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COMO A PERDA DE COBERTURA FLORESTAL AFETA A ABUNDÂNCIA E AS CARACTERÍSTICAS CORPORAIS DE ESPÉCIES FLORESTAIS QUE HABITAM PAISAGENS URBANAS AMAZÔNICAS? UM ESTUDO DE CASO COM ROLA BOSTAS

GLENDA VANESSA DOS SANTOS BERNARDINO

Manaus, Amazonas

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ATA DA DEFESA PÚBLICA DA DISSERTAÇÃO DE MESTRADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA DO INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA.

Aos 12 dias do mês de Agosto do ano de 2022, às 15h00min, por videoconferência. Reuniu-se a Comissão Examinadora de Defesa Pública, composta pelos seguintes membros: a Dra. **Thamyrys Bezerra de Souza**, do Instituto Nacional da Mata Atlântica – INMA, a Dra. **Juliana Hipólito de Sousa**, da Universidade Federal da Bahia – UFBA, e o Dr. **Fredy Alexander Alvarado Roberto**, do Instituto Potosino de Investigação Científica e Tecnológica – IPICYT, tendo como suplentes o Dr. Igor Luis Kaefer, da Universidade Federal do Amazonas – UFAM, e o Dr. Sérgio Henrique Borges, da Universidade Federal do Amazonas – UFAM, sob a presidência do orientador, a fim de proceder à arguição pública do trabalho de DISSERTAÇÃO DE MESTRADO de **GLENDA VANESSA DOS SANTOS BERNARDINO**, intitulado: **"COMO A PERDA DE COBERTURA FLORESTAL AFETA A ABUNDÂNCIA E AS CARACTERÍSTICAS CORPORAIS DE ESPÉCIES FLORESTAIS QUE HABITAM PAISAGENS URBANAS AMAZÔNICAS? UM ESTUDO DE CASO COM ROLA-BOSTAS"**, orientada pelo Dr. Renato Portela Salomão, co-orientada pelo Dr. Paulo Estefano Dineli Bobrowiec, ambos do Instituto Nacional de Pesquisas da Amazônia – INPA e pela Dra. Luciana Iannuzzi, da Universidade Federal de Pernambuco – UFPE.

Após a exposição, o discente foi arguido oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final:

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Nada mais havendo, foi lavrada a presente ata, que, após lida e aprovada, foi assinada pelos membros da Comissão Examinadora.

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Sinopse:

Estudamos as características morfológicas de duas espécies de rola bostas (*Dichotomius boreus* e *Dichotomius quadrilobatus*) em seis cidades amazônicas. Avaliamos o efeito da estrutura da paisagem nas escalas do local e da cidade sobre a abundância, tamanho do corpo individual e comprimento relativo do chifre (dos machos) de rola bostas.

Palavras chaves: Crescimento urbano, conservação, floresta tropical úmida, Scarabaeinae, urbanização.

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RESUMO

A perda de cobertura florestal em paisagens urbanas altera as dinâmicas de recursos espaciais e alimentares, desafiando a manutenção de espécies florestais, que podem ter a sua condição e aptidão comprometidas. Os besouros rola bosta são sensíveis às mudanças na estrutura da vegetação e do uso da terra causadas por atividades antrópicas, processos que estão intrinsecamente relacionados com o estabelecimento e desenvolvimento das cidades. O objetivo deste estudo foi avaliar o efeito da estrutura da paisagem sobre a abundância e características morfológicas de duas espécies de besouros rola bosta (*Dichotomius boreus* e *Dichotomius quadrilobatus*) que habitam áreas florestais em paisagens urbanizadas na região amazônica. Realizamos o estudo em 38 paisagens localizadas em seis regiões urbanas na região central da Amazônia. Avaliamos o efeito da estrutura da paisagem, nas escalas do local e de cidade, sobre a abundância de besouros, tamanho do corpo individual e comprimento relativo do chifre dos machos. A escala local, paisagens com maior cobertura florestal apresentaram maiores abundância de rola bostas, bem como maiores comprimentos dos chifres de *D. boreus*. As cidades com maior quantidade de cobertura florestal apresentaram indivíduos maiores do que aquelas com menor cobertura florestal. Concluímos que áreas florestais em paisagens urbanas apresentam-se como habitat-chave para a manutenção das populações de rola bostas com uma relação marcante entre a quantidade de cobertura florestal na paisagem. A manutenção de populações saudáveis e abundantes de besouros nas paisagens urbanas amazônicas garante a persistência dos serviços ecossistêmicos prestados por estes organismos em ecossistemas urbanos.

ABSTRACT

The loss of forest cover in urban landscapes alters the dynamics of spatial and food resources, challenging the maintenance of forest species, which may have their condition and suitability compromised. Dung beetles are sensitive to changes in vegetation structure and land use caused by human activities, processes that are intrinsically related to the establishment and development of cities. The aim of this study was to evaluate the effect of landscape structure on the abundance and morphological characteristics of two species of dung beetle (*Dichotomius boreus* and *Dichotomius quadrilobatus*) that inhabit forested areas in urbanized landscapes in the Amazon region. We carried out the study in 38 landscapes located in six urban regions in the central region of the Amazon. We evaluated the effect of landscape structure, at the site and city scales, on beetle abundance, individual body size, and relative horn length of males. At the local scale, landscapes with greater forest cover showed greater abundance of dung beetles, as well as greater lengths of D. boreus horns. Cities with a greater amount of forest cover had larger individuals than those with less forest cover. We conclude that forested areas in urban landscapes are a key habitat for the maintenance of dung beetle populations with a strong relationship between the amount of forest cover in the landscape. The maintenance of healthy and abundant populations of beetles in urban Amazonian landscapes guarantees the persistence of ecosystem services provided by these organisms in urban ecosystems.

SUMÁRIO

INTRODUÇÃO GERAL

O rápido crescimento urbano nas últimas décadas compreende um dos principais fatores de perda de biodiversidade do Antropoceno (Batáry *et al.*, 2018; Dáttilo & MacGregor-Fors, 2021). Os centros urbanos impõem um grande desafio para a conservação do meio ambiente porque os moradores das cidades produzem uma pegada ecológica *per capita* muito maior do que as populações rurais (Martine *et al.*, 2008; Ahmed *et al.*, 2020; Hasan *et al.*, 2020). Durante o processo de urbanização, a perda e a fragmentação do habitat compõem duas importantes dinâmicas que são as principais ameaças para a biodiversidade nativa em paisagens urbanas (Fischer & Lindenmayer, 2007; Li *et al.*, 2017; Dadashpoor *et al.*, 2019; Reinmann *et al.*, 2020). O aumento da cobertura urbana apresenta novos desafios para indivíduos e populações que habitam manchas florestais imersas nas cidades (Mckinney, 2002; Bonier, 2012). Tais desafios podem resultar em diminuição da condição e aptidão individual (Giraudeau *et al.*, 2014; Salomão *et al.*, 2020a; Corsini *et al.*, 2021), prejudicando a manutenção de muitas espécies nativas nessas paisagens urbanas. As limitantes a biodiversidade imposta pelas cidades podem afetar diretamente o bem-estar das pessoas, pois cidades com maior biodiversidade são cidades mais saudáveis e com melhor qualidade de vida (Taylor & Hochuli, 2014; Carrus *et al.*, 2015; Marselle *et al.*, 2019). Para manter os ecossistemas urbanos estáveis e saudáveis, é fundamental entender como o contexto espacial das paisagens urbanas e fragmentos florestais urbanos funcionam como reservatórios de biodiversidade (Faeth *et al.*, 2011).

A distribuição espacial e o arranjo dos diferentes tipos de uso da terra (i.e., a estrutura da paisagem) têm uma estreita relação com a diversidade de espécies e suas características (Fahrig, 2005; Callaghan *et al.*, 2018; Palacio, 2020; Gaona *et al.*, 2021; Millard *et al.*, 2021). Do ponto de vista ecológico, uma das principais consequências da expansão espacial urbana é a diminuição da cobertura florestal e o aumento de matrizes não-florestais (Piano *et al.*, 2020). Tais mudanças na paisagem alteram a qualidade ambiental das manchas florestais cercadas por matrizes urbanas (He *et al.*, 2017; Zhu *et al.*, 2020), consequentemente prejudicando o deslocamento e a ocupação de espécies florestais em manchas urbanas (Vergnes *et al.*, 2012; Bonebrake & Cooper, 2014; Fattorini *et al.*, 2018; Palácio, 2020). A forma como as espécies nativas percebem e respondem aos elementos da paisagem pode variar de acordo com as diferentes escalas analisadas (Murray *et al.*, 2019). Uma vez que cada cidade tem uma distribuição de cobertura do solo particular, é esperado que a mudança na cobertura do solo dentro das cidades e entre elas mostre diferentes respostas da estrutura da paisagem na dinâmica ecológica. Portanto, a escala em que um processo ecológica está sendo observado destaca-se como um parâmetro chave com respeito as dinâmicas ecológicas em paisagens urbanas (Tscharntke *et al.*, 2002; Grimm *et al.*, 2008; Su *et al*., 2015; Magura & Lovei, 2020).

A perda florestal na região Neotropical, especialmente nas florestas amazônicas, vem aumentando a taxas alarmantes nas últimas décadas, principalmente devido à expansão agrícola e à exploração de recursos naturais (Fearnside, 2005; Sonter *et al*., 2017; Ribeiro *et al*., 2019). Na Amazônia, as atividades antrópicas têm demandado um aumento de infraestrutura causando a expansão de centros urbanos (Sonter *et al*., 2017; Cortês & Silva Jr, 2021). Embora escassos, estudos em cidades amazônicas indicam que comunidades e populações são afetadas por mudanças na paisagem causadas pela urbanização (Lees & Moura, 2017; Leveau *et al*., 2017, Avilla *et al* 2021). Por exemplo, apenas 13% do conjunto regional de espécies de aves nativas persiste na cidade de Belém (Lees & Moura, 2017). Além disso, na cidade de Manaus, as populações urbanas de uma ave especialista em florestas foram diferenciadas morfologicamente e comportamentalmente das populações de florestas preservadas (Avilla *et al*., 2021). Embora pouco estudadas, abordagens em escala populacional e individual que abranjam os efeitos da urbanização sobre a biodiversidade são essenciais para um bom entendimento sobre a importância de manchas de habitats nativos para a conservação da biodiversidade em paisagens urbanas.

Entre os organismos bioindicadores, os besouros rola-bosta (Coleoptera: Scarabaeinae) têm sido amplamente utilizados em estudos ecológicos (Nichols *et al*., 2007; Nichols & Gardner, 2011). Os rola-bosta são altamente sensíveis às mudanças ambientais, como mudanças na estrutura da vegetação, fragmentação florestal e modificações do uso da terra causadas por atividades antrópicas (Andresen, 2003; Filgueiras *et al*., 2015). No entanto, ainda há um número limitado de estudos que abrangem suas respostas às paisagens urbanas (ver Korasaki *et al*., 2013; Ramírez-Restrepo & Halffter, 2016; Salomão *et al*., 2019; Correa *et al*., 2021), a maioria deles concentrando-se nos efeitos da urbanização em nível comunitário. Ao estudar as características das populações de rola bostas (e.g., biomassa, abundância, dieta) é possível obter respostas finas sobre os efeitos das mudanças ambientais nas espécies animais (Larsen *et al*., 2008; Bui *et al*.,2020; Whitworth *et al*., 2021). O tamanho corporal se destaca como uma característica chave, estando relacionado à fisiologia, aptidão física, bem como à quantidade de serviços ecossistêmicos prestados pelos organismos (Kingsolver & Huey, 2008; Larsen *et al*., 2008; Magura *et al*., 2020). Ainda, nos rola bostas o comprimento dos chifres dos machos é uma característica que responde diretamente à quantidade e qualidade do alimento fornecido aos besouros durante seu desenvolvimento larval (Emlen, 1997; Scholtz, 2009). Além disso, o comprimento do chifre é uma característica chave na competição intraespecífica por parceiros (Pomfret & Knell, 2006; Scholtz *et al*., 2009). Nesse sentido, o comprimento do corpo individual e o comprimento do chifre masculino servem como uma aproximação para entender a dinâmica da disponibilidade de recursos nas diferentes paisagens.

OBJETIVOS

O objetivo deste estudo foi avaliar o efeito da cobertura da paisagem sobre a distribuição espacial e características corporais de populações de besouros rola bostas em paisagens urbanas da região amazônica. Para as paisagens, consideramos a quantidade de cobertura florestal e de cobertura agrícola e de pastagem; para as características corporais, medimos o tamanho corporal e o comprimento do chifre dos machos. Analisamos os efeitos da cobertura da paisagem na escala do local (i.e., entre os locais) e na escala da cidade (i.e., entre as cidades). Analisamos duas espécies-chave de rola bostas, *Dichotomius boreus* (Olivier) e *Dichotomius quadrilobatus* Chamorro, Lopera & Rossini, que são abundantes e amplamente distribuídas nas paisagens urbanas amazônicas. Machos e fêmeas podem apresentar diferentes necessidades energéticas (Adler *et al*., 2013) e, consequentemente, a resposta dos besouros rola bosta às condições ambientais pode ser dependente do sexo (Salomão *et al*., 2020a, 2021). Portanto, analisamos os dados para ambos os sexos e para cada um, separadamente. As espécies estudadas são de grande porte (Cultid-Medina *et al*., 2015; Chamorro *et al*., 2021), característica que está relacionada a espécies sensíveis a perdas florestais (Fuzessy *et al*., 2015). Portanto, esperamos que, em locais e cidades com maior quantidade de cobertura florestal, (i) haja maior abundância de *D. boreus* e *D. quadrilobatus* e (ii) os indivíduos possuam maior tamanho corporal e os machos tenham maiores chifres. Como as fêmeas demandam mais energia associada à oviposição e proteção da ninhada do que os machos (Klemperer, 1983; Scholtz *et al*., 2009), também esperamos que (iii) os efeitos da perda de cobertura florestal sejam mais severos nas fêmeas do que nos machos.

Capítulo 1

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How does the loss of forest cover affect abundance and body traits in forest-dwelling species that inhabit Amazonian urban landscapes? A study case with dung beetles

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Running title: Forest cover affect beetles in Amazon cities

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Abstract

1- The loss of forest cover in urban landscapes challenges the maintenance of forest-dwelling species. As urban land cover increases, there are shifts in spatial and trophic resources, as well as in the interactions with exotic species, and such factors may impair forest-species individual condition and fitness.

2- The goal of this study was to assess the effect of landscape cover on the abundance and morphological traits of two dung beetle species (*Dichotomius boreus* and *Dichotomius quadrilobatus*) that inhabit forest areas in urbanized landscapes in the Amazonian region.

3- We studied dung beetles in 38 sites located in six urban landscapes in the central Amazonian region and assessed the effect of landscape cover at the site and city scales on the variation in beetle abundance, individual body size and males` relative horn length.

4- The increase of forest cover positively affected abundance of both species and males` horn length of *D. boreus* beetles. Cities with higher amounts of forest cover dwelled larger individuals compared to those with less forest cover.

5- Forest patches in urban landscapes feature as key habitats to maintain dung beetle populations with a marked relation between the amount of forest cover in the landscape. The maintenance of healthy and abundant beetle population in Amazonian urban landscapes will guarantee the persistence of ecosystem services provided by dung beetles in cities.

Keywords: conservation, Scarabaeinae, tropical rainforest, urban sprawl, urbanization

Introduction

The rapid urban growth in the last decades comprises one of the main drivers of biodiversity loss of the Anthropocene (Batáry et al., 2018; Dáttilo & MacGregor-Fors, 2021). Such abrupt environmental transformation results from the process that involves the migration of people from rural to urban areas, which nowadays dwell more than half of the world population (Gómez-Baggethun et al., 2013; Sejati et al., 2018). Urban centers impose a great challenge for the conservation of the global environment because city-dwellers produce an ecological footprint per capita far greater than rural populations (Martine et al., 2008; Ahmed et al., 2020; Hasan et al., 2020). During the urbanization process, habitat loss and fragmentation comprise two important dynamics that are the main threat for native biodiversity in urban landscapes (Fischer & Lindenmayer, 2007; Li et al., 2017; Dadashpoor et al., 2019; Reinmann et al., 2020). The increase of urban cover poses novel challenges to individuals and populations that inhabit in urban native habitat patches (Mckinney, 2002; Bonier, 2012). Such challenges may result in a decrease of individual condition and fitness (Giraudeau et al., 2014; Salomão et al., 2020a; Corsini et al., 2021), impairing the maintenance of many native species in these urban landscapes. This may have direct consequences for people's well-being because cities with greater biodiversity are healthier cities with a better quality of life (Taylor & Hochuli, 2014; Carrus et al., 2015; Marselle et al., 2019). In order to maintain stable and healthy urban ecosystems for both human and natural communities, it is crucial to understand how the spatial context of urban landscapes and urban forest fragments work as biodiversity reservoirs (Faeth et al., 2011).

The spatial distribution and arrangement of the different land-use types (i.e., landscape structure) have a narrow relationship with the diversity of species and their traits (Fahrig, 2005 Callaghan et al., 2018; Palacio, 2020; Gaona et al., 2021; Millard et al., 2021). From an ecological perspective, one of the main consequences of the urban spatial expansion is the decrease of the amount of forest remnants, which comes together with the increase of non-forest matrices (Piano et al., 2020). Such landscape changes alter the environmental quality of forest patches surrounded by urban matrices (He et al., 2017; Zhu et al., 2020), consequently impairing the displacement and occupation of forest-dweller species in urban patches (Vergnes et al., 2012; Bonebrake & Cooper, 2014; Fattorini et al., 2018; Palacio, 2020). The way in which native species perceive and respond to landscape elements may vary according to the different scale analyzed (Murray et al., 2019). Since cities have their own socioeconomical and historical contexts, land-cover distribution may vary enormously among cities. In this sense, it is reasonable to expect different ecological dynamics in response to landscape change within cities and among them. Therefore, a key parameter is scale at which ecological dynamics are being analyzed in urban landscapes (Tscharntke et al., 2002; Grimm et al., 2008; Su et al., 2015; Magura & Lövei, 2020).

Forest loss in the Neotropical region, especially in Amazonian rainforests, has been increasing at alarming rates in the last decades mostly due to the agricultural expansion and the exploration of natural resources (e.g., mining activity) (Fearnside, 2005; Sonter et al., 2017; Ribeiro et al., 2019). Anthropogenic activities in the Amazon have demanded an increase in infrastructure causing direct and indirect environmental shifts in the region due to the establishment and expansion of urban centers (Sonter et al., 2017; Cortês & Silva Jr, 2021). Although very scarce, previous studies in Amazonian cities indicate that communities and populations are affected by landscape changes caused by urbanization (Lees & Moura, 2017; Leveau et al., 2017, Avilla et al., 2021). For example, only 13% of the regional pool of native bird species persist in a major Amazonian city (Lees & Moura, 2017). Furthermore, in another major Amazonian city, urban populations of a forest specialist bird were morphological and behaviorally differentiated from preserved forest populations (Avilla et al., 2021). Although far less studied, population and individual-scale approaches encompassing the urbanization effects on biodiversity are essential for a fine understanding of the importance of native habitat patches for biodiversity conservation in urban landscapes.

In the last decades, dung beetles (Coleoptera: Scarabaeinae) have been widely used as a reliable indicator group in ecological studies (Nichols et al., 2007; Nichols & Gardner, 2011). Dung beetles are highly sensitive to environmental changes, such as shifts in vegetation structure, forest fragmentation, and modifications of land use caused by anthropogenic activities (Andresen, 2003; Filgueiras et al., 2015). Nonetheless, the number of studies encompassing their responses in urban landscapes are still limited (see Korasaki et al., 2013; Ramírez-Restrepo & Halffter, 2016; Salomão et al., 2019; Correa et al., 2021), and most of them focuses on the effects of urbanization at community level (but see Salomão et al., 2020a). By studying dung-beetle population traits (e.g., biomass, abundance, diet) it is possible to obtain fine responses regarding the effects of environmental changes on animal species (Larsen et al., 2008; Bui et al., 2020; Whitworth et al., 2021). Individual body size highlights as a key trait for animal species, being markedly related to specimen morphology, physiology, fitness, as well as to the amount of ecosystem services provided by them (Kingsolver & Huey, 2008; Larsen et al., 2008; Nichols et al., 2008; Magura et al., 2020). Males' horn length is a body trait that directly responds to the quantity and quality of food provided for the dung beetles during its larval development (Emlen, 1997; Scholtz, 2009). Furthermore, horn length is a key trait in intraspecific competition for mates and a great indicator of immunity (Pomfret & Knell, 2006; Scholtz et al., 2009). In this sense, individual body length and male horn length serve as a proxy to understand the dynamics of resource availability in different landscapes.

Dung beetles are a key group for the maintenance of ecosystem services in urban landscapes, as they contribute to the removal of decomposing matter, improvement of soil quality, and the control of disease vectors (Nichols et al., 2008; Salomão et al., 2019). The aim of this study was to assess the effects of landscape cover (i.e., amount of forest and agriculture-pasture cover) on the abundance and body traits (individual body size and males' horn length) of forest dung beetle populations in urban landscapes of the Amazonian region. We analyzed the effects of landscape cover at the site scale (i.e., among sites) and at the city scale (i.e., among cities). To attain this objective, we analyzed two key dung beetle species, *Dichotomius boreus* (Olivier) and *Dichotomius quadrilobatus* Chamorro, Lopera & Rossini, which are highly abundant and widespread in the urban landscapes of Amazon cities. Males and females may present different energetical requirements (Adler et al., 2013), and, consequently, dung beetles' response to environmental conditions may be sex dependent (Salomão et al., 2020a, 2021). Therefore, species abundance and body size were also analyzed for males and females separately. The studied species dwell native Amazon forests and are large bodied (Cultid-Medina et al., 2015; Chamorro et al., 2021), a trait that is related to sensitivity to forest loss in other tropical ecosystems (Fuzessy et al., 2021).

Therefore, we expect that sites and cities with higher amount of forest cover will (i) dwell higher abundances of *D. boreus* and *D. quadrilobatus* and (ii) positively affect the size of body traits of both species. As females demand more energy associated with oviposition and brood protection than males (Klemperer, 1983; Scholtz et al., 2009), we also expect that (iii) the effects of loss of forest cover will be more severe on females than on males.

2. Material and methods

2.1. Study area

This study was conducted in 38 sites locates in six urban landscapes corresponding to six cities in the State of Amazonas, Brazil: Iranduba, Itacoatiara, Manacapuru, Manaus, Presidente Figueiredo and Rio Preto da Eva (ranging from 2°00'S; 58°24'W to 3°17'S; 60°36'W, see Fig. 1). These cities comprise different historical origins and have different socioeconomical contexts in the Amazonian region. Manaus is the most urbanized city of our study, encompassing the largest urban area and population size, while Presidente Figueiredo and Rio Preto da Eva have, respectively, the smallest urban area and population size of the studied cities (IBGE, 2022, see Table 1). The matrix of our studied landscapes is composed by urban areas, agricultural fields and water cover in the surroundings of cities (Table 1). Agricultural areas are used for crop and family agriculture plantations and for livestock. The native vegetation in the study area is mostly composed by ombrophilous tropical rainforest (*Terra firme*), but there are also patches of sandy tropical forest (white-sand *Campinarana*) and seasonal flooded forests (*Várzea* and *Igapó*). In order to standardize the ecosystem studied, we collected beetle data exclusively in the most widespread vegetation, the *Terra firme* forests.

The climate is classified as Af according to Köppen's classification, presenting an average annual temperature of 26.2 °C and with a mean annual precipitation of 3,038 mm (Climate-Data, 2022, see Table 1). The dry season comprises the period between June and November (mean monthly rainfall: 152 mm), while the rainy season comprises the period between December and May (mean monthly rainfall: 337 mm, Climate-Data, 2022).

2.2. Study species

Among the dung beetles, *Dichotomius* Hope features a genus of dung beetles that is widely distributed in America, with its higher diversity being found in South America (Sarmiento-Garcés & Germán, 2009). *Dichotomius* species body length ranges from *ca.* 10 mm to more than 25 mm, species diet ranges from strictly coprophagous to diet generalists, most of them are nocturnal and their spatial distribution ranges from stenotopic to eurytopic species, although most of them are forest-dwellers (Chamorro et al., 2021; Sarmiento-Garcés & Germán, 2009). Moreover, *Dichotomius* beetles have successfully being used as models to understand the consequences of environmental transformation at population level (França et al., 2016; Salomão et al., 2020a; Vieira et al., 2022).

Dichotomius boreus and *D. quadrilobatus* are part of a species complex, which is mostly distributed in the Amazon region (Chamorro et al., 2021). The Rio Negro River acts as a biogeographic barrier for *D. boreus* and *D. quadrilobatus*, separating these two species. In our study area four cities (Itacoatiara, Manaus, Presidente Figueiredo, and Rio Preto da Eva) are located in the North bank of the Rio Negro river, and two cities in the South bank of the river (Iranduba and Manacapuru). Therefore, *D. boreus* is only found in the four northern cities and *D. quadrilobatus* in the two southern cities. Regarding body size, pronotum width ranges from 11.3 to 21.2 mm in *D. quadrilobatus* and ranges from 9.4 to 19.5 in *D. boreus*

2.3. Sampling sites and landscape cover

We used a sample site-landscape-approach (Fahrig, 2013) to assess *D. boreus* and *D. quadrilobatus* abundance in 38 sampling sites located in forested areas throughout an urbanization gradient (6 sampling sites per city, except for Manaus, in which we sampled 8, see Fig. 1). We obtained landscape cover variables for the year of 2017 with 30 × 30 m resolution from MapBiomas (MapBiomas Amazon Project – Collection 2017). The MapBiomas Amazon project - is a multi-institutional initiative to generate annual land use maps based on automatic classification processes applied to satellite imagery.

We quantified the amount of forest (old-growth and/or secondary vegetation in different stages of regeneration), urban, agriculture, pasture, and water cover at different scales for each sampling site. We considered five different spatial scales (within a buffer radius of 200, 400, 600, 800, and 1000 m centered in each sampling site. The center of the buffer was defined from the center of a forest fragment) in order to cover maximum home range size of large *Dichotomius* species (their linear movement distance ranges from ca. 280 to ca. 580 m, see Cultid-Medina et al., 2015; Barretto et al., 2021). We obtained the amount of landscape cover for each sampling site at the different scales using the QGIS 3.20.1-Odense software (QGIS, 2021). Agriculture and pasture cover were grouped into the same landscape-cover class (hereafter agriculture-pasture cover class).

Before performing the statistical models, we tested multicollinearity among the landscape cover variables at different spatial scales through Pearson correlations. There was a high negative correlation ($r > 0.75$) between forest cover and urban cover, and thus we excluded urban cover from all models. Since water cover was present in the buffers of only three sampling sites, we did not consider this land-cover in our analyses.

2.4. Dung beetle data collection

We sampled dung beetles in each of the 38 sites from March to June 2021, in the end of the rainy season. Twenty pitfall traps were installed per sampling site, 10 traps baited with ca. 25 g of human excrement and 10 baited with ca. 25 g of rotten bovine liver. In each sampling site, paired traps (each baited with one bait type, spaced 10 m between them) were installed each 25 m across a 250 m-long linear transect. Traps were installed with at a minimum distance of 20 m from the forest edge. All traps were removed 48 h after their installation, and dung beetles were deposited in the entomological collections of the *Instituto Nacional de Pesquisas da Amazônia* (INPA) and the *Universidade Federal do Mato Grosso* (UFMT). *Dichotomius boreus* and *D. quadrilobatus* were identified and sexed using the taxonomic key provided by Chamorro et al. (2021).

To analyze the effects of landscape cover on *D. boreus* and *D. quadrilobatus* body size and males' relative horn length, we measured all collected individuals. Body size was estimated as pronotum width measured horizontally at the widest portion of the pronotum (referência). Horn length of males was estimated measuring from the base to the apex of their horns, and the relative horn length was obtained by the division "horn length / body size". Both measurements were obtained from digital pictures taken using a Motorola E7 Plus digital camera under a microscope (Opton TIM-2B), analyzed in ImajeJ software version 1.46r. All measurements were performed by GVSB.

2.5. Data analysis

We analyzed the spatial relationships of each species by using data from sampling sites in the cities in which they dwell. *Dichotomius boreus* was analyzed by using data obtained from sites in Itacoatiara, Manaus, Presidente Figueiredo, and Rio Preto da Eva (26 sites), while *D. quadrilobatus* was analyzed by using the data obtained from Iranduba and Manacapuru (12 sites).

We analyzed land-cover effects at the site scale and at the city scale. All the analyses were performed in R software version 4.1.3 (R Development Core Team, 2022).

2.5.1. Site-scale analyses

To test the effect of landscape cover variables (i.e., amount of forest cover and agriculture-pastureland cover) on the abundance (total abundance, abundance of males, abundance of females) and body traits (body size of males and females, and male relative horn size), we carried out Generalized Linear Mixed Models with Template Model Builder (GLMM-TMB). These models were performed in glmmTMB package (Brooks et al., 2017). Cities were included as random effect, in order to compensate potential spatial autocorrelation issues among sampling sites of each city. The residuals of each model were tested using the DHARMa package (Hartig, 2021), which was used to select the family distribution (Gaussian, Poisson or Negative Binomial) with the best correction of data dispersion. We only show results from GLM models with adequate dispersion. We selected the spatial scale (200, 400, 600, 800, and 1000 m of radius centered at each site) that best explained the variation of our response variables (abundances and body traits) using R^2 which was used as an estimator of goodness of fit. R^2 was obtained through the function r.squaredGLMM of MuMIn package (Barton, 2020). For *D. boreus* the spatial scale of landscape-cover that best explained its abundance was 200 m and the scale that best explained Males' relative horn length was 1000 m. For *D. quadrilobatus* 1000 m was the scale with best explanative power for abundance and no scale explained body traits. Models were performed with forest cover and agriculture/pastureland cover as fixed effects for each sampling site. Table 2 shows the distribution family and spatial scale that best explained the response variables and were selected in each model.

2.5.2. City-scale analyses

Since each city has a different scenario of urbanization (Table 1) and amounts of forest cover within and outside cities (Fig. 1), we compared abundances and body traits of the two species of *Dichotomius* beetles among each city. Such analyses were performed using Generalized Linear Models (GLM) with Gaussian family distribution. Post-hoc comparisons between each paired city were assessed by the lsmeans function of emmeans package (Lenth, 2021), which were followed by Tukey (HSD). In order to normalize data distribution, all response variables were log-transformed.

3. Results

We collected 302 individuals throughout the 38 sampling sites, of which 53% were *D. boreus* individuals and 47% were *D. quadrilobatus* individuals (see Supplementary material). Itacoatiara and Manaus were the cities with the highest abundances of *D. boreus* and Manacapuru the city with the highest abundance of *D. quadrilobatus* (N = 89, 60 and 120, respectively). Regarding the abundance distribution of females : males, similar proportions were observed both for *D. boreus* (79 : 81) and for *D. quadrilobatus* (71 : 72). These proportions were constant throughout the cities (Supplementary material).

Dichotomius boreus had a mean body size of 1.38±0.11 mm (mean ± Standard Deviation), while *D. quadrilobatus* had a mean body size of 1.52±0.12 mm. In *D. boreus,* males were slightly larger than females (males, 1.39±0.16 mm; females, 1.37±0.16 mm), the same being observed in *D. quadrilobatus* (males, 1.52±0.16 mm; females, 1.51±0.17 mm). Males' horn length for *D. boreus* was 0.10±0.01 mm long, while for *D. quadrilobatus* the horn was 0.13±0.01 mm long (Supplementary material).

Site-scale effects on Dichotomius abundance and body traits

For both species, the increase of forest cover positively affected abundance, but the amount of agriculture and pastureland cover had no significant effect (Fig. 2). The effect of forest cover was observed both for total abundance, as well as for the abundance of males and females separately (Fig. 2). There was a positive relation between male's horn length and forest cover for *D. boreus* beetles (Fig. 3), but no significant relationship was observed between the amounts of land cover and male's horn length in *D. quadrilobatus* (Table 2). There was no significant effect of the amounts of land cover and beetles body size (Table 2).

City-scale effects on Dichotomius abundance and body traits

Abundance of *D. boreus* among cities was distinct, but only for males (Table 3). Males of *D. boreus* had a higher abundance in Itacoatiara (the city with the second highest percentage of urbanization, see Table 1) when compared to President Figueiredo and Rio Preto da Eva (Fig. 4), the cities with the lowest percentage of urbanization. Females did not show marked differences in their abundances among cities. When analyzing body size, *D. boreus* beetles from Itacoatiara and Manaus were smaller than those from Presidente Figueiredo and Rio Preto da Eva (Fig. 5). When analyzing by gender, males' beetles from Itacoatiara and Manaus were smaller than those from Rio Preto da Eva (Fig. 5B), while females from Itacoatiara and Manaus were smaller than females from Presidente Figueiredo (Fig. 5C). In *D. quadrilobatus,* neither abundance nor body size varied between the two cities in which they were recorded (Table 4). Nonetheless, males' horn length differed between cities in *D. quadrilobatus*, with males from Manacapuru presenting larger horns than in Iranduba (Fig. 5D).

4. Discussion

With the increase of urbanization, it is essential to seek alternatives that allow the coexistence of urban landscapes and green infrastructure that maintain a significant portion of native biodiversity. The maintenance of native vegetation patches in cities is determinant to maintain a subset of the regional biodiversity, thus playing a key role for ecological conservation and human health. Healthy dung beetle populations can play a key role in the maintenance and recovery of environmental quality in human-modified landscapes (Nichols et al., 2008; Servín-Pastor et al., 2020). Here we show that in our studied urban landscapes at the site scale, where individual processes are more likely related to habitat quality, the decrease of forest cover results in 1) decrease of beetle abundance and 2) males with smaller horns. At the city scale, were population processes most likely respond to the regional landscape context resulting from the historical and socioeconomical development of cities, we found that more urbanized cities (i.e., cities with higher population size and population density) have 3) higher abundance of beetles but 4) smaller individuals. Furthermore, the reduction in beetle abundance was not sex-dependent and both males and females are negatively affected by the loss of forest cover. These results present strong evidence for landscape change effects that result from an ongoing urbanization process in the Amazon with effects on population and individual processes impairing abundance and body traits of native species. Most studies have shown that effects of habitat loss are intrinsically related to species loss and decreases of native species population (Pimm & Askins, 1995; He & Hubbell, 2011; Chase et al., 2020). Nonetheless, population and individual level responses have strong consequences on ecosystem functioning. Therefore, the maintenance of native habitat fragments in urban areas is determinant not only to keep a subset of the rich regional biodiversity, especially in Amazonian cities, but also to keep functional ecosystems that play a key role improving the quality of urban environment and human health.

In accordance to our first prediction, there was a marked decrease of beetle abundance with the decrease of forest cover in the urban landscapes. The modification of the abundance of species as a consequence of environmental degradation is a trend observed in populations (including dung beetles) that persist in anthropogenic landscapes (Korasaki et al., 2013; Newbold et al., 2014; Piano et al., 2020; Salomão et al., 2020b). Environmental pressures in anthropogenic landscapes driven by reduction of habitat and food resource availability, and by changes in microclimatic conditions, negatively affect individual survival leading to changes in abundance (Nichols et al., 2007; McKinney, 2008; Fuzessy et al., 2021). For dung beetle species, the quantity and quality of food resources (i.e., feces from native mammals, decaying corpses) is determinant for the fitness of individuals and consequent success in population establishment in the environments (Favila, 1993; Moczek, 2002; Servín-Pastor et al., 2021). The urban matrix is an inhospitable environment that strongly contrasts with the native forest habitat in many aspects including contrasting microclimatic conditions and a different suite of predators. These contrasting conditions may strongly affect habitat quality via edge effects reducing food resources and increasing mortality of individuals within remnant habitat patches in cities. Therefore, we conclude that the decrease in *Dichotomius* abundance within habitat patches is a consequence of the reduction of their native habitats, which comes together with changes in food availability, in addition to dispersal barriers imposed by the harsh urban matrix that limits the movement of individuals among patches. Moreover, it is important to consider that *D. boreus* and *D. quadrilobatus* are one of the largest species in the region. Large-bodied species tend to be sensitive to human activities that drive landscape change, usually decreasing their abundances (Gardner, 2008; Braga et al., 2013). Our data present a clear negative effect of the habitat loss due to the urbanization process in Amazon cities, which impair the maintenance of abundant dung beetle populations. With the decrease of beetle abundance, there is a loss of key ecosystem services, as secondary seed dispersal, soil bioturbation, and the control of parasitic transmission (Nichols, 2008; Servín-Pastor et al., 2020; Rivera et al., 2021).

The city with the second largest amount of urban area and the second smallest amount of forest cover (Itacoatiara) was the city with the highest abundance of *D. boreus*. In spite of that, the small size of *D. boreus* individuals recorded in the most urbanized cities (Itacoatiara and Manaus) suggest a negative effect of urban ecosystems on dung beetle populations (Halffter & Arellano, 2002; Nichols et al., 2013). Habitat quality and landscape configuration are important drivers of dung beetle distribution (which includes *Dichotomius* beetles) in urban ecosystems (Salomão et al., 2019, 2020b; Correa et al., 2021). Habitat quality, type or availability of resources are determinant for individual body size in dung beetles (Nichols et al., 2007; McKinney, 2008; Servín-Pastor et al., 2021). It is interesting to note that more urbanized cities dwell larger populations but small-bodied individuals, which suggest a compensatory effect of *D. boreus* biomass in the most urbanized cities (Itacoatiara and Manaus). The body size of species may be indirectly correlated with species persistence in the landscapes (Gaston and Blackburn 1996; Chown et al., 2010, but see Davies et al., 2000). Considering the energetical demand to maintain a large body (Kotze et al., 2003; Ulrich et al., 2008), we believe that the limiting spatial and trophic resource availability in more urbanized landscapes may be exerting a populational pressure on *D. boreus* beetles, resulting in abundant populations of small-bodied individuals. This data presents a novel finding, highlighting how population persistence may compensate its ecological role by a trade-off between individual biomass and species abundance. Future studies should evaluate if this trade-off is affecting ecosystem services provided by dung beetles.

In accordance to our second prediction, males' relative horn length was also negatively affected by urbanization (at both site-scale and city-scale), which was observed in *D. boreus* and *D. quadrilobatus*. Intraspecific variations of horn length in dung beetle populations may be driven by different factors, including genetic and environmental effects (West-Eberhard, 1992; Moczek & Emlen, 1999). The decreased forest cover as a consequence of urbanization results in sharp increases in temperature (e.g. urban heat islands, see Zhang et al., 2013; Roth, 2020). These environmental conditions influence larval development of dung beetles, which consequently reduce male horn length (Moczek & Emlen, 1999; Scholtz et al., 2009). The decrease of forest cover also decrease vertebrate diversity (e.g. McKinney, 2008) – the main food providers for the dung beetles (Hanski & Cambefort, 1991; Scholtz et al., 2009). The physical and chemical characteristics of vertebrates' dung (e.g. nutrient, fiber content, moisture) influences dung beetle morphological characteristics, such as males' horn size (Tonelli et al., 2021). Thus, the scarcity of dung quality and quantity can decrease dung beetles' fitness because horn length is a morphological trait related to sexual selection in dung beetles (Pomfret & Knell, 2006). Similarly, in the largest city studied here (Manaus), individuals form a forest-specialist bird species were smaller and behaved differently in urban forest fragments than in the nearby continuous and preserved forest (Avilla et al., 2021). These studies present an alarming scenario in which the decrease of forest cover in urban landscapes leads to shifts in intraspecific dynamics with decreasing fitness of individuals.

In our study, site-scale effects on *Dichotomius* beetles were distinct from those observed at city scale. For example, *D. boreus* body size and *D. quadrilobatus* horn size only differed in the analyses performed at city scale. Human population density in cities, distribution of land cover types, urban growth speed, and spatial configuration of forest remnants may modulate effects of urbanization on biodiversity (Burdine & McCluney, 2019; Uchida et al., 2021). The site and city scales analyzed in this study most probably comprise processes that occur at individual and population levels, respectively, and thus the ecological dynamics and filters that exist for *Dichotomius* beetles at the city scale and the site scale are markedly distinct. Among the differences that encompass these scales, rapid environmental changes may mask the effects of landscape transformations on ecological communities (Uchida et al., 2021). The effects observed at the site scale (i.e. as a response to the amount of forest cover within a 200 m scale) were mostly related to beetle abundance, which may indicate that this population parameter is very sensitive to local changes in habitat quality. Nevertheless, by assessing the city-scale, we observe a potential compensatory mechanism encompassing beetle abundance and body size. Although the city scale and the site scale comprise different scales and therefore different ecological processes, both were determinant for a broader comprehension of the mechanisms driving dung beetle distribution in urban ecosystems.

Contrary to our third prediction, both sexes were negatively affected by the loss of forest cover. This result may be associated with the energy requirement of both males and females. Females have a high energy demand linked to reproduction, which includes egg development and nest protection, while males disperse larger distances through the landscape making them more susceptible to parasites (Klemperer, 1983; Salomão et al., 2020b, 2021). Small forest patches may not provide food in sufficient quantity and quality for female reproduction and also limit the optimum functioning of the physiological condition of males (Zanette et al., 2000; Salomão et al., 2020a), which can lead to unsuitable environments for both sexes. Moreover, isolation of forest patches due to the advancement of urbanization may further reduce the number of females, which can result in local extinction of populations. . The forest cover in large urban centers in the tropical region has dramatically decreased mostly because of the migration of people towards cities and lack of appropriate urban planning. Consequently, those landscape and population dynamics has been putting the preservation of forested areas in urban regions at risk, diminishing the quality of life in tropical cities.

The Amazon region has been suffering from a set of anthropogenic activities that are affecting biodiversity at different spatial scales (e.g. forest loss and fragmentation, climatic changes, see Sobral-Souza et al., 2018). Landscape transformations that have occurred during the Anthropocene are resulting in cascading environmental consequences for the ecosystems, which affect ecological communities, population structure and the individual condition of organisms (McKinney, 2006; Filloy et al., 2019; Onandia et al., 2019; Magura et al., 2021). In this study, we focused in understanding how population structure and morphological traits of *D. boreus* and *D. quadrilobatus* respond to changes in forest cover assessed at different scales in Amazon cities. Our results showed marked negative effects of forest loss on population dynamics of dung beetles, indicating that urban landscapes with more forest cover are the best ones to conserve abundant and healthy dung beetle populations ensuring their ecosystem services. Compared to other tropical rainforests, the Amazon still maintains a relatively high amount of native vegetation (Ribeiro et al., 2009; Vega-Vela et al., 2020). Therefore, it is of utmost importance to develop environmental policies that conserve large forest patches in urban landscapes, which will maintain a high biodiversity, stable populations and healthier cities.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Author contributions

RPS, GVSB, CC, PEBD and LI designed the study. GVSB, VPM and RPS collected the data. GVSB, VPM and RPS sorted the material and performed the laboratory part of the study. PEBD and RPS analyzed the data. All authors wrote the paper.

Conflict of interest statement

The authors declare that there is no conflict of interest that could influence this work.

Supporting Information

Supplementary material. Data base encompassing morphological traits and abundance *D. boreus* and *D. quadrilobattus* beetles.

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Figure captions

Figure 1. Study area showing the Brazilian Legal Amazonia (in green on the left map) in which the six studied urban landscapes were located (a); the sampling sites were dung beetles were sampled in each city (b); and an example of the 200 – 1,000 m radius buffer centered at each site (c). The dung beetles were sampled in the centroid of each sampling site

Figure 2. Relationships between the amount of forest cover and total abundance and of male and female *D. boreus* (a-c) and *D. quadrilobatus* (d-f) beetles collected in 38 sites located in six urban landscapes of the Central Amazonian region

Figure 3. Relationship between forest cover and *D. boreus* male horn length in 26 sites located in four urban landscapes in the Central Amazonian region

Figure 4. Abundance of *D. boreus* beetles (a-c) and *D. quadrilobatus* (d-f) sampled in six cities located in the Central Amazonian region. The white dot represents the mean abundance and the gray area shows the frequency of the dat

Figure 5. Males' horn length, body size of all beetles and separated by sex of *D. boreus* (a-d) and *D. quadrilobatus* (e-h) sampled in six cities located in Central Amazonian region. The white dot represents the mean abundance and the gray area shows the frequency of the data

Table 1. Land use cover (at 10 km²), population size and urban area of the six studied cities in the Central Amazon region, state of Amazonas, Brazil. Municipality population size and population density were obtained from IBGE (2022).

	Presidente Figueiredo	Rio Preto da Eva	Iranduba	Itacoatiara	Manacapuru	Manaus
Land use cover (%)						
Forest	92.9	87.9	63.4	60.1	51.1	44.6
Urban	1.0	1.3	2.1	3.2	3.0	53.2
Agriculture and pasturelands	6.0	10.6	10.4	9.0	9.1	2.1
Water	0.0	0.1	24.1	27.7	36.9	0.2
Municipality population size	38,095	34,856	49,718	104,046	99,613	2,255,903
Municipality population density (hab/km²)	1.07	4.4	18.4	9.7	11.6	158.0

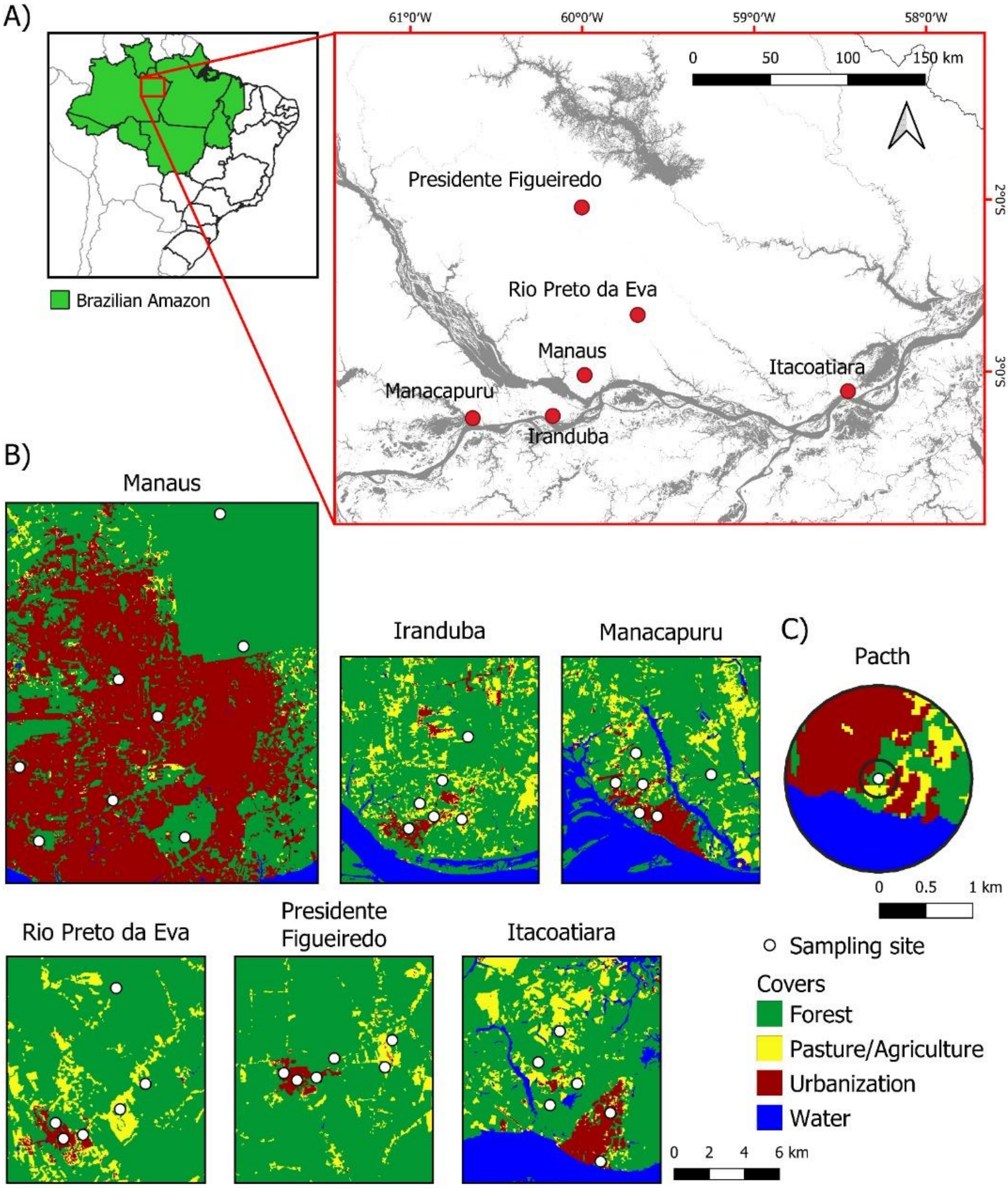
Table 2. Selected models testing the effect of the forest cover and agriculture-pastureland cover on abundance (total, males and females separately) and body traits of *D. boreus* and *D. quadrilobatus* beetles. Statistically significant variables are shown in bold. NA = variables not included in the model.

Species	Forest cover (%)		Agriculture and pastureland (%)		R2m	R2c	Model family	Spatial scale (Buffer in m)
	z	*P*	*z*	*P*				
Dichotomius boreus								
All beetles' abundance	3.51	**<0.001**	-0.05	0.96	0.37	0.49	Gaussian	200
Male abundance	2.72	**0.007**	0.48	0.63	0.21	0.42	Gaussian	200
Female abundance	3.47	**<0.001**	-0.25	0.80	0.39	0.48	Gaussian	200
All beetles body size					NA			
Males body size					NA			
Female body size					NA			
Males' relative horn length	1.90	**0.057**	-1.27	0.20	0.06	0.06	Gaussian	1,000
Dichotomius quadrilobatus								
All beetles' abundance	2.67	**0.008**	1.57	0.12	0.37	0.66	Gaussian	1,000
Male abundance	2.51	**0.012**	1.39	0.16	0.36	0.61	Gaussian	1,000
Female abundance	2.60	**0.009**	1.12	0.26	0.30	0.64	Gaussian	1,000
All beetles body size	1.25	0.21	1.29	0.20	0.01	0.01	Gaussian	200
Males body size	0.03	0.76	0.31	0.76	0.001	0.001	Gaussian	200
Female body size	1.64	0.10	1.71	0.09	0.04	0.04	Gaussian	200
Males' relative horn length	0.81	0.42	0.31	0.76	0.10	0.10	Gaussian	200

Table 3. Results showing the comparisons of *D. boreus* and *D. quadrilobatus* abundance and body traits effects among the different cities in which these species were recorded. Statistically significant variables are shown in bold.

Cities	All beetles' abundance		Male abundance		Female abundance		All beetles body size		Males body size		Females body size		Males' relative horn length	
Dichotomius boreus	*t*	*P*	*T*	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*	*t*	*P*
Itacoatiara - Manaus	-0.58	0.94	-1.05	0.72	-0.66	0.91	0.47	0.97	0.07	1.00	0.90	0.81	0.33	0.94
Itacoatiara - Presidente Figueiredo	-2.45	0.10	**-3.16**	**0.02**	-2.24	0.14	**2.99**	**0.02**			**3.23**	**0.01**		
Itacoatiara - Rio Preto da Eva	-2.45	0.10	**-2.70**	**0.06**	-2.52	0.08	**3.33**	**0.01**	**2.80**	**0.02**	2.13	0.15	1.09	0.53
Manaus - Presidente Figueiredo	-2.04	0.20	-2.33	0.12	-1.73	0.33	**2.78**	**0.03**			**2.72**	**0.04**		
Manaus - Rio Preto da Eva	-2.04	0.20	-1.83	0.29	-2.03	0.21	**3.12**	**0.01**	**2.78**	**0.02**	1.74	0.31	0.97	0.60
Presidente Figueiredo - Rio Preto da Eva	0.00	1.00	0.46	0.97	-0.28	0.99	0.25	0.99			-0.35	0.98		
Dichotomius quadrilobatus														
Iranduba - Manacapuru	1.52	0.16	1.42	0.19	1.99	0.08	0.69	0.49	0.94	0.35	-0.12	0.90	**2.88**	**0.005**

Figure 1



A)
Brazilian Amazon
61°0′W
60°0′W
59°0′W
58°0′W
2°0′S
3°0′S
0 50 100 150 km
Presidente Figueiredo
Rio Preto da Eva
Manaus
Itacoatiara
Manacapuru
Iranduba
B)
Manaus
Iranduba
Manacapuru
Rio Preto da Eva
Presidente Figueiredo
Itacoatiara
0 2 4 6 km
C)
Pacth
0 0.5 1 km
Sampling site
Covers
Forest
Pasture/Agriculture
Urbanization
Water

Figure 2

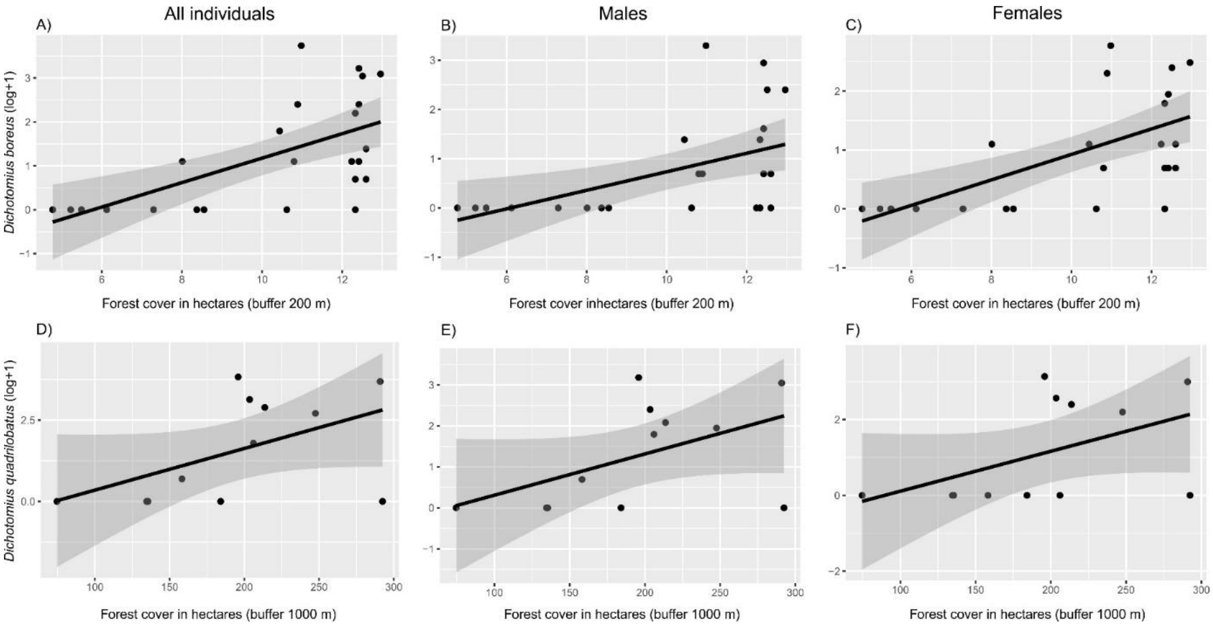

All individuals
Males
Females
A)
B)
C)
D)
E)
F)
Dichotomius boreus (log+1)
Dichotomius quadrilobatus (log+1)
Forest cover in hectares (buffer 200 m)
Forest cover inhectares (buffer 200 m)
Forest cover in hectares (buffer 200 m)
Forest cover in hectares (buffer 1000 m)
Forest cover in hectares (buffer 1000 m)
Forest cover in hectares (buffer 1000 m)

Figure 3

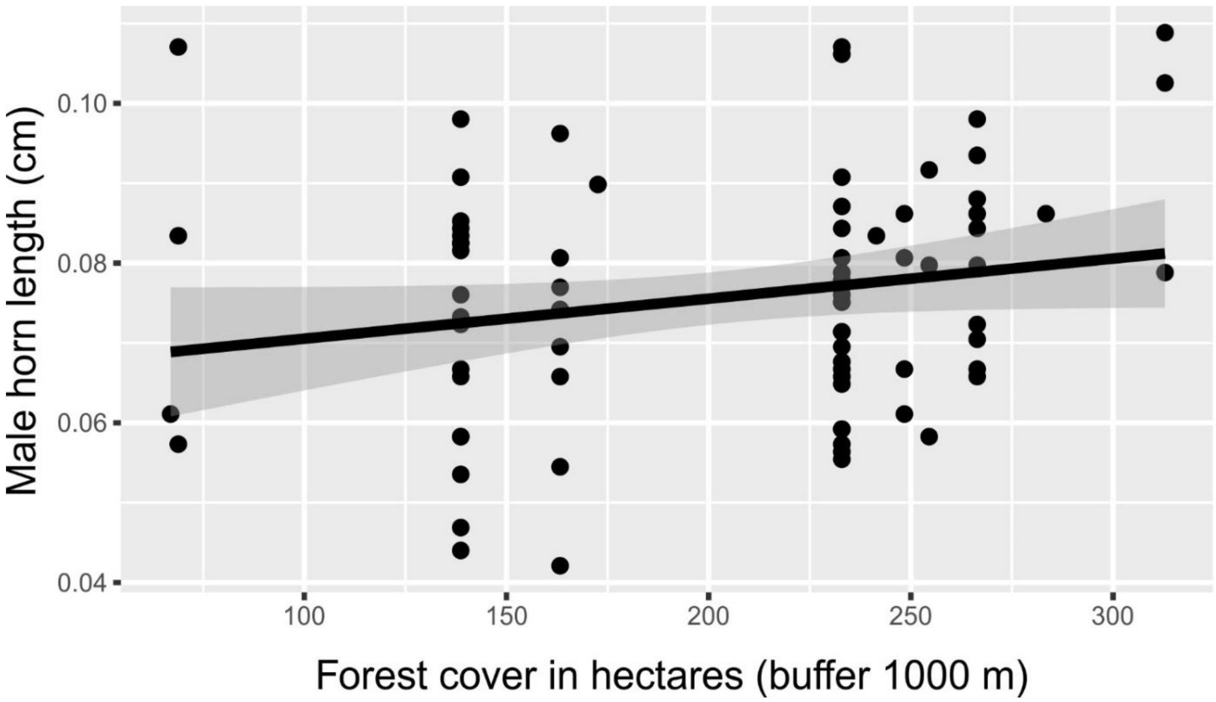

Male horn length (cm)
0.10
0.08
0.06
0.04
100
150
200
250
300
Forest cover in hectares (buffer 1000 m)

Figure 4

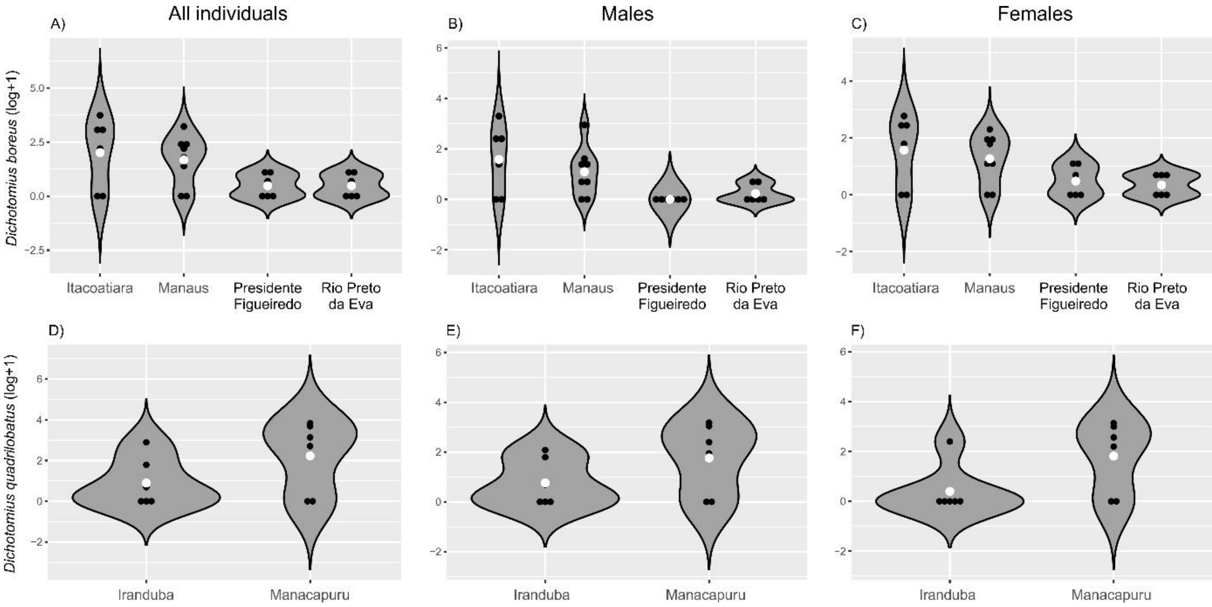
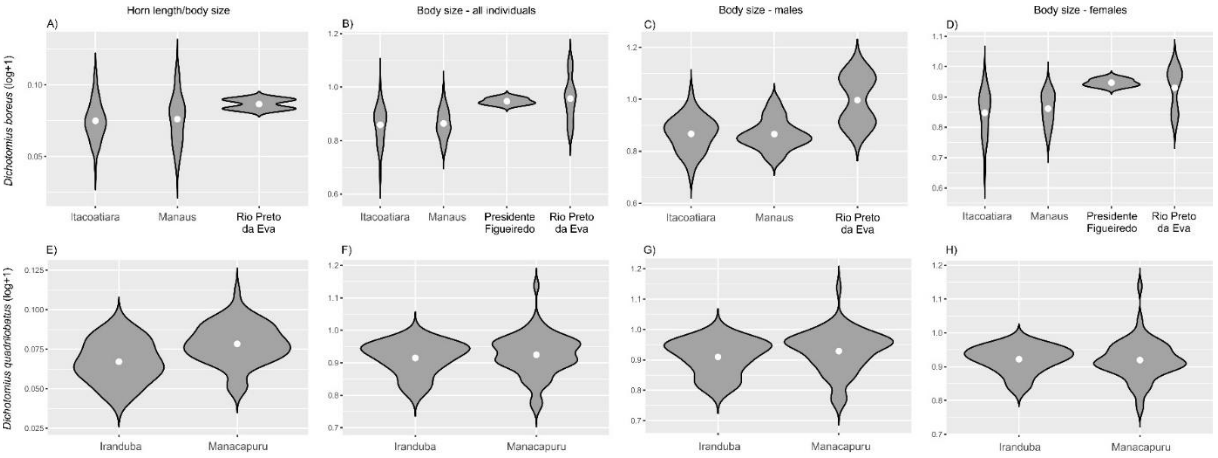

All individuals
Males
Females
A)
B)
C)
D)
E)
F)
Dichotomius boreus (log+1)
Dichotomius quadrilobatus (log+1)
Itacoatiara
Manaus
Presidente Figueiredo
Rio Preto da Eva
Iranduba
Manacapuru

Figure 5


Horn length/body size
Body size - all individuals
Body size - males
Body size - females
A)
B)
C)
D)
E)
F)
G)
H)
Dichotomius boreus (log+1)
Dichotomius quadrilobatus (log+1)
Itacoatiara
Manaus
Rio Preto da Eva
Presidente Figueiredo
Iranduba
Manacapuru

CONCLUSÕES

Mudanças na paisagem resultantes de um processo de urbanização em andamento na Amazônia causam efeitos sobre a população e processos individuais prejudicando a abundância e as características corporais das espécies nativas. Nosso estudo evidenciou efeitos negativos marcantes da perda florestal na dinâmica populacional de rola bostas, indicando que paisagens urbanas com mais cobertura florestal são as melhores para conservar populações abundantes e saudáveis. Diante disso, é importante desenvolver políticas públicas ambientais que assegurem a manutenção de fragmentos urbanos na Amazônia, mantendo assim um subconjunto da biodiversidade regional, que desempenha um papel fundamental para a conservação ecológica e a saúde humana.

CONCLUSIONS

Changes in the landscape resulting from an ongoing urbanization process in the Amazon have effects on the population and individual processes, impairing the abundance and bodily characteristics of native species. Our study showed marked negative effects of forest loss on dung beetle population dynamics, indicating that urban landscapes with more forest cover are the best for conserving abundant and healthy populations. In view of this, it is important to develop public environmental policies that ensure the maintenance of urban fragments in the Amazon, thus maintaining a subset of regional biodiversity, which plays a fundamental role for ecological conservation and human health.