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WELTON DIONISIO DA SILVA

EFEITO DO MICRO-HABITAT SOBRE A RELAÇÃO PREDADOR-PRESA DOS ESCORPIÕES DE LITEIRA *Tityus pusillus* e *Ananteris mauryi* NA FLORESTA ATLÂNTICA

RECIFE
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Dissertação apresentada ao Programa de Pós-Graduação em Biologia Animal, Área de Concentração Ecologia, da Universidade Federal de Pernambuco, como requisito parcial para obtenção do título de mestre em Biologia Animal.

Orientador (a) – Profa. Dra. Cleide Maria Ribeiro de Albuquerque

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Orientador (a) – Dra. Cleide Maria Ribeiro de Albuquerque

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COMISSÃO EXAMINADORA

Titulares

Dr. Paulo Jorge Parreira dos Santos /UFPE

Dr. Simão Dias de Vasconcelos Filho /UFPE

Dr. Rodrigo Felipe Rodrigues Carmo

Suplentes

Dr. José Roberto Botelho de Souza /UFPE

Tiago Jordão Porto /INEMA

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“ Faça ou não faça. Tentativa não há. ”

- Mestre Yoda.

RESUMO

A fragmentação é amplamente reconhecida como um fator que amplia as margens florestais, afetando a estrutura do habitat bem como dos organismos que nele habitam. Entender como esses efeitos atuam sobre as espécies e suas relações tem sido um desafio devido, particularmente, à sensibilidade diferencial dos indivíduos. Nesse estudo avaliou-se como alterações do microhabitat (profundidade da serapilheira, massa seca e forma das folhas) decorrentes do efeito de borda, influenciam a atividade de superfície de duas espécies de escorpiões (*Tityus pusillus* Pocock, 1893 e *Ananteris mauryi* Lourenço, 1982) e suas presas potenciais. Investigou-se também como a disponibilidade de presas e o regime pluviométrico se relaciona com a atividade reprodutiva desses escorpiões. As coletas foram realizadas em três pontos (10, 100 e 200 m de distância da borda) ao longo de um ano em fragmento de floresta secundária no Campo de Instrução Marechal Newton Cavalcante, Brasil, de Abril 2016 a Março 2017. Os animais foram coletados através de coleta ativa, armadilhas de chão e quadrantes de 625cm². O material da serapilheira também foi coletado nos quadrantes. *Tityus pusillus* foi o único escorpião afetado pelo efeito de borda, com aumento gradual de atividade de superfície em direção ao interior da floresta. Por ser mais ativo na camada superior da serapilheira, *T. pusillus* é vulnerável ao efeito de borda, enquanto *A. mauryi* que habita camadas inferiores e mais úmidas não é afetado. As presas potenciais tiveram uma relação fraca com a atividade de superfície de *A. mauryi* e nenhuma com a atividade de *T. pusillus*. O período reprodutivo não apresentou correlação com a abundância de presas ou com a taxa de precipitação mensal (mm), ocorrendo na estação seca para *T. pusillus* enquanto o de *A. mauryi* foi na estação chuvosa. Por serem predadores generalistas num ambiente diverso e com menor variação sazonal que locais sazonalmente secos, essas espécies não teriam sua atividade de superfície e período reprodutivo afetados por alterações na disponibilidade de presas, uma vez que enquanto algumas presas reduzem em abundância, outras aumentam mantendo estável os recursos alimentares para sua população. Ainda, o período reprodutivo de *A. mauryi* concentrado da estação chuvosa, pode ser vantajoso para essa espécie umícola e o seu término no início do período reprodutivo de *T. pusillus*, é importante para evitar predação.

Palavras-chave: Fragmentação florestal. Efeito de borda. Período reprodutivo.

ABSTRACT

Fragmentation is widely recognized as a factor that increases the forest margins, affecting the habitat structure as well the organisms that inhabits it. Understanding how these effects act on species and its relationship has been a challenge due, particularly, to differential sensibility of the individuals. In this study was evaluated how microhabitat alterations (litter depth, dry mass and leaf shape), resulting of edge effect, influence the surface activity of two scorpions (*Tityus pusillus* Pocock, 1893 e *Ananteris mauryi* Lourenço, 1982) and their potential prey. It also investigat how prey availability and pluviometry are related with reproductive activity of these scorpions. The collections were realized in three plots (10, 100 and 200 m of distance of theedge) in a secondary-growth forest at Campo de Instrução Marechal Newton Cavalcante, Brazil, of April 2016 to March 2017. The animals were collected through of active collection, pitfall traps and quadrats of 625cm². The leaf-litter material was also collected in the quadrats. *Tityus pusillus* was the only scorpion affected by edge effect with gradual increase of surface activity towards the forest interior. Because is more active in the top-layer of leaf litter, *T. pusillus* is vulnerable to edge effect, while *A. mauryi* is not affected. The potential prey had a weak relationship with surface activity of A. mauryi and nothing to T. pusillus. The reproductive period do not show relationship with the prey abundance or monthly precipitation (mm), occurring predominantly in the dry season for *T. pusillus,* whereas *A. mauryi* was in the wet season. Because of the generalist food regime, these species would not their surface activity and reproductive period affected by prey availability, since that throughout the year, while some prey orders decline in abundance, others increase remaining stable the food resources necessary to their population. Yet, the reproductive period of *A. mauryi* focused in the wet season, may be beneficial to this humicolous species and its ending at the beginning of the reproductive period of *T. pusillus*, is important to avoid predation.

Key Words: Forest fragmentation. Edge effect. Reproductive period.

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1 INTRODUÇÃO

A Floresta Atlântica brasileira possui hoje apenas 12% de sua área original, composta principalmente por fragmentos menores que 100ha de floresta de crescimento secundário que já foram impactadas anteriormente. A fragmentação florestal, que é causada por atividades humana como agricultura, desmatamento e urbanização, gera não apenas a perda de hábitat natural, mas também uma série de efeitos na região marginal das florestas que são chamados de efeito de borda. Essa borda florestal fica mais exposta às condições microclimáticas externas à floresta, causando um aumento na incidência solar e de ventos nesses locais, além de aumento de temperatura e redução de umidade. Há também um rápido recrutamento de árvores pioneiras que têm ciclo de vida rápido, pequeno diâmetro à altura do peito (DAP) e que devido à condição climaticamente seca da borda, possuem rápida taxa de substituição de folhas. Isso gera uma maior taxa de queda de folhas das árvores nesses locais e que devido às condições climáticas da borda também levam mais tempo para decompor. Como consequência, há um maior acúmulo de serapilheira na borda florestal do que no interior na floresta.

Na serapilheira vivem diversos artrópodes que contribuem para o equilíbrio da floresta e que respondem à heterogeneidade ambiental, inclusive às variações geradas pelo gradiente borda-interior da floresta. Além disso, artrópodes de nível trófico mais alto são mais sensíveis às perturbações da borda porque podem ser afetados não apenas diretamente, mas como consequência do efeito de borda sobre suas presas. Estudos prévios indicam que escorpiões respondem às variações espaciais e temporais na disponibilidade de presa e têm um aumento na atividade reprodutiva quando há maior disponibilidade alimentar. Nesse período, machos adultos forrageiam com maior frequência à procura de fêmeas para reproduzir. Assim, a abundância de escorpiões pode estar relacionada à estrutura da serapilheira e à disponibilidade de presas.

Os escorpiões mais abundantes na Floresta Atlântica nordestina são *Tityus pusillus* Pocock 1893 e *Ananteris mauryi* Lourenço 1982 que são predadores generalistas, sendo o *T. pusillus* um caçador senta-e-espera mais ativo na camada superior da serapilheira, enquanto o *A. mauryi* é um predador ativo mais frequente na camada inferior. Embora estudos anteriores tenham investigado a relação da abundância desses escorpiões com a estrutura da serapilheira, não avaliaram o efeito do micro-habitat como mitigador do efeito de borda nessas espécies ao longo de um gradiente borda-interior de floresta. Além disso, espécies respondem diferentemente ao efeito de borda, portanto o estudo do efeito de borda em espécies com hábitos similares levanta informações importantes sobre quais processos podem mitigar esse efeito sobre os organismos. Assim, esse estudo investiga o efeito de borda sobre o micro-habitat e a disponibilidade de presas dessas duas espécies de escorpiões. Além de determinar o período reprodutivo de populações dessas duas espécies e investigar a relação desse período com a disponibilidade de alimentos.

Esta dissertação está estruturada na forma de seções seguindo as normas da Associação Brasileira de Normas Técnicas (ABNT) no que se refere aos elementos pré-textuais e textuais (Introdução e Referencial Teórico). O desenvolvimento está apresentado no capítulo apresentado na forma de manuscrito a ser submetido para publicação em um periódico científico e, portanto, em exceção, o capítulo segue as normas do periódico.

2 REFERENCIAL TEÓRICO

2.1 Abundância de artrópodes na Floresta Atlântica brasileira: influência do efeito de borda e do micro-habitat.

Os artrópodes constituem o mais abundante e diverso grupo de animais em florestas tropicais (GILLER, 1996; BASSET et al., 2012) e são sensíveis a perturbações ambientais até mesmo de micro escala (MURCIA, 1995; UEHARA-PRADO et al., 2009). Dentre os fatores que causam maior dano ao ambiente florestal está a fragmentação, que causa marcantes alterações no habitat e é uma ameaça à biodiversidade e funcionamento do ecossistema (FAHRIG, 2003; PARDINI et al., 2010; MAGNAGO et al., 2014).

No Brasil, um bioma altamente fragmentado em decorrência de ações antrópicas é a Floresta Atlântica que atualmente possui apenas cerca de 12% de sua área total original (Figura 1) (RIBEIRO et al., 2009; SOS MATA ATLÂNTICA, 2015). Os remanescentes são, em sua maioria, compostos de fragmentos menores que 100 ha de florestas de crescimento secundário em estágio inicial de sucessão, nos quais o efeito de borda tem uma área de efeito maior (RANTA et al., 1998; METZGER, 2000; METZGER et al., 2009). Apesar do elevado nível de perturbação nesses ambientes, a Floresta Atlântica brasileira é considerada um dos mais importantes hotspots de biodiversidade, devido à sua riqueza de espécies e grau de endemismo (LAURANCE, 2009; FORZZA et al., 2012). Vários autores indicam que sua conservação é fundamental para a manutenção da biodiversidade (MITTERMEIER et al., 1998; TABARELLI et al., 2005; BROOKS et al., 2006; RIBEIRO et al., 2009), sendo importante para a preservação de aracnídeos como descrito em aranhas e escorpiões (RAUB et al., 2014; LIRA et al., 2016).

Por aumentar drástica e abruptamente as margens dos remanescentes, a fragmentação expõe a vegetação da borda a condições climáticas atípicas, gerando diferenças entre os fatores físicos e bióticos da borda e do interior da floresta, alterando o microclima e, consequentemente as características dos microhabitats (LAURANCE; YENSEN, 1991; LAURANCE et al., 2002; EWERS; BANKS-LEITE, 2013; MAGNAGO et al., 2015). Essas variações impactam na distribuição e abundância dos artrópodes nos ambientes florestais onde esses animais são fundamentais contribuindo para serviços ecossistêmicos como formação do solo, polinização, controle populacional e ciclagem de nutrientes (CURRY, 1994; MURRAY et al., 2008, WEISSER; SIEMANN, 2008; FARWIG et al., 2009).

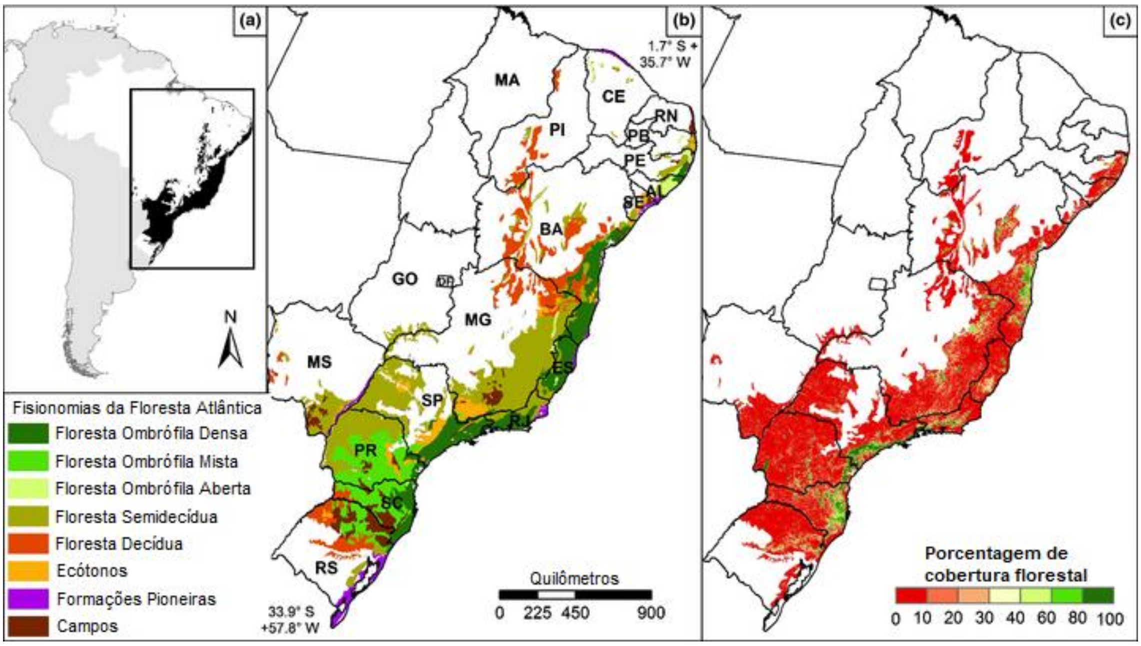
As variações encontradas próximas à borda florestal são chamadas de efeito de borda, definido como uma alteração na estrutura, na composição e/ou na abundância relativa de espécies na parte marginal de um fragmento (LOVEJOY et al., 1986). Segundo Murcia (1995), o efeito de borda pode ser classificado em: 1 – abiótico (efeitos físico e climático próximos às margens florestais); 2 - biológico direto (efeito sobre a abundância e composição de espécies nas bordas florestais, o qual é dependente da tolerância dos organismos às alterações locais); e 3 - biológico indireto (efeito sobre as interações interespécies).

Em comparação ao interior do fragmento, na borda há maior incidência de luz e ventos, maior temperatura e menor umidade, além de maior produtividade primária, decorrente da maior taxa fotossintética nesses locais (DIDHAM; LAWTON, 1999; GEHLHAUSEN et al., 2000; MAGNAGO et al., 2015). Nessa área, ocorre maior mortalidade de árvores de grande porte, tolerantes à sombra, e consequente recrutamento de vegetação pioneira, de vida curta, tolerante às condições climáticas externas (LAURANCE, 1991; LAURANCE et al., 1998a, 1998b; TABARELLI; PERES, 2002). Essas condições favorecem a uma cobertura de solo, ou seja, serapilheira mais espessa nas bordas comparadas ao interior dos fragmentos (TABARELLI et al., 2010). Além da profundidade, a complexidade da serapilheira também é afetada em bordas de florestas secundárias (BURGHOUTS et al., 1992) pela alteração na composição vegetal e tem efeito sobre a composição e abundância de artrópodes que habitam esses locais (UETZ, 1991; BURGHOUTS et al., 1992; HERRMANN et al., 2005; NASCIMENTO; LAURANCE, 2006; HOPP et al., 2010; PODGAISKI; RODRIGUES, 2017).

Vários estudos têm relatado as consequências das alterações de aspectos estruturais da serapilheira sobre a abundância e distribuição dos artrópodes de solo, embora sem abordagem quanto ao efeito de borda sobre essas alterações, o que reforçaa necessidade de maior conhecimento sobre esse efeito nesses animais. Em florestas temperadas, aranhas construtoras de teia são mais abundantes em serapilheira com maior profundidade (UETZ, 1979) e complexidade (folhas de espécies diferentes e com formas distintas) enquanto maior abundância de aranhas errantes é relacionada somente à complexidade da serapilheira (PODGAISKI; RODRIGUES, 2017). Serapilheira composta de folhas curvas, ao invés de planas, tem maior densidade da aranha *Enoplognatha ovata* Clerck, 1757, uma espécie típica de habitats abertos com vegetação baixa (STEVENSON; DINDAL, 1982). Na Floresta Atlântica, maior abundância de *T. pusillus* foi associada à serapilheira com maior massa seca (LIRA et al., 2015).

As alterações climáticas e estruturais que ocorrem da borda em direção ao interior da floresta podem afetar diferentemente os padrões de abundância e distribuição dos artrópodes nesses ambientes (PAJUNEN et al., 1995; MAGURA, 2002; FERGUSON, 2004; NOREIKA; KOTZE, 2012). Magura (2002), por exemplo, encontrou maior riqueza de carabídeos generalistas e especialistas de hábitats abertos nas bordas florestais e no pasto adjacente do que no interior da floresta. Similarmente, Noreika e Kotze (2012) encontraram variação na composição de carabídeos de acordo com a afinidade de habitat das espécies. Carabídeos de floresta foram mais abundantes no interior, enquanto espécies generalistas e de hábitat abertos foram mais abundantes nas bordas florestais ou não variaram em abundância entre os ambientes (NOREIKA; KOTZE, 2012). Em aranhas, Muff et al. (2009) encontraram que 40% da variação na composição das comunidades é devido ao microambiente, avaliado através de variáveis diretamente ligadas à proporção de luz que atinge o solo (densidade de árvores, radiação disponível, abertura do dossel e galhos distante do chão e de áreas abertas), enquanto apenas 24,5% era explicada pelas suas posições espaciais em relação ao gradiente entre área aberta e floresta. Em um estudo sobre formigas que fazem ninhos em galhos caídos na serapilheira, em 75% dos fragmentos estudados por Carvalho & Vasconcelos (1999), não houve diferença entre a distribuição de ninhos ao longo do gradiente borda-interior da floresta, embora locais com maior densidade de ninhos tenham tido maior riqueza de formigas. Esses estudos demonstram que para avaliar o efeito de borda em um fragmento, é importante investigar não apenas as variações na abundância e composição de espécies, mas também compreender como as condições ambientais de menor escala (i.e micro-habitat), das quais os organismos dependem, estão sendo afetadas pela borda (MURCIA, 1995, CARVALHO et al., 2012).

Figura 1. (a) Área original da Floresta Atlântica brasileira (em preto); (b) Principais fisionomias vegetais que compõem esse bioma; (c) Área restante do seu domínio (baseado em Ribeiro et al., 2009). Abreviações dos estados brasileiros em (b): MA, Maranhão; PI, Piauí; CE, Ceará; RN, Rio Grande do Norte; PB, Paraíba; PE, Pernambuco; AL, Alagoas; SE, Sergipe; BA, Bahia; GO, Goiás; DF, Distrito Federal; MG, Minas Gerais; ES, Espírito Santo; RJ, Rio de Janeiro; SP, São Paulo; MS, Mato Grosso do Sul; PR, Paraná; SC, Santa Catarina; RS, Rio Grande do Sul.



Fonte: Adaptado de Joly et al. (2014).

2.2 Relação predador-presa: contribuição na regulação das comunidades de artrópodes e período reprodutivo

A interação entre uma espécie (predador) que se alimenta de outra (presa) é o que define a relação predador-presa. Essa interação tem um papel fundamental na determinação da estrutura e do funcionamento do ecossistema influenciando a composição da comunidade e sua cascata trófica (BERGER et al., 2001; KNEITEL; CHASE, 2004; HAWLENA; SCHMITZ, 2010; MOONEY et al., 2010; BELGRAD; GRIFFEN, 2016). Assim, muitos autores têm discutido como consumidor e recurso contribuem na regulação das comunidades através de controle top-down e bottom-up, respectivamente (SINCLAIR; KREBS, 2002; GRUNER, TAYLOR, 2006; GREENVILLE et al., 2014; LAUNDRÉ et al., 2014; SCHULDT et al., 2014).

Nas relações tróficas, predadores que têm uma dieta diversa são chamados de predadores generalistas, como aranhas e escorpiões (MCCORMICK; POLIS, 1990; BIRKHOFER; WOLTERS, 2012). Por consumirem uma ampla diversidade de presas auxiliam na estabilidade das comunidades em que habitam, pois exercem predação em diversos níveis tróficos (POLIS, 1990). Apesar de se beneficiarem pela capacidade de utilizar diferentes tipos de presas, em geral, o aumento na disponibilidade de recursos alimentares, tem levado a uma maior atividade de forrageamento e consequentemente da população desses artrópodes predadores generalistas (POLIS; MCCORMICK, 1986; SINCLAIR; KREBS, 2002; ARAÚJO et al., 2010). Por exemplo, *Smeringurus mesaensis* (Stahnke, 1957), anteriormente chamado *Paruroctonus mesaensis,* é a espécie mais abundante de escorpião na região desértica do Coachella Valley, California e sua abundância é significativamente correlacionada com a disponibilidade de recursos alimentares (POLIS; MCCORMICK, 1986). Similarmente, na Caatinga, bioma exclusivamente brasileiro, maior atividade de escorpiões foi registrada durante a estação chuvosa (ARAÚJO et al., 2010), período de maior disponibilidade de recurso alimentar nesse bioma (WOLDA, 1988; WHITFORD, 1996).

Por outro lado, em florestas tropicais, a abundância de presas também está sujeita a flutuações, particularmente influenciadas pelas variações climáticas sazonais, as quais alteram a estrutura do ambiente (WOLDA, 1978, 1988). Pequenos insetos e aracnídeos relativamente sedentários são bastante sensíveis às variações na heterogeneidade do ambiente (DENIS et al., 1998). Recentemente Torode et al. (2016) chamaram a atenção para o efeito das mudanças climáticas sobre o padrão de precipitação anual, ocasionando períodos prolongados de seca a chuvas extremas. No estudo realizado por esses autores, foi registrada alta sensibilidade dos herbívoros sugadores às mudanças de precipitação, com maior abundância desses animais em períodos secos de verão, sendo o maior responsável pelo aumento da abundância absoluta de artrópodes nessa estação e, por isso, havendo potencial para alteração na cadeia alimentar dos invertebrados de níveis tróficos mais altos. Assim, espera-se que predadores que se alimentam desses herbívoros sejam mais abundantes na estação em que há maior disponibilidade deles (WOLDA, 1978).

A maioria dos estudos que investiga a correlação entre a abundância de escorpiões e a presas tem sido realizada em áreas de clima árido com fortes variações climáticas sazonais (POLIS; MCCORMICK, 1986; ARAÚJO et al., 2010), havendo uma lacuna de informações sobre essas relações em florestas tropicais úmidas onde as variações sazonais são fracas. Na Floresta atlântica brasileira, *T. pusillus* e *A. mauryi* têm maior abundância durante o período seco (DIAS et al., 2006; LIRA et al., 2013) e Lira et al. (2013) sugerem que essa abundância poderia estar relacionada ao aumento de atividade durante o período de maior abundância de presas nesses locais. Por isso, estudos fenológicos são importantes não somente para levantar informações de oscilações populacionais e de comunidades, mas também para elucidar como a sazonalidade influencia as espécies, seja diretamente ou através do efeito sobre os recursos que utilizam. Alguns desses estudos têm sido realizados sobre aracnídeos na região Neotropical (ADIS et al., 2001; GONZALEZ et al., 2014; PAGOTI; WILLEMART, 2015; RODRIGUES et al., 2015), incluindo alguns estudos sobre escorpiões (MACHADO; VASCONCELLOS-NETO, 2000; DIAS et al., 2006; YAMAGUTI; PINTO-DA-ROCHA, 2006).

A disponibilidade de recursos alimentares e as variações sazonais climáticas também podem ter forte influência na determinação do período reprodutivo dos escorpiões, uma vez que as fêmeas precisam alocar reservas nutritivas para a produção dos filhotes pós-copulação (LOURENÇO et al., 1996). Além disso, nesse período, os machos se tornam mais ativos, saindo à procura das fêmeas para acasalamento, o que eleva seu custo metabólico e a necessidade de mais recursos alimentares (POLIS, 1990). Esse comportamento dos machos tem sido considerado em estudos de campo que visam determinar o período reprodutivo dos escorpiões (POLIS; FARLEY, 1979ª; YAMAGUTI; PINTO-DA-ROCHA, 2006; CALA-RIQUELME; COLOMBO, 2011). Nesse período os machos utilizam o pécten à procura dos sinais químicos deixados pelas fêmeas, seguindo-os num comportamento de trilha até o encontro dela e iniciando o comportamento copulatório (GAFFIN; BROWNELL, 2001; MELVILLE et al., 2003; MILLER; FORMANOWICZ, 2011). Ainda, o aumento da atividade de juvenis tem sido uma evidência complementar na determinação do período reprodutivo é o aparecimento dos filhotes. No entanto, nesse caso, é necessário se conhecer o período gestacional da fêmea. O aumento do número de filhotes de segundo instar do escorpião de buraco *Smeringurus mesaensis* foi associado a um pico das presas disponíveis que ocorreu durante a gestação das fêmeas, o qual teria acelerado o crescimento embriônico de suas progênies (POLIS & FARLEY, 1979b).

Dada a importância de escorpiões como predadores de uma ampla variedade de presas e sua distribuição em todo o mundo, com exceção do Ártico e Antártica (POLIS, 1990), é importante compreender as relações top-down e bottom-up desses organismos em florestas tropicais úmidas, nas quais há maior diversidade de presas e menor efeito da sazonalidade sobre os recursos disponíveis.

2.3 *Tityus pusillus* Pocock, 1893 e *Ananteris mauryi* Lourenço, 1982 (Scorpiones: Buthidae).

Os escorpiões são um grupo ancestral de aracnídeos que possui, hoje, 2.349 espécies descritas (REIN, 2017). Podem ser, grosseiramente, divididos em escorpiões de solo e de vegetação, neste último estão inclusos os escorpiões que vivem em vegetação morta, como os que habitam a serapilheira (POLIS, 1990).

Tityus pusillus e *Ananteris mauryi* pertencem à família Buthidae, a maior e mais amplamente distribuída família de escorpiões do mundo (SISSOM, 1990). No território brasileiro, *T. pusillus* é encontrado nos estados da Bahia, Pernambuco, Piauí (BRAZIL; PORTO, 2010) e Sergipe (DIAS et al., 2006). Além desses estados, *A. mauryi* ocorre também no Rio Grande do Norte (BRAZIL; PORTO, 2010). *Tityus pusillus* e *A. mauryi* têm uma coloração amarela variegada com manchas escuras ao longo do corpo (LOURENÇO, 2002) (Figura 2), que pode estar relacionada à camuflagem dessas espécies dentro do ambiente escuro que vivem na serapilheira (LOURENÇO; CLOUDSLEY-THOMPSON, 1996; LIRA et al., 2016b). *Tityus pusillus* tem entre 3,3 a 3,6 mm de comprimento do prosoma (ALBUQUERQUE; LIRA, 2016), enquanto *A. mauryi* tem 2,6 mm (LOURENÇO, 1982). Também há dimorfismo sexual em ambas as espécies, com as fêmeas sendo maiores que os machos (ALBUQUERQUE; LIRA, 2016; Observação pessoal para *A. mauryi*). Esses escorpiões coabitam a serapilheira na Floresta Atlântica brasileira (DIAS et al., 2006; LIRA et al., 2013) sendo as espécies de escorpiões mais abundantes nesses locais, principalmente na estação seca (DIAS et al., 2006; LIRA et al., 2013). Apesar disso, *T. pusillus* é reportado frequentemente com maior abundância que *A. mauryi* (LIRA et al., 2013; 2015). Embora uma razão sexual 1:1 tenha sido descrita para *A. mauryi* por Dias et al. (2006) na Mata do Buraquinho (Paraíba), mais recentemente Lira (2014) reportou maior abundância de machos para essa espécie em Pernambuco. Esse mesmo autor registrou que as populações de *T. pusillus* possuem maior número de fêmeas comparado aos machos. Contudo, mecanismos que optimizam a reprodução foram evoluíram nessa espécie, como a iteroparidade e a maturidade sexual acelerada nos machos (ALBUQUERQUE & LIRA, 2016). O desenvolvimento sexual mais acelerados nos machos, aumenta as chances de acasalamento, enquanto na iteroparidade as fêmeas geram mais de uma ninhada (registradas até três) através de uma única inseminação devido a estocagem de sêmen estocado após a cópula. Isso permite a geração de novas proles, mesmo quando o período não favorece o encontro com machos. Contrariamente, não há estudos ontogênicos sobre *A. mauryi*, havendo apenas alguns trabalhos desse tipo para o gênero

Ananteris que descrevem o tamanho e o número de filhotes das espécies analisadas (LOURENÇO; CUELLAR, 1999; OUTEDA-JORGE et al., 2009).

Figura 2. Espécimes fêmeas adultos de (a) *Tityus pusillus* Pocock, 1893 e (b) *Ananteris mauryi* Lourenço, 1982.

Fonte: João Regueira.

Tityus pusillus e *A. mauryi* apresentam hábitos de caça distintos e utilizam diferentemente as camadas da serapilheira. *T. pusillus* é um escorpião sedentário, que fica em postura de senta-e-espera na camada superior da serapilheira, onde é mais frequente, aguardando o encontro com a presa (LIRA; DESOUZA, 2014; LIRA et al., 2013; 2015). Ao contrário, *A. mauryi* caça ativamente suas presas no espaço intersticial das folhas, sendo mais ativo na camada inferior da serapilheira (LIRA et al., 2013; 2015), onde há presas menores e a complexidade do habitat permite evitar predação intraguilda (SCHMIDT; RYPSTRA, 2010; KALINKAT et al., 2013; LIRA et al. 2017).

Os escorpiões do gênero *Ananteris* são capazes de realizar autotomia, podendo partir, voluntariamente, seu metassoma nas articulações entre os segmentos I e II, II e III ou III e IV, escapando do predador enquanto seu metassoma fragmentado mantém-se movendo sozinho em movimentos de ferroadas (MATTONI et al., 2015). A autotomia já foi registrada para *A. mauryi* (LIRA et al., 2014) e ao menos 15 outras espécies de *Ananteris* (MATTONI et al., 2015), sendo hipotetizada como uma sinapomorfia do gênero por Mattoni et al. (2015). Além disso, os Ananterinae têm sido apontados como escorpiões dependentes de umidade (LOURENÇO, 2005; LOURENÇO, 2015). Apesar do uso espacial distinto da serapilheira e da autotomia, o tamanho pequeno de *A. mauryi* em relação a *T. pusillus* pode ser desvantajoso em suas interações antagonistas com esse competidor intraguilda, o qual já foi registrado predando *A. mauryi* em um fragmento de Floresta Atlântica brasileira (LIRA et al., 2017).

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3 OBJETIVOS

3.1 Geral

Avaliar a influência da fragmentação florestal em parâmetros populacionais de *T. pusillus* e *A. mauryi* e aspectos fenológicos da relação predador-presa em um fragmento de Floresta Atlântica.

3.2 Específicos

1. Determinar a atividade de superfície de *T. pusillus* e *A. mauryi* ao longo de um gradiente espaço-temporal em um fragmento de Floresta Atlântica.

2. Relacionar a distribuição com a heterogeneidade do micro-habitat (estrutura da serapilheira) e possíveis presas (aranhas e insetos) encontradas no gradiente borda-interior

3. Avaliar como a disponibilidade de presas e regime pluviométrico se relacionam com o período reprodutivo de *T. pusillus* e *A. mauryi*.

4 HIPÓTESES

1. *T. pusillus* e *A. mauryi* apresentarão maior abundância no interior do fragmento, onde ocorrerá maior disponibilidade de abrigo e de presas em decorrência do efeito de borda.

2. *Tityus pusillus* e *A. mauryi* que devem ser mais abundantes em micro-habitats mais complexos como o interior da floresta, que possui maior disponibilidade de recursos alimentares (presas) e de exploração (estrutura do habitat).

3. O período reprodutivo de *T. pusillus* e *A. mauryi* ocorre associado ao período com maior disponibilidade alimentar que suprirá os custos energéticos para mobilidade dos machos, assim como servirá de nutrição para as fêmeas que ficarão gestantes.

5 CAPÍTULO – Distinct edge effect and reproductive period of sympatric litter-dwelling scorpions (Arachnida: Scorpiones) in a Brazilian Atlantic forest

Este capítulo contém o artigo intitulado acima a ser submetido para publicação no periódico científico Zoology.

Distinct edge effects and reproductive periods of sympatric litter-dwelling scorpions (Arachnida: Scorpiones) in a Brazilian Atlantic forest

Welton Dionisio-da-Silva[1]*, André Felipe de Araujo Lira[1], Cleide Maria Ribeiro de Albuquerque[1].

[1]Programa de Pós-graduação em Biologia Animal, Departamento de Zoologia, Universidade Federal de Pernambuco, UFPE, Rua Prof, Moraes Rego S/N, Cidade Universitária, Recife, Pernambuco, CEP 50670-420, Recife, PE, Brazil.

*Corresponding Author: weltonxdc@gmail.com

Highlights

- Microhabitat exploitation by scorpions influences their persistence in forest edges.
- Spatial and temporal variations in prey abundance have no effect on surface activity or reproductive period of litter-dwelling scorpions of the Atlantic rainforest.
- Intraguild competitors may have non-overlapping reproductive periods.

Abstract

Edge effects have drastically affected species living in tropical forests. However, understanding how species respond to edge effects remains a challenge, due to the many factors involved and the different ways each species responds to them. Here, we analyzed how surface activity of two sympatric scorpion species (*Tityus pusillus* and *Ananteris mauryi*) and their potential prey varied as a function of microhabitat changes (litter depth, dry mass, and leaf shape) from edge to the interior forest habitats. We further analyzed the contribution of potential prey to scorpion surface activity and reproductive periods. Data were collected monthly at three 300-m² transects/site at distances of 10, 100, and 200 m from the forest edge in a fragment of the Atlantic forest in northeast Brazil, between April 2016 and March 2017. Scorpions responded differentially to edge effects, with surface activity of the *A. mauryi* being similar along the edge-interior gradient, whereas *T. pusillus* had a higher surface acitivty in the interior. Because *T. pusillus* inhabits the top layer of the leaf litter, this species is likely to be more influenced by edge effects. In contrast, being a humicolous scorpion and inhabiting the bottom-layers of leaf litter, *A. mauryi* would not be influenced by edge effects as much as *T. pusillus*. The reproductive period also was distinct between the two species, with *T. pusillus* reproducing in the dry season and *A. mauryi* in the rainy season. The oscillation in the abundance of different groups of prey at different periods maintained the overall prey abundance at a relatively constant level throughout the year, mitigating the effects of prey availability on the surface activity and reproductive period of the scorpions. These results suggest that microhabitat exploitation is a key factor to sustain litter-dwelling scorpions in forest remnants and that *T. pusillus* can be a biological indicator of edge effects.

Keywords: Microhabitat effect; Prey abundance; Arachnids; Phenology.

Introduction

Anthropogenic activities such as agriculture, logging, and urbanization have caused habitat loss and fragmentation in most tropical forests, drastically increasing the quantity of margins in forest remnants (Murcia, 1995; Morellato and Haddad, 2000; Geist and Lambin, 2002; Ewers and Didham, 2006). Consequently, vegetation in forest margins become more exposed to external climatic effects, creating differences in microenvironments situated between the forest margin and interior. Such situations result in habitat loss for many species, negatively impacting biodiversity and biomass (Ewers and Banks-Leite, 2013; Magnago et al., 2015), and producing a more attenuated edge effect in the interior, compared to the margin of the forests (Ewers and Banks-Leite, 2013).

Habitat disturbance not only alters ecosystem structure, but also can impact forest ecological processes, such as litter production (Riutta et al., 2012, Hastwell and Morris, 2013). For instance, fast leaf replacement in vegetation at the margin results in a deeper leaf-litter at forest edges than in forest interiors (Laurance et al., 2002). A large number of invertebrates, particularly arthropods, live in leaf litter where they play an important role in forest maintenance contributing to nutrient cycling, carbon content, and are important for forest restoration (Cole et al., 2016) and as food resources for other forest animals (Moore et al., 1988, Wardle et al., 2002; Jouquet et al., 2006; Kattan et al., 2006; David, 2014). Distribution and abundance of leaf-litter arthropods between the forest edge and its interior generally depend on habitat heterogeneity along the gradient, providing different types of shelters and nutrient resources (Stevenson and Dindal, 1982; Silva et al., 2011a; Podgaiski and Rodrigues 2017).

In this context, many studies emphasize the role of leaf shapes in providing shelter and creating favorable physical conditions for foraging activities for litter-dwelling arthropods (Stevenson and Dindal, 1982; Uetz, 1991; Silva et al., 2011a). For instance, leaf litter composed of curled instead of flat leaves, provides better habitat complexity for the spider *Enoplognatha ovata* Clerck, 1757, to build three-dimensional webs and retreats, favoring a higher density of this species in this environment (Stevenson and Dindal, 1982). Leaf shape diversity also was positively related with the density of ant species in edge and interior plots of forest in a remnant of the Brazilian Atlantic forest (Silva et al., 2011a). The accumulation of leaves and leaf morphotypes meant there was increased structural heterogeneity, reduction of desiccation risk and an increase in the number of prey available to ants (Silva et al., 2011a). In a managed landscape of *Pinus* trees in southern Brazil, the abundance of web-building and hunting spiders was positively correlated with greater leaf-litter complexity (pine needles and native broadleaves with different shapes) and not positively correlated with simple leaf-litter complexity (only pine needles) (Podgaiski and Rodrigues, 2017).

Litter depth and dry mass are other factors that have a considerable influence on arthropod community composition and abundance in tropical forests (Burghouts et al. 1992, Yang et al. 2007, Sayer et al., 2010; Lira et al. 2016). Studies in a tropical forest in Panama (Sayer et al., 2010) have shown clear differences in arthropod community composition and abundance related to forest floor depth, with an increase in Arachnida at greater litter depths. Deeper leaf litter provides more habitat space (Uetz, 1979) and refugia from predators (Karban et al., 2013; 2015). Despite such differences, species respond to edges in their own particular way, even those species inhabiting the same forest margin have particular affinities with it (e.g. Magura, 2002). Magura (2002) found that four carabid beetles, *Abax ovalis* (Duftschmid, 1812), *Abax carinatus* (Duftschmid, 1812), *Aptinus bombarda* (Illiger, 1800), and *Harpalus latus* (Linnaeus, 1758), whose were not related with the cover of the leaf litter were more abundant in the forest edge, while *Pterostichus burmeisteri* Heer, 1838, that was positively related with leaf litter, inhabits both forest interior and edge.. Thus, understanding how changes in leaf-litter complexity across an edge gradient affect these invertebrates may be essential to understanding how fragmentation contributes to the establishment of litter-dwelling arthropods and their contribution to the forest ecosystem.

Scorpions are predatory arthropods largely distributed throughout the world with the exception of Arctic and Antarctic (Polis, 1990). Although many species inhabit tropical rainforests, in our literature review, edge effect on scorpion was only investigated in *Cercophonius squama* (Gervais, 1844) in an inner zone of a hardwood forest dominated by *Eucalyptus* surrounding by an outer zone of a clear area of softwood *(Pinus radiata)* plantation in Australia (Margules et al., 1994). According to these authors, no variation in scorpion abundance was found between both zones. However, no data has been collected on edge effects on scorpions in tropical rainforest with distinct successional stages and neither data on scorpions living in leaf litter.

. In the Brazilian Atlantic forest, *Tityus pusillus* Pocock, 1893 and *Ananteris mauryi* Lourenço, 1982 are two sympatric scorpion species in the leaf litter (Lira et al. 2013). Therefore, these scorpions are good organisms to study the effects of microenvironmental changes caused by edge effects in species with slightly distinct habitat requirements. *Tityus pusillus*, an ambush predator that inhabits the top layer of litter and their abundance is positively correlated with dry mass of leaf litter (Lira et al. 2013). In contrast, the abundance of *A. mauryi*, an active forager predominantly found in the bottom of the leaf litter layer, is not correlated with any leaf litter structures measured in previous studies (Lira et al., 2013). Yet, such as other *Ananteris, A. mauryi* is a humiculous scorpion (Lourenço, 2005; Lourenço, 2012, Lira et al. 2018). Nevertheless, these studies did not consider differences in litter structure (dry mass, depth and foliar shape) along margin-interior gradients as a possible determinant of the distribution and surface activity of these species.

Many other ground-dwelling arthropods that can be used as prey by scorpions are affected by habitat heterogeneity, both in terms of occurrence and abundance, which in turn can contribute to oscillations in the number of scorpions and their surface activity (Warburg and Polis, 1990). A clear positive relationship between potential prey abundance and the surface activity of the desert scorpion, *Smeringurus* (formerly *Paruroctonus*) *mesaensis* (Stahnke, 1957) was observed by Polis and McCormick (1986). Similarly, in the Caatinga of northeastern, Brazil, Araújo et al. (2010) found more surface activity of scorpions in the wet season. These authors suggested that the increase in abundance of scorpions during this period was related to the increase in reproductive activity, reaching its maximum when there are abundant food resources. All these studies have been performed in arid environments with a paucity of information about predator-prey relationships of scorpions in tropical rainforests such as Atlantic forest a biome with high biodiversity (Mittermeier et al., 2004). Nevertheless, Lira et al. (2013) suggested that the increase in abundance of *T. pusillus* and *A. mauryi* in the dry season could be related to higher prey availability, indicating the need for additional research in this regard.

Higher surface activity of adult male scorpions in search of females during the reproductive period (Polis and Farley, 1979; Melville et al., 2003) may contribute to misleading results in studies on the abundance of these animals. Mature males leave their shelters and move more frequently on the surface during the mating season searching for mature females (Polis, 1990). The reproductive period varies among species and in many scorpions it is related to warm, wet periods (Peretti, 1997; Machado and Vasconcellos-Neto, 2000, Yamaguti and Pinto-da-Rocha, 2006; Cala-Riquelme and Colombo, 2011) similar to what occurs in the Argentinean species *Thestylus aurantiurus* Yamaguti & Pinto-da-Rocha 2003 (Yamaguti and Pinto-da-Rocha, 2006). The population of *Th. aurantiurus* in the Parque Estadual Serra da Cantareira has a reproductive period from September to November, months with high temperatures and precipitation (Yamaguti and Pinto-da-Rocha, 2006). In contrast, the South American scorpion

Tityus bahiensis (Perty, 1833) does not have a well-defined reproductive period and has similar reproductive activity throughout the year (Matthiesen, 1968).

In this study, we performed a one-year investigation with *T. pusillus* and *A. mauryi* populations in order to evaluate how available resources (habitat structure and food) could affect them along an edge-interior gradient in a fragment of tropical rainforest in Brazil and to determine the reproductive period of them. Our main goals were to: (1) assess the extent of spatial variations in surface activity relative to habitat complexity and availability of resources in the leaf litter (depth, dry mass, leaf shape and prey abundance) along an edge-interior gradient in both scorpion species; (2) evaluate surface activity of males as an indicator of the reproductive period; (3) estimate the relative contribution of overall prey abundance and precipitation to the reproductive period of each scorpion species. We expected: (1) a greater surface activity of scorpions in forest interior, where edge effects are lower or absent, due to distinct habitat complexity along the gradient; (2) higher male surface activity searching for females in the dry season for *T. pusillus* when prey availability will be also greater and in the wet season for *A. mauryi* because they are moisture dependent; (3) male scorpion activity to be positively associated with prey abundance for both species and negatively associated with rain regime for *T. pusillus* and positively for *A. mauryi.*

Materials and methods

Study area

Field study was performed into a semideciduous secondary-growth Atlantic forest in northeastern Brazil (07°50′00″S–35°06′00″W – 7324 ha). Since 1944, the remnant has been a military area, Campo de Instrução Marechal Newton Cavalcante (CIMNC), that was originally built on a sugar plantation area inserted in the forest fragment. Since then, it has undergone processes of natural restoration, and currently consists of a mosaic of forested areas of different successional stages (Guimarães 2008, Lucena 2009). Vegetation in the study area is mainly composed of pioneer trees and a low density of epiphytes. Exotic plants, such as dendê (*Elaeis guineensis*), olive (*Syzygium cumini*), mango (*Mangifera indica*) and jack (*Artocarpus heterophyllus*), are also found in this environment (Lucena 2009). The local climate is tropical humid and the rain season is between February and September. (Beltrão et al. 2005). The annual mean precipitation is 1,856 mm and annual mean temperature of 25.5º C (CLIMATE-DATA ORG, 2018).

Sample Collection

All collections – scorpions, potential prey, and leaf litter have been performed monthly between April 2016 and March 2017. Three plots were established along an edge-interior gradient of forest (10, 100 and 200 m of edge distance). In each plot was distributed three transects (30 m each, spaced 20 m apart from each other), totalizing nine transects/month. To avoid pseudo replication, every month treatments were performed at different sites (100 m apart from each other). Scorpions were actively collected, between 19:00 h and 22:00 h during the new moon phase, by four collectors with UV flashlights during 1 h sampling periods per transect. Scorpions were identified to the species level and sex was determined (except juveniles) following Lourenço (2002). The surface activities of *T. pusillus* and *A. mauryi* were considered the sum of all specimens collected of these species per month or per site. The active collection of the scorpion allow us to measure the surface activity that is an indicative of abundance and foraging activities related with predation and reproductive periods.

Microhabitat characterization was based on three traits of leaf-litter structure: depth, dry mass, and leaf shape (flat or curled leaves) according to Lira et al. (2015) and Stevenson and Dindal (1982). Litter depth was estimated as the average of the height of the four corners of three 25-cm² quadrats randomly established at each 30 m transect. After this procedure, the leaves that composed the leaf litter were classified according to leaf shape (flat or curled leaves) and counted, using an aliquot of 150 leaves/transect. Only leaves presenting as at least 50% of their full size were considered in these analyses. After this, total leaf litter in each quadrat was collected and dried in an oven at 50 °C for 24 h and then samples were weighed using an analytical balance to measure dry mass.

Before the drying procedure, leaf litter collected in the quadrats mentioned above was sifted in a strainer of 3 cm mesh and the invertebrates found were collected for identification to order. In addition, invertebrates also were collected using pitfall traps, containing 70% ethanol and drops of detergent to break the surface tension, placed at 10 m apart from each other along each transect. The traps stayed in the field for five days. Collected specimens were identified, to order using the identification key of Constantino (2012). All voucher specimens of arachnids were deposited in the collection at Coleção Aracnológica da Universidade Federal de Pernambuco and the insects were deposited in the collection at Coleção Entomológica da Universidade Federal de Pernambuco. Pluviometric data were obtained of the Agência Pernambucana de Águas e Clima (APAC, 2017).

Data analysis

All sample data were checked for normality and homoscedasticity and non-normal data were log transformed. Analysis of Variance (ANOVA – one way) was used to test if the abundance of scorpions, leaf litter structure (depth, dry mass and leaf shapes), and prey abundance (discriminated as total potential preys and as taxonomical groups) were different across the edge-interior gradient. When main effects were significant, a Least Significant Difference (LSD) post-hoc test was performed to compare individual differences between the groups analyzed. In addition, to the heteroscedastic and non-normal data (even after log transformation) were performed, respectively, an ANOVA Welch's test and a Kruskal-Wallis test with Dunn's post hoc tests.

A multiple correlation analysis was performed to evaluate the relationship between microhabitat traits (structure and potential prey abundance) throughout a covariance matrix. After this, we performed two stepwise regressions, excluding the collinear variables of the microhabitat, to evaluate: (1) the effect of microhabitat traits on surface activity of *T. pusillus* and (2) on *A. mauryi,* including months as a cofactor variable. Multiple regressions also were used to detect correlations between the monthly surface activity of males of *T. pusillus* and *A. mauryi* and monthly prey abundance and precipitation.

Months with higher surface activity of males were interpreted as the reproductive period. Because the gestation period for *T. pusillus* averages 60 days (unpublished data), months in which second instar scorpions (carapace mean size: 1.61 ± 0.19 mm, Mean ± SD) were more abundant, were taken to infer the months in which the females mated and therefore, reinforced our determinations of the reproductive period. All statistical analyses in this study were performed in BioEstat v 5.3 (Ayres et al. 2007).

Results

Surface activity of scorpions across an edge-interior gradient

In total, 1,497 scorpions were collected, from these 1,170 *T. pusillus* and 327 *A. mauryi*. Surface activity of *T. pusillus*, but not *A. mauryi*, was affected by edge distance. Surface activity of *T. pusillus* was three times lower at the edge than in the interior of the forest with a progressive increase towards the forest interior, corresponding to 15.1% (10 m), 32.9% (100 m), and 51.9% (200 m) of collections occurring from edge to interior (Fig. 1). ANOVA results showed an overall significant difference across the gradient ($F_{2,108} = 26.1146$; $P < 0.001$), with the residuals indicating differences between 10 m and 100 m (LSD-test, $t = 3.9010$; $P < 0.001$), 10 m and 200 m (LSD-test, $t = 7.2192$; $P < 0.001$) and 100 m and 200 m (LSD-test, $t = 3.3181$; $P < 0.001$) distances from the forest edge. In contrast, surface activity of *A. mauryi* was not affected by the edge, it was similar throughout the edge-interior gradient ($F_{2,108} = 0.052$; $P = 0.9493$), corresponding to 34.2% (10 m), 30.5% (100 m) and 35.1% (200 m).

The stepwise regressions indicate that the resources availability that better explained the variations in surface activity of the scorpions throughout the gradient was the dry mass of leaf litter for *T. pusillus* ($R^2 = 0.08$; $P = 0.0047$) and the prey availability for *A. mauryi* ($R^2 = 0.104$; $P = 0.0012$).

Microhabitat structure

The leaf litter structures depth and dry mass, but not leaf shapes (flat and curled leaves), changed along the gradient. Overall leaf-litter depth across the edge-interior gradient was significantly different ($F_{2,108} = 7.6049$; $P = 0.0012$), with the leaf-litter at a 10 m distance from the forest edge being significantly deeper (5.52 cm ± 2.44, Mean ± SD) than leaf-litter at 100 m (3.95 cm ± 1.58, Mean ± SD) (LSD-test, $t = 3.5367$; $P < 0.001$) and 200 m (4.02 cm ± 1.57, Mean ± SD) (LSD-test, $t = 3.1917$; $P < 0.05$) (Fig. 2A). Dry mass in the interior (200 m) was significantly lighter compared to the margin (10 m) (ANOVA Welch test: $F_{68.45,108} = 6.238$; $P = 0.00328$) (Dunn's test: $Z = 2.952$, $P = 0.0094$), but showed no other between-distance differences (10 m = 0.298 g ± 0.098; 100 m = 0.256 g ± 0.113; 200 m = 0.232 g ± 0.083; Mean ± SD) (Fig. 2B). A similar proportion of different leaf shapes was found along the gradient with flat leaves comprising 57.9%, 54.6%, and 54.2% of samples at 10 m, 100 m, and 200 m, respectively ($F_{2,108} = 0.692$; $P = 0.503$).

Prey availability

Overall, 2,688 potential prey specimens (arthropods adults) were analyzed (in terms of abundance). Flying prey (Diptera, Lepidoptera and flying Hymenoptera) and specimens with hard carapaces (Coleoptera, Diplopoda, Opiliones) were excluded from the analysis because the difficult for scorpions to feed on these types of organisms and not being part of their usual dietary regime. In the samples, there were 1,035 terrestrial Hymenoptera (Formicidae), 591 Araneae, 244 Hemiptera, 219 Orthoptera, 139 Archaeognatha, 118 Chilopoda, 98 Isoptera, 93 Blattaria, 84 Dermaptera, 54 Isopoda, and 13 Mantodea. Overall, total potential prey abundance was similar across the edge-interior gradient of the remnant. Except for Blattaria, which was negatively affected by the edge (Kruskal-Wallis: H: 10.723. df = 2, $P = 0.0047$), the leaf litter structure had no effect on potential prey abundance. Individuals from Blatodea were significantly less abundant at 10 m (mean ± SD: 0.91 ± 1.31) from the forest edge compared to individuals collected at distances of 100 m (3.75 ± 2.86; Z = 2.47, $P = 0.0012$) and 200 m from the forest edge (3.08 ± 2.39; Z = 3.05, $P = 0.002$).

Despite the overall similarity in prey abundance throughout the year, there was oscillation in the abundance of different groups between seasons, with declines in some orders and increases in others. During the dry season (October to January), Hemiptera, Chilopoda, Dermaptera, and Mantodea were more abundant, whereas Hymenoptera, Araneae, Orthoptera, Archaeognatha, Isoptera, Blattariaa, and Isopoda predominated during the wet season (Fig. 3). Prey abundance (total of prey or total amount of individual/order) showed no correlation with scorpion abundance along the edge-interior gradient. Monthly precipitation showed no correlation with the variation of prey group or male surface activity of *T. pusillus* and *A. mauryi*.

Reproductive period

Distinct reproductive periods were observed between *T. pusillus* and *A. mauryi*. Of all *T. pusillus* collected, 284 were juveniles and 886 were adults. From these, 27.31% were males and 72.69% were females (sex ratio ~1:2.67), with more females than males throughout the year (Fig. 4A). The reproductive period of *T. pusillus* was defined as October to January based on the number of males obtained in this period compared to other months. From the total collected males (*n* = 242), the majority (58.1%) were found in these months, particularly in November (*n* = 35) and January (*n* = 31) (Figs. 4A, 5). This period corresponds to dry season, with average rainfall of 25.47 ± 16.36 mm. Although juveniles were found during the year, most (57.74%) were registered from December to March, two months after the reproductive period, additional indication of the timing of reproductive period. In April had a decline in number of juveniles, therefore, the male adult scorpions do not had mating in February.

Adult *A. mauryi* comprised a sample of 272 specimens. From these, 43% were males and 57% were females (sex ratio ~1:1.32). Possibly due to their small size, no juveniles were found during field collections. Other cause could be the endogean behavior of their juveniles suggested by Lourenço (2012). The greater surface activity of males occurred between May to October, during the rainy period (average rainfall of 136.3 ± 180.5 mm), corresponding to 84.15% of the total of males (*n* = 101) found and with peak of activity in July (*n* = 23) (Figs. 4B and 5). Although overall annual precipitation does not have correlation with the male activity of the scorpions, the beginning of the reproductive period of *A. mauryi* corresponded to a peak of precipitation in May (491.8 mm) and ending at the lower precipitation value (10.4 mm) in October. Interestingly, the reproductive period of *T. pusillus*, started with the end of the rainy season (October) and extended until January (45.1 mm), ending of dry season.

Discussion

Our study investigated the effects of forest edges, resource availability and the reproductive period of two co-occurring scorpion species in Atlantic forests in Brazil. Our results suggest that there was a differential response to forest edges among scorpion species living in same micro-habitat and with same trophic habits (i.e., leaf litter and preys) along a habitat gradient (margin-forest interior). Although both *T. pusillus* and *A. mauryi* were able to colonize and persist on leaf litter, *T. pusillus* was less frequently observed in forest margins (negative edge effect), while the surface activity of *A. mauryi* did not change from the forest interior to the edge (no edge effect).

Distinct responses to edge effects observed between the two scorpion species, may be driven by behavioral differences associated with microhabitat exploitation. *Tityus pusillus* is a sit-and-wait predator, more active in the top layer of leaf litter, *A. mauryi* is more active in the bottom layer (Lira et al., 2013; 2015). Overall, bottom layers provide more humidity and environmental protection than top-layers because they are covered by other layers and constituted of higher organic matter decomposition (Sampaio et al., 1993), resulting in a more stable microclimate, which is ideal for humicolous scorpions such as *Ananteris* (Lourenço, 2005; Lourenço, 2012) and may have favored *A. mauryi* persistence on edge. Slightly similar to what occurs with *C. squama* in the study of Margules et al., although associated with wetter habitat, the scorpions were not affected by edge effect probably because their behavioral features associated with microhabitat exploitation. *Cercophonius squama* can dig burrows of different depth to be isolated of extreme environment conditions, furthermore this burrows also were covered by leaf litter of the *Eucalyptus* and *P. radiata* plantation, what also may help to grant a steady microclimate in its deeper layers. In contrast to *A. mauryi,* by inhabiting the top layer of litter, *T. pusillus* are more exposed to edge effects, in comparison to the interior of fragments, including an increase in light incidence, wind, and temperature (Saunders et al. 1991, Laurance et 2007). The present study found significant higher values of leaf litter depth and dry mass on the edge compared to of the forest interior, according to Laurance et al. (2002), which may provide more area of stable conditions for species that inhabit bottom litter layers similar to those described in other forests (Donoso et al., 2010; Sayer et al., 2010). Thus, the bottom layer of leaf-litter would aid *A. mauryi* in avoiding exposure to edge effects, besides providing a high-complexity microhabitat, helping to avoid predation (Schimidt and Rypstra, 2010). The bottom layer also has smaller prey (Polis and McCormick, 1986) suitable for small species of scorpions like *A. mauryi* (2.0–2.4 cm, data not shown). Variation in prey size in the leaf litter layers could also result in a differential preference in the type of prey between the two species of scorpions, a hypothesis that needs further investigations.

Prey abundance also plays a key role in overall surface activity and triggering the reproductive period of scorpions, mainly in species from arid regions, such as desert (*S. mesaensis*) (Polis and McCormick, 1986) and Caatinga biomes (Buthidae and Bothriuridae) (Araújo et al., 2010). However, in our study total potential prey did not affect abundance of *T. pusillus* and affected very few the abundance of *A. mauryi,* having no relationship with the reproductive period of the scorpions. The potential prey of *T. pusillus* and *A. mauryi* remained stable even with seasonal variations in climate. As generalist predators that feed on a large variety of insects and spiders (McCormick and Polis, 1990), the high biodiversity in the Atlantic forest and the absence of seasonal patterns in some arthropods (Duarte-Júnior and Schlindwein, 2005) could still result in enough food resources being available to these animals throughout the year. Furthermore, a more stable climate (temperature and rainfall amongst seasons) in the Atlantic forest compared to the climate in arid regions (Silva et al., 2011b) may have contributed to the different results found between the two biomes. In a similar way, the absence of seasonality in the abundance of Sphingidae was attributed to the local climatic stability, which would not affect the resource availability of these lepidopterans in the Atlantic forest (Silva et al., 2011b). The potential prey of *T. pusillus* and *A. mauryi* remained stable even with seasonal variations.

Tityus pusillus and *A. mauryi* had a clear difference in the reproductive periods, corresponding to dry period (*T. pusillus*) and wet season (*A. mauryi*). As a humicolous scorpion, reproduction in a more humid period would favor *A. mauryi* improving their survival in this period.

In a previous study, Lira et al. (2013) found greater abundance of *T. pusillus* in the dry period and their results could be related to the reproductive period of the populations previously studied by these authors in the same remnant as the present study. In another study, in the Atlantic forest remnant, Mata do Buraquinho, Paraíba, Brazil, Dias et al. (2006) found a higher abundance of male *A. mauryi* in the dry season, suggesting that dry season could be the reproductive period of this species. Two major differences from our study may account for our contrasting results. First, these authors collected the scorpions only one month in each the dry and wet seasons, while in our study, scorpions were collected throughout a 12-month period. Second, the sample size of our study was almost five times greater than in previous studies. Differential reproduction of *A. mauryi* may also represent a mechanism of avoiding predation during the period of higher activity of male of *T. pusillus* (in the dry season). Many species have evolved behaviors to avoid predation in the presence of their predators (Snyder and Wise, 2000; Okuyama, 2002). This strategy has been observed even between intraguild predators when one species is susceptible to predation by its intraguild competitor, which is a relationship documented in jumping spiders by Okuyama (2000). In an experimental study on jumping spiders (Salticidae), *Phidippus octopunctatus* reduced their foraging activity on *Drosophila melanogaster* in the presence of *Phidippus audax,* its intraguild predator. Yet, predation of *A. mauryi* by *T. pusillus* in Atlantic forests has already been registered (Lira et al., 2017). Therefore, it can be speculated that *A. mauryi* could sense the presence of *T. pusillus* and avoid the reproductive period of its intraguild predator, although more studies are needed to confirm this.

In conclusion, our results suggest that *T. pusillus* and *A. mauryi*, two scorpion species that compete for shared resources, are differentially affected by forest edges. Behavior particularity associated with distinct microhabitat exploration may favor persistence of *A. mauryi* at the forest edge, but not *T. pusillus*. The large population abundance and the decline in their surface activity near the forest edge allow them to be used as a biological indicator of edge effects. Furthermore, variations in the edge effect on leaf litter structure (particularly litter depth and dry mass) indirectly affected the persistence of scorpions by mitigating the effects on species with different microhabitat exploitation strategies. Although oscillations in specific prey abundance have been observed throughout the year (dry and wet seasons), this aspect had no influence on surface activity of the scorpions or reproductive periods, which may have been assuaged by the generalist food regime of scorpions. Because edge effects vary among species, studies focusing on species with similar resource requirements (habitat and prey) can improve our knowledge on edge effects.

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Figures (Zoology)

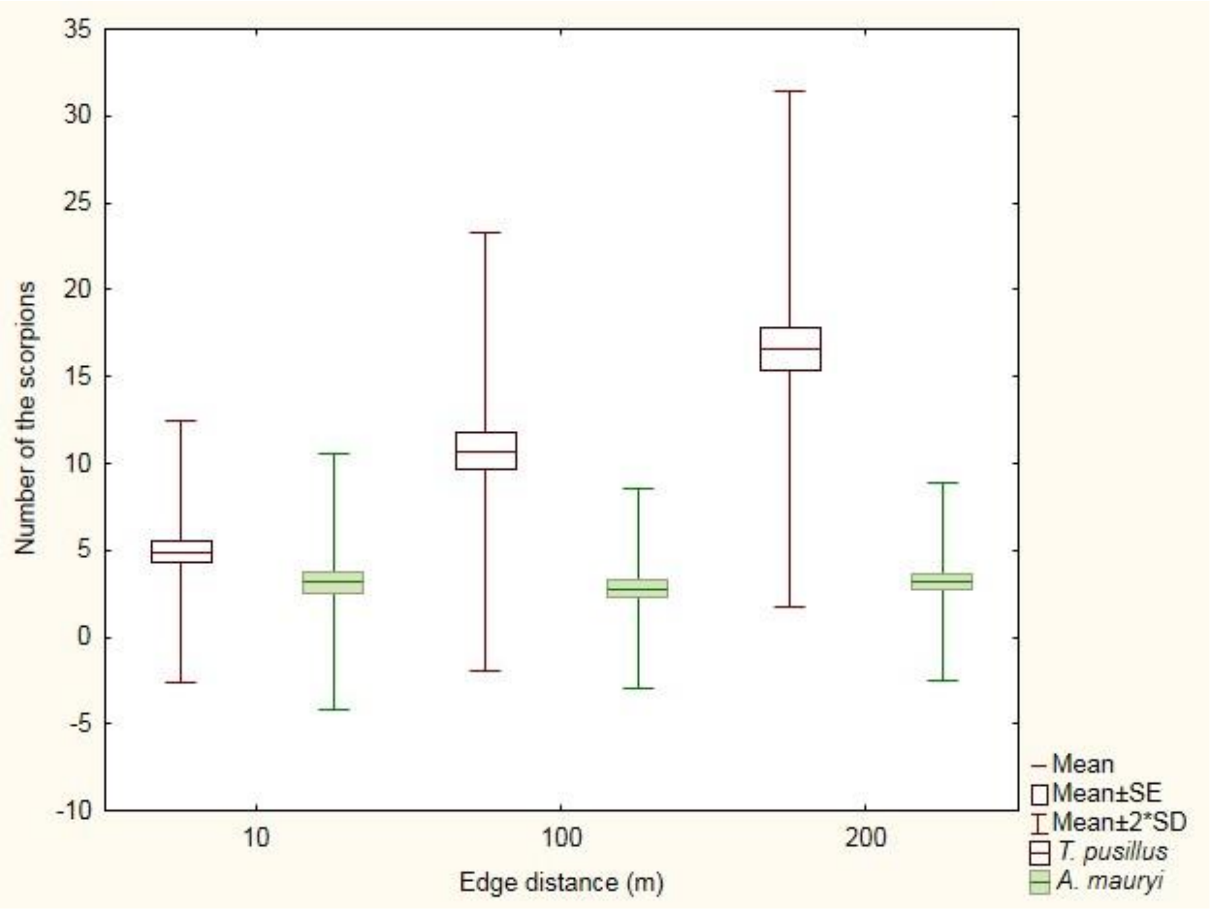

Fig. 1. Surface activity of *Tityus pusillus* Pocock, 1893 and *Ananteris mauryi* Lourenço, 1982 across the edge-interior gradient (10 m, 100 m and 200 m) in a fragment of the Atlantic forest in northeastern Brazil.

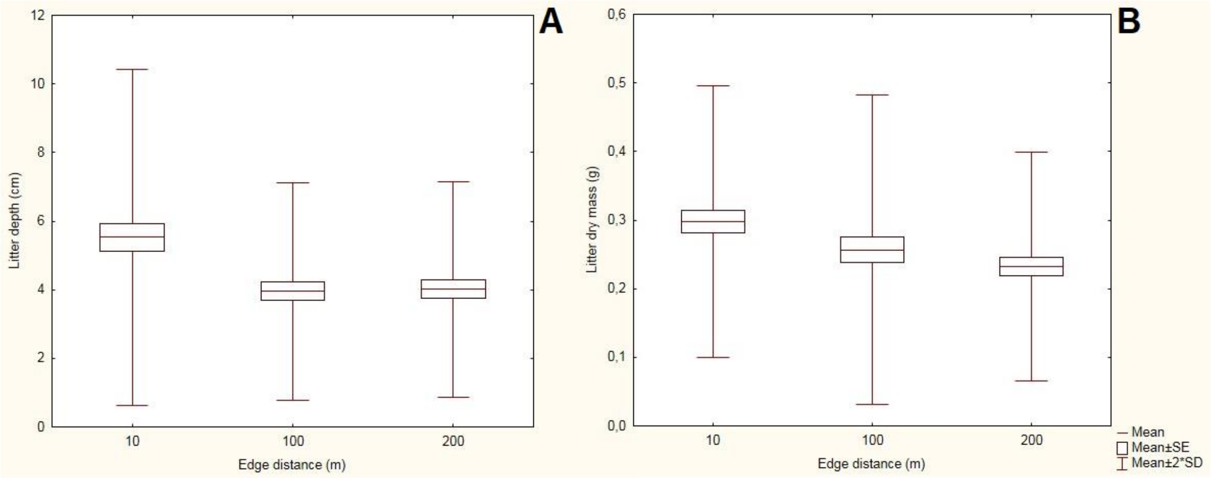

Fig. 2. Boxplots of the: (A) leaf-litter depth and (B) dry mass across the edge-interior gradient (10 m, 100 m, and 200 m) in a fragment of the Atlantic forest in northeastern Brazil.

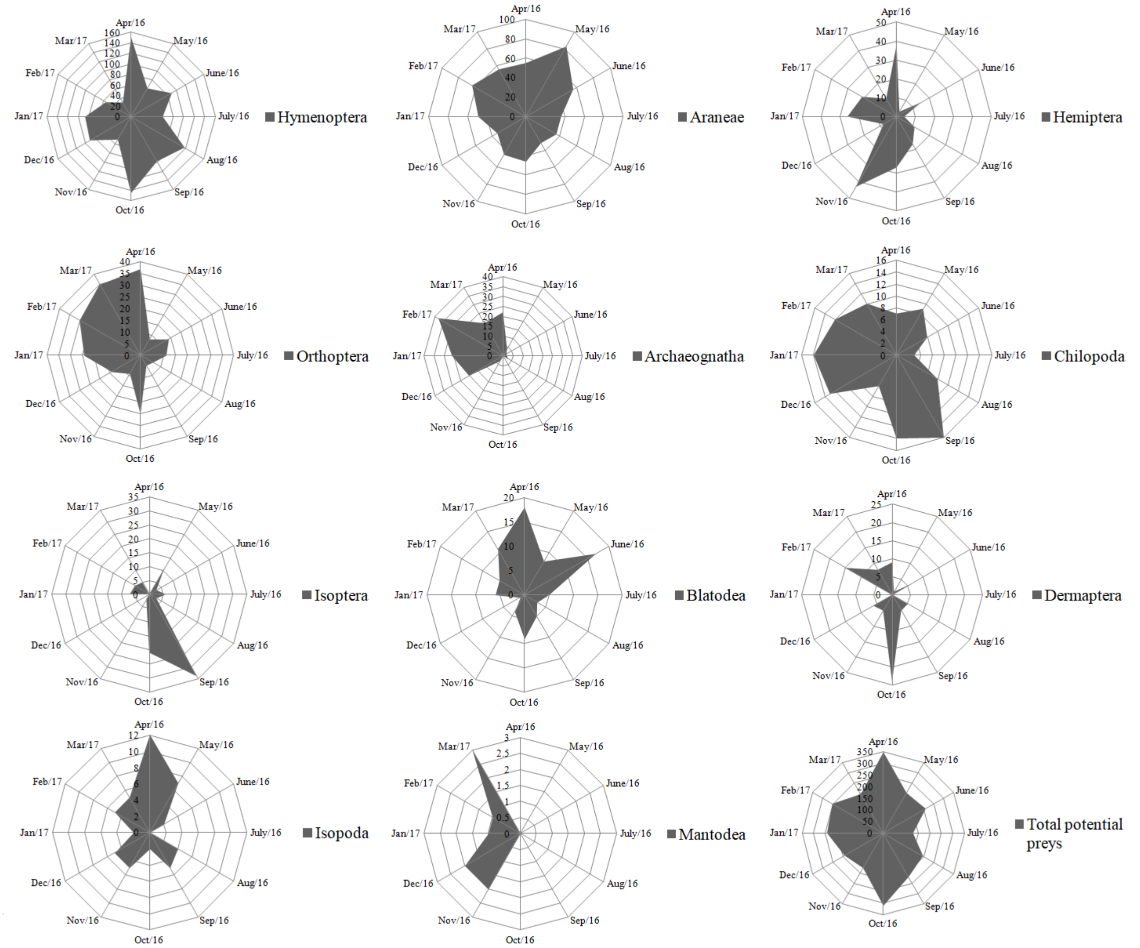

Fig. 3. Abundance variation of the potential prey orders and total potential prey between April 2016 and March 2017 in a fragment of the Atlantic forest in northeastern Brazil.

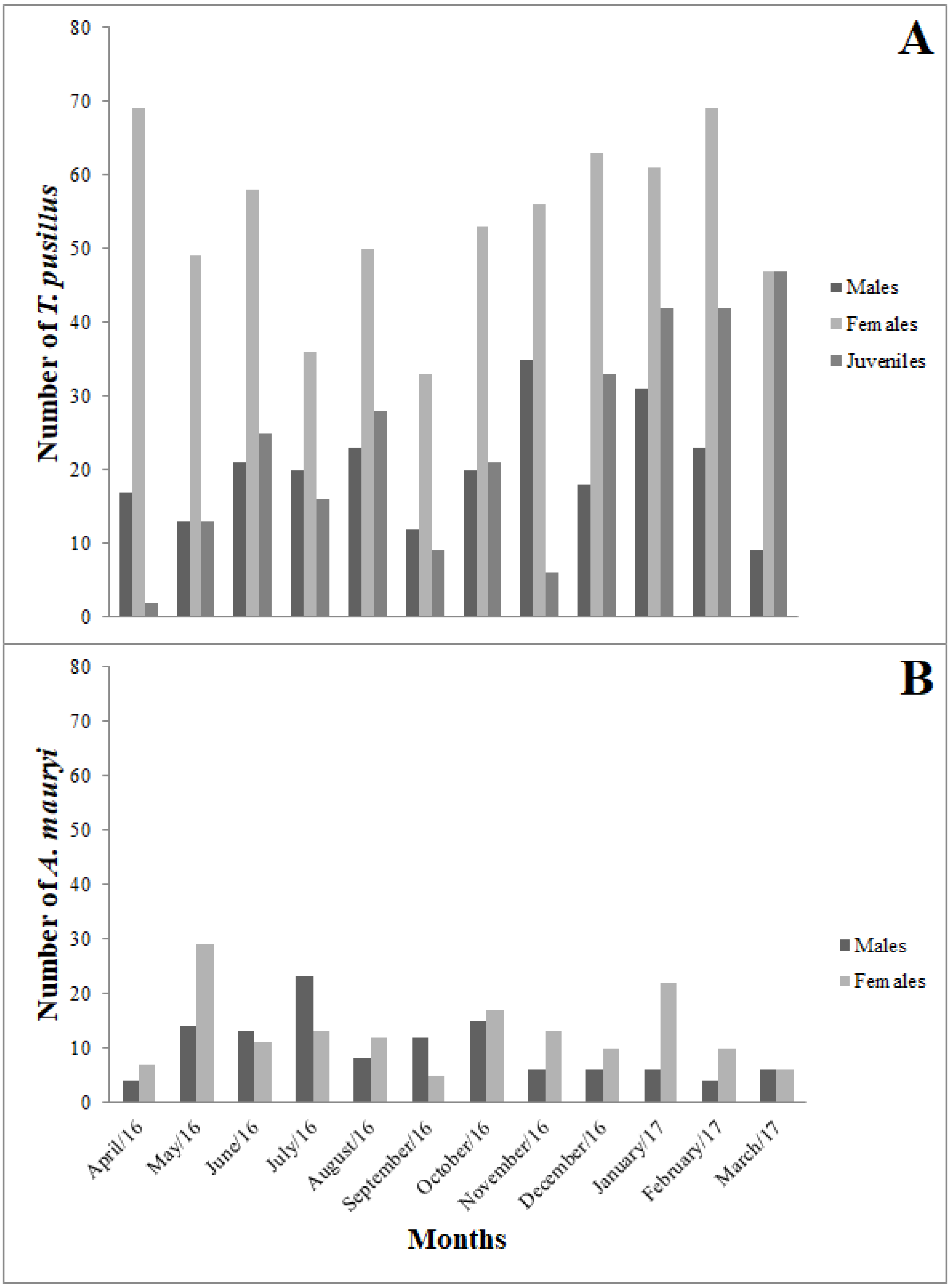

Fig. 4. Surface activity of (A) *Tityus pusillus* Pocock, 1893 and (B) *Ananteris mauryi* Lourenço, 1982, throughout the 12 months of observation (April 2016 to March 2017) in a fragment of the Atlantic forest in northeastern Brazil.

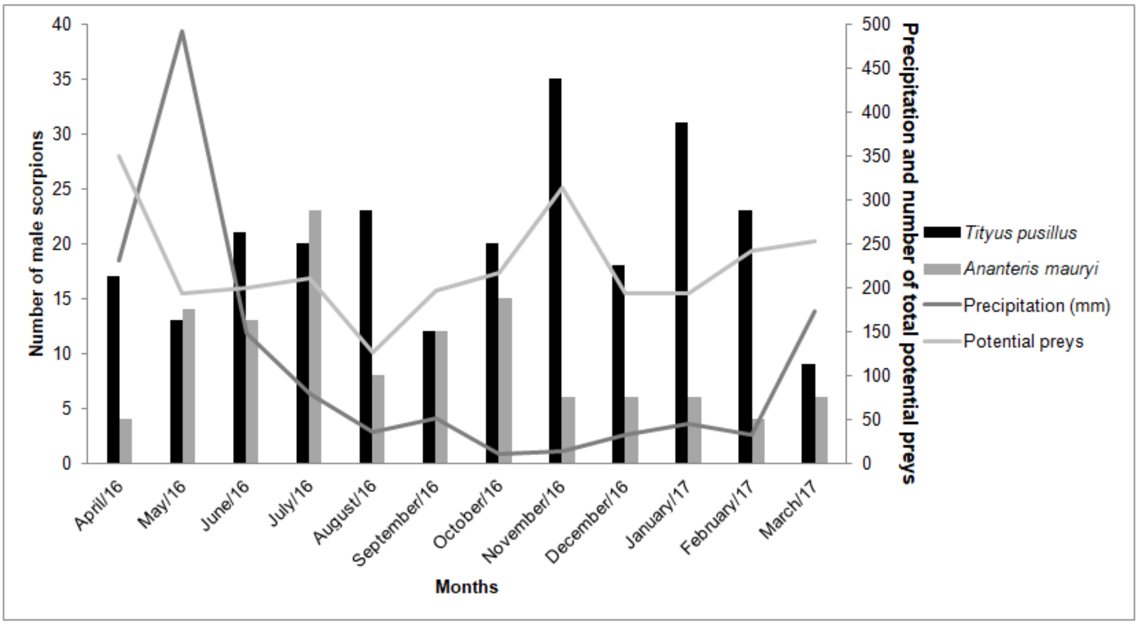

Fig. 5. Surface activity of males of *Tityus pusillus* and *Ananteris mauryi* and their potential prey and pluviometry in Campo de Instrução Marechal Newton Cavalcante between April 2016 and March 2017.

6 CONCLUSÕES

A distinta exploração de micro-habitat por *T. pusillus* e *A. mauryi*, conferem-lhes diferentes respostas ao efeito de borda. Por ser mais ativo na camada superior da serapilheira, *T. pusillus* é mais afetado pelas condições climáticas da borda, sendo mais abundante no interior da floresta. Enquanto *A. mauryi*, mais ativo na camada inferior da serapilheira (úmida), não é afetado pela borda. Além da abundância de *T. pusillus*, a estrutura da serapilheira também foi afetada pela borda, sendo muito mais pesada e profunda nas margens florestais, onde há maior produtividade primária e queda de folhas, do que no interior da floresta. Apesar disso, a estrutura da serapilheira não teve efeito direito sobre a abundância de *T. pusillus*, *A. mauryi* ou de suas presas potenciais. A disponibilidade de presas, não afetou a abundância, nem o período reprodutivo dos escorpiões, isso pode ter ocorrido devido às oscilações de abundância ao longo do ano entre as distintas ordens de presas potenciais dos escorpiões. Por serem generalistas, ainda que algumas presas tenham sua abundância reduzida, outras sem oscilações, podem ser utilizadas como alimento. Assim, o período reprodutivo dos escorpiões parece estar mais ligado às estações do ano, com o período de *T. pusillus* concentrado na estação seca e o de *A. mauryi* na estação chuvosa. A maior atividade reprodutiva de *A. mauryi* durante o período chuvoso pode ser vantajoso para essa espécie, cujo gênero é conhecido por possuir escorpiões umícolas. A diminuição da atividade de superfície dessa espécie coincide com o início do período reprodutivo de *T. pusillus*, competidor e predador intraguilda, parece ser um comportamento adaptativo do *A. mauryi* para evitar predação por *T. pusillus*.

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ANEXO

As normas da revista Zoology para a submissão do artigo do capítulo “Distinct edge effect and reproductive period of co-occurring litter-dwelling scorpions (Arachnida: Scorpiones) in a Brazilian Atlantic forest” podem ser encontradas no endereço eletrônico: https://www.elsevier.com/wps/find/journaldescription.cws_home/701811?generatepdf=true.