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ANDREZA CARVALHO FERREIRA

DIVERSIDADE DE BESOUROS ROLA BOSTA EM CAMPINARANAS CONSERVADAS E DEGRADADAS NA AMAZÔNIA CENTRAL

MANAUS, AMAZONAS

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Dissertação apresentada ao Instituto Nacional de Pesquisas da Amazônia como parte dos requerimentos para obtenção do título de mestre em Biologia (Ecologia).

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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 26 dias do mês de julho do ano de 2023, às 15h00min, via videoconferência, reuniu-se a Comissão Examinadora de Defesa Pública, composta pelos seguintes membros: a Drª. **Priscila Paixão Lopes**, da Universidade Estadual de Feira de Santana – UEFS, o Dr. **Ricardo José da Silva**, da Universidade do Estado de Mato Grosso – UNEMAT e o Dr. **Hedinaldo Narciso Lima**, da Universidade Federal do Amazonas – UFAM, tendo como suplentes o Dr. Igor Luis Kaefer, da Universidade Federal do Amazonas – UFAM e a Dr. Lucas Ramos Costa Lima, da Universidade Estadual do Piauí – UESPI, sob a presidência do orientador, a fim de proceder a arguição pública do trabalho de **DISSERTAÇÃO DE MESTRADO** de **ANDREZA CARVALHO FERREIRA**, intitulado: **"DIVERSIDADE DE ROLA BOSTA EM CAMPINARANAS CONSERVADAS E DEGRADADAS NA AMAZÔNIA CENTRAL"**, orientada pelo Dr. Renato Portela Salomão, da Universidad Nacional Autónoma de Mexico – UNAM e coorientada pelos Drs. Marcelo Gordo, da Universidade Federal do Amazonas – UFAM e César Murilo de Albuquerque Correa, da Universidade Federal de Mato Grosso – UFMT.

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

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[X] POR UNANIMIDADE [ ] POR MAIORIA

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

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Sinopse:

Estudamos o efeito da transformação de hábitats naturais em áreas de Campinaranas, localizadas nos municípios de Manaus, Itacoatiara e Manacapuru, Amazonas, Brasil. Comparamos o efeito do tipo do hábitat (conservado e degradado) sobre a diversidade, estrutura da assembleia, abundância, biomassa e espécies indicadoras de besouros rola bosta.

Palavras chaves: Campinarana perturbada, florestas tropicais chuvosas, mineração de areia, Scarabaeinae

“*A Deus, a meus eternos amores da minha vida, meu pai João Batista Ferreira (in memoriam) e a minha mãe Izolina Carvalho Ferreira, dedico*”.

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"Todos os nossos sonhos podem se tornar realidade, se tivermos a coragem de persegui-los". Walt Disney

RESUMO

As Campinaranas consistem em um frágil ecossistema Amazônico de solo arenoso, no qual as atividades de mineração se destacam como um importante promotor de transformações das paisagens naturais, ameaçando a manutenção da biodiversidade. Através de dados de diversidade taxonômica, grupos funcionais e biomassa, os besouros rola bosta tem sido utilizados como uma excelente ferramenta para compreender as consequências das transformações ambientais sobre a biodiversidade nos trópicos. O objetivo deste estudo foi analisar os impactos da transformação do habitat em Campinaranas, proveniente de atividades de mineração de extração de areia, sobre as assembleias de besouros rola bosta, bem como de seus grupos funcionais. Os besouros rola bostas foram amostrados em dois habitats: Campinaranas conservadas (12 áreas) e Campinaranas degradadas (11 áreas). Avaliamos o efeito do tipo do habitat sobre a abundância, diversidade, estrutura da assembleia e biomassa de rola bostas. No total, foram coletados 1.592 indivíduos e 43 espécies nas Campinaranas conservadas, enquanto nas Campinaranas degradadas foram coletados 459 indivíduos identificados em 11 espécies. As Campinaranas conservadas apresentaram assembleias mais abundantes, diversificadas, com maior biomassa e estruturalmente distintas quando comparadas as Campinaranas degradadas. Os besouros roladores foram os únicos que não tiveram sua abundância afetada pelo tipo de habitat. Nossos resultados demonstraram que as áreas naturais de Campinaranas são compostas por comunidades ecológicas sensíveis a alterações ambientais intensas, como as atividades de mineração. A distinta estrutura da assembleia entre os hábitats estudados sugere que existe um sub-grupo da assembleia regional que é especializado a ocupar áreas abertas. Considerando a atual expansão do desmatamento em florestas Amazônicas, é de extrema importância traçar estratégias que visem mitigar os efeitos deletérios de novos mosaicos sobre as comunidades ecológicas.

ABSTRACT

Campinarana is a fragile white-sand Amazonian ecosystem, in which mining activities highlight as an important driver of landscape transformation that challenges biodiversity maintenance. Through taxonomic diversity, functional-group approaches, and species biomass, the dung beetles have been successfully used as proxies to understand the consequences of habitat transformation on ecological communities in the tropics. The aim of this study was to assess the effects of habitat transformation in Campinaranas on the dung beetle assemblages, by analyzing their total data and its functional groups. Dung beetles were sampled in two habitat types: conserved Campinaranas (12 sites), and disturbed ones (11 sites), which were deforested due to mining activities. A total of 1,592 beetles from 43 species were collected in conserved Campinaranas and 459 beetles from 11 species were collected in disturbed Campinaranas. Conserved Campinaranas encompassed higher abundance, diversity, biomass, and their dung beetle assemblages were structurally distinct from disturbed Campinaranas. The abundance of roller dung beetles was not affected by habitat type. Our results suggest that conserved Campinaranas dwell sensitive ecological communities, with most of the species being unable to colonize mining sites. The distinct assemblage observed between the two studied Campinaranas suggest that a subset of species of the regional pool are specialized in inhabiting open areas. Under the current alarming deforestation rates in Amazon, it is urgent to unravel how tolerant are the ecological communities towards novel variegated landscape to mitigate the negative effects of human activities on biodiversity.

SUMÁRIO

INTRODUÇÃO GERAL

Uma das ameaças mais alarmantes para a biodiversidade tropical advém das atividades humanas que transformam as paisagens naturais (Laurance, 1999; Carreno-Rocabado et al., 2012; Vijay et al., 2018; Cruz et al., 2021). A distribuição de espécies tende a ser modificada com estas transformações e consequentemente as comunidades ecológicas são contrastantes quando comparadas às dos ecossistemas originais (Suazo-Ortuno et al., 2008; Senior et al., 2013; Philip et al., 2017; Rurangwa et al., 2021). Essa mudança de comunidades acarreta numa diminuição do número de espécies (Gibson et al., 2011; Barlow et al., 2016; Alroy, 2017; Luther et al., 2020), devido à incapacidade de espécies nativas colonizarem habitats tropicais modificados. Nos trópicos, as florestas úmidas destacam-se como um dos biomas mais ameaçados, devido à expansão de urbanização e extrativismo que vem ocorrendo nos últimos séculos (Myers et al., 2000; Hill & Hamer, 2004). Com isso, ressalta-se que muitos ecossistemas de florestas tropicais estão desaparecendo sem que saibamos sequer a sua importância (Gardner et al., 2009; Ter Steege et al., 2015; Edwards et al., 2019). Conhecendo os níveis de resiliência das espécies à perturbação ambiental, é possível elaborar estratégias que estabeleçam níveis de perturbação antrópica que permitam a manutenção de comunidades saudáveis e que mantenham o funcionamento dos ecossistemas (Stork et al., 2009; Cole et al., 2014; Berenguer et al., 2018).

Embora a Amazônia seja reconhecida como uma floresta tropical relativamente conservada, esse ecossistema tem enfrentado ameaças antrópicas alarmantes que desafiam a manutenção da biodiversidade (Barlow et al., 2016; Nobre et al., 2016). Entre as diversas fitofisionomias Amazônicas, as Campinaranas são caracterizadas por serem vegetações singulares, com diversidade biológica adaptadas a solos constantemente encharcados, com uma florística dominada por alguns gêneros endêmicos e espécies raquíticas (IBGE, 2012; Ferreira et al., 2013; Demarchi et al., 2019; Demarchi et al., 2022). A expansão das atividades pecuárias, plantações, mineração e exploração madeireira se destacam como as principais atividades que transformam as paisagens naturais das Campinaranas (Ferreira et al., 2013; Adeney et al., 2016; Demarchi et al., 2019). Estudos recentes têm apresentado sinais indicando que as Campinaranas são um ecossistema frágil e com baixa resiliência a perturbações ambientais (Adeney et al., 2016; Demarchi et al., 2019; Capurucho et al., 2020). As comunidades biológicas de Campinarana são pouco estudadas, com tendências ainda incipientes quanto à sua dinâmica ecológica, ou seja, ainda não se compreende claramente de que forma responderão as transformações ambientais relativas as atividades humanas (Borges et al., 2016; Demarchi et al., 2022). Neste sentido, devido às constantes e atuais perdas e transformações da vegetação natural das Campinaranas, estudos sobre a biodiversidade desse ecossistema são necessários e urgentes. Para entender melhor como a comunidade de Campinaranas respondem à perturbação ambiental, é crucial avaliar como habitats naturais e alterados moldam a diversidade das suas comunidades ecológicas.

Os besouros rola bostas (Coleoptera: Scarabaeinae) constituem um responsivo grupo para compreender as consequências ecológicas das transformações ambientais nos trópicos (Navarrete & Halffter, 2008; Korasaki et al., 2013; Filgueiras et al., 2015; Moura et al., 2021). As modificações nos ambientes tendem a afetar negativamente, a distribuição das espécies, diminuindo a diversidade e abundância das assembleias de rola bostas (Filgueiras et al., 2015; Carrión-Paladines et al., 2021; Moura et al., 2021). Somado a isso, a biomassa destes insetos também pode indicar pistas sobre as consequências das transformações ambientais, tendo em vista que ambientes antropizados são pouco favoráveis a espécies de maior biomassa (Horgan, 2005; Braga et al., 2013; Nependa et al., 2021). Para obter respostas mais detalhadas das assembleias de besouros rola bostas, estudos dos seus diferentes grupos funcionais têm sido utilizado nas últimas décadas (Louzada et al., 2010; Nichols et al., 2013; Gómez-Cifuentes et al., 2019). Como a biologia desses insetos está intimamente relacionada com o comportamento de localização e remoção de excremento, as estratégias de remoção de recursos têm sido amplamente usadas como um agrupamento de espécies de acordo com a sua função (Louzada et al., 2010; Latha, 2020; Hussain et al., 2021). As espécies cavadoras estruturam galerias abaixo ou ao lado da fonte de alimento. As espécies roladoras fazem esferas de esterco e posteriormente as rolam a diferentes distâncias; as espécies residentes se alimentam e nidificam dentro da própria fonte de alimento utilizando este recurso para alimentação e nidificação (Campos & Hernández, 2013; Pessoa et al., 2017; Huerta et al., 2018). Devido a essas diferentes estratégias de alimentação e reprodução, cada grupo funcional percebe o ambiente de uma forma diferente (Gómez-Cifuentes et al., 2017; Carvalho et al., 2020). Além de desempenharem papel fundamental como bioindicadores a humanidade, os rola bostas também prestam serviços ecossistêmicos importantes. Devido ao enterramento de recursos em decomposição (p.ex. excremento e carniça), os rola bostas aumentam a aeração e incorporação de nutrientes ao solo, favorecem o estabelecimento de mudas e promovem a dispersão secundária de sementes (Nichols et al., 2008; Beynon et al., 2012; Manning et al., 2016).

As assembleias de rola bostas que ocorrem na floresta tropicais são sensíveis à transformação dos ambientes naturais devido a atividades humanas, que resultam em uma redução na sua diversidade (Vulinec, 2002; Scheffler, 2005; Braga et al., 2013; Giménez-Gómez et al., 2020). Entre as atividades que afetam a diversidade dos rola bostas estão as atividades de mineração, que acarretam uma redução do número de espécies quando comparado a habitats conservados (Davis et al., 2002; Hernández et al., 2014). Além disso, as espécies que toleram ambientes desmatados apresentaram hábitos generalistas e, tamanhos corporais reduzidos (Davis et al., 2002; Hernández et al., 2014; Giménez-Gómez et al., 2020). Com relação às Campinaranas Amazônicas, a incipiente quantidade de estudos sobre besouros rola bosta sugere que suas assembleias são relativamente pobres, especialmente quando comparadas a ecossistemas Amazônicos vizinhos (Silva, 2009; Filho et al., 2017; Salomão et al., 2023). Entretanto, até o momento não há estudos que avaliaram os efeitos das transformações humanas do habitat na diversidade de besouros rola bosta em Campinaranas.

OBJETIVOS

O objetivo deste estudo foi analisar os impactos da transformação de habitats nas Campinaranas (devido a atividades de extração de areia) sobre as assembleias de besouros rola bosta. Mais especificamente, comparamos a diversidade taxonômica, abundância, estrutura da assembleia (distribuição de cada espécie), biomassa e espécies indicadoras entre Campinaranas conservadas e perturbadas na Amazônia Central. A fim de obter respostas mais precisas, analisamos os rola bostas através dos dados totais, bem como por grupo funcional de acordo com a estratégia de remoção de recursos (rolador, cavador, residente).

Capítulo 1

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Manuscrito enviado à *Biotropica*.

What do we lose by removing sand from Amazonian forests? Dung beetle diversity in conserved and deforested white-sand rainforests

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Abstract

Campinarana is a fragile white-sand Amazonian ecosystem, in which mining activities highlight as an important driver of landscape transformation that challenges biodiversity maintenance. Through taxonomic diversity, functional-group approaches, and species biomass, ~~the~~ dung beetles have been successfully used as proxies to understand the consequences of habitat transformation on ecological communities in the tropics. The aim of this study was to assess the effects of habitat transformation in Campinaranas on the dung beetle assemblages, by analyzing their total data and its functional groups. Dung beetles were sampled in two habitat types: conserved Campinaranas (12 sites), and disturbed ones (11 sites), which were deforested due to mining activities. A total of 1,592 beetles from 42 species were collected in conserved Campinaranas and 459 beetles from 11 species were collected in disturbed Campinaranas. Conserved Campinaranas encompassed higher abundance, diversity, biomass, and their dung beetle assemblages were structurally distinct from disturbed Campinaranas. The abundance of roller dung beetles was the only parameter that was not affected by habitat type. Our results suggest that conserved Campinaranas dwell sensitive ecological communities, with most of the species being unable to colonize mining sites. The distinct assemblage observed between the two studied Campinaranas suggest that a subset of species of the regional pool are specialized in inhabiting open areas. Under the current alarming deforestation rates in Amazon, it is urgent to unravel how tolerant are the ecological communities towards novel variegated landscape to mitigate the negative effects of human activities on biodiversity.

Keywords: Biodiversity monitoring, Ecological indicators, Scarabaeinae, sand mining, tropical rainforest

Introduction

One of the most alarming threats for tropical biodiversity comes from the human activities that transform natural landscapes (Carreno-Rocabado et al., 2012; Vijay et al., 2018; Cruz et al., 2021). Together with the transformation of native habitats into human ones, the species distribution and assemblage structure tend to be modified, with novel ecological communities that contrasts with those from the original pristine ecosystems (Suazo-Ortuno et al., 2008; Senior et al., 2013; Rurangwa et al., 2021). Such communities shift comes together with decreased species richness (Gibson et al., 2011; Alroy, 2017; Luther et al., 2020), since most native species are unable to colonize and use the modified tropical habitats. In the tropics, the tropical rainforests are highlighted as one of the most threatened biomes (Myers et al., 2000), which have been highly impacted in the last centuries due to natural resource extraction, pasturelands, and plantations (Hill & Hamer, 2004), jeopardizing tropical biodiversity. By analyzing different parameters of communities (e.g., taxonomic diversity, abundance, biomass, functional groups) it is possible to depict how these novel ecosystems drive species distribution (Carreno-Rocabado et al., 2012; Cruz et al., 2021). The assessment of the biological consequences of habitat transformation due to human activities in poorly studied tropical rainforests are essential for broader comprehensions of the landscape transformation in the tropics.

Although Amazonian has been recognized as a huge and relatively conserved rainforest, this ecosystem has been facing alarming human threats that challenge biodiversity maintenance (Barlow et al., 2016; Nobre et al., 2016). Among the Amazonian physiognomies, Campinaranas highlight due to its vegetation highly adapted to floodable soils, as well as notable endemic genera (e.g. Anona, Galactophora, Chaunochiton, Dendropanax, Protium) (IBGE, 2012; Ferreira et al., 2013; Demarchi et al., 2019; Demarchi et al., 2022). The expansion of livestock activities, plantation, mining, and logging are the main human activities that transforms natural landscapes of the Campinaranas (Ferreira et al., 2013; Adeney et al., 2016; Demarchi et al., 2019). Recent studies have pointed out Campinaranas as a fragile ecosystem with low resilience to environmental disturbances (Ferreira et al., 2013; Adeney et al., 2016; Demarchi et al., 2019). Campinarana communities are poorly studied, with still incipient trends regarding its ecological dynamics (Borges et al., 2016; Demarchi et al., 2022). To better understand how Campinaranas' communities respond to environmental disturbance, it is crucial to assess how natural and non-natural habitats shape species diversity.

Dung beetles (Coleoptera: Scarabaeinae) comprise a noteworthy biological group to analyze the ecological consequences of environmental transformation in the tropics (Navarrete & Halffter, 2008; Korasaki et al., 2013; Filgueiras et al., 2015; Moura et al., 2021). These beetles are sensitive to environmental transformation, with marked and rapid shifts in species distribution, diversity, and abundance patterns due to the change in native habitats (Filgueiras et al., 2015; Carrión-Paladines et al., 2021; Moura et al., 2021). Moreover, dung beetle biomass is also related to environmental transformations, since the transformation of native habitats into human ones tends to filter large-bodied species (Horgan, 2005; Braga et al., 2013; Nependa et al., 2021). For a more detailed response of dung beetle assemblages, studies comprising their functional groups have successfully been used in the tropics (Louzada et al., 2010; Nichols et al., 2013; Gómez-Cifuentes et al., 2019). One of the most studied dung beetles' functional groups encompass the resource removal strategies, in which species are classified as tunnellers, dwellers, or rollers (Louzada et al., 2010; Latha, 2020; Hussain et al., 2021). Tunnellers dig galleries beneath or aside from the dung pad, removing the food resource that is used for feeding and nesting (Halffter & Edmonds, 1982). Roller dung beetles roll dung portions that are used for feeding (food balls) or breeding (brood balls), while dwellers feed and nest inside dung pad (Campos & Hernández, 2013; Huerta et al., 2018). Due to these different feeding and breeding strategies, each functional group perceive the environment in a different way (Gómez-Cifuentes et al., 2017; Carvalho et al., 2020). Besides their key role as bioindicators, dung beetles also perform key ecosystem services. By the removal and burial of decomposing resources (e.g., dung and carrion), dung beetles increase aeration and incorporate nutrients to the soil, favor seedling establishment and promote secondary seed dispersal (Nichols et al., 2008; Korasaki et al., 2013; Moura et al., 2021).

Previous studies suggest that Amazon Forest harbors sensitive dung beetles assemblages that are sensitive to human habitat transformation, which negatively affect their species richness, abundance, and biomass (Vulinec, 2002; Scheffler, 2005; Braga et al., 2013). The currently scarce literature suggests that dung beetle assemblages from Campinaranas comprise relatively poor assemblages, especially when compared to neighboring Amazonian ecosystems (Silva, 2009; Filho et al., 2017; Salomão et al., 2023). To our knowledge, there are no studies that assessed the effects of human habitat transformations on dung beetle diversity in Campinaranas. The aim of this study was to analyze the impacts of habitat transformation of Campinaranas on dung beetle assemblages. More specifically, we compared dung beetle diversity, abundance, assemblage structure (i.e. distribution of species' abundances), biomass, and indicator species between conserved and disturbed Campinaranas in Central Amazon. As disturbed Campinaranas we used sites that were used for mining activities for sand extraction. To obtain finer responses regarding habitat transformation dynamics on dung beetle assemblage, we analyzed total data and each functional group according to resource removal strategy (roller, tunneller, dweller). Tropical rainforests are strongly sensitive to human habitat transformation, which includes mining activities (Ibrahim et al., 2020; Jordão et al., 2021; Chaddad et al., 2022). Since Campinaranas are sensitive ecosystems (Ferreira et al., 2013; Adeney et al., 2016; Demarchi et al., 2019), we expect that conserved Campinaranas will have higher diversity, abundance, biomass, and number of indicator species compared to disturbed

Campinaranas. Consequently, it is expected a distinct assemblage structure between conserved and disturbed Campinaranas.

2. Material and methods

2.1. Study site

This study was carried out in three Brazilian municipalities of the Amazonas state (Manaus, Itacoatiara, Manacapuru) located in Central Amazonia (ranging from 2°32’ to 3°09’S, and from 60°45’ to 58°59’W, Fig. 1). According to Köppen-Geiger, the climate of the region is classified as humid equatorial (Af), with mean annual temperature of 26.7 °C and mean annual rainfall of 2,277 mm (Emidio da Silva et al., 2011; Souza & Alvalá, 2014). The region is markedly seasonal, with a dry period ranging between June and December (mean monthly rainfall: 100.17 mm), and the rainy period ranging from January to May (mean monthly rainfall: 279.3 mm) (Emidio da Silva et al., 2011; Souza & Alvalá, 2014).

In the study region, there are different native Amazonian physiognomies, with *terra firme* (non-floodable tropical rainforest) being the most widespread one. Besides, *várzea* and *igapó* (floodable forests), Campina and Campinarana are also widely distributed in the region (Hopkins, 2005; Ferreira, 2009; Carvalho et al., 2018; Demarchi et al., 2022). For this study, we focused on Campinaranas, which comprise a closed-canopy forest with sandy soils and shallow water tables (Lima, 2015; Adeney et al., 2016; Demarchi et al., 2018; Demarchi et al., 2022). It is important to consider that Campinaranas have been recently deforested due to sand extraction for construction of human settlements.

We studied dung beetle assemblages in conserved and disturbed Campinaranas. Conserved Campinaranas had minimum human disturbances, conserving the original vegetation structure of these physiognomies, with closed canopy with trees ranging from 5 to

15 m of height. Disturbed Campinaranas are mostly open forests, with its vegetation structure ranging from sites with no plants and only exposed soils to sites with a few sparse grasses and shrubs. In these degraded environments, the original vegetation and most of the sand in the soil were removed.

2.2. Sampling design

We sampled dung beetles in conserved and disturbed Campinaranas. Disturbed and conserved Campinarana sites were spatially paired, each site being ca. 100 m apart from each other. In all, 12 areas were sampled, each area with a point in a conserved Campinarana and another point in a disturbed Campinarana. Each of the 12 areas was at least 1 km distant from the nearest area, to guarantee the independence of the samples (Silva et al., 2020). At each studied point (i.e., conserved, or disturbed Campinarana), dung beetles were sampled in a 100 m long transect. In each transect, a set of five pitfall traps was installed, at ca. 20 m from each other (Silva & Hernandez, 2015). We had a total effort of 120 pitfall traps (5 pitfalls per Campinarana * 2 habitats [conserved Campinarana and disturbed Campinarana] * 12 areas). One of the disturbed Campinaranas had their pitfalls destroyed in the field, thus this sample was discarded.

We made pitfall traps consisting of plastic containers (500 ml) installed at ground level. We partially filled each container with 250 ml of saline solution + neutral detergent (1.5%) to conserve the sampled dung beetles (Correa et al., 2016). We placed a plastic lid (15 cm in diameter) supported by three wooden sticks (25 cm) above each trap, suspending them 20 cm above the ground to reduce bait desiccation and prevent potential rain damage. We positioned the bait (ca. 25 fresh human excrement) in 50 ml plastic containers at the center of each trap using a wire as a bait holder. This bait was used due to its high attractiveness for dung beetles (Silva et al., 2012; Correa et al., 2016). The traps were placed in the field for 48 h, and the beetles were collected after this interval.

To identify the collected dung beetles, we consulted specialized literature (e.g., Edmonds & Zidek, 2010; Vaz-de-Mello et al., 2011; Gonzáles-Alvarado & Vaz-de-Mello, 2021) and comparison with material deposited in the entomological collection from the Federal University of Mato Grosso (CEMT-UFMT). We considered as rare species only those that presented between one and two individuals (i.e., singleton or doubleton). We classified the sampled species into three functional groups related to resource removal strategies (tunneller, dweller, roller) (Halffter & Edmonds, 1982).

To estimate the species average weight, the sampled beetles were first dried in an oven at 50° C for 72 hours, then 1 to 20 individuals of each species were weighed (depending on the availability of individuals) on a precision scale (model AB265 -S, FACT, 10^{-5} g accuracy) (Salomão et al., 2020). The biomass of dung beetles was estimated for each sampled site through the dry weight values of the species, using the total biomass (average biomass of each species * number of individuals of each species collected) and the average biomass (sum of the average biomass of each species).

2.3. Data analysis

So that the analyzes of dung beetle assemblages were properly sampled in each habitat type (disturbed and conserved Campinaranas), sampling coverage was estimated using individual-based approach in iNEXT online software (Chao, 2022).

Dung beetle diversity was estimated by using Hill numbers. Diversity was analyzed under three orders: q0 (species richness), q1 (exponential of Shannon diversity), and q2 (inverse of Simpson) (Hill, 1973; Jost, 2006). Diversity order q0 do not consider species abundance from the assemblages, thus representing species richness *per se*. Diversity order q1 is sensitive to species' relative abundances, and this order indicates the number of abundant species from an assemblage. Diversity order q2 gives more weight to species abundance than q1 and indicate the number of dominant species. To obtain diversity numbers, we used individual-based approach, thus estimating diversity for each study habitat (i.e., calculating q0, q1, and q2 for conserved and disturbed Campinaranas). Diversity numbers were estimated for the entire assemblage and for each functional group (rollers, tunnellers, dwellers) separately. Comparisons of diversity between the conserved and disturbed Campinaranas were conducted based on the confidence intervals of the estimated diversity numbers, which were obtained in the software online iNEXT (Chao, 2022). The comparisons between habitats were analyzed based on confidence intervals.

To assess the effect of habitat type on dung beetles' abundance, total and mean biomass, both for the entire assemblage, and for each functional group, Generalized Linear Models with Mixed Effects (GLMM) and Linear Mixed Effects Models (LME) were used. Habitat type (conserved and disturbed Campinaranas) was the predictor variable, and abundance, total and mean biomass were the response variables. All the sampling sites are located near Negro river, which is an important biogeographic barrier for ecological communities of the region (Naka & Brumfield, 2018; Nazareno et al., 2019). Therefore, river margin was used as random effect in the models. Samples performed in Manacapuru municipality were located at the right margin of the Negro river, while samples located in Manaus and Itacoatiara municipalities were located at left margin of the river (Fig. 1). Proper models and data distribution families were used for each response variable, which were selected based on data normality and dispersion, homocedasticity, and outliers (see Supplementary material). GLMMs and LMEs were done with car, lme4, and MASS packages (Bates et al., 2022; Fox et al., 2022; Ripley et al., 2023) in R software version 4.2.0 (R Development Core Team, 2022).

Nonmetric Multidimensional Scaling (NMDS) were performed to explore dung beetle assemblages (entire assemblage and for each functional group) sampled in conserved and disturbed Campinaranas. To statistically compare differences of dung beetle assemblages between habitat types, Permutational Analysis of Variance (PERMANOVA) were used. Furthermore, Permutational Analysis of Dispersion (PERMDISP) was performed to compare the heterogeneity of multivariate dispersion between habitat types. NMDS, PERMANOVA, and PERMDISP were performed using Bray-Curtis similarity matrix, which is sensitive to species abundance in each sample. NMDS was performed in PRIMER software version 6 (Clarke & Gorley, 2006). PERMANOVA and PERMDISP were performed in vegan, permute, and lattice packages, in R software (Oksanen et al., 2022; R Development Core Team, 2022; Sarkar et al., 2022; Simpson et al., 2022).

Indicator Value method (IndVal) was used to assess the potential of each species as indicator of conserved or disturbed Campinaranas. This method was based on species abundances (specificity degree) and frequency (fidelity degree) throughout the samples. In this sense, species with high fidelity to one of the studied habitats (high abundance and frequency) were classified as indicators (Pimenta & De Marco, 2015; Gonçalves et al., 2022). IndVal was performed with indicspecies package in R software (Caceres et al., 2022; R Development Core Team, 2022).

3. Results

We collected a total of 2,051 individuals from 51 species and 16 genera of dung beetles (Table 1). In conserved Campinaranas, we collected 1,592 individuals (*s* = 43), while we collected 459 individuals (*s* = 11) in disturbed Campinaranas. In conserved Campinaranas *Canthidium deyrollei* Harold, 1867 (*n* = 479), *Dichotomius lucasi* (Harold, 1869) (*n* = 212), *Hansreia grossi* (Valois, Vaz-de-Mello e Silva, 2015) (*n* = 121), and *Canthon sordidus* Harold, 1868 (*n* = 112) were the most abundant species, representing 53% of the total individuals collected in this habitat (Fig. 2). In disturbed Campinaranas, the most abundant species were *Pseudocanthon xanthurus* (Blanchard, 1843) (*n* = 161), *Canthon* sp1 (*n* = 80), *Canthon* sp6 (*n* = 71), and *Tetraechma liturata* (Germar, 1822) (*n* = 60), which comprised 81% of the individuals collected in this habitat (Fig. 2). There was a total of 12 rare species (i.e., singleton or doubleton). Eleven rare species were exclusively found in conserved Campinaranas (Table 1), and *Canthidium* cf. *melanocephalum* (Olivier, 1789), was the only rare species that co-occurred in both habitat types. Sampling coverage was high for both conserved (99%) and disturbed (100%) Campinaranas.

Among the functional groups, tunnellers were the more speciose (*s* = 26) and abundant (*n* = 985) dung beetles in the studied Campinaranas (Table 1). All tunneller species were recorded in conserved Campinaranas (*n* = 948), and only three of them (*n* = 37) were recorded in disturbed Campinaranas (*C.* cf. *melanocephalum, Canthidium humerale* (Germar, 1813), *D. lucasi*). Roller was the second most speciose (*s* = 17) and abundant (*n* = 926) functional group. Eleven of the roller species were recorded exclusively in conserved Campinaranas (*n* = 504) (Table 1), while six species were exclusively recorded in disturbed Campinaranas (*n* = 422). No roller species co-occurred in conserved and disturbed Campinaranas. Dweller dung beetles were the least speciose and abundant group in the studied sites (*s* = 6, *n* = 280), being collected exclusively in conserved Campinaranas.

Due to the absence of dweller beetles in disturbed Campinaranas, no analyses were performed regarding the effect of habitat type on their diversity, abundance, biomass, or assemblage structure.

3.1. Diversity, abundance, and biomass

Dung beetle species richness (q0) was higher in conserved Campinaranas compared to disturbed ones. Such difference was found both for the entire assemblage (Fig. 3A), as well as for the different functional groups (tunnellers – Fig. 3B, rollers – Fig.3C). Likewise, the number of abundant (q1) and dominant (q2) dung species were also higher in conserved than disturbed Campinaranas, being such pattern observed for the entire assemblage and for each functional group separately (Figs. 3D-I). Dung beetle abundance, total and mean biomass were also higher in conserved Campinaranas than in disturbed Campinaranas (Fig. 4). The only non-significant group was the roller species, being its abundance similar between conserved and disturbed Campinaranas ($X^2_1 = 0.09$; $p = 0.76$).

3.2. Assemblage structure and indicator species

Of the 51 species recorded in the studied Campinaranas, 40 were exclusively recorded at conserved Campinaranas and seven were exclusively recorded in disturbed Campinaranas (Fig. 2, Table 1). Only three species (*C. humerale, C. cf. melanocephalum*, and *D. lucasi*) co-occurred in both Campinaranas. When analyzing the entire assemblage, dung beetle assemblage was structurally different between conserved and disturbed Campinaranas (Fig. 5A, PERMANOVA: $F_{1,21} = 7.05$, $P < 0.01$). The same pattern was observed when analyzing roller (Fig. 5B, $F_{1,21} = 6.61$, $P < 0.01$) and tunneller (Fig. 5C, $F_{1,13} = 3.44$, $P < 0.01$) assemblages. Regarding the heterogeneity of the multivariate dispersion (PERMDISP), no statistical difference was found for the entire assemblage ($F_{1,21} = 1.04$, $P = 0.30$), as well as for roller ($F_{1,21} = 0.04$, $P = 0.84$) and tunneller ($F_{1,13} = 0.03$, $P = 0.85$) assemblages.

Of all the collected species, 20 of them (39%) were categorized as indicator species, 14 of them considered as indicator of conserved Campinaranas and six as indicators of disturbed Campinaranas (Table 2).

4. Discussion

Tropical rainforests are especially sensitive to environmental transformations resulting from human activities (Araújo et al., 2014; Stratford & Stouffer, 2015; Chamberlain et al., 2017; Chaddad et al., 2022). The results of our study demonstrate that the deforestation of native Campinarana for the sand-extraction practice results in a novel and impoverished dung beetle assemblage. Except for the roller beetles, all other functional groups followed this marked decrease of diversity and abundance with the conversion of conserved into disturbed Campinarana, highlighting the harmful conditions posed by the transformation of this ecosystem. Such results are surprising, considering that disturbed Campinaranas are surrounded by conserved forest, which could promote the movement of species from conserved Campinaranas to the deforested ones.

Dung beetle diversity was markedly reduced in disturbed Campinaranas s, presenting ca. 25% of the species richness found in conserved Campinaranas. Regarding the biotic homogenization of dung beetles in tropical rainforests, many abiotic (e.g., temperature) and biotic factors (e.g., resource availability) has been proposed as key parameters that drive species distribution (Edwards et al., 2017; Raine et al., 2018; Beiroz et al., 2019; Correa et al., 2020a; Daniel et al., 2022). The reduced diversity of dung beetles in disturbed Campinaranas may indicate that most of the species pool in this ecosystem are unable to use open-canopy habitats. In other tropical rainforests, the substitution of closed-canopy cover (as the one found in conserved Campinarana) by open-canopy cover (e.g. herbaceous, secondary vegetation, as the one found in disturbed Campinarana) lead to a reduced number of dung beetle species (Attuquayefio et al., 2017; Rajpar, 2018; Gomez-Cifuentes et al., 2020; Noriega et al., 2021). According to our results, we may propose that with the spread of deforestation in Campinaranas, dung beetle diversity may suffer from a regional biotic homogenization process. Such trend has been already observed in other Amazon phytophysiognomies (Lees & Peres, 2006; Spaniol et al., 2020; Borges et al., 2021), as well as in other tropical rainforests (Pavlacky Jr et al., 2015; Zemanova et al., 2017; Tchoumbou et al., 2020). In a functional perspective, the decrease of dung beetle diversity has clear negative consequences on ecosystem functioning, limiting their roles in seed dispersal and soil bioturbation (Campos & Hernández, 2015; Gomez-Cifuentes et al., 2017; Correa et al., 2020a; Noriega et al., 2021; Stanbrook et al., 2021). Thus, one of the main threats that the decrease dung beetle diversity in disturbed Campinaranas may come from the functions provided by these insects (Feer & Boissier, 2015; Batista et al., 2016; Daniel et al., 2022). Since reforestation practices are uncommon in this system, it is crucial to understand the dynamics of forest regeneration and how the services come along through such process.

Abundance and biomass were also markedly reduced in deforested Campinaranas compared to conserved ones. In the current study, the species with highest biomass (*Coprophanaeus lancifer* (Linnaeus, 1767), *Coprophanaeus jasius* (Olivier, 1789), *Dichotomius boreus* (Olivier, 1789)) were collected exclusively in conserved Campinaranas, while some of the species with lowest biomass (e.g. *T. liturata*, *P. xanthurus*, *Onthophagus bidentatus* Drapiez, 1819) were more commonly found in disturbed Campinaranas. There are deforested ecosystems that encompass highly-abundant arthropods assemblages compared to its original vegetation (Adu-Acheampong et al., 2016; Kyerematen et al., 2018; Kyerematen et al., 2020). Nonetheless, most ecosystems present a decrease in abundance and biomass of dung beetles, which comes together with deforestation in the tropics (Nichols et al., 2007), as observed herein. The low abundance and biomass in deforested Campinaranas could reflect the limiting energetical and physiological scenario for the establishment of higher populations of the species found in this region. This limitation may be analyzed under two interesting perspectives: the resource avaiability and the thermo regulation.

The environmental conditions posed by the deforested Campinarana potentially result in an ecosystem with limited food availability, since mammals (main food providers of dung beetle, see Feer & Boissier 2015; Bogoni et al., 2016; Chiew et al., 2022) may avoid using this habitat. For conserved Campinaranas, previous studies reported the presence of the following mammals who habit in this habitat type, such as *Pecari tajacu*, *Tayassu pecari*, *Alouatta seniculus*, *Cebus apella* (Endo, 2005; Pontes et al., 2012; Caramaschi et al., 2013; Andrade Melo et al., 2015). Furthermore, the high light incidence and temperatures found in open-canopy habitats cause rapid drought of juicy food resources as the excrements (Costa et al., 2013; Gomez-Cifuentes et al., 2017; Correa et al., 2020b; Latha & Thomas, 2020), causing them to rapidly be unavailable for dung beetles.

Besides the potential food limitation for dung beetles in deforested Campinarana, the higher temperatures found in open habitats compared to closed ones (Gomez-Cifuentes et al., 2017; Correa et al., 2020a; Giménez-Gómez et al., 2020) work as a physiological barrier for larger dung beetles, which may not properly thermoregulate in warmer habitats (Gomez-Cifuentes et al., 2017; Correa et al., 2020a; Giménez-Gómez et al., 2020). The scenario drawn by the dung beetle assemblages in deforested Campinarana are worrysome, in which we observe a decrease of both diversity, abundance, and biomass. As well as diversity, biomass and abundance are key factors for the provision of dung beetle services (Campos & Hernández, 2015; Gomez-Cifuentes et al., 2017; Correa et al., 2020b; Noriega et al., 2021; Stanbrook et al., 2021). With less and lower-biomass individuals, lower amounts of ecological services are performed (Campos & Hernández, 2015; Salomão et al., 2018; Correa et al., 2020a; Noriega et al., 2021). Under this rationale, our study reinforces the scenario of decreases of dung beetle activity with the loss of native vegetal cover in the tropics. Moreover, compared to other tropical rainforests (e.g. Carpio et al., 2009; Costa et al., 2013; França et al., 2018) Amazonian ecological communities seems to be more sensitive, which may be a result of the still conserved status of its vegetation.

While tunnellers and dwellers presented marked lower diversity and abundances in disturbed Campinaranas than conserved Campinaranas, roller beetles showed similar abundances in both studied habitats. This pattern was observed by the dominant species in each habitat type, with disturbed Campinaranas being dominated by roller species (*Canthon* species and *P. xanthurus*), while conserved Campinarana was dominated by species from different functional groups (tunneller – *C. deyrollei*, roller – *C. sordidus*, and dweller – *Eurysternus atrosericus* Génier, 2009). The relative small body size, high tolerance to sunlight exposure, and rapid resource removal are some aspects often inherent to roller dung beetles (Quintero & Roslin, 2005; Vieira et al., 2008; Peyras et al., 2013; Ribeiro et al., 2022). The roller species found in disturbed Campinaranas of the current study comprise some of the smallest dung beetles of the regional pool of species. It is important to consider that two of the most abundant roller species found in disturbed Campinaranas (*P. xanthurus* and *T. liturata*) are widespread species, being highly abundant in pastures of the different South American ecosystems (Silva et al., 2014; Rangel-Acosta et al., 2020; Nazare-Silva & Silva, 2021), which indicates that they are tolerant to open and anthropogenic sites. This could suggest that the abundant roller dung beetles found in disturbed Campinaranas comprise species that tolerate different environmental conditions, including the limiting ones found in deforested habitats of this study. By the functional approach used in this study, we presented trustworthy data indicating that although overall diversity and abundance is reduced in disturbed Campinaranas, there are a few roller species that thrive in this habitat type, presenting a relatively high abundance. This result seems to indicate that few widespread species allow the maintenance of a similar abundance of roller species between conserved and deforested habitats.

Assemblage structure was markedly distinct between conserved and disturbed Campinaranass, with only three of the 51 recorded species co-occurring in both studied habitats. Furthermore, the number of indicator species of conserved Campinaranas were higher than those of disturbed Campinaranas. Such pattern is in accordance to those observed in neighboring tropical ecosystems of South America. For example, the conversion of native tropical forests into plantation matrices (e.g. sugarcane), livestock, and urban ecosystems structured novel and markedly distinct dung beetle assemblages compared to those observed in conserved habitats (Farias & Hernández, 2017; Salomão et al., 2019; Correa et al., 2020b; Correa et al., 2021). Two possible dynamics may explain the patterns found herein, which come from the ecological dynamics of the Campinaranas, or from the expansion of deforestation of South American ecosystems. Since there are natural open habitats in tropical rainforests (e.g. forest clearings), there are dung beetle species that are adapted (and even specialized to dwell in such sites (Costa et al., 2013). Another hypothesis is that the expansion of deforestation, consequently increasing the amount of open habitats, results in the dispersal of species from neighboring savannah-like ecosystems (e.g. Cerrado and Tepuis) (Maldaner et al., 2021). These two hypotheses need to be carefully tested in order to present a clear assessment of the impacts of Campinarana habitat transformation. In spite of that, the distinct dung beetle assemblage and indicator species found in each Campinarana suggest that a species substitution process is the one that drives assemblage heterogeneity in this Amazonian mosaic of conserved and disturbed ecosystems.

4.1. Conclusions and conservation implications

The transformation of native forests due to human activities in the tropics is an example of the challenging issues for the establishment of sustainable land uses worldwide (Myers et al., 2000). Amazon forest highlight due to the recent alarming growth of deforestation practices, which threatens its ecological communities (Fearnside, 2005; Garrett et al., 2021; López, 2022). Our findings demonstrate that Campinaranas are composed by sensitive dung beetle assemblages, which have low tolerance to the novel habitats that come from the deforestation practices. The disturbed Campinaranas showed a marked turnover in species composition, with a drastic decrease of key species groups (e.g. tunnellers, dwellers, and large-bodied species). With this transformation of the original dung beetle assemblage, our results suggest that the structure and ecological functioning of Campinaranas are constrained after the removal of the original forest cover. Considering the imminent expansion of deforestation practices in tropical rainforests, it is of utmost importance to design strategies aiming to decrease the deleterious effects of deforestation in sensitive ecosystems as the Campinaranas.

Finally, environmental restauration programs in deforested areas for mining activities, as well as studies of landscape ecology and long-term effects of habitat loss may be crucial for biodiversity conservation of Campinarana political scenario (Haddad et al., 2015; Arroyo-Rodríguez et al., 2020; Fahrig, 2020). In a study performed in a temperate ecosystem, Dulias (2010) provided cues indicating how the management and restoration of mining sites can promote biodiversity recovery. Thus, considering the alarming scenario of Campinarana deforestation, studies on ecological impacts of anthopic activities on biodiversity may assist to provide information that support public policies to mitigate ecological lossess causes by deforestation in this Amazonian ecosystem.

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References

Adeney, J. M., Christensen, N. L., Vicentini, A., & Cohn-Haft, M. (2016). White-sand ecosystems in Amazonia. *Biotropica*, 48(1), 7-23. https://doi.org/10.1111/btp.12293

Adu-Acheampong, S., Bazelet, C. S., & Samways, M. J. (2016). Extent to which an agricultural mosaic supports endemic species-rich grasshopper assemblages in the Cape Floristic Region biodiversity hotspot. Agriculture, *Ecosystems & Environment*,227, 52-60. https://doi.org/10.1016/j.agee.2016.04.019

Alroy, J. (2017). Effects of habitat disturbance on tropical forest biodiversity. *Proceedings of the National Academy of Sciences*, 114(23), 6056-6061. www.pnas.org/lookup/suppl/doi:10.1073/pnas.1611855114

Andrade Melo, É. R., Gadelha, J. R., de Nazaré Domingos da Silva, M., da Silva, A. P., & Pontes, A. R. M. (2015). Diversity, abundance and the impact of hunting on large mammals in two contrasting forest sites in northern amazon. *Wildlife Biology*, 21(5), 234-245. doi: 10.2981/wlb.00095

Araújo, W. S., do Espírito-Santo Filho, K., Bergamini, L. L., Gomes, R., & Morato, S. A. A. (2014). Habitat conversion and galling insect richness in tropical rainforests under mining effect. *Journal of insect conservation*, 18, 1147-1152. https://doi.org/10.1007/s10841-014-9725-6

Arroyo-Rodríguez, V., Fahrig, L., Tabarelli, M., Watling, J. I., Tischendorf, L., Benchimol, M. *et al.* (2020). Designing optimal human-modified landscapes for forest biodiversity conservation. *Ecology letters*, 23(9), 1404-1420. https://doi.org/10.1111/ele.13535

Attuquayefio, D. K., Owusu, E. H., & Ofori, B. Y. (2017). Impact of mining and forest regeneration on small mammal biodiversity in the Western Region of Ghana. *Environmental monitoring and assessment*, 189, 1-9. doi 10.1007/s10661-017-5960-0

Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Nally, R. M. *et al.* (2016). Human disturbance in tropical forests can double biodiversity loss from deforestation. *Nature*, 535(7610), 144-147, doi:10.1038/nature18326

Bates, D., Maechler, M., Bolker, B., Krivitsky, P.N. *et al.* (2022). Linear Mixed-Effects Models using 'Eigen' and S4. Versão 1.1-31. R packages lme4. Available from: https://github.com/lme4/lme4

Batista, M. C., Lopes, G. D. S., Marques, L. J. P., & Teodoro, A. V. (2016). The dung beetle assemblage (Coleoptera: Scarabaeinae) is differently affected by land use and seasonality in northeastern Brazil. *Entomotropica*, v. 31(13), 95-104.

Beiroz, W., Barlow, J., Slade, E. M., Borges, C., Louzada, J., & Sayer, E. J. (2019). Biodiversity in tropical plantations is influenced by surrounding native vegetation but not yield: A case study with dung beetles in Amazonia. *Forest Ecology and Management*, 444, 107-114. https://doi.org/10.1016/j.foreco.2019.04.036

Berenguer, E., Gardner, T. A., Ferreira, J., Aragão, L. E., Mac Nally, R., Thomson, J. R. *et al.* (2018). Seeing the woods through the saplings: Using wood density to assess the recovery of human-modified Amazonian forests. *Journal of Ecology*, 106(6), 2190-2203. doi: 10.1111/1365-2745.12991

Beynon, S. A., Mann, D. J., Slade, E. M., & Lewis, O. T. (2012). Species-rich dung beetle communities buffer ecosystem services in perturbed agro-ecosystems. Journal of Applied Ecology, 49(6), 1365-1372. doi: 10.1111/j.1365-2664.2012.02210.x

Bitencourt, B. S. (2018). *Efeito da sucessão florestal e da estrutura da vegetação sobre assembleias de Scarabaeinae (Insecta: Coleoptera) em uma Floresta Tropical.* Dissertação (Mestrado). Universidade Federal do Acre, Programa de Pós-Graduação em Ecologia e Manejo de Recursos Naturais. Rio Branco, AC, p. 18.

Bogoni, J. A., Graipel, M. E., de Castilho, P. V., Fantacini, F. M., Kuhnen, V. V., Luiz, M. R. *et al.* (2016). Contributions of the mammal community, habitat structure, and spatial distance to dung beetle community structure. *Biodiversity and conservation*, 25, 1661-1675. doi 10.1007/s10531-016-1147-1

Borges, S. H., RS Tavares, T., Crouch, N. M., & Baccaro, F. (2021). Sucessional trajetories of bird assemblages in amazonian secondary forests: Perspectives from complementary biodiversity dimensions. *Forest Ecology and Management*, 483, 118731.https://doi.org/10.1016/j.foreco.2020.118731

Borges, S. H., Cornelius, C., Ribas, C., Almeida, R., Guilherme, E., Aleixo, A. *et al.* (2016). What is the avifauna of Amazonian white-sand vegetation? *Bird Conservation International*, 26(2), 192-204. doi:10.1017/S0959270915000052

Braga, R. F., Korasaki, V., Andresen, E., & Louzada, J. (2013). Dung beetle community and functions along a habitat-disturbance gradient in the Amazon: a rapid assessment of ecological functions associated to biodiversity. *PLoS One*, 8(2), e57786. doi:10.1371/journal.pone.0057786

Caceres, M., Jansen, F., Dell, N. (2022). Relationship Between Species and Groups of Sites. Versão 2.6-4. R packages indicspecies. Available from: https://emf-creaf.github.io/indicspecies

Campos, R. C., & Hernández, M. I. (2015). Changes in the dynamics of functional groups in communities of dung beetles in Atlantic forest fragments adjacent to transgenic maize crops. *Ecological Indicators*, 49, 216-227. https://doi.org/10.1016/j.ecolind.2014.09.043

Campos, R. C., & Hernández, M. I. M. (2013). Dung beetle assemblages (Coleoptera, Scarabaeinae) in Atlantic forest fragments in southern Brazil. *Revista Brasileira de Entomologia*, 57, 47-54. http://dx.doi.org/10.1590/S0085-56262013000100008

Capurucho, J. M. G., Borges, S. H., Cornelius, C., Vicentini, A., Prata, E. M. B., Costa, F. M. *et al.* (2020). Patterns and processes of diversification in Amazonian white sand ecosystems: insights from birds and plants. *Neotropical diversification: patterns and processes*, 245-270. https://doi.org/10.1007/978-3-030-31167-4_11

Caramaschi, F. P., Junqueira, A., & Bonvicino, C. R. (2013). The geographic distribution of Didelphis imperfecta (Marsupialia: Didelphimorphia): an endemic species to the Guiana Shield, Eastern Amazonia. *Bol. Soc. Bras. Mastozool.*, 68, 65-67.

Carpio, C., Donoso, D. A., Ramón, G., & Dangles, O. (2009). Short term response of dung beetle communities to disturbance by road construction in the Ecuadorian Amazon. *In Annales de la Société entomologique de France*, v. 45, n, 4, 455-469. https://doi.org/10.1080/00379271.2009.10697629

Carreno-Rocabado, G., Peña-Claros, M., Bongers, F., Alarcón, A., Licona, J. C., & Poorter, L. (2012). Effects of disturbance intensity on species and functional diversity in a tropical forest. *Journal of Ecology*, 100, 1453-1463, doi: 10.1111/j.1365-2745.2012.02015.x

Carrión-Paladines, V., Fries, A., Muñoz, A., Castillo, E., García-Ruiz, R., & Marín-Armijos, D. (2021). Effects of land-use change on the community structure of the dung beetle (Scarabaeinae) in an altered ecosystem in Southern Ecuador. *Insects*, 12, 306. https://doi.org/10.3390/insects12040306

Carvalho, W. D., Costa Gomes, L. A., De Castro, I., Martins, A. C., Lustosa Esberard, C. E., & Mustin, K. (2018). Beyond the Amazon forest: richness and abundance of bats in the understory of savannahs, campinaranas and terra firme forest. *Acta Chiropterologica*, 20(2), 407-419. doi: 10.3161/15081109ACC2018.20.2.011

Carvalho, R. L., Andresen, E., Barônio, G. J., Oliveira, V. H., Louzada, J., & Braga, R. F. (2020). Is dung removal a good proxy for other dung beetle functions when monitoring for conservation? A case study from the Brazilian Amazon. *Ecological Indicators*, 109, 105841. https://doi.org/10.1016/j.ecolind.2019.105841

Chaddad, F., Mello, F. A., Tayebi, M., Safanelli, J. L., Campos, L. R., Amorim, M. T. A. *et al.* (2022). Impact of mining-induced deforestation on soil surface temperature and carbon stocks: A case study using remote sensing in the Amazon rainforest. *Journal of South American Earth Sciences*, 119, 103983. https://doi.org/10.1016/j.jsames.2022.103983

Chamberlain, D., Kibuule, M., Skeen, R., & Pomeroy, D. (2017). Trends in bird species richness, abundance and biomass along a tropical urbanization gradient. *Urban Ecosystems*, 20, 629-638. https://doi.org/10.1007/s11252-016-0621-6

Chao, A (2022). Individual-based approach in software online iNEXT. iNEXT online website. Available from: chao.stat.nthu.edu.tw/wordpress/software_download/inext-online

Chiew, L. Y., Hackett, T. D., Brodie, J. F., Teoh, S. W., Burslem, D. F., Reynolds, G. *et al.* (2022). Tropical forest dung beetle–mammal dung interaction networks remain similar across an environmental disturbance gradient. *Journal of Animal Ecology*, 91(3), 604-617. https://doi.org/10.1111/1365-2656.13655

Clark, K. R., & Gorley, R. N. (2006). PRIMER v6: user manual/tutorial. *Primer-E, Plymouth*, 192.

Cole, L. E., Bhagwat, S. A., & Willis, K. J. (2014). Recovery and resilience of tropical forests after disturbance. *Nature communications*, 5(1), 3906. https://doi.org/10.1038/ncomms4906

Correa, C. M., Puker, A., & Abot, A. R. (2020a). Impacts of exotic pasture establishment on dung beetle assemblages (Coleoptera: Scarabaeidae: Scarabaeinae) in the Brazilian cerrado. *Environmental Entomology*, 49(6), 1335-1344. https://doi.org/10.1093/ee/nvaa132

Correa, C. M., Audino, L. D., Holdbrook, R., Braga, R. F., Menéndez, R., & Louzada, J. (2020b). Successional trajectory of dung beetle communities in a tropical grassy ecosystem after livestock grazing removal. *Biodiversity and Conservation*, 29, 2311-2328. https://doi.org/10.1007/s10531-020-01975-x

Correa, C. M., Ferreira, K. R., Puker, A., Audino, L. D., & Korasaki, V. (2021). Greenspace sites conserve taxonomic and functional diversity of dung beetles in an urbanized landscape in the Brazilian Cerrado. *Urban Ecosystems*, 24(5), 1023-1034. https://doi.org/10.1007/s11252-021-01093-8

Correa, C. M., Puker, A., Korasaki, V., Ferreira, K. R., & Abot, A. R. (2016). Attractiveness of baits to dung beetles in Brazilian savanna and exotic pasturelands. *Entomological Science*, 19(2), 112-123. doi: 10.1111/ens.12169

Costa, F. C., Pessoa, K. K., Liberal, C. N., Filgueiras, B. K., Salomão, R. P., & Iannuzzi, L. (2013). What is the importance of open habitat in a predominantly closed forest area to the dung beetle (Coleoptera, Scarabaeinae) assemblage? *Revista Brasileira de Entomologia*, 57, 329-334. http://dx.doi.org/10.1590/S0085-56262013000300012

Costa, M. K. S. (2021). *Respostas das assembleias de Besouros Escarabeíneos às mudanças ambientais e presença de silvicultura na Amazônia Oriental*. Dissertação (Mestrado). Universidade Federal do Oeste do Pará, Programa de Pós-Graduação em Biodiversidade. Santarém – PA, p. 28.

Cruz, D. C., Benayas, J. M. R., Ferreira, G. C., Santos, S. R., & Schwartz, G. (2021). An overview of forest loss and restoration in the Brazilian Amazon. *New Forests*, 52, 1-16. https://doi.org/10.1007/s11056-020-09777-3

Daniel, G. M., Noriega, J. A., Silva, P. G., Deschodt, C. M., Sole, C. L., Scholtz, C. H., & Davis, A. L. (2022). Soil type, vegetation cover and temperature determinants of the diversity and structure of dung beetle assemblages in a South African open woodland and closed canopy mosaic. *Austral Ecology*, 47(1), 79-91. https://doi.org/10.1111/aec.13138

Davis, A. L., Van Aarde, R. J., Scholtz, C. H., & Delport, J. H. (2002). Increasing representation of localized dung beetles across a chronosequence of regenerating vegetation and natural dune forest in South Africa. *Global Ecology and Biogeography*, 11, 191-209. https://doi.org/10.1046/j.1466-822X.2002.00283.x

Demarchi, L. O., Klein, V. P., Aguiar, D. P. P., Marinho, L. C., Ferreira, M. J., Lopes, A. et al. (2022). The specialized white-sand flora of the Uatumã Sustainable Development Reserve, central Amazon, Brazil. *Check List*, 18, 187-217. https://doi.org/10.15560/18.1.187

Demarchi, L. O., Scudeller, V. V., Moura, L. C., Dias-Terceiro, R. G., Lopes, A., Wittmann, F. K., & Piedade, M. T. F. (2018). Floristic composition, structure and soil-vegetation relations in three white-sand soil patches in central Amazonia. *Acta Amazonica*, 48, 46-56. http://dx.doi.org/10.1590/1809-4392201603523

Demarchi, L. O., Scudeller, V. V., Moura, L. C., Lopes, A., & Piedade, M. T. F. (2019). Logging impact on Amazonian white-sand forests: perspectives from a sustainable development reserve. *Acta Amazonica*, 49, 316-323. https://doi.org/10.1590/1809-4392201802332

Dulias, R. (2010). Landscape planning in areas of sand extraction in the Silesian Upland, Poland. *Landscape and Urban Planning*, 95(3), 91-104. https://doi.org/10.1016/j.landurbplan.2009.12.006

Edmonds, W. D., & Zídek, J. (2010). A taxonomic review of the neotropical genus Coprophanaeus Olsoufieff, 1924 (Coleoptera: Scarabaeidae, Scarabaeinae). *Insecta Mundi*, 0129, 1-111.

Edwards, F. A., Finan, J., Graham, L. K., Larsen, T. H., Wilcove, D. S., Hsu, W. W. *et al.* (2017). The impact of logging roads on dung beetle assemblages in a tropical rainforest reserve. Biological conservation, 205, 85-92. https://doi.org/10.1016/j.biocon.2016.11.011

Edwards, D. P., Socolar, J. B., Mills, S. C., Burivalova, Z., Koh, L. P., & Wilcove, D. S. (2019). Conservation of tropical forests in the anthropocene. *Current Biology,* 29(19), R1008-R1020. https://doi.org/10.1016/j.cub.2019.08.026

Emidio da Silva, K., Martins, S. V., Alvares Soares Ribeiro, C. A., Terra Santos, N., de Azevedo, C. P., de Almeida Matos, F. D., & do Amaral, I. L. (2011). Floristic composition and similarity of 15 hectares in Central Amazon, Brazil. *Revista de Biología Tropical*, 59(4), 1927-1938.

Endo, W. (2005). *Campinarana e Índios Baniwa: Influências ambientais e culturais sobre a comunidade de vertebrados terrestres no Alto Rio Negro, AM.* Dissertação (Mestrado em Ciências Biológicas). Instituto Nacional de Pesquisas da Amazônia, Manaus-AM, p. 35.

Fahrig, L. (2020). Why do several small patches hold more species than few large patches? *Global Ecology and Biogeography*, 29(4), 615-628. doi: 10.1111/geb.13059

Farias, P. M. D., & Hernández, M. I. M. (2017). Dung beetles associated with agroecosystems of southern Brazil: relationship with soil properties. *Revista Brasileira de Ciência do Solo,* 41. https://doi.org/10.1590/18069657rbcs20160248

Fearnside, P. M. (2005). Deforestation in Brazilian Amazonia: history, rates, and consequences. *Conservation biology*, 19(3), 680-688. https://doi.org/10.1111/j.1523-1739.2005.00697.x

Feer, F., & Boissier, O. (2015). Variations in dung beetle assemblages across a gradient of hunting in a tropical forest. *Ecological Indicators,* 57, 164-170. https://doi.org/10.1016/j.ecolind.2015.04.034

Ferreira, C. A. C. (2009). *Análise comparativa de vegetação lenhosa do ecossistema campina na Amazônia brasileira*. Tese (Doutorado em Ciências Biológicas). Instituto Nacional de Pesquisas da Amazônia, Manaus-AM, p. 2.

Ferreira, L. V., Chaves, P. P., Cunha, D. D. A., Rosário, A. D., & Parolin, P. (2013). A extração ilegal de areia como causa do desaparecimento de campinas e campinaranas no Estado do Pará, Brasil. *Pesquisas, Botânica,* 64, 157-173.

Filgueiras, B. K., Tabarelli, M., Leal, I. R., Vaz-de-Mello, F. Z., & Iannuzzi, L. (2015). Dung beetle persistence in human-modified landscapes: combining indicator species with human land use and fragmentation-related effects. *Ecological Indicators,* 55, 65-73. http://dx.doi.org/10.1016/j.ecolind.2015.02.032

Filho, A. N. S. G., Borges, L. H. M., & Morato, E. F. (2017). Composição e tamanho corporal de besouros escarabeídeos no complexo vegetacional sobre areia branca do sudoeste da Amazônia, Acre. In: Brito, T. F., Silva, R. C., Oliveira, S.A.V., Silveira, M. (Org). *Complexo vegetacional sobre areia branca: campinaranas do sudoeste da Amazônia* (25-30). Universidade Federal do Acre, Rio Branco.

Fox, J., Weisberg, S., Price, B., Adler, B., Bates, D., Baud-Bovy, G. *et al.* (2022). Companion to Applied Regression. Versão 3.1-1. R packages car. Available from: https://r-forge.r-project.org/projects/car

França, F., Louzada, J., & Barlow, J. (2018). Selective logging effects on 'brown world' faecal-detritus pathway in tropical forests: A case study from Amazonia using dung beetles. *Forest Ecology and Management*, 410, 136-143. https://doi.org/10.1016/j.foreco.2017.12.027

Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A., & Sodhi, N. S. (2009). Prospects for tropical forest biodiversity in a human-modified world. *Ecology letters*, 12(6), 561-582. https://doi.org/10.1111/j.1461-0248.2009.01294.x

Garrett, R. D., Cammelli, F., Ferreira, J., Levy, S. A., Valentim, J., & Vieira, I. (2021). Forests and sustainable development in the Brazilian Amazon: history, trends, and future prospects. *Annual Review of Environment and Resources*, 46, 625-652. https://doi.org/10.1146/annurev-environ-012220-010228

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J. *et al.* (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, 478(7369), 378-381. doi:10.1038/nature10425

Giménez-Gómez, V. C., Verdú, J. R., & Zurita, G. A. (2020). Thermal niche helps to explain the ability of dung beetles to exploit disturbed habitats. Scientific reports, 10(1), 1-14. https://doi.org/10.1038/s41598-020-70284-8

Gómez-Cifuentes, A., Gómez, V. C. G., Moreno, C. E., & Zurita, G. A. (2019). Tree retention in cattle ranching systems partially preserves dung beetle diversity and functional groups in the semideciduous Atlantic forest: The role of microclimate and soil conditions. *Basic and Applied Ecology*, 34, 64-74. https://doi.org/10.1016/j.baae.2018.10.002

Gómez-Cifuentes, A., Munevar, A., Gimenez, V. C., Gatti, M. G., & Zurita, G. A. (2017). Influence of land use on the taxonomic and functional diversity of dung beetles (Coleoptera: Scarabaeinae) in the southern Atlantic forest of Argentina. *Journal of Insect Conservation*, 21 , 147-156. doi 10.1007/s10841-017-9964-4

Gómez-Cifuentes, A., Vespa, N., Semmartin, M., & Zurita, G. (2020). Canopy cover is a key factor to preserve the ecological functions of dung beetles in the southern Atlantic Forest. *Applied Soil Ecology*, 154, 103652. https://doi.org/10.1016/j.apsoil.2020.103652

Gonçalves, T. F., Correa, C. M., Audino, L. D., Vaz-de-Mello, F. Z., Fontoura, F. M., & Guedes, N. M. (2022). Quantifying the post-fire recovery of taxonomic and functional diversity of dung beetles in the Brazilian Pantanal. *Ecological Entomology*, 47(4), 601-612. https://doi.org/10.1111/een.13144

Gonzalez-Alvarado, A., & Vaz-de-Mello, F. Z. (2021). Towards a comprehensive taxonomic revision of the Neotropical dung beetle subgenus Deltochilum (Deltohyboma) Lane, 1946 (Coleoptera: Scarabaeidae: Scarabaeinae): Division into species-groups. *Plos one*, 16(1), e0244657. https://doi.org/10.1371/journal.pone.0244657

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D. *et al.* (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science advances*, 1(2), e1500052. doi: 10.1126/sciadv.1500052

Halffter, G.; Edmonds, W. D. The nesting behavior of dung beetles (Scarabaeinae). An ecological and evolutive approach. *Instituto de Ecologia*, México DF, 1982.

Hernández, M. I., Barreto, P. S., Costa, V. H., Creao-Duarte, A. J., & Favila, M. E. (2014). Response of a dung beetle assemblage along a reforestation gradient in Restinga forest. *Journal of insect conservation*, 18, 539-546. doi 10.1007/s10841-014-9645-5

Hill, M. O. (1973). Diversity and evenness: a unifying notation and its consequences. *Ecology*, 54(2), 427-432.

Hill, J. K., & Hamer, K. C. (2004). Determining impacts of habitat modification on diversity of tropical forest fauna: the importance of spatial scale. *Journal of Applied Ecology*, 41(4), 744-754.

Hopkins, M. J. (2005). Flora da Reserva Ducke, Amazonas, Brasil. *Rodriguésia*, 56, 09-25.

Horgan, F. G. (2005). Effects of deforestation on diversity, biomass and function of dung beetles on the eastern slopes of the Peruvian Andes. *Forest Ecology and Management*, 216 (1-3), 117-133. doi:10.1016/j.foreco.2005.05.049

Huerta, C., Arellano, L., & Cruz, M. (2018). Dung beetles (Coleoptera: Scarabaeidae, Scarabaeinae) and dung removal in Mexican livestock pastures. *Revista mexicana de biodiversidad*, 89, 1280-1292. https://doi.org/10.22201/ib.20078706e.2018.4.2495

Hussain, M., Kanwal, M., Aftab, K., Khalid, M., Liaqat, S., Iqbal, T. *et al.* (2021). Distribution patterns of dung beetle (Coleoptera: Scarabaeidae) assemblages in croplands and pastures across two climatic zones of Pakistan. *Oriental Insects*, 56, 392-407. https://doi.org/10.1080/00305316.2021.2010617

IBGE (Instituto Brasileiro de Geografia e Estatística). Manual Técnico em Geociências. *Manual Técnico da Vegetação Brasileira*. 2ª Edição, Rio de Janeiro, 2012.

Ibrahim, E., Lema, L., Barnabé, P., Lacroix, P., & Pirard, E. (2020). Small-scale surface mining of gold placers: Detection, mapping, and temporal analysis through the use of free satellite imagery. *International Journal of Applied Earth Observation and Geoinformation*, 93, 102194. https://doi.org/10.1016/j.jag.2020.102194

Jordão, T. C., Oliveira Prado, I. G., Silva, M. D. C. S., Diogo, N. V., Júnior, P. P., Veloso, T. G. R. *et al.* (2021). Shifts in Arbuscular Mycorrhizal fungal properties due to vegetative remediation of mine spoil contamination from a dam rupture in Mariana, Brazil. *Applied Soil Ecology*, 162, 103885. https://doi.org/10.1016/j.apsoil.2021.103885

Jost, L. (2006). Entropy and diversity. *Oikos*, 113(2), 363-375.

Korasaki, V., Braga, R. F., Zanetti, R., Moreira, F. M., Vaz-de-Mello, F. Z., & Louzada, J. (2013). Conservation value of alternative land-use systems for dung beetles in Amazon: valuing traditional farming practices. *Biodiversity and Conservation*, 22, 1485-1499. doi 10.1007/s10531-013-0487-3

Kyerematen, R., Adu-Acheampong, S., Acquah-Lamptey, D., & Anderson, R. S. (2020). Using Orthoptera and Hymenoptera indicator groups as evidence of degradation in a mining concession (Tarkwa gold mine) in Ghana. *International Journal of Tropical Insect Science*, 40, 221-224. https://doi.org/10.1007/s42690-019-00053-2

Kyerematen, R., Kaiwa, F., & Acquah-Lamptey, D. (2018). Butterfly Assemblages of Two Wetlands: Response of Biodiversity to Different Environmental Stressors in Sierra Leone. *Open Journal of Ecology*, 8, 379-395. https://doi.org/10.4236/oje.2018.87023

Latha, T. (2020). Rainfall seasonality and guild composition of scarabaeinae dung beetles in a forest in South Western Ghats. *Journal of Entomology and Zoology Studies,* 8, 459-464.

Latha, T., & Thomas, S. K. (2020). Edge effect on roller dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) in the moist South Western Ghats. *J. Entomol. Zool. Stud*, 8, 1044-1047.

Laurance, W. F. (1999). Reflections on the tropical deforestation crisis. *Biological conservation*, 91, 109-117.

Lees, A. C., & Peres, C. A. (2006). Rapid avifaunal collapse along the Amazonian deforestation frontier. *Biological conservation*, 133(2), 198-211. https://doi.org/10.1016/j.biocon.2006.06.005

Lima, L. (2015). *Atributos funcionais da flora arbórea e arbustiva de campina e campinaranas na Amazônia Central*. Dissertação (Mestrado em Botânica). Instituto Nacional de Pesquisas da Amazônia, Manaus, p. 9.

López, S. (2022). Deforestation, forest degradation, and land use dynamics in the Northeastern Ecuadorian Amazon. Applied Geography, 145, 102749. https://doi.org/10.1016/j.apgeog.2022.102749

Louzada, J., Lima, A. P., Matavelli, R., Zambaldi, L., & Barlow, J. (2010). Community structure of dung beetles in Amazonian savannas: role of fire disturbance, vegetation and landscape structure. *Landscape ecology*, 25, 631-641. doi 10.1007/s10980-010-9448-3

Luther, D. A., Cooper, W. J., Wolfe, J. D., Bierregaard Jr, R. O., Gonzalez, A., & Lovejoy, T. E. (2020). Tropical forest fragmentation and isolation: Is community decay a random process? *Global Ecology and Conservation*, 23, e01168.

Maldaner, M. E., Sobral-Souza, T., Prasniewski, V. M., & Vaz-de-Mello, F. Z. (2021). Effects of climate change on the distribution of key native dung beetles in South American grasslands. *Agronomy*, 11(10), 2033. https://doi.org/10.3390/agronomy11102033

Manning, P., Slade, E. M., Beynon, S. A., & Lewis, O. T. (2016). Functionally rich dung beetle assemblages are required to provide multiple ecosystem services. *Agriculture, Ecosystems & Environment*, 218, 87-94. http://dx.doi.org/10.1016/j.agee.2015.11.007

Moura, R. S., Noriega, J. A., Cerboncini, R. A. S., Vaz-de-Mello, F. Z., & Junior, L. K. (2021). Dung beetles in a tight-spot, but not so much: Quick recovery of dung beetles assemblages after low-impact selective logging in Central Brazilian Amazon. *Forest Ecology and Management*, 494, 119301. https://doi.org/10.1016/j.foreco.2021.119301

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853-858.

Naka, L. N., & Brumfield, R. T. (2018). The dual role of Amazonian rivers in the generation and maintenance of avian diversity. *Science advances*, 4(8), eaar8575. doi: 10.1126/sciadv.aar8575

Navarrete, D., & Halffter, G. (2008). Dung beetle (Coleoptera: Scarabaeidae: Scarabaeinae) diversity in continuous forest, forest fragments and cattle pastures in a landscape of Chiapas, Mexico: the effects of human changes. *Biodiversity and Conservation*, 17, 2869-2898. doi 10.1007/s10531-008-9402-8

Nazareno, A. G., Dick, C. W., & Lohmann, L. G. (2019). A biogeographic barrier test reveals a strong genetic structure for a canopy-emergent Amazon tree species. *Scientific reports*, 9(1), 18602. https://doi.org/10.1038/s41598-019-55147-1

Nazare-Silva, E. E., & Silva, F. A. (2021). A taxonomic revision of the South American species of Pseudocanthon Bates, 1887 (Coleoptera: Scarabaeidae: Scarabaeinae: Deltochilini). *Zootaxa*, 5027(1), 61-86. https://doi.org/10.11646/zootaxa.5027.1.3

Nependa, H. U., Pryke, J. S., & Roets, F. (2021). Replacing native mammal assemblages with livestock in African savannahs, impacts dung beetle diversity and reduces body size. *Biological Conservation*, 260, 109211. https://doi.org/10.1016/j.biocon.2021.109211

Nichols, E., Larsen, T., Spector, S., Davis, A. L., Escobar, F., Favila, M. *et al.* (2007). Global dung beetle response to tropical forest modification and fragmentation: a quantitative literature review and meta-analysis. *Biological conservation*, 137, 1-19. doi:10.1016/j.biocon.2007.01.023

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M. E., Network, T. S. R. (2008). Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological conservation*, 141(6), 1461-1474. doi:10.1016/j.biocon.2008.04.011

Nichols, E., Uriarte, M., Bunker, D. E., Favila, M. E., Slade, E. M., Vulinec, K. *et al.* (2013). Trait-dependent response of dung beetle populations to tropical forest conversion at local and regional scales. *Ecology*, 94(1), 180-189. https://doi.org/10.1890/12-0251.1

Nobre, C. A., Sampaio, G., Borma, L. S., Castilla-Rubio, J. C., Silva, J. S., & Cardoso, M. (2016). Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. *Proceedings of the National Academy of Sciences*, 113(39), 10759-10768. http://www.pnas.org/cgi/doi/10.1073/pnas.1605516113

Noriega, J. A., March-Salas, M., Castillo, S., García-Q, H., Hortal, J., & Santos, A. M. (2021). Human perturbations reduce dung beetle diversity and dung removal ecosystem function. *Biotropica*, 53(3), 753-766. https://doi.org/10.1111/btp.12953

Oksanen, J., Simpson, L.G., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P. R. *et al.* (2022). Community Ecology Package. Versão 2.6-4. R packages vegan. Available from: https://github.com/vegandevs/vegan

Pavlacky Jr, D. C., Possingham, H. P., & Goldizen, A. W. (2015). Integrating life history traits and forest structure to evaluate the vulnerability of rainforest birds along gradients of deforestation and fragmentation in eastern Australia. Biological Conservation, 188, 89-99. https://doi.org/10.1016/j.biocon.2014.10.020

Pessôa, M. B., Izzo, T. J., & Vaz-de-Mello, F. Z. (2017). Assemblage and functional categorization of dung beetles (Coleoptera: Scarabaeinae) from the Pantanal. *PeerJ*, 5, e3978. https://doi.org/10.7717/peerj.3978

Peyras, M., Vespa, N. I., Bellocq, M. I., & Zurita, G. A. (2013). Quantifying edge effects: the role of habitat contrast and species specialization. *Journal of Insect Conservation*, 17, 807-820. doi 10.1007/s10841-013-9563-y

Phillips, H. R., Newbold, T., & Purvis, A. (2017). Land-use effects on local biodiversity in tropical forests vary between continents. *Biodiversity and Conservation*, 26(9), 2251-2270. doi 10.1007/s10531-017-1356-2

Pimenta, M., & De Marco, P. (2015). Leaf beetle (Chrysomelidae: Coleoptera) assemblages in a mosaic of natural and altered areas in the Brazilian Cerrado. *Neotropical entomology*, 44, 242-255. doi 10.1007/s13744-015-0280-y

Pontes, A. R. M., de Paula, M. D., & Magnusson, W. E. (2012). Low primate diversity and abundance in Northern Amazonia and its implications for conservation. *Biotropica*, 44(6), 834-839. doi:10.1111/j.1744-7429.2012.00873.x

Quintero, I., & Roslin, T. (2005). Rapid recovery of dung beetle communities following habitat fragmentation in Central Amazonia. *Ecology*, 86(12), 3303-3311. https://doi.org/10.1890/04-1960

Raine, E. H., Mikich, S. B., Lewis, O. T., Riordan, P., Vaz-de-Mello, F. Z., & Slade, E. M. (2018). Extinctions of interactions: quantifying a dung beetle–mammal network. *Ecosphere*, 9(11), e02491. https://doi.org/10.1002/ecs2.2491

Rajpar, M. N. (2018). Tropical forests are an ideal habitat for wide array of wildlife species. *Tropical Forests* - New Edition, 37. doi: 10.5772/intechopen.73315

Rangel-Acosta, J. L., Martínez-Hernández, N. J., & Yonoff-Zapata, R. (2020). Respuesta de los escarabajos coprófagos (Scarabaeidae: Scarabaeinae) a la modificación del hábitat causada por un incendio forestal en la Reserva Bijibana, Atlántico-Colombia. *Revista mexicana de biodiversidad*, 91.

R Development Core Team. (2022). R: A Language and Environment for Statistical Computing**.** R Foundation for Statistical Computing, Vienna. Versão 4.2.0. Available from: www.r-project.org

Ribeiro, P. H. O., Togni, P. H. B., & Frizzas, M. R. (2022). Spatial and temporal segregation in dung beetles (Coleoptera: Scarabaeinae) in the Cerrado of Central Brazil. *Biodiversity and Conservation*, 31(11), 2723-2740. https://doi.org/10.1007/s10531-022-02453-2

Ripley, B., Venables, B., Bates, M. D., Horni, K., Gebhardt, A., Firth, D. (2023). Support Functions and Datasets for Venables and Ripley's MASS. Versão 7.3-58.3. R packages mass. Available from: www.stats.ox.ac.uk/pub/MASS4

Rurangwa, M. L., Aguirre-Gutiérrez, J., Matthews, T. J., Niyigaba, P., Wayman, J. P., Tobias, J. A., & Whittaker, R. J. (2021). Effects of land-use change on avian taxonomic, functional and phylogenetic diversity in a tropical montane rainforest. *Diversity and Distributions*, 27(9), 1732-1746. DOI: 10.1111/ddi.13364

Salomão, R. P., Alvarado, F., Baena-Díaz, F., Favila, M. E., Iannuzzi, L., Liberal, C. N. *et al.* (2019). Urbanization effects on dung beetle assemblages in a tropical city. *Ecological Indicators*, 103, 665-675. https://doi.org/10.1016/j.ecolind.2019.04.045

Salomão, R. P., Correa, C. M. D. A., Santorelli Junior, S., Lima, A. P., Magnusson, W. E., Arruda, E. F. *et al.* (2023). Species diet and the effect of different spatial bait distribution on assemblage of dung beetles in Amazonian white-sand forest. *International Journal of Tropical Insect Science*, 1-10. https://doi.org/10.1007/s42690-023-01012-8

Salomão, R. P., Favila, M. E., & Gonzalez-Tokman, D. (2020). Spatial and temporal changes in the dung beetle diversity of a protected, but fragmented, landscape of the northernmost Neotropical rainforest. *Ecological Indicators*, 111, 105968. https://doi.org/10.1016/j.ecolind.2019.105968

Salomão, R. P., González-Tokman, D., Dáttilo, W., López-Acosta, J. C., & Favila, M. E. (2018). Landscape structure and composition define the body condition of dung beetles (Coleoptera: Scarabaeinae) in a fragmented tropical rainforest. Ecological Indicators, 88, 144-151. https://doi.org/10.1016/j.ecolind.2018.01.033

Sarkar, D., Andrews, F., Wright, k., Klepeis, N., Larsson, J., Murrell, P. (2022). Trellis Graphics for R. Versão 0.20-45. R packages lattice. Available from: https://lattice.r-forge.r-project.org

Scheffler, P. Y. (2005). Dung beetle (Coleoptera: Scarabaeidae) diversity and community structure across three disturbance regimes in eastern Amazonia. *Journal of Tropical Ecology*, 21, 9-19. doi: 10.1017/S0266467404001683

Senior, M. J., Hamer, K. C., Bottrell, S., Edwards, D. P., Fayle, T. M., Lucey, J. M. *et al.* (2013). Trait-dependent declines of species following conversion of rain forest to oil palm plantations. *Biodiversity and Conservation*, 22, 253-268. doi 10.1007/s10531-012-0419-7

Silva, P. C. R. D. (2009). Scarabaeidofauna (insecta: Coleoptera) Copronecrófaga da Reserva Biologica da Campina, Manaus, Amazonas, Brasil, em um período chuvoso e em um período menos chuvoso. *XVIII Jornada de Iniciação Científica PIBIC CNPq/FAPEAM/lNPA.*

Silva, R. J., Coletti, F., Costa, D. A., & Vaz-De-Mello, F. Z. (2014). Rola-bostas (Coleoptera: Scarabaeidae: Scarabaeinae) de florestas e pastagens no sudoeste da Amazônia brasileira: Levantamento de espécies e guildas alimentares. Acta amazônica, 44, 345-352. http://dx.doi.org/10.1590/1809-4392201304472

Silva, P. G. D., & Hernández, M. I. M. (2015). Spatial patterns of movement of dung beetle species in a tropical forest suggest a new trap spacing for dung beetle biodiversity studies. *PloS one*, 10(5), e0126112. https://doi.org/10.1371/journal.pone.0126112

Silva, J. L. D., Silva, R. J. D., Fernandes, I. M., Sousa, W. O. D., & Vaz-de-Mello, F. Z. (2020). Species composition and community structure of dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) compared among savanna and forest formations in the southwestern Brazilian Cerrado. *Zoologia* (Curitiba), 37. https://doi.org/10.3897/zoologia.37.e58960

Silva, P. D., Vaz-de-Mello, F. Z., & Di Mare, R. A. (2012). Attractiveness of different bait to the Scarabaeinae (Coleoptera: Scarabaeidae) in forest fragments in extreme southern Brazil. *Zoological Studies*, 51(4), 429-441.

Simpson, G. L., R Core Team., Bates, M.D., Okasen, J. (2022). Functions for Generating Restricted Permutations of Data. Versão 0.9-7. R packages permute. Available from: https://github.com/gavinsimpson/permute

Souza, D. O., & Alvalá, R. C. S. (2014). Observational evidence of the urban heat island of Manaus City, Brazil. *Meteorological Applications*, 21(2), 186-193. doi: 10.1002/met.1340

Spaniol, R. L., Mendonça, M. D. S., Hartz, S. M., Iserhard, C. A., & Stevens, M. (2020). Discolouring the Amazon Rainforest: how deforestation is affecting butterfly coloration. *Biodiversity and Conservation*, 29, 2821-2838. https://doi.org/10.1007/s10531-020-01999-3

Stanbrook, R., Norrey, J., Kisingo, A. W., & Jones, M. (2021). Dung beetle diversity and community composition along a land use gradient in a Savannah Ecosystem of North Western Tanzania. *Tropical Conservation Science*, 14, 19400829211008756. https://doi.org/10.1177/19400829211008756

Stork, N. E., Coddington, J. A., Colwell, R. K., Chazdon, R. L., Dick, C. W., Peres, C. A. *et al.* (2009). Vulnerability and resilience of tropical forest species to land-use change. *Conservation Biology*, 23(6), 1438-1447. doi: 10.1111/j.1523-1739.2009.01335.x

Stratford, J. A., & Stouffer, P. C. (2015). Forest fragmentation alters microhabitat availability for Neotropical terrestrial insectivorous birds. *Biological Conservation*, 188, 109-115. https://doi.org/10.1016/j.biocon.2015.01.017

Suazo-Ortuño, I. R. E. R. I., Alvarado-Díaz, J. A. V. I. E. R., & Martínez-Ramos, M. I. G. U. E. L. (2008). Effects of conversion of dry tropical forest to agricultural mosaic on herpetofaunal assemblages. Conservation Biology, 22, 362-374. https://doi.org/10.1111/j.1523-1739.2008.00883.x

Tchoumbou, M. A., Mayi, M. P. A., Malange, E. N., Foncha, F. D., Kowo, C., Fru-Cho, J. *et al.* (2020). Effect of deforestation on prevalence of avian haemosporidian parasites and mosquito abundance in a tropical rainforest of Cameroon. *International journal for parasitology*, 50(1), 63-73. https://doi.org/10.1016/j.ijpara.2019.10.006

Ter Steege, H., Pitman, N. C., Killeen, T. J., Laurance, W. F., Peres, C. A., Guevara, J. E. *et al.* (2015). Estimating the global conservation status of more than 15,000 Amazonian tree species. *Science advances*, 1(10), e1500936. https://doi.org/10.1126/sciadv.1500936

Vaz de Mello, F. Z., Edmonds, W. D., Ocampo, F. C., & Schoolmeesters, P. (2011). A multilingual key to the genera and subgenera of the subfamily Scarabaeinae of the New World (Coleoptera: Scarabaeidae). *Zootaxa*, 2854 (1), 1-73.

Vieira, L., Louzada, J. N., & Spector, S. (2008). Effects of degradation and replacement of Southern Brazilian coastal sandy vegetation on the dung beetles (Coleoptera: Scarabaeidae). *Biotropica*, 40(6), 719-727. https://doi.org/10.1111/j.1744-7429.2008.00432.x

Vijay, V., Reid, C. D., Finer, M., Jenkins, C. N., & Pimm, S. L. (2018). Deforestation risks posed by oil palm expansion in the Peruvian Amazon. *Environmental Research Letters*, 13, 114010. https://doi.org/10.1088/1748-9326/aae540

Vulinec, K. (2002). Dung Beetle Communities and Seed Dispersal in Primary Forest and Disturbed Land in Amazonia1. *Biotropica*, 34, 297-309. https://doi.org/10.1111/j.1744-7429.2002.tb00541.x

Zemanova, M. A., Perotto-Baldivieso, H. L., Dickins, E. L., Gill, A. B., Leonard, J. P., & Wester, D. B. (2017). Impact of deforestation on habitat connectivity thresholds for large carnivores in tropical forests. *Ecological Processes*, 6, 1-11. https://doi.org/10.1186/s13717-017-0089-1

Figure captions

Fig. 1. Map showing the 23 study sites (12 conserved Campinaranas and 11 disturbed Campinaranas) located in the municipalities of Manaus, Itacoatiara, and Manacapuru, in Central Amazon, Brazil.

Fig. 2. Distribution of collected dung beetle species based on their abundance transformed in log (X + 1). Species recorded exclusively in one of the habitats are shown in black bars; species recorded in both habitats are shown in grey bars for the disturbed Campinaranas, and in white bars for the conserved Campinaranas.

Fig. 3. Hill numbers of orders q0 (A-C), q1 (D-F), and q2 (G-I) comparing dung beetle diversity between conserved and disturbed Campinaranas, considering the entire assemblage and from each functional group (tunnellers and rollers).

Fig. 4. Statistically significant effect of habitat type (conserved and disturbed Campinarana) on dung beetle abundance (A-B), total biomass (C-E), and mean biomass (F-H).

Fig. 5. NMDS of dung beetle assemblages found in conserved in disturbed Campinaranas, considering the total assemblage (A), rollers (B), and tunnellers (C).

Table 1. Abundances, species mean biomass, and sample coverage of dung beetle species collected in conserved and disturbed Campinaranas in Central Amazon, Brazil.

Species	Mean biomass (g)	Conserved Campinaranas	Disturbed Campinaranas	Total
Ateuchus cereus (Harold, 1868)	0.015	1	0	1
Ateuchus globulus (Boucomont, 1928)	0.004	4	0	4
Ateuchus murrayi (Harold, 1868)	0.007	1	0	1
Ateuchus pygidialis (Harold, 1868)	0.010	4	0	4
Canthidium aff. *depressum* (Boucomont, 1928)	0.019	4	0	4
Canthidium cf. *melanocephalum* (Olivier, 1789)	0.012	1	1	2
Canthidium deyrollei Harold, 1867	0.009	479	0	479
Canthidium dohrni Harold, 1867	0.033	2	0	2
Canthidium humerale (Germar, 1813)	0.004	2	30	32
Canthidium gr *lentum* Erichson, 1847	0.020	13	0	13
Canthidium sp1 Erichson, 1847	0.019	3	0	3
Canthon quadrigutattus (Olivier, 1789)	0.011	84	0	84
Canthon aff. *subcyanaeus* Erichson, 1848	0.009	0	8	8
Canthon sp1 Hoffmannsegg 1817	0.006	0	64	64

Species	Mean biomass (g)	Conserved Campinaranas	Disturbed Campinaranas	Total
Canthon sp3 Hoffmannsegg 1817	0.007	0	39	39
Canthon sp6 Hoffmannsegg 1817	0.007	0	67	67
Canthon sordidus Harold, 1868	0.018	129	0	129
Canthon triangularis (Drury, 1770)	0.050	8	0	8
Coprophanaeus jasius (Olivier, 1789)	0.724	4	0	4
Coprophanaeus lancifer (Linnaeus, 1767)	2.852	18	0	18
Cryptocanthon peckorum Howden, 1973	0.005	7	0	7
Deltochilum aspericolle Bates, 1870	0.046	1	0	1
Deltochilum femorale Bates, 1870	0.096	4	0	4
Deltochilum guyanense Paulian, 1933	0.105	29	0	29
Deltochilum submetallicum (Castelnau, 1840)	0.107	6	0	6
Dichotomius aff *robustus* (Lüederwaldt, 1935)	0.163	1	0	1
Dichotomius boreus (Olivier, 1789)	0.715	51	0	51
Dichotomius lucasi (Harold, 1869)	0.060	250	3	253
Dichotomius mamilatus (Felsche, 1901)	0.753	2	0	2

Species	Mean biomass (g)	Conserved Campinaranas	Disturbed Campinaranas	Total
Dichotomius quadrilobatus Chamorro, Lopera e Rossini, 2021	0.608	6	0	6
Dichotomius robustus (Lüederwaldt, 1935)	0.076	2	0	2
Eurysternus atrosericus Génier, 2009	0.008	91	0	91
Eurysternus cayennensis Castelnau, 1840	0.024	7	0	7
Eurysternus caribaeus (Herbst, 1789)	0.081	20	0	20
Eurysternus foedus Guérin-Ménéville, 1844	0.114	6	0	6
Eurysternus gracilis Génier, 2009	0.017	4	0	4
Eurysternus hypocrita Balthasar, 1939	0.137	12	0	12
Hansreia grossii Valois, Vaz-de-Mello e Silva, 2015	0.030	128	0	128
Isocopris nitidus (Luederwaldt, 1922)	0.106	1	0	1
Ontherus aff *appendiculatus* (Mannerheim, 1829)	0.038	2	0	2
Onthophagus bidentatus (Drapiez, 1819)	0.008	0	3	3
Onthophagus rubrescens Blanchard, 1846	0.003	1	0	1
Onthophagus sp Latreille, 1802	0.009	13	0	13

Species	Mean biomass (g)	Conserved Campinaranas	Disturbed Campinaranas	Total
Oxysternon festivum (Linnaeus, 1758)	0.500	14	0	14
Phanaeus chalcomelas (Perty 1830)	0.209	1	0	1
Pseudocanthon xanthurus (Blanchard, 1845)	0.003	0	161	161
Sylvicanthon proseni (Martínez, 1949)	0.090	81	0	81
Sylvicanthon seag Cupello e Vaz-de-Mello, 2018	0.036	27	0	27
Tetraechma liturata (Germar, 1822)	0.007	0	83	83
Uroxys sp1 Westwood, 1842	0.002	59	0	59
Uroxys sp2 Westwood, 1842	0.002	9	0	9
Total abundance		1.592	459	2.051
Total species richness		44	10	51
Sample coverage (%)		99	100	

Table 2. Indicator Vale of dung beetle indicators of conserved and disturbed Campinaranas in Central Amazon. All species had its IndVal statistically distinct between habitat types ($p < 0.05$).

Indicator species	Conserved Campinaranas	Disturbed Campinaranas
Canthidium gr lentum	81.6	
Canthidium deyrollei	86.6	
Canthon quadrigutattus	81.6	
Canthon sordidus	81.6	
Canthon sp1		90.5
Canthon sp2		60.3
Canthon sp3		73.9
Canthon sp6		67.4
Coprophanaeus lancifer	76.4	
Deltochilum guyanense	64.5	
Dichotomius boreus	76.4	
Dichotomius lucasi	95.1	
Eurysternus atrosericus	81.6	
Eurysternus caribaeus	76.4	
Hansreia grossii	81.6	
Oxysternon festivum	70.7	
Pseudocanthon xanthurus		85.3
Sylvicanthon seag	64.5	
Tetraechma liturata		73.9
Uroxys sp1	70.7	

Supplementary material

S1. Models used for GLMM and LME to assess the effects of habitat type on abundance, mean and total biomass. NA = model not performed.

Response variable	Model used	Family distribution	Variance structure
Entire assemblage abundance	Generalized Linear Mixed Model	Negative binomial	Standard
Roller abundance	Generalized Linear Mixed Model	Negative binomial	Standard
Tunneller abundance	Linear Mixed Effect	Gaussian	VarExp
Dweller abundance	NA	NA	NA
Entire assemblage total biomass	Linear Mixed Effect	Normal	VarIdent
Roller total biomass	Linear Mixed Effect	Normal	VarExp
Dweller total biomass	NA	NA	NA
Tunneller total biomass	Linear Mixed Effect	Normal	VarIdent
Entire assemblage mean biomass	Linear Mixed Effect	Normal	VarExp
Roller mean biomass	Linear Mixed Effect	Normal	VarExp
Tunneller mean biomass	Linear Mixed Effect	Normal	VarExp
Dweller mean biomass	NA	NA	NA

S2. Dung beetle species abundance in each of the 23 study sites (12 conserved and 11 disturbed Campinaranas).

Species	Conserved Campinarana												Disturbed Campinarana												Total
	Area 1 Gil	Area 2 Sidney	Area 3	CEPLAC P1	Gordo 5	Gordo 7	IBAMA P2	Milt 1	Milt 2	Ponto 5	Ponto 6	PPBIO	Area 1 Gil	Area 2 Sidney	Area 3	CEPLAC P1	Gordo 5	Gordo 7	IBAMA P2	Milt 1	Milt 2	Ponto 5	Ponto 6	PPBIO	
Ateuchus cereus								1																	1
Ateuchus globulus									3			1													4
Ateuchus murrayi							1																		1
Ateuchus pygidialis	2				2																				4
Canthidium aff. *depressum*	4																								4
Canthidium cf. *melanocephalum*								1															1		2
Canthidium deyrollei	37	8	13	141			71	32	83	7	87														479
Canthidium dohrni				1				1																	2
Canthidium humerale					1				1								7	23							32
Canthidium gr. *lentum*	3	1	1	1	4		1			1		1													13
Canthidium sp1							2	1																	3
Canthon quadrigutattus		11	2	6			17	6	17	2	23														84
Canthon aff. *Subcyanaeus*														8											8
Canthon sp1													1				4	33	3	9	3	1	10		64
Canthon sp3																2		7	1	1	1		27		39
Canthon sp6													7	56	2		1	1							67
Canthon sordidus	2	59		6			8	25	13	7	9														129

Species	Conserved Campinarana												Disturbed Campinarana	Total
Canthon triangularis		3	4	1										8
Coprophanaeus jasius								1	3					4
Coprophanaeus lancifer		1		2	2	5	3				4	1		18
Cryptocanthon peckorum						6	1							7
Deltochilum aspericolle		1												1
Deltochilum femorale						4								4
Deltochilum guyanense	1	16		1		4						7		29
Deltochilum submetallicum	6													6
Dichotomius aff *robustus*			1											1
Dichotomius boreus	9	11	2				2	12	14		1			51
Dichotomius lucasi	2	3	1	4	6	14	7	11	16	16	170		3	253
Dichotomius mamilatus		2												2
Dichotomius quadrilobatus					4	2								6
Dichotomius robustus					1							1		2

Species	Conserved Campinarana												Disturbed Campinarana												Total
Eurysternus atrosericus	1	30	15	4				8	3	3	27														91
Eurysternus cayennensis			1		2	2						2													7
Eurysternus caribaeus	2	1	1		4	2					2	8													20
Eurysternus foedus			3					2	1																6
Eurysternus gracilis								3		1															4
Eurysternus hypocrita	5	4							3																12
Hansreia grossii		8	2	11			13	77	10	4	3														128
Isocopris nitidus	1																								1
Ontherus aff. *appendiculatus*					1	1																			2
Onthophagus bidentatus																	3								3
Onthophagus rubrescens												1													1
Onthophagus sp	3	6	3						1																13
Oxysternon festivum	3	2	3		1	4			1																14
Phanaeus chalcomelas	1																								1
Pseudocanthon xanthurus														82	7	1		3	10	1		3	54		161
Sylvicanthon proseni					50	12						19													81
Sylvicanthon seag	4	3	16			3						1													27

Species	Conserved Campinarana												Disturbed Campinarana											Total
Tetraechma liturata														8		1	7	19				9	39	83
Uroxys sp1			4	1		15	2	29				8												59
Uroxys sp2						4	1					4												9
Total abundance	86	170	72	179	78	78	129	210	169	41	326	54	8	154	9	7	22	86	14	11	4	13	131	2.051
Total species richness	17	18	16	12	12	14	13	15	14	8	9	12	2	4	2	4	5	6	3	3	2	3	5	51

Figure 1

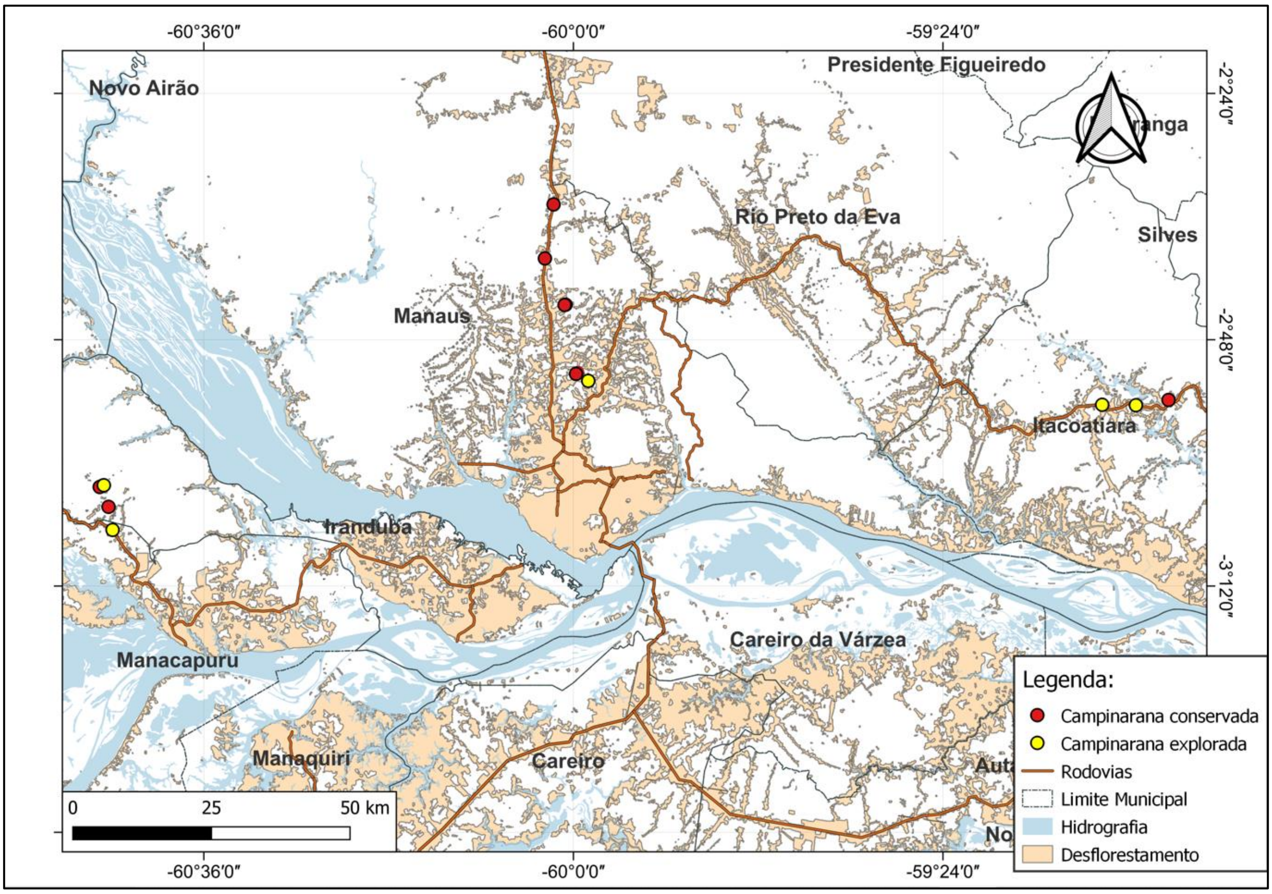

-60°36′0″
-60°0′0″
-59°24′0″
-2°24′0″
-2°48′0″
-3°12′0″
Presidente Figueiredo
Novo Airão
Rio Preto da Eva
Silves
Manaus
Itacoatiara
Iranduba
Manacapuru
Careiro da Várzea
Manaquiri
Careiro
0
25
50 km
Legenda:
Campinarana conservada
Campinarana explorada
Rodovias
Limite Municipal
Hidrografia
Desflorestamento

Figure 2

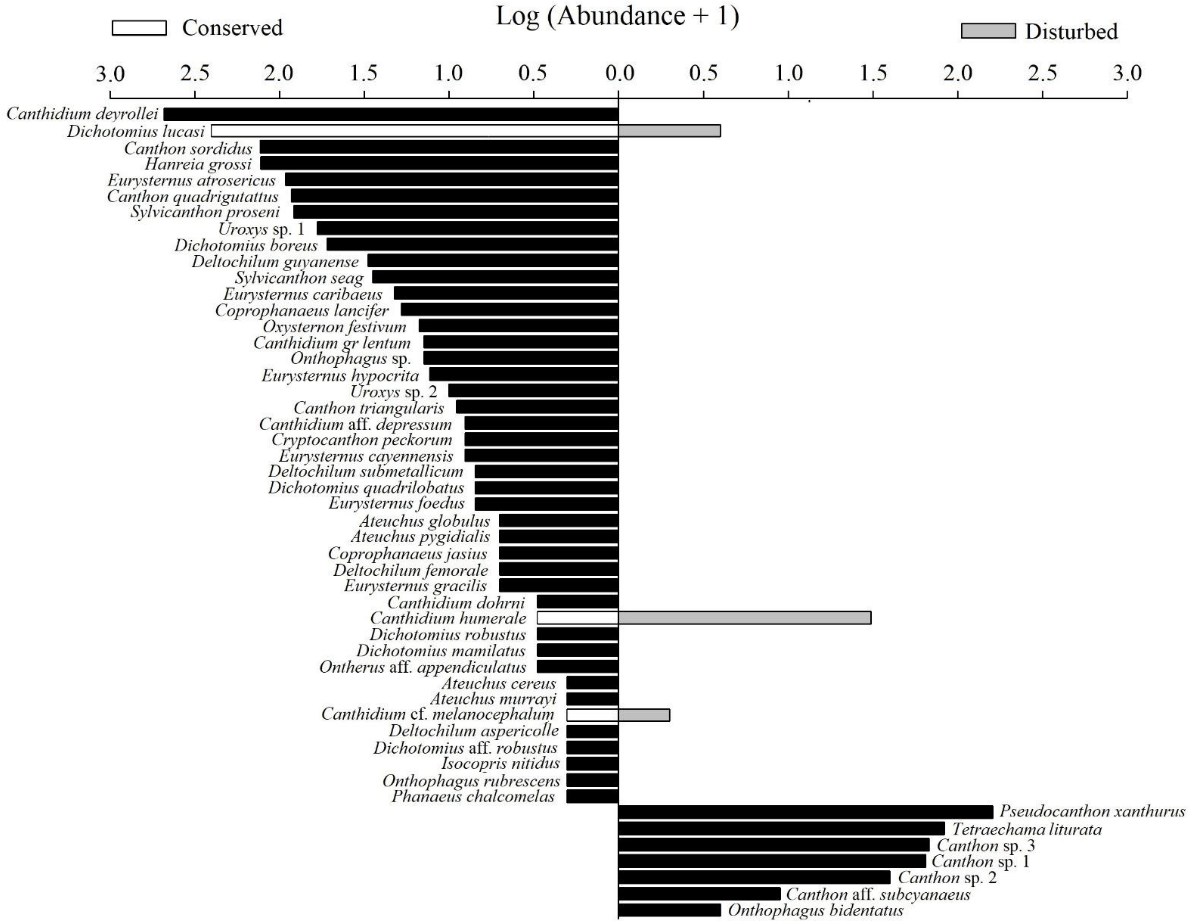

Conserved
Log (Abundance + 1)
Disturbed
3.0 2.5 2.0 1.5 1.0 0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0
Canthidium deyrollei
Dichotomius lucasi
Canthon sordidus
Hanreia grossi
Eurysternus atrosericus
Canthon quadrigutattus
Sylvicanthon proseni
Uroxys sp. 1
Dichotomius boreus
Deltochilum guyanense
Sylvicanthon seag
Eurysternus caribaeus
Coprophanaeus lancifer
Oxysternon festivum
Canthidium gr lentum
Onthophagus sp.
Eurysternus hypocrita
Uroxys sp. 2
Canthon triangularis
Canthidium aff. depressum
Cryptocanthon peckorum
Eurysternus cayennensis
Deltochilum submetallicum
Dichotomius quadrilobatus
Eurysternus foedus
Ateuchus globulus
Ateuchus pygidialis
Coprophanaeus jasius
Deltochilum femorale
Eurysternus gracilis
Canthidium dohrni
Canthidium humerale
Dichotomius robustus
Dichotomius mamilatus
Ontherus aff. appendiculatus
Ateuchus cereus
Ateuchus murrayi
Canthidium cf. melanocephalum
Deltochilum aspericolle
Dichotomius aff. robustus
Isocopris nitidus
Onthophagus rubrescens
Phanaeus chalcomelas
Pseudocanthon xanthurus
Tetraechama liturata
Canthon sp. 3
Canthon sp. 1
Canthon sp. 2
Canthon aff. subcyanaeus
Onthophagus bidentatus

Figure 3

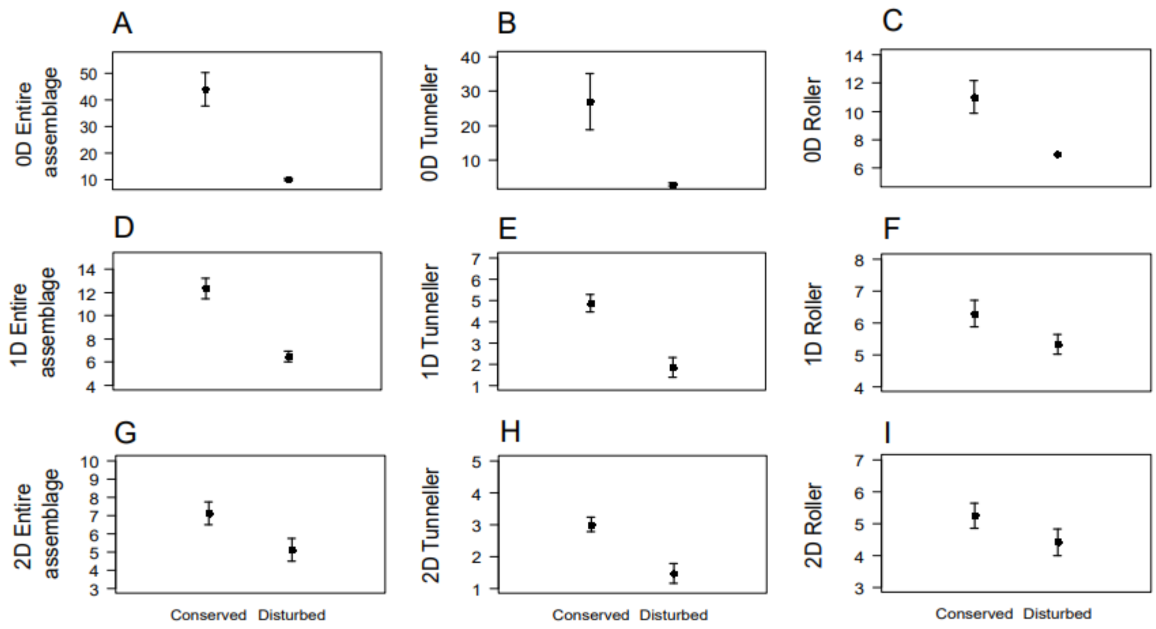

A
B
C
0D Entire assemblage
0D Tunneller
0D Roller
D
E
F
1D Entire assemblage
1D Tunneller
1D Roller
G
H
I
2D Entire assemblage
2D Tunneller
2D Roller
Conserved
Disturbed

Figure 4

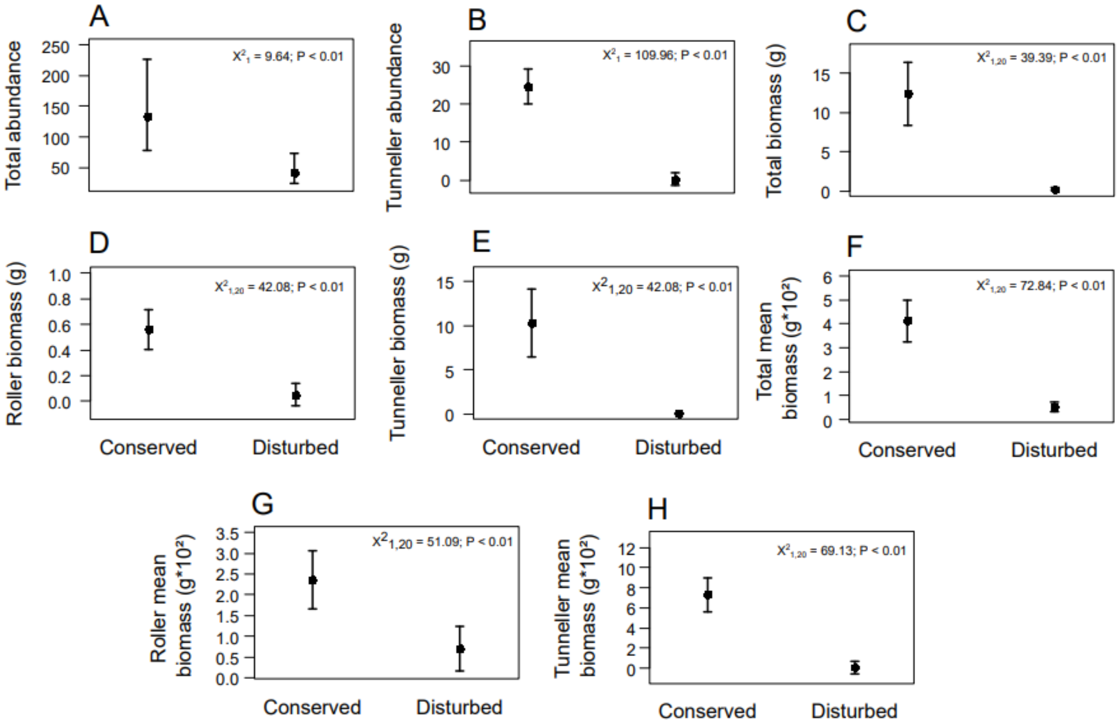
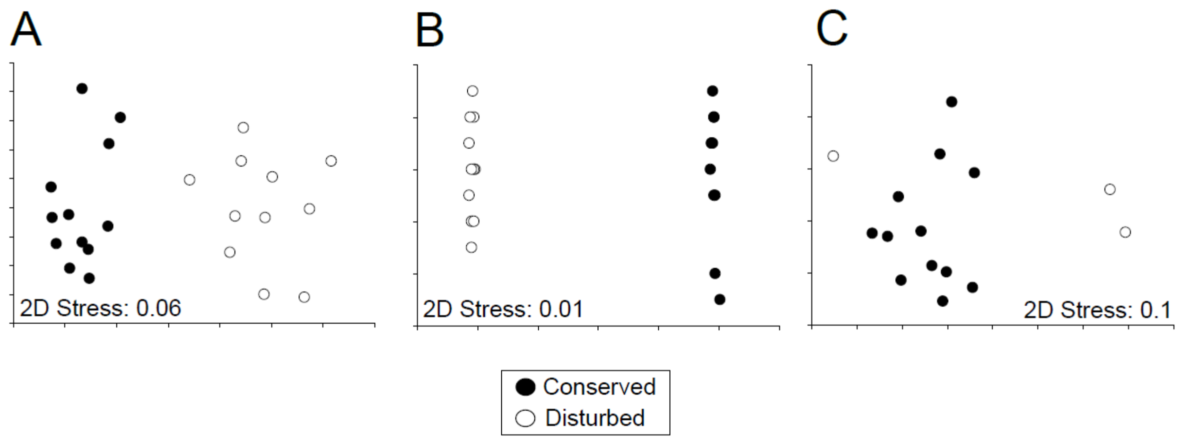

A
Total abundance
250
200
150
100
50
X²₁ = 9.64; P < 0.01
B
Tunneller abundance
30
20
10
0
X²₁ = 109.96; P < 0.01
C
Total biomass (g)
15
10
5
0
X²1,20 = 39.39; P < 0.01
D
Roller biomass (g)
1.0
0.8
0.6
0.4
0.2
0.0
X²1,20 = 42.08; P < 0.01
Conserved
Disturbed
E
Tunneller biomass (g)
15
10
5
0
X²1,20 = 42.08; P < 0.01
Conserved
Disturbed
F
Total mean biomass (g*10²)
6
5
4
3
2
1
0
X²1,20 = 72.84; P < 0.01
Conserved
Disturbed
G
Roller mean biomass (g*10²)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
X²1,20 = 51.09; P < 0.01
Conserved
Disturbed
H
Tunneller mean biomass (g*10²)
12
10
8
6
4
2
0
X²1,20 = 69.13; P < 0.01
Conserved
Disturbed

Figure 5


A
2D Stress: 0.06
B
2D Stress: 0.01
C
2D Stress: 0.1
Conserved
Disturbed

CONCLUSÕES

Mudanças relativas as atividades humanas, como a extração de areia vêm ocorrendo cada vez mais em áreas de Campinaranas na Amazônia Central. Consequentemente, estas atividades impactam negativamente na biodiversidade local, o que pode acarretar no funcionamento dos ecossistemas. Nossa pesquisa constatou efeitos deletérios da transformação de hábitats nativos da Campinarana sobre a assembleia de rola bostas. Esta primeira avaliação dos impactos da transformação de habitats em Campinarana devido a mineração, sugerem que suas comunidades ecológicas são bastante sensíveis aos efeitos dessa atividade. É fundamental um maior planejamento para as atividades de extração de areia, incluindo a fase exploratória e pós-exploratória, visando o acompanhamento e monitoramento destas atividades pelos órgãos ambientais públicos competentes. Exemplos em outros ecossistemas dentro e fora do Brasil (Dulias, 2010; Hernández et al., 2014) demonstram que o manejo e práticas de recuperação ambiental ativa e passiva em áreas de mineração podem promover o reestabelecimento de comunidades ecológicas equilibradas. Para alcançar uma recuperação efetiva e manutenção das Campinaranas, estudos espaço-temporais (e.g. estudos de cronossequencias e de ecologia de paisagem) necessitam ser realizados para uma compreensão mais fina das dinâmicas ecológicas neste ecossistema Amazônico.

CONCLUSIONS

Human changes, such as sand extraction activities, are increasing in Campinaranas of Central Amazonia. These activities impair local biodiversity and ecosystem functioning. Our research found deleterious effects on dung beetle assemblages, which resulted from the conversion of native Campinaranas into disturbed habitats. This first assessment of the impacts of habitat transformation in the Campinarana due to mining suggests that its ecological communities are quite fragile. A functional polytic planning is essential for sand extraction activities, including the exploratory and post-exploratory phases, following up and monitoring these activities by the competent public environmental agencies. Studies performed in other ecosystems (Dulias, 2010; Hernández et al., 2014) demonstrate that the management and practices of active and passive environmental recovery in mining areas can promote the re-establishment of balanced ecological communities. To achieve an effective recovery and maintenance of the

Campinaranas, finer spatial and long-term studies (e.g. chronosequence and landscape ecology studies) need to be carried out for a finer understanding of the ecological dynamics in this Amazonian ecosystem.