limitation of predaceous arthropods in a detritus-based terrestrial food web. **Ecology**, v. 80, n. 3, p. 761-772, 1999.

CRESSEY, Daniel. Ecologists embrace their urban side. **Nature**, v. 524, n. 7566, p. 399-400, 2015.

DALLE LASTE, Keila Caroline; DURIGAN, Giselda; ANDERSEN, Alan N. Biodiversity responses to land-use and restoration in a global biodiversity hotspot: Ant communities in Brazilian Cerrado. **Austral Ecology**, v. 44, n. 2, p. 313-326, 2019.

DAVISON, Charles W.; RAHBEK, Carsten; MORUETA-HOLME, Naia. Land-use change and biodiversity: Challenges for assembling evidence on the greatest threat to nature. **Global Change Biology**, v. 27, n. 21, p. 5414-5429, 2021.

DE QUEIROZ, Antonio CM et al. Cerrado vegetation types determine how land use impacts ant biodiversity. **Biodiversity and Conservation**, v. 29, p. 2017-2034, 2020.
DE QUEIROZ, Luciano Paganucci et al. Diversity and evolution of flowering plants of the Caatinga domain. **Caatinga: the largest tropical dry forest region in South America**, p. 23-63, 2017.

DU TOIT, Marié J.; HAHS, Amy K.; MACGREGOR-FORS, Ian. The effect of landscape history on the urban environment: past landscapes, present patterns. **Urban ecology in the global south**, p. 51-78, 2021.

DREWNOWSKI, Adam. Sensory properties of fats and fat replacements. 1992.

DUNNING, John B.; DANIELSON, Brent J.; PULLIAM, H. Ronald. Ecological processes that affect populations in complex landscapes. **Oikos**, p. 169-175, 1992.

EISENLOHR, Pedro V. Persisting challenges in multiple models: a note on commonly unnoticed issues regarding collinearity and spatial structure of ecological data. **Brazilian Journal of Botany**, v. 37, p. 365-371, 2014.

ELMQVIST, Thomas et al. **Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment**. Springer Nature, 2013.

FAHRIG, Lenore; MERRIAM, Gray. Habitat patch connectivity and population survival: Ecological archives e066-008. **Ecology**, v. 66, n. 6, p. 1762-1768, 1985.

FANG, Zhou et al. Impacts of land use/land cover changes on ecosystem services in ecologically fragile regions. **Science of the Total Environment**, v. 831, p. 154967, 2022.

FEITOSA, Matheus Leonydas Borba et al. Effects of landscape metrics on scorpion (Arachnida: Scorpiones) assemblage in a tropical urban ecosystem. **Ecology and Evolution**, v. 14, n. 2, p. e11026, 2024.

FERRAZ, Gonçalo et al. A large-scale deforestation experiment: effects of patch area and isolation on Amazon birds. **science**, v. 315, n. 5809, p. 238-241, 2007.

FILGUEIRAS, Bruno KC et al. Dung beetle persistence in human-modified landscapes: combining indicator species with anthropogenic land use and fragmentation-related effects. **Ecological Indicators**, v. 55, p. 65-73, 2015.

FOERSTER, Stenio Italo Araujo et al. New records of the not-so-rare males of the parthenogenetic scorpion Tityus stigmurus (Thorell, 1876)(Scorpiones: Buthidae). **The Journal of Arachnology**, v. 50, n. 1, p. 27-29, 2022.

FORMAN, Richard TT; GODRON, Michel. Patches and structural components for a landscape ecology. **BioScience**, v. 31, n. 10, p. 733-740, 1981.

GARDNER, Toby A. et al. Prospects for tropical forest biodiversity in a human-modified world. **Ecology letters**, v. 12, n. 6, p. 561-582, 2009.

GOLDSPINK, David F.; GARLICK, Peter J.; MCNURLAN, M. A. Protein turnover measured in vivo and in vitro in muscles undergoing compensatory growth and subsequent denervation atrophy. **Biochemical Journal**, v. 210, n. 1, p. 89-98, 1983.

GOPALAN, Radha; RADHAKRISHNA, Sindhu. Cities and Biodiversity: Hidden connections between the built form and life. In: **Blue-Green Infrastructure Across Asian Countries: Improving Urban Resilience and Sustainability**. Singapore: Springer Singapore, 2022. p. 141-162.

HAHS, Amy K. et al. Urbanisation generates multiple trait syndromes for terrestrial animal taxa worldwide. **Nature Communications**, v. 14, n. 1, p. 4751, 2023.

HILL, Mark O.; GAUCH JR, Hugh G. Detrended correspondence analysis: an improved ordination technique. **Vegetatio**, v. 42, n. 1, p. 47-58, 1980.

HUGHES, Alice C. Understanding the drivers of S outheast A sian biodiversity loss. **Ecosphere**, v. 8, n. 1, p. e01624, 2017.

IBGE. (2022). Instituto Brasileiro de Geografia e Estatística. https://cidades. ibge.gov.br/brasil/pe/paulista/panorama

KÉRY, Marc; MADSEN, Jesper; LEBRETON, JEAN-DOMINIQUE. Survival of Svalbard pink-footed geese Anser brachyrhynchus in relation to winter climate, density and land-use. **Journal of Animal Ecology**, v. 75, n. 5, p. 1172-1181, 2006.

LATHA, Thomas; SABU, Thomas K. Effects of land use change on dung beetle (Scarabaeinae) community structure in South Western Ghats. **Int. J. Environ. Agric. Biotechnol**, v. 4, p. 198-208, 2019.

LAURANCE, William F. et al. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. **Conservation biology**, v. 16, n. 3, p. 605-618, 2002.

LAURANCE, William F.; SAYER, Jeffrey; CASSMAN, Kenneth G. Agricultural expansion and its impacts on tropical nature. **Trends in ecology & evolution**, v. 29, n. 2, p. 107-116, 2014.

LEAL, Inara R. et al. Mudando o curso da conservação da biodiversidade na Caatinga do Nordeste do Brasil. **Megadiversidade**, v. 1, n. 1, p. 139-146, 2005.

LE PROVOST, Gaëtane et al. Land-use history impacts functional diversity across multiple trophic groups. **Proceedings of the National Academy of Sciences**, v. 117, n. 3, p. 1573-1579, 2020.

LEGENDRE, Pierre; LEGENDRE, Louis. **Numerical ecology**. Elsevier, 2012.

LEGENDRE, Pierre; BORCARD, Daniel; PERES-NETO, Pedro R. Analyzing beta diversity: partitioning the spatial variation of community composition data. **Ecological monographs**, v. 75, n. 4, p. 435-450, 2005.

LIRA, Andre Felipe de Araujo et al. Potential distribution patterns of scorpions in north-eastern Brazil under scenarios of future climate change. **Austral Ecology**, v. 45, n. 2, p. 215-228, 2020.

LIRA, Andre Felipe de Araujo et al. Linking scorpion (Arachnida: Scorpiones) assemblage with fragment restoration in the Brazilian Atlantic Forest. **Studies on Neotropical Fauna and Environment**, v. 53, n. 2, p. 107-112, 2018a.

LIRA, A. F. A.; DESOUZA, A. M.; ALBUQUERQUE, C. M. R. Environmental variation and seasonal changes as determinants of the spatial distribution of scorpions (Arachnida: Scorpiones) in Neotropical forests. **Canadian Journal of Zoology**, v. 96, n. 9, p. 963-972, 2018b.

LIRA, André FA et al. Contrasting patterns at interspecific and intraspecific levels in scorpion body size across a climatic gradient from rainforest to dryland vegetation. **Zoology**, v. 146, p. 125908, 2021a.

LIRA, Andre FA et al. Understanding the effects of human disturbance on scorpion diversity in Brazilian tropical forests. **Journal of Insect Conservation**, v. 25, n. 1, p. 147-158, 2021b.

LOURENÇO, Wilson R. **Scorpions of Brazil**. Paris: Les editions de l'If, 2002.

LO-MAN-HUNG, Nancy F. et al. Impact of different land management on soil spiders (Arachnida: Araneae) in two Amazonian areas of Brazil and Colombia. **The Journal of Arachnology**, v. 39, n. 2, p. 296-302, 2011.

MACGREGOR-FORS, Ian. Misconceptions or misunderstandings? On the standardization of basic terms and definitions in urban ecology. **Landscape and Urban Planning**, v. 100, n. 4, p. 347-349, 2011.

MAGURRAN, Anne E.; MCGILL, Brian J. (Ed.). **Biological diversity: frontiers in measurement and assessment**. OUP Oxford, 2010.

MAGIOLI, Marcelo et al. Land-use changes lead to functional loss of terrestrial mammals in a Neotropical rainforest. **Perspectives in Ecology and Conservation**, v. 19, n. 2, p. 161-170, 2021.

MOREIRA, Milena OM; MOURA, Geraldo JB; LIRA, André FA. Sexual differences on body condition in litter-dwelling scorpion Tityus pusillus Pocock, 1893 (Scorpiones: Buthidae). **Revista Chilena de Entomología**, v. 50, n. 1, 2024.

MCCARY, Matthew A.; MINOR, Emily; WISE, David H. Covariation between local and landscape factors influences the structure of ground-active arthropod communities in fragmented metropolitan woodlands. **Landscape ecology**, v. 33, p. 225-239, 2018.

MCCUNE, B. Analysis of ecological communities. **MjM Software Design**, v. 300, 2002.

MENTA, Cristina; REMELLI, Sara. Soil health and arthropods: From complex system to worthwhile investigation. **Insects**, v. 11, n. 1, p. 54, 2020.

MILLARD, Joseph et al. Global effects of land-use intensity on local pollinator biodiversity. **Nature Communications**, v. 12, n. 1, p. 2902, 2021.

MORELLI, Federico; MOUSSEAU, Timothy A.; MØLLER, Anders Pape. Cuckoos vs. top predators as prime bioindicators of biodiversity in disturbed environments. **Journal of environmental radioactivity**, v. 177, p. 158-164, 2017.

OKSANEN, Jari et al. Community ecology package. **R package version**, v. 2, n. 0, p. 321-326, 2013.

OLIVER, Tom et al. Heterogeneous landscapes promote population stability. **Ecology letters**, v. 13, n. 4, p. 473-484, 2010.

OLIVEIRA HAGEN, Emily et al. Impacts of urban areas and their characteristics on avian functional diversity. **Frontiers in Ecology and Evolution**, v. 5, p. 267008, 2017.

OLIVERO, Paola Andrea et al. Sensitivity of genital and somatic traits of scorpions to developmental instability caused by increasing urbanization: a 20-year experiment. **Ecological Indicators**, v. 122, p. 107272, 2021.

PENG, Ming-Hsiao et al. Landscape configuration and habitat complexity shape arthropod assemblage in urban parks. **Scientific reports**, v. 10, n. 1, p. 16043, 2020.

POLIS, Gary A. (Ed.). **The biology of scorpions**. 1990.

PORTO, Tiago Jordão; PINTO-DA-ROCHA, Ricardo; DA ROCHA, Pedro Luís Bernardo. Regional distribution patterns can predict the local habitat specialization of arachnids in heterogeneous landscapes of the Atlantic Forest. **Diversity and Distributions**, v. 24, n. 3, p. 375-386, 2018.

Projeto MapBiomas. (2023). Projeto MapBiomas – Coleção [versão 6] da Série Anual de Mapas de Cobertura e Uso da Terra do Brasil. https:// brasil.mapbiomas.org/

QGIS.org. (2022). QGIS geographic information system. QGIS Association. http://www.qgis.org

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. http://www.R-project. org/

Rasband, W. S. (2018). Imagej, Us National Institutes of Health, Bethesda, Maryland, USA, https://imagej.net/ij/.

RODRIGUES, Paulo Cesar Guimarães et al. Ecologia dos Brejos de Altitude do agreste pernambucano. **Revista de Geografia**, v. 25, n. 3, p. 20-34, 2008.

RITCHIE, Hannah; ROSER, Max. How urban is the world?. **Our World in Data**, 2024.

ROBINSON, Robert A.; SUTHERLAND, William J. Post-war changes in arable farming and biodiversity in Great Britain. **Journal of applied Ecology**, v. 39, n. 1, p. 157-176, 2002.

RULLI, Maria Cristina et al. Land-use change and the livestock revolution increase the risk of zoonotic coronavirus transmission from rhinolophid bats. **Nature Food**, v. 2, n. 6, p. 409-416, 2021.

SACHS, Jeffrey D. et al. Biodiversity conservation and the millennium development goals. **Science**, v. 325, n. 5947, p. 1502-1503, 2009.

SALA, Osvaldo E. et al. Global biodiversity scenarios for the year 2100. **science**, v. 287, n. 5459, p. 1770-1774, 2000.

SALOMÃO, Renato Portela et al. Landscape structure and composition define the body condition of dung beetles (Coleoptera: Scarabaeinae) in a fragmented tropical rainforest. **Ecological Indicators**, v. 88, p. 144-151, 2018.

SALOMÃO, Renato Portela et al. Habitat type affects the diversity of dung beetle (Coleoptera: Scarabaeidae) assemblages in a neotropical mountainous region of Colombia. **International Journal of Tropical Insect Science**, v. 43, n. 3, p. 793-803, 2023.

SCHNEIDER, Caroline A.; RASBAND, Wayne S.; ELICEIRI, Kevin W. NIH Image to ImageJ: 25 years of image analysis. **Nature methods**, v. 9, n. 7, p. 671-675, 2012.

SEIBOLD, Sebastian et al. Microclimate and habitat heterogeneity as the major drivers of beetle diversity in dead wood. **Journal of Applied Ecology**, v. 53, n. 3, p. 934-943, 2016.

SHARMA, Ankita et al. Impact of urbanisation on the taxonomic and functional diversity of spider assemblages in Guwahati City, Assam, India. **Urban Ecosystems**, v. 27, n. 1, p. 239-249, 2024.

SIMONE, Yuri; MEIJDEN, Arie van der. Armed stem to stinger: a review of the ecological roles of scorpion weapons. **Journal of Venomous Animals and Toxins including Tropical Diseases**, v. 27, p. e20210002, 2021.

SIMONS, Nadja K.; WEISSER, Wolfgang W.; GOSSNER, Martin M. Multi-taxa approach shows consistent shifts in arthropod functional traits along grassland land-use intensity gradient. **Ecology**, v. 97, n. 3, p. 754-764, 2016.

STEIN, Anke; KREFT, Holger. Terminology and quantification of environmental heterogeneity in species-richness research. **Biological Reviews**, v. 90, n. 3, p. 815-836, 2015.

THOM, Dominik et al. Effects of disturbance patterns and deadwood on the microclimate in European beech forests. **Agricultural and Forest Meteorology**, v. 291, p. 108066, 2020.

TÓTH, Zsolt; HORNUNG, Elisabeth. Taxonomic and functional response of millipedes (Diplopoda) to urban soil disturbance in a metropolitan area. **Insects**, v. 11, n. 1, p. 25, 2019.

TSCHARNTKE, Teja et al. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. **Ecology letters**, v. 8, n. 8, p. 857-874, 2005.

TSCHARNTKE, Teja et al. Landscape moderation of biodiversity patterns and processes-eight hypotheses. **Biological reviews**, v. 87, n. 3, p. 661-685, 2012.Tukey, J. 1955. Answer to query no. 113. Biometrics.,11:111-113.

URBAN, Mark C. et al. The evolutionary ecology of metacommunities. **Trends in ecology & evolution**, v. 23, n. 6, p. 311-317, 2008.

VAN DER MEIJDEN, A.; HERREL, A.; SUMMERS, A. Comparison of chela size and pincer force in scorpions; getting a first grip. **Journal of Zoology**, v. 280, n. 4, p. 319-325, 2010.

VANDEWALLE, Marie et al. Functional traits as indicators of biodiversity response to land use changes across ecosystems and organisms. **Biodiversity and Conservation**, v. 19, p. 2921-2947, 2010.

VILLARD, Marc-André; METZGER, Jean Paul. Beyond the fragmentation debate: a conceptual model to predict when habitat configuration really matters. **Journal of Applied Ecology**, v. 51, n. 2, p. 309-318, 2014.

WILSON, Edward O. Success and dominance in ecosystems: the case of the social insects. 1990.

WYMANN, Matthias P.; SCHNEITER, Roger. Lipid signalling in disease. **Nature reviews Molecular cell biology**, v. 9, n. 2, p. 162-176, 2008.

ZUUR, Alain F.; IENO, Elena N.; ELPHICK, Chris S. A protocol for data exploration to avoid common statistical problems. **Methods in ecology and evolution**, v. 1, n. 1, p. 3-14, 2010.

Figure captions

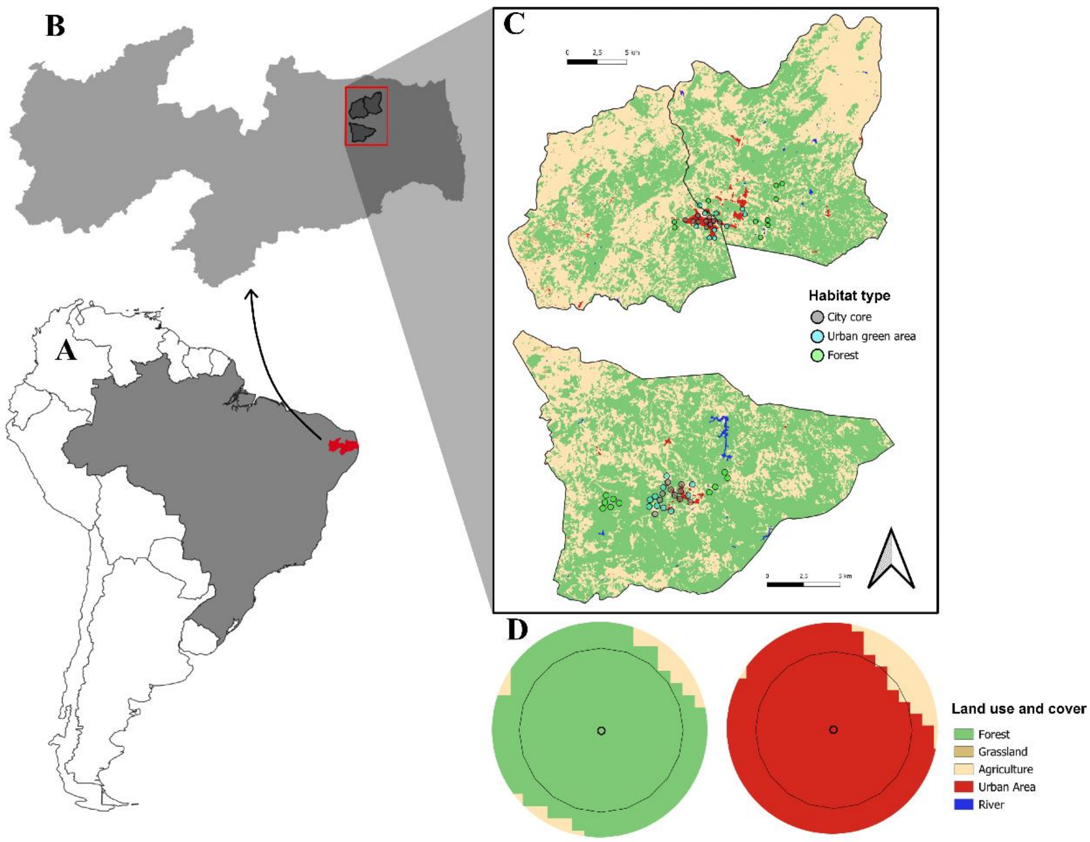

FIGURE 3. Distribution of sampling units with a buffer of 200 in different habitat type (A), map of the state of Paraiba showing the location of the municipality in the study (B).

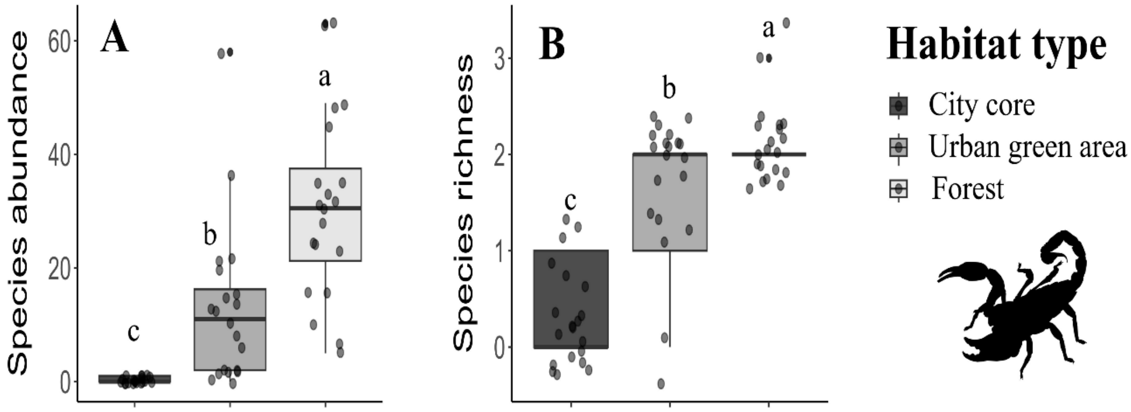

FIGURE 4. Variation in abundance (A), species richness (B) of scorpions across different habitat types. *Letters above the bars indicate statistically significant differences (P < 0.05).

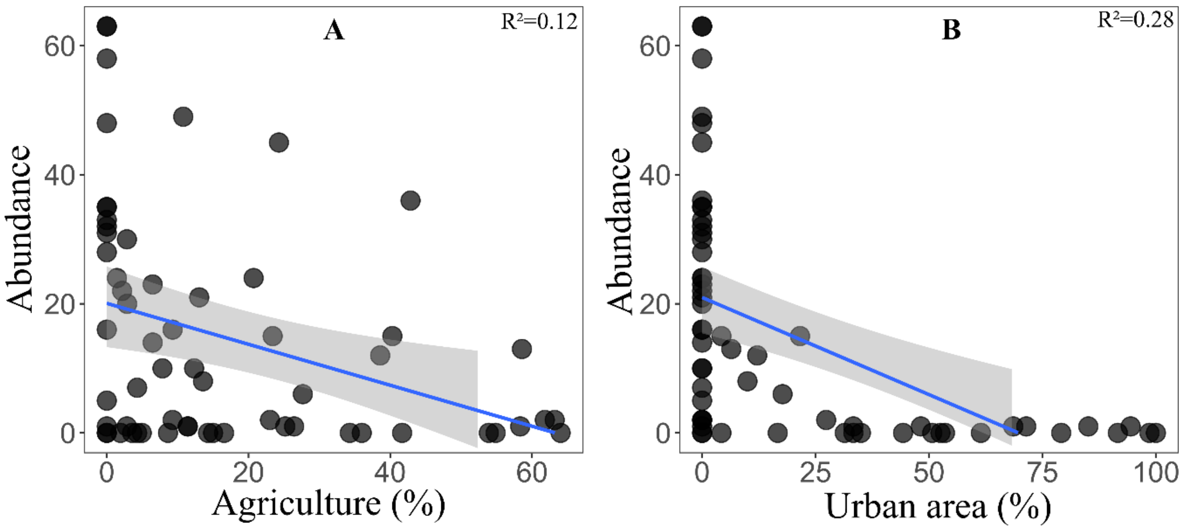

FIGURE 5. Relationship between abundance of scorpions and the percentage of agriculture (A) and percentage of urban area (B) in in Neotropical submontane forest.

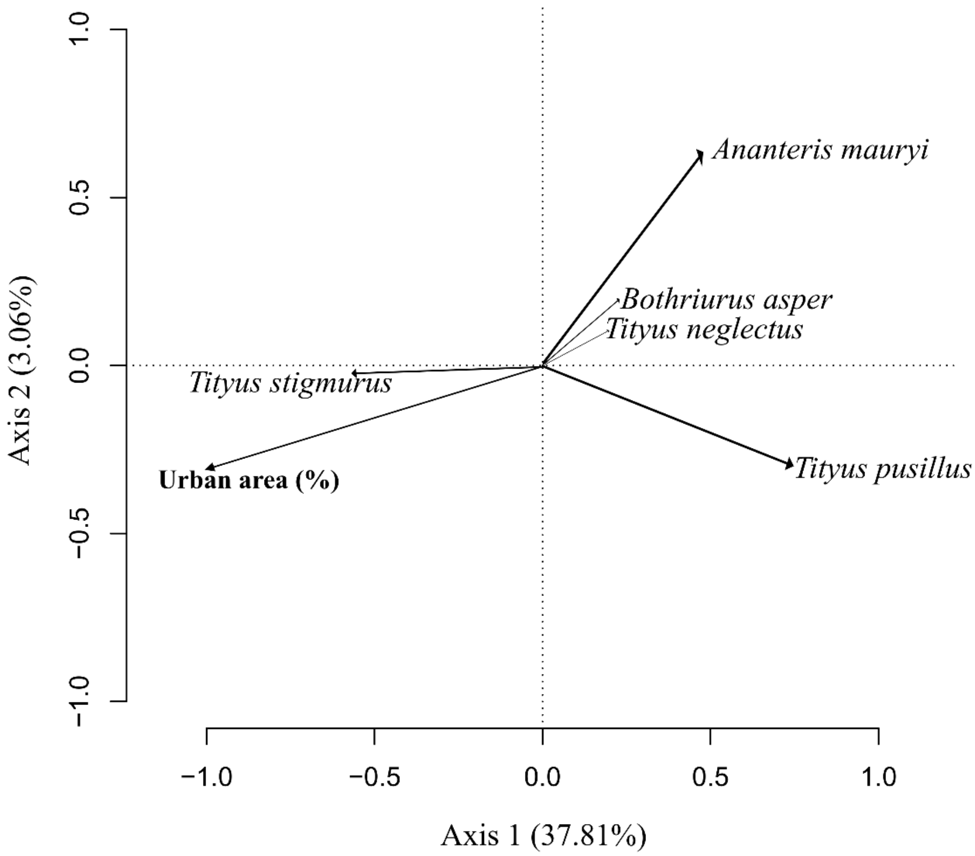

FIGURE 6. Ordination diagram of the redundancy analysis of the species composition of the scorpion assemblage in response to the percentage of landscape cover in Neotropical submontane forest.

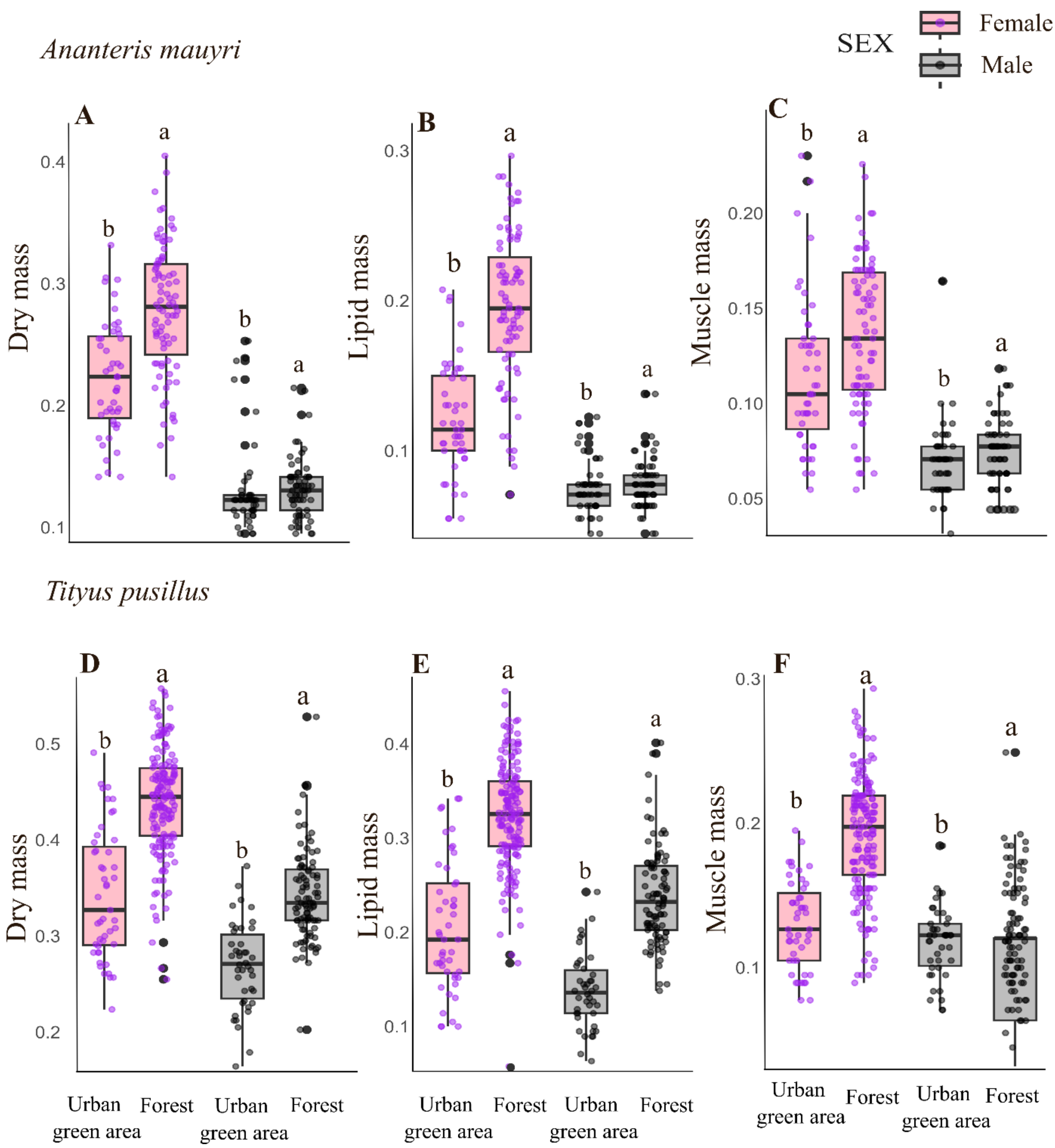

FIGURE 7. Ratio of body condition indicators in different habitat types for males and females of the species *Tityus pusillus* and *Ananteris mauryi*. For Ananteris mauryi specimens, (A) Dry mass, (B) Lipid mass, and (C) Muscle mass are represented. For *Tityus pusillus* individuals, (D)

Dry mass, (E) Lipid mass, and (F) Muscle mass are represented. Different letters above the bars indicate statistically significant differences (P < 0.05).

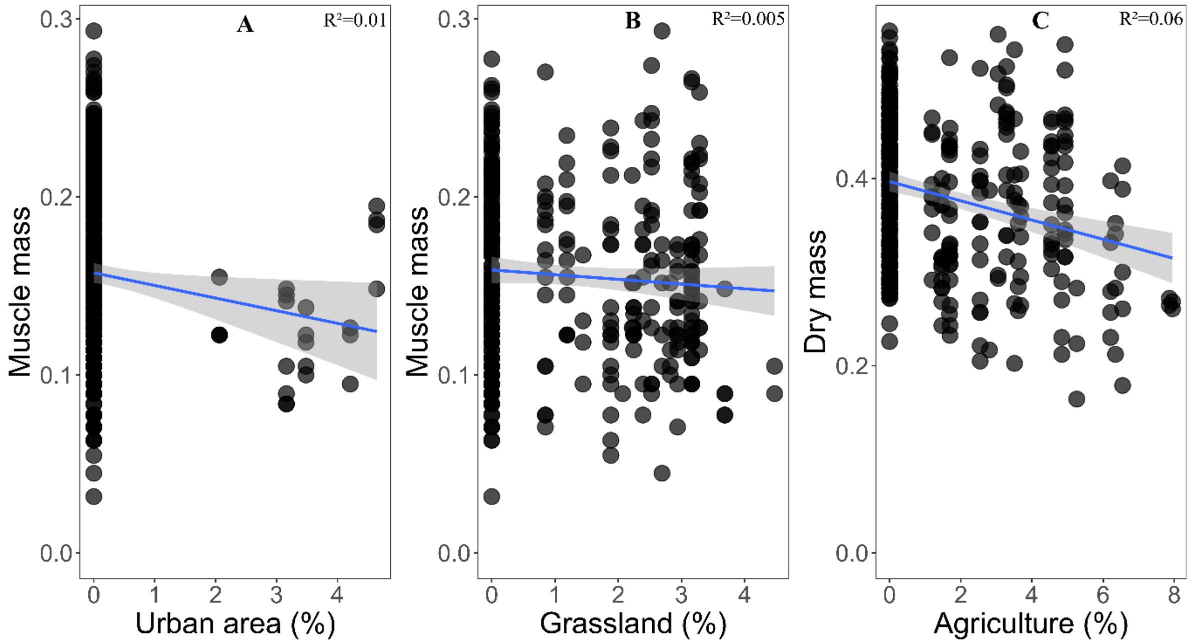

FIGURE 8. Effects of increasing urban area (A) and grassland (B) on muscle mass, increasing agriculture on dry mass of *Tityus pusillus* at a landscape scale (C).

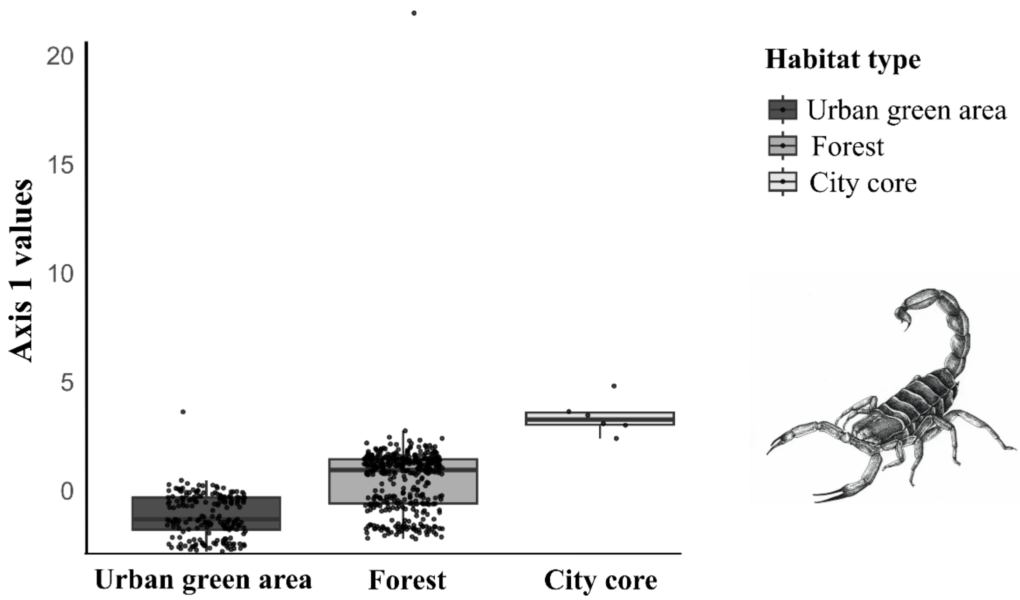

FIGURE 9. The distribution of values on axis 1 of the PCA corresponds to the functional traits of the scorpion assembly in different habitat types.

Supplementary material

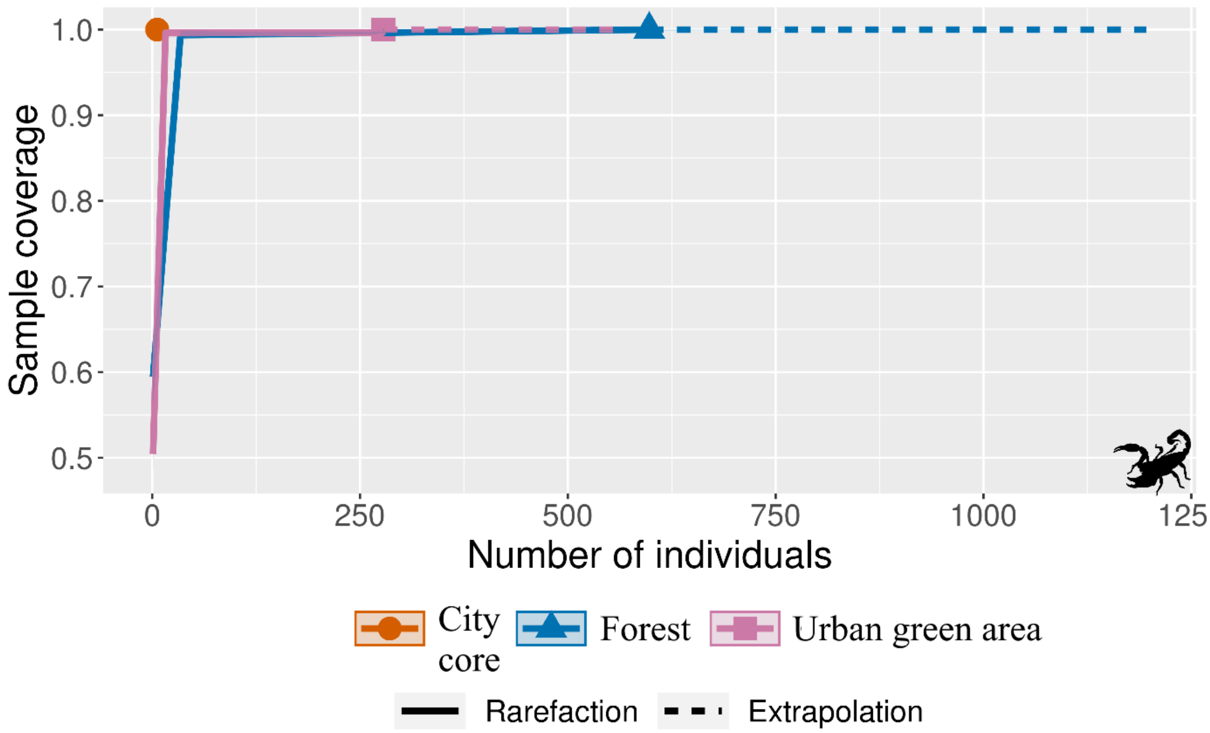

FIGURE S1. Scorpion sampling coverage across three habitats in Neotropical submontane forest.

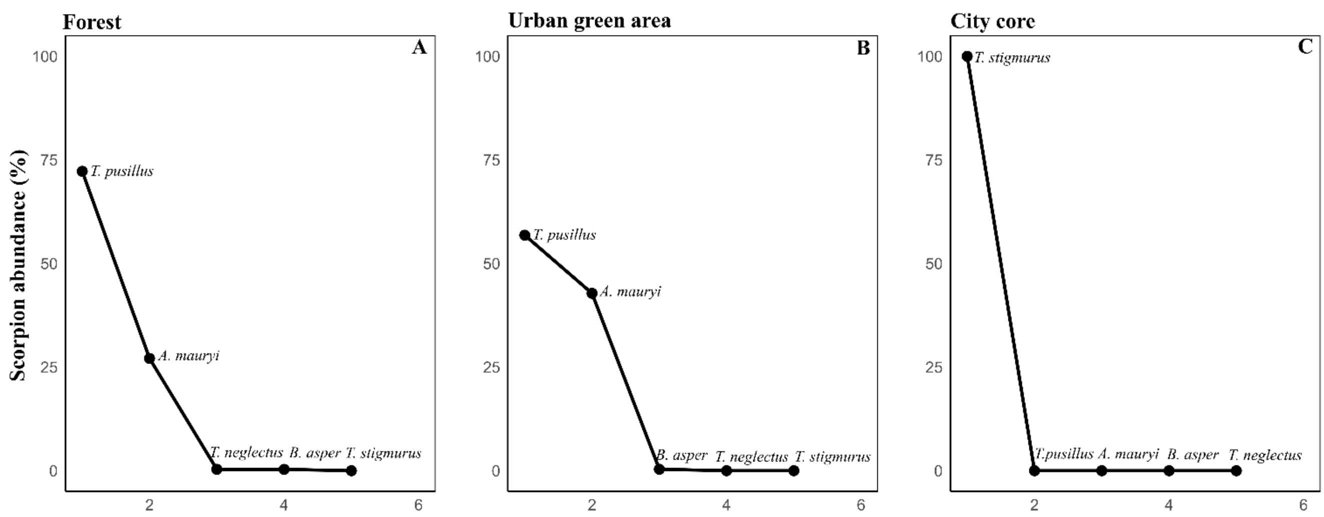

FIGURE S2.A Rank abundance of scorpion species assemblage in different habitat types, (A) forests, (B) urban green areas, (C) city core, in Neotropical submontane forest, Paraiba state, Brazil.

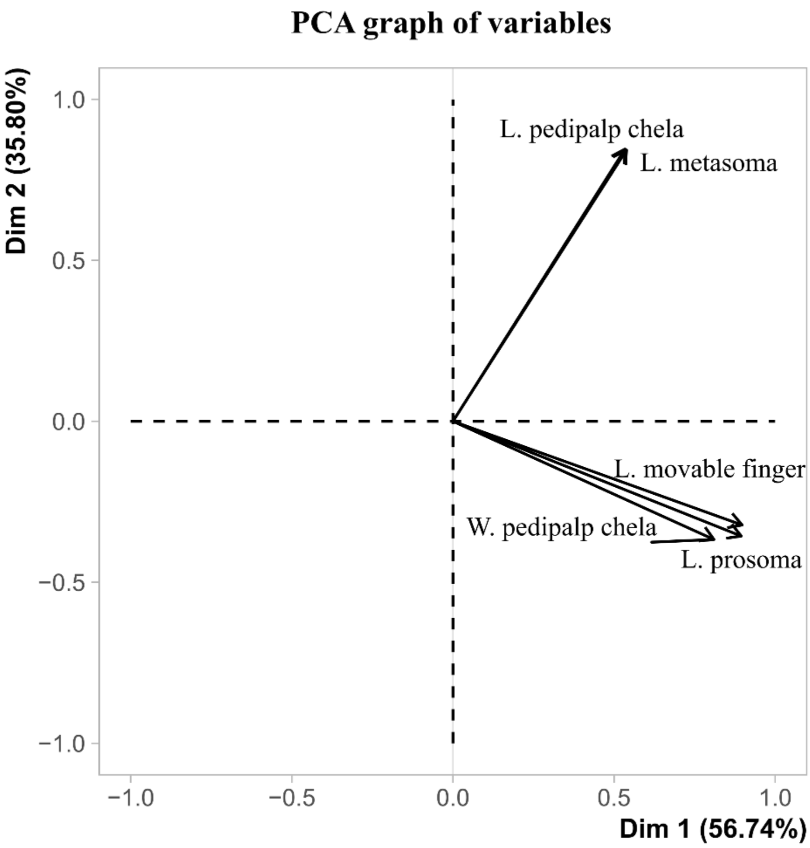

FIGURE S3. Principal component analysis of the functional characteristics of scorpions in different habitat types of a Neotropical submontane forest.

Tables

TABLE 1. Scorpion diversity 60 sampling units across three municipalities Neotropical submontane forest

	Buthidae				**bothriuridae**	**Land use and cover**				
Habitat type	*Tityus pusillus*	*Ananteris mauryi*	*Tityus neglectus*	*Tityus stigmurus*	*Bothriurus asper*	Forest	Grassland	Agriculture	Urban area	River
City core	0	0	0	0.3±0.45(n=6)	0	26.76±22.07	2.06±3.26	17.77±18.96	53.89±32.29	0
Urban green area	6.95±9.9(n=158)	5.95±6.22(n=119)	0	0	0.05±0.21(n=1)	57.58±25.11	4.72±5.54	28.42±21.18	9.26±13.36	0
Forest	22.55±13.27(n=432)	8.1±5.13(n=162)	0.1±0.43(n=2)	0	0.1±0.43(n=2)	92.01±16.95	3.21±4.23	4.62±7.12	0	0.14±0.62

TABLE 2. Scorpion functional body traits measurements (in cm) of individuals from different habitat types on Brazilian montane forest. PMFL = pedipalp movable finger length, PCL = pedipalp chela length, PQW = pedipalp chela width, PL = prosoma length and ML = metasoma length.

Functional body traits	Habitat type		
	Forest (n = 406)	Urban green area (n = 193)	City core (n = 6)
PMFL	0.34 ± 0.07	0.25 ± 0.05	0.570 ± 0.062
PCL	3.70 ± 63.85	0.38 ± 0.10	0.917 ± 0.812
PCW	0.12 ± 0.04	0.08 ± 0.05	0.185 ± 0.019
PL	0.35 ± 0.06	0.25 ± 0.04	0.475 ± 0.043
ML	4.15 ± 53.57	1.03 ± 0.24	2.103 ± 1.947

TABLE S1. Correlogram matrix illustrating pairwise correlations among land use and cover types: Grassland, Agriculture, Urban area, and River. Values range from -1 to 1, with <0.05 indicating statistically significant correlations, demonstrating adherence to a significance threshold of 5%.

	Grassland	**Agriculture**	**Urban area**	**River**
Grassland	1.000	0.045	-0.366	-0.074
Agriculture	0.045	1.000	0.122	-0.069
Urban area	-0.366	-0.122	1.000	-0.088
River	-0.074	-0.069	-0.088	1.000