ICARO WILKER GONZAGA DE CARVALHO

LAND USE CHANGES AFFECT ANT ASSEMBLAGES, RESOURCE PREFERENCE, AND ECOSYSTEM FUNCTIONS IN NEOTROPICAL BIOMES

LAVRAS - MG
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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para a obtenção do título de Doutor.

Profa. Dra. Carla Rodrigues Ribas
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MUDANÇAS NO USO DO SOLO AFETAM ASSEMBLEIAS DE FORMIGAS, PREFERÊNCIA POR RECURSOS E FUNÇÕES ECOSSISTÊMICAS EM BIOMAS NEOTROPICAIS

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para a obtenção do título de Doutor.

APROVADA em 24 de abril de 2025

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Dedico este trabalho à minha mãe, Lediene, ao meu pai, Ademilson, à minha irmã, Ágatha, ao meu irmão, Kaique, e à minha namorada, Enggel.

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RESUMO GERAL

As conversões no uso do solo são a principal causa da perda de biodiversidade em ambientes tropicais terrestres. Nessas regiões, essas alterações modificam drasticamente a estrutura e composição da vegetação, afetando o microclima e a disponibilidade de recursos alimentares. Apesar de muitos estudos avaliarem os impactos das mudanças no uso do solo, ainda há necessidade de sínteses e revisões e de uma abordagem mais ampla que vá além da ecologia taxonômica (*e.g.*, riqueza de espécies), incluindo efeitos na preferência de recursos e nas funções ecossistêmicas, que têm ligações diretas com o funcionamento dos ecossistemas e pode auxiliar em estratégias de conservação. Nesta tese de doutorado, busquei avaliar nesta tese como as mudanças no uso do solo e as variações microclimáticas afetam em assembleias de formigas a riqueza de espécies, preferência por nutrientes e predação de insetos. Além disso, fiz uma revisão sistemática com meta-análise sobre os efeitos do uso do solo nas assembleias de formigas no Brasil. Encontrei que no bioma Mata Atlântica as formigas apresentam maior preferência por aminoácidos e maior predação de insetos. Além disso, apesar de formigas predadoras terem a base da sua alimentação com proteínas e aminoácidos, aumentam a sua preferência por recursos energéticos devidos limitações nutricionais por carboidratos e lipídeos. Encontrei também que o microclima afeta a preferência nutricional em formigas, onde o aumento da temperatura tende a diminuir a preferência por recursos ricos em aminoácidos em relação a carboidratos e lipídios. Além disso, encontrei que as mudanças no uso do solo afetam direta e indiretamente as assembleias de formigas. A redução na predação de insetos causada pelas alterações no uso do solo é mediada pela perda da riqueza de espécies de formigas e, especificamente, das espécies predadoras. Por fim, na revisão e meta-análise, evidenciei que alterações muito contrastantes no uso do solo (e.g., conversão de floresta para pastagem) reduzem a riqueza de espécies e alteram a composição das assembleias de formigas, provavelmente devido à perda de espécies sensíveis e especialistas. Dessa forma, concluo que alterações nos usos do solo podem desencadear efeito negativos em diferentes aspectos das comunidades terrestres, como número e composição de espécies e funções ecossistêmicas, principalmente em conversões de habitat mais contrastantes. Assim, sugiro que, sempre que possível, habitats antropizados sejam mantidos o mais próximo possível do ambiente original, a fim de favorecer a conservação das espécies e das funções ecossistêmicas.

Palavras-chave: Ecologia Nutricional; Função Ecossistêmica; Formicidae; Brasil; Tropical.

GENERAL ABSTRACT

Land-use changes are the primary cause of biodiversity loss in terrestrial tropical environments. In these regions, such changes drastically alter vegetation structure and composition, affecting the microclimate and the availability of food resources. Despite numerous studies assessing the impacts of land-use changes, there is still a need for syntheses, reviews, and a broader approach that goes beyond taxonomic ecology (e.g., *species* richness), including effects on resource preference and ecosystem functions. These aspects are directly linked to ecosystem functioning and can help guide conservation strategies. In this PhD thesis, I aimed to evaluate how land-use changes and microclimatic variations affect ant assemblages, specifically species richness, nutrient preference, and insect predation. Additionally, I conducted a systematic review with a meta-analysis on the effects of land use on ant assemblages in Brazil. I found that in the Atlantic Forest biome, ants show a greater preference for amino acids and higher predation on insects. Furthermore, although predatory ants have a diet primarily based on proteins and amino acids, they increase their preference for energetic resources due to nutritional limitations in carbohydrates and lipids. I also found that the microclimate affects the nutritional preference in ants, where an increase in temperature tends to reduce the preference for amino acid-rich resources compared to carbohydrates and lipids. Furthermore, I found that land-use changes affect ant assemblages both directly and indirectly. The reduction in insect predation caused by land-use changes is mediated by the loss of ant species richness, particularly predatory species. Finally, in my review and meta-analysis, I demonstrated that highly contrasting land-use changes (e.g., from forest to pasture conversion) reduce species richness and alter the composition of ant assemblages, likely due to the loss of sensitive and specialist species. Thus, I conclude that land-use changes can cause negative effects on various aspects of terrestrial communities, such as species richness, composition, and ecosystem functions, particularly in more extreme habitat conversions. Therefore, I suggest that, whenever possible, anthropized habitats should be maintained as close as possible to their original environment to promote species conservation and ecosystem functions.

Keywords: Nutritional Ecology; Ecosystem Function; Formicidae; Brazil; Tropical.

INDICADORES DE IMPACTO

O Brasil abriga grande parte da biodiversidade global. Entretanto, as constantes e crescentes ameaças aos ambientes naturais vêm colocando a biodiversidade brasileira em risco. Diversos estudos ecológicos buscam avaliar os impactos antrópicos na biodiversidade, mas frequentemente de maneira limitada, como acessando apenas o número de espécies e identidade delas. Nessa tese, composta por três capítulos, foram encontrados resultados relevantes a respeito de impactos antrópicos na biodiversidade brasileira, mais especificamente dos efeitos das conversões dos usos do solo na riqueza, composição e função ecossistêmica em formigas. Esses resultados podem impactar de forma científica e social, com avanços no conhecimento ecológico e identificação de efeitos negativos na biodiversidade causadas por atividade humanas frequentes como agricultura e pecuária. Além disso, alguns resultados dessa tese têm caráter extensionista, divulgando os achados de artigo científico para um público adulto, e criando um jogo de cartas didático para crianças a partir de 8 anos. Essas atividades foram desenvolvidas com a colaboração de uma docente e um pós-doutorado interno, uma pós-doutoranda externa, dois discentes de doutorado e uma discente de mestrado. Dentro da Política Nacional de Extensão, essa tese compreende as áreas temáticas de Cultura e Meio ambiente, onde foi identificado que ações humanas afetam a biodiversidade de diferentes maneiras, e as áreas temáticas Comunicação e Educação com as Mídias de Divulgação geradas. Por fim, os impactos da pesquisa e se estão alinhados com quatro dos 17 (dezessete) Objetivos de Desenvolvimento Sustentável (ODS) da Organização das Nações Unidas (ONU): ODS 2 – Fome zero e agricultura sustentável: com resultados que auxiliam na busca pela agricultura que impactam menos o meio ambiente; ODS 4 – Educação de qualidade: com as Mídias de Divulgação voltada ao público não acadêmico; ODS 13 – Ação contra a mudança global do clima: identificando que alterações dos usos do solo podem afetar o clima local, e servir de base para estudos em escalas maiores; e ODS 15 – Vida terrestre: identificando impactos antrópicos que alteram a biodiversidade terrestre, além de discutir e sugerir alternativas.

IMPACT INDICATORS

Brazil harbours a large portion of global biodiversity. However, the constant and growing threats to natural environments have been putting Brazilian biodiversity at risk. Several ecological studies aim to assess the anthropogenic impacts on biodiversity, but often in a limited way, such as only assessing the number of species and their identity. In this thesis, composed of three chapters, relevant results regarding anthropogenic impacts on Brazilian biodiversity were found, specifically the effects of land-use conversions on species richness, composition, and ecosystem function in ants. These results can impact both scientifically and socially, with advances in ecological knowledge and the identification of negative effects on biodiversity caused by frequent human activities such as agriculture and livestock farming. Furthermore, some results from this thesis have an extensionist nature, disseminating the findings of scientific articles to an adult audience and creating an educational card game for children aged 8 and above. These activities were developed with the collaboration of a faculty member, an internal postdoctoral researcher, an external postdoctoral researcher, two doctoral students, and a master's student. Within the National Extension Policy, this thesis encompasses the thematic areas of Culture and Environment, where it was identified that human actions affect biodiversity in different ways, and the thematic areas of Communication and Education, with the Outreach Media generated. Finally, the research impacts are aligned with four of the 17 Sustainable Development Goals (SDGs) of the United Nations (UN): SDG 2 – Zero Hunger and Sustainable Agriculture: with results that assist in the search for agriculture that impacts the environment less; SDG 4 – Quality Education: with Outreach Media aimed at a non-academic audience; SDG 13 – Climate Action: identifying that land-use changes can affect the local climate and serve as a basis for studies on larger scales; and SDG 15 – Life on Land: identifying anthropogenic impacts that alter terrestrial biodiversity, in addition to discussing and suggesting alternatives.

SUMÁRIO

PRIMEIRA PARTE

INTRODUÇÃO GERAL

Os ambientes tropicais abrigam a maior parte da biodiversidade do planeta, mas enfrentam ameaças crescentes devido às ações humanas, especialmente a conversão do uso do solo (Newbold *et al*., 2020). Esse processo ocorre quando um habitat natural é transformado em outro, como no desmatamento de florestas tropicais para expansão agrícola. Isso pode causar grandes alterações nas condições ambientais e na disponibilidade de recursos (Stein; Gerstner; Kreft, 2014; Machado *et al*., 2020), o que por sua vez, impactam as comunidades biológicas, levando à perda de espécies sensíveis e à redução da biodiversidade local (Filgueiras *et al*., 2021). Embora os estudos frequentemente abordem essas perdas do ponto de vista taxonômico, aspectos relacionados às preferências por recursos e à ecologia funcional, áreas ainda emergentes (Luza *et al*., 2023), são pouco estudados. Assim, investigar os efeitos da conversão do uso do solo além da diversidade taxonômica pode contribuir para uma compreensão mais ampla dos impactos antrópicos em ambientes tropicais, relacionada ao ecossistema como um todo.

Na região Neotropical, a conversão do uso do solo ocorre principalmente pela substituição de florestas e savanas por áreas agrícolas e pastagens (Fao, 2016). No Brasil, esse processo tem sido historicamente intenso, gerando dois *hotspots* de biodiversidade: o Cerrado e a Mata Atlântica (Kong; Zhou; Jiao, 2021). A substituição da vegetação nativa por cultivos pode provocar mudanças drásticas na estrutura e composição da vegetação, incluindo a redução da cobertura vegetal e da diversidade de espécies de plantas (Castillo-Campos *et al*., 2024). Como consequência, ocorrem modificações no microclima e na disponibilidade de recursos (Stein; Gerstner; Kreft, 2014; Machado *et al*., 2020), afetando a fauna local e levando à perda de espécies especializadas e termossensíveis.

Além de afetar a riqueza e diversidade de espécies, as alterações no uso do solo podem modificar a atividade das espécies remanescentes. Ambientes mais extremos, com temperaturas elevadas, tendem a terem menor riqueza e redução da atividade das espécies devido aos riscos de dissecação (Parr; Bishop, 2022). No entanto, algumas espécies ajustam seu comportamento para lidar com essas mudanças. Por exemplo, temperaturas mais altas podem aumentar o metabolismo, elevando a busca por recursos energéticos (Riemer *et al*., 2018). Da mesma forma, a limitação de certos nutrientes pode intensificar o esforço de forrageamento e alterar a preferência pelos nutrientes mais escassos (Kaspari *et al.,* 2012). Assim, compreender como o uso do solo altera as condições ambientais e a oferta de recursos é fundamental para avaliar a

dinâmica das comunidades ecológicas em áreas antropizadas, além das avaliações microclimáticas poderem auxiliar estudos sobre mudanças climáticas em escalas mais amplas.

Essas mudanças na disponibilidade de recursos e no comportamento das espécies podem ter consequências diretas sobre as funções ecossistêmicas. Alguns mecanismos alternativos podem explicar esses impactos. Primeiro, a perda de espécies pode comprometer determinadas funções ecossistêmicas, uma vez que a redução do número de espécies e indivíduos pode diminuir a realização de determinada função (Biggs *et al.*, 2020). Segundo, a perda de muitas espécies sensíveis e ganho de poucas generalistas ("*few winners, many losers*"; Mckinney; Lockwood, 1999) pode, em alguns casos, intensificar certas funções ecossistêmicas, já que espécies generalistas podem ser mais ativas em ambientes antropizados e ocupar o nicho das espécies perdidas (Manlick; Newsome, 2021). Terceiro, a substituição de espécies, especialmente com a predominância de espécies dominantes, pode levar à homogeneização das funções ecossistêmicas (Wong; Guénard; Lewis, 2020). Assim, avaliar como as alterações nos usos do solo modificam as funções ecossistêmicas se torna relevante para estratégias de conservação, como o planejamento de paisagens multifuncionais, incluindo sistemas agrícolas e áreas naturais e/ou corredores ecológicos, propiciando conservação das espécies e suas funções.

Apesar dos esforços crescentes para compreender os impactos antrópicos na biodiversidade, a maioria dos estudos foca principalmente na riqueza e diversidade taxonômica, deixando outras áreas ainda pouco exploradas, como preferências por recursos e funções ecossistêmicas (Moses *et al*., 2023). Investigar esses aspectos pode ser crucial para entender como as comunidades se ajustam a ambientes antropizados, especialmente diante das alterações na atividade de forrageio resultantes da redução de recursos e das mudanças microclimáticas. Além disso, essas modificações no forrageio podem afetar diretamente a realização de funções ecossistêmicas, um tema que também é pouco avaliado em relação a ecologia taxonômica, mas essencial para dinâmicas ecológicas em ambientes naturais e serviços ecossistêmicos em áreas antropizadas (Luza *et al.,* 2023).

Para compreender como os usos do solo impactam a biodiversidade terrestre tropical, levando em consideração aspectos taxonômicos (riqueza e composição), preferências por recursos e funções ecossistêmicas, utilizei as formigas como modelo de estudo. As formigas são um grupo megadiverso, especialmente em regiões tropicais como o Brasil (Feitosa *et al*., 2022). Além de sua vasta diversidade de espécies e grupos funcionais, elas forrageiam por diferentes tipos de alimento e desempenham funções ecológicas essenciais, como predação,

herbivoria e proteção de plantas (Folgarait, 1998). Por outro lado, as formigas são altamente sensíveis a impactos antrópicos, como a conversão do uso do solo, o que pode reduzir a riqueza de espécies e alterar os padrões de forrageio e as funções ecossistêmicas (Moses *et al*., 2023; Wilker *et al*., 2023). Embora já exista uma grande quantidade de estudos sobre efeitos dos usos do solo nas formigas no Brasil, ainda há uma necessidade de uma revisão abrangente que sintetize os resultados existentes e identifique lacunas no conhecimento da área da mirmecologia (Wilker *et al*., 2024).

Assim, meu objetivo geral nesta tese foi avaliar como as alterações no uso do solo e as mudanças microclimáticas afetam a diversidade de formigas, suas preferências alimentares e a função ecológica de predação, além de realizar uma revisão sistemática com meta-análise sobre os efeitos do uso do solo sobre as formigas no Brasil. Para isso, dividi a tese em três capítulos:

1) *Land use and microclimate changes alter ant foraging in Neotropical biomes*

No primeiro capítulo da tese, atualmente na segunda rodada de revisão na revista *Ecological Entomology*, avaliamos como a conversão de florestas para plantações de café nos biomas Cerrado e Mata Atlântica afeta o forrageio de formigas por nutrientes (aminoácidos, carboidratos, lipídios e sódio) e larvas de insetos (*Tenebrio molitor* Linnaeus, 1758).

2) *Land use changes have direct and indirect negative effects on ant species richness and predation*

No segundo capítulo, formatado conforme as normas da *Biodiversity and Conservation*, avaliamos os efeitos diretos e indiretos da conversão de áreas de floresta para plantações de café sobre o microclima, a riqueza de espécies de formigas e, consequentemente, sobre a predação de insetos.

3) *A systematic review of the land use change effects on ant diversity in Neotropics*

No terceiro capítulo, publicado na revista *Biological Conservation*, realizamos uma revisão sistemática com meta-análise sobre os estudos de caso que investigam os efeitos do uso do solo sobre as formigas no Brasil.

Além dos artigos científicos, a tese também inclui duas mídias de divulgação científica: uma notícia publicada no Portal da Ciência da Universidade Federal de Lavras, voltada para o público adulto, sobre os efeitos do uso do solo nas formigas no Brasil, um jogo de cartas com livro ilustrado, ainda em desenvolvimento, destinado a adultos e crianças acima de 8 anos, sobre interações tróficas e os impactos antrópicos na biodiversidade do Cerrado.

REFERÊNCIAS

ALKAMA, R.; CESCATTI, A. Biophysical climate impacts of recent changes in global forest cover. **Science**, v. 351, n. 6273, p. 600–604, 2016.

BIGGS, C. R. *et al*. Does functional redundancy affect ecological stability and resilience? A review and meta-analysis. **Ecosphere**, v. 11, n. 7, e03184, 2020.

CASTILLO-CAMPOS, G. *et al*. Assessing the impact of land use change on different components of plant diversity in a tropical montane cloud forest of Mexico. **Biodiversity and Conservation,** v. 33, n. 4, p. 1523-1559, 2024.

FAO. The State of the World's Forests 2016: Forests and Agriculture-Land-use Challenges and Opportunities. UN, 2016.

FEITOSA, R. M. *et al*. Ants of Brazil: an overview based on 50 years of diversity studies. **Systematics and Biodiversity**, v. 20, n. 1, p. 1–27, 2022.

FILGUEIRAS, B. K. *et al*. Winner–loser species replacements in human-modified landscapes. **Trends in Ecology & Evolution**, v. 36, n. 6, p. 545–555, 2021.

FOLGARAIT, P. J. Ant biodiversity and its relationship to ecosystem functioning: a review. **Biodiversity & Conservation**, v. 7, p. 1221-1244, 1998.

KASPARI, M. *et al*. Using nutritional ecology to predict community structure: a field test in Neotropical ants. **Ecosphere**, v. 3, n. 11, p. 1–15, 2012.

KONG, X.; ZHOU, Z.; JIAO, L. Hotspots of land-use change in global biodiversity hotspots. **Resources, Conservation and Recycling**, v. 174, p. 105770, 2021.

LUZA, A. L.; *et al*. Going across taxa in functional ecology: Review and perspectives of an emerging field. **Functional Ecology**, v. 37, n. 12, p. 3091-3110, 2023.

MACHADO, N. G. *et al*. Effects of deforestation on microclimate in a Cerrado-Amazonia Transition area. **Ciência Florestal**, v. 33, n. 2, e70199, 2023.

MANLICK, P. J.; NEWSOME, S. D. Adaptive foraging in the Anthropocene: can individual diet specialization compensate for biotic homogenization?. **Frontiers in Ecology and the Environment,** v. 19, n. 9, p. 510–518, 2021.

McKINNEY, M. L.; LOCKWOOD, J. L. Biotic homogenization: a few winners replacing many losers in the next mass extinction. **Trends in Ecology & Evolution**, v. 14, n. 11, p. 450-453, 1999.

MOSES, J. *et al*. Nutrient use by tropical ant communities varies among three extensive elevational gradients: A cross-continental comparison. **Global Ecology and Biogeography**, v. 32, n. 12, p. 2212–2229, 2023.

NEWBOLD, T. *et al*. Tropical and Mediterranean biodiversity is disproportionately sensitive to land-use and climate change. **Nature Ecology & Evolution**, v. 4, n. 12, p. 1630–1638, 2020.

PARR, C. L.; BISHOP, T. R. The response of ants to climate change. **Global Change Biology**, v. 28, n. 10, p. 3188–3205, 2022.

RIEMER, K. *et al*. Body size shifts influence effects of increasing temperatures on ectotherm metabolism. **Global Ecology and Biogeography**, v. 27, n. 8, p. 958–967, 2018.

STEIN, A.; GERSTNER, K.; KREFT, H. Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. **Ecology Letters**, v. 17, n. 7, p. 866–880, 2014.

WILKER, I. *et al*. Land-use change in the Amazon decreases ant diversity but increases ant-mediated predation**. Insect Conservation and Diversity**, v. 16, n. 3, p. 379–392, 2023.

WILKER, I. *et al*. A systematic review of the land use change effects on ant diversity in Neotropics. **Biological Conservation**, v. 299, p. 110778, 2024.

WONG, M. K.; GUÉNARD, B.; LEWIS, O. T. The cryptic impacts of invasion: functional homogenization of tropical ant communities by invasive fire ants. **Oikos**, v. 129, n. 4, p. 585–597, 2020.

SEGUNDA PARTE

ARTIGO 1 - The preference for energetic resources is positively associated with predatory activity in ants

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ABSTRACT

1. Land use changes can alter resource availability and microclimate variables in tropical ecosystems, generally altering community structure by decreasing species richness and changing its composition. These changes affect foraging activity, nutrient preferences, and consequently ecosystem functions.

2. Our aim was to assess how foraging activity and nutrient preference is influenced by changes in land use and microclimate.

3. We sampled ants (Formicidae) at 32 sites undergoing conversion from natural habitats to coffee systems in two Neotropical biomes: the Atlantic rainforest and the Cerrado. We assessed nutrient preference (amino acids, carbohydrates, lipids, and sodium) and predation using mealworm larvae, while also measuring temperature and humidity.

4. We found the same ants foraged for different resources, likely because generalist species can perform these activities on the ground. Furthermore, foraging for energetic resources (carbohydrates and lipids) positively correlated with foraging for larvae. This indicates that the limitation of energetic resources can contribute to an increase in foraging and predatory activity. Moreover, ant preference for amino acids decreases with increasing temperature, indicating that ants prefer to consume energetic resources to support metabolic processes.

5. In conclusion, foraging is primarily carried out by generalist species. In addition, the preference for energetic nutrients, driven by energetic limitations, is linked to predatory activity. Moreover, ant species richness increases foraging for larvae, while rising temperatures decrease the preference for amino acids. Thus, conserving species richness and mitigating temperature increases may enhance larval foraging and support the insect predation function in Neotropical habitats.

Keywords: Disturbance, ecosystem function, macronutrients, nutritional ecology, nutrient preference, temperature, tropical biodiversity

INTRODUCTION

Land use changes drive tropical biodiversity loss primarily through the conversion of forest to agriculture (Jayathilake et al., 2021; Williams & Newbold, 2020). This conversion alters environmental conditions (Machado et al., 2023) and decrease the resources that are available to resident species (Stein et al., 2014; Tews et al., 2004). This can decrease species richness (McKinney & Lockwood, 1999; Wilker et al., 2024) and select for organisms with different ecological adaptations, such as modifications in their foraging activity and diet (Castillo-Guevara et al., 2019; Manlick & Newsome, 2021). In turn, changes in foraging activity and nutrient preference can alter ecosystem functions (Dudley et al., 2012; Maisey et al., 2021). Consequently, understanding how land use in the tropics affects foraging activity and nutrient preference would provide a better comprehension of the impacts of land use beyond community structure (e.g., species richness), laying the groundwork for future conservation practices.

The foraging activity of animals can be altered by microclimate alterations resulting from land use changes. For example, as forest vegetation is converted to open vegetation land uses, there is a reduction in available shade and an increase in solar radiation (Machado et al., 2023). This leads to an increase in maximum temperature and a decrease in minimum temperature and humidity (Alkama & Cescatti, 2016; Trancoso et al., 2022). Consequently, many animals tend to reduce their foraging activity to minimize thermal and desiccation risks (Parr & Bishop, 2022). On the other hand, increased temperatures may enhance foraging activity on average, especially in ectotherms. This happens because higher temperatures raise animals' metabolic rates, thus allowing them to forage for greater durations relative to when it is cooler (Riemer et al., 2018). Therefore, changes in foraging due to microclimatic changes can have opposite effects in tropical habitats.

The other way in which land use change impacts foraging activity and nutrient preference is by decreasing the quantity and variety of resources provided by plants and animals (Adkins et al.,

2023; Tilman et al., 1996). This occurs because, according to the compensation hypothesis, animals tend to increase their foraging activity for nutrients that are scarce in their environment or diet (Kaspari et al., 2012; Kaspari & Yanoviak, 2001). In this sense, as agricultural systems reduce the productivity of native plant resources (Barnes et al., 2017), a scarcity of energetic nutrients occurs. This can lead both to a decrease in overall foraging activity due to smaller population sizes and to an increase in the search for specific limiting energetic nutrients (e.g., carbohydrates and lipids) compared to non-energetic nutrients (e.g., amino acids and sodium; Lasmar et al., 2021; Peters et al., 2014). Moreover, the decline in productivity commonly associated with anthropogenic land uses may lead to increased foraging for energetic resources (Lasmar et al., 2021), including a greater preference for lipids over amino acids among predatory groups due to energetic limitations (Lasmar et al., 2023; Mayntz et al., 2005). In contrast, species that forage on the ground in natural tropical environments are typically not constrained by sodium availability (Lasmar et al., 2021). Additionally, sodium availability may rise through practices such as fertilization and irrigation (Hopmans et al., 2021), which could reduce the preference for this nutrient. Thus, despite an expected decrease in foraging activity due to the low population sizes in agricultural land uses, animals may alter nutrient preference, focusing primarily on energetic resources, due to there being a greater number of limiting nutrients caused by the land use change.

Despite the negative impacts of land use on community structure, the effects on foraging activity and nutrient preference are still poorly evaluated (but see Lasmar et al., 2023; Moses et al., 2023). Several studies have identified a decline in species richness due to the local extinction of sensitive species and the survival of generalist species (e.g., Tabarelli et al., 2012). This may lead to a reduction in overall foraging activity due to the positive relationship between species richness and the intensity of foraging (Lasmar et al., 2021; Noriega et al., 2021). On the other hand, generalist species can forage for a variety of resources in anthropogenic land uses

(Dehling et al., 2021; Manlick & Newsome, 2021), changing their patterns of nutrient preference. Additionally, the impact of land use changes can vary in magnitude depending on the type of natural habitat (Carvalho et al., 2022; López-Bedoya et al., 2022; Wilker et al., 2024). For example, land use changes in different biomes may select for different species based on the original species pool (Corbelli et al., 2015). Consequently, these species may alter their foraging patterns in various ways, influenced by their response to changes in the microclimate and resource availability, as well as by the impacts of land use modifications on foraging activity and nutrient preferences. Thus, assessing the effects of land use changes on nutrient preference, considering the biome context and microclimatic variables, may contribute to the conservation in both natural and anthropized habitats.

Ants (Hymenoptera: Formicidae) are excellent models for assessing the effects of land use changes (Andersen, 2019; Ribas et al., 2012) on foraging effort and nutrient preference (Lasmar et al., 2021, 2023; Peters et al., 2024). This is because ants exhibit a high diversity of species and life histories among animals (Feitosa et al., 2022). They also exhibit decreases in species richness and changes in community composition in response to anthropogenic impacts, including land use change (Andersen, 2019; Ribas et al., 2012). Furthermore, ants forage for various nutrients such as carbohydrates and lipids as energy sources, amino acids for body growth, and sodium for metabolic processes (Riemer et al., 2018). For example, ants may exhibit increased predatory activity in anthropogenic land uses, driven by the heightened activity of generalist groups (Wilker et al., 2023). Moreover, the consumption of lipids has been linked to predatory activity in ants and ground-dwelling communities (Lasmar et al., 2023). Consequently, in predatory behaviour, which is most exhibited by generalist ants (Cerdá & Dejean, 2011), these arthropods may forage more for carbohydrates and lipids due to their limited availability at the trophic level (Kaspari et al., 2012; Lasmar et al., 2023; Wilder et al., 2013). Alternatively, the scarcity of these nutrients in their diet can lead to increased lipid intake

from prey bodies (Mayntz et al., 2005). However, ant foraging activity and nutrient preferences may be affected by changes in land use. Due to ants being thermosensitive, microclimate changes in anthropogenic land uses can decrease their foraging activity (Parr & Bishop, 2022). Additionally, a lower number of species associated with intensified land use is linked to reduced foraging activity, likely due to a smaller number of foraging ants (Lasmar et al., 2021). Thus, ants may exhibit changes in foraging patterns with alterations in land uses in tropical ecosystems.

Here, our aim was to assess whether changes in land use and microclimate explain the foraging activity and nutrient preference of ants. We considered foraging activity for the following resources: nutrients (lipids, carbohydrates, amino acids, sodium) and mealworm larvae (*Tenebrio molitor* Linnaeus, 1758). More specifically, we asked: (i) How similar is the species composition across land uses and resources? We expected that ant composition would differ across land uses due to species turnover but would be similar among ants that forage for larvae, carbohydrates, and lipids, indicating limiting resources for predatory ants; (ii) Is foraging for larvae explained by nutrient preference? We expected that foraging for larvae would be positively associated with foraging for carbohydrates and lipids, as predatory ants should increase their foraging for energy sources; (iii) How are changes in foraging activity (foraging for larvae and nutrient preference) explained by ant species richness, land use, and microclimate changes? We expected that foraging activity would be positively associated with increases in ant species richness and temperature but negatively associated with extreme temperatures and low humidity in agricultural systems. Moreover, we expected that foraging for lipids, carbohydrates (energetic resources), and larvae would increase in anthropogenic land uses due to resource limitations.

METHODS

Study site

We collected data on ant foraging activity in the state of Minas Gerais, Brazil. Minas Gerais has a territory of 586,528 km^2, mainly composed of the Atlantic rainforest (40%) and the Cerrado (54%) (Figure 1; Biomas, 2019). The Atlantic rainforest and Cerrado are considered global biodiversity hotspots due to their high species numbers, endemism, and the significant threat by land use changes (Trew & Maclean, 2021). The Atlantic rainforest (tropical forest) extends into tropical and subtropical regions, generating diverse rainforest environments. On the other hand, the Cerrado (Brazilian savannah) features various vegetation types, ranging from open vegetation habitats to closed forests, including grasslands, shrublands, typical savannas, and woodland savannah (cerradão). These regions are characterized by a wet summer (October to March) and a dry winter (April to September). In the winter, Cerrado has an average precipitation of 23.50 mm and average temperature of 18.25 °C, while the Atlantic rainforest has an average precipitation of 26.75 mm and average temperature of 18.97 °C. In the summer, Cerrado has an average precipitation of 212.87 mm and average temperature of 22.16 °C, while Atlantic rainforest has an average precipitation of 134.54 mm and an average temperature of 20.41 °C (INMET, 2024).

Experimental design

We sampled between January and March of 2022 and 2023. In total, we sampled 32 sites (n = 32). The sites are composed of six woodland savannahs (cerradão), six tropical forests in Atlantic rainforest, eight coffee plantations in Cerrado and 12 coffee plantations in Atlantic rainforest (Figure 1; Table S1). The collections in the Cerrado were conducted in the rural areas of the municipality of Patrocínio (14 sites), while the collections in the Atlantic rainforest were conducted in the rural areas in the municipalities of Lavras (4 sites) and Santo Antônio do Amparo (SAA) (14 sites). Each site had only one transect per sampling, and the sites were spaced at least 322 m apart.

We collected data from coffee plantations of the species *Coffea arabica* L. All plantations were unshaded and mechanized (e.g., use of tractors). In the Atlantic rainforest, all coffee plantations were conventional (12 sites). In the Cerrado, four sites were conventional coffee (with the use of fertilizers and insecticides), and four sites were organic coffee (without the use of fertilizers and insecticides). Before conducting our hypothesis tests, we assessed the possible influence of these variables on our analyses and found that the type of coffee management (conventional or organic) did not affect the results, allowing us to combine the data and disregard management type in the analyses.

Foraging activity for resources

In each transect, we assessed ant foraging activity for resources, including nutrients (amino acids, carbohydrates, lipid, and sodium) and larvae. Nutrients were offered in the liquid form, and we used water as control. In each site, we created a transect with 25 sampling points spaced 10 meters apart (totalling 240 m). In each transect, we sampled ants, between 7 a.m. and 8 a.m, using the nutrients in Fisher 50 mL tubes. Each tube contained 10 ml of an aqueous solution of each type of nutrient. The nutrients included 20% amino acids (AA, made with Whey Protein Isolate and unflavoured containing L-glutamine and other amino acids such as leucine, isoleucine, and valine), 20% carbohydrates (CHO, made with sucrose), lipids (100% extra virgin olive oil, without water), 1% sodium solution (NaCl, made with salt), and tap water (Lasmar et al. 2021; 2023). The tubes were placed horizontally on the ground and closed at the end of sampling, with the ants inside collected and stored in 70% alcohol for preservation.

After the nutrient experiment, in the same transect but only at five sampling points spaced 50 m apart (totalling 200 m), we assessed foraging for larvae as a proxy measure for insect predation by ants. At each sampling point, we installed two beetle larvae (*Tenebrio molitor*). The larvae were attached with Velcro to an ethylene-vinyl acetate (EVA) surface to prevent them from escaping. At each sampling point, between 8 a.m. and 12 p.m., we observed foraging

activity in four rounds of five minutes each. First, we attached the larvae to the ground at the first sampling point and immediately observed the foraging for larvae for five minutes. Then, we attached larvae at the second sampling point and observed the foraging for larvae for five minutes. We repeated this process until completing the transect and then started again for the second, third, and fourth rounds. This totaled 20 minutes per sampling point and 100 minutes per transect. We considered the foraging activity by ants when they attacked the larvae, either by stinging or biting (Wilker et al., 2023). The ants that engaged in predation were collected and stored in 70% alcohol for later identification.

Microclimate measurements

We measured temperature and humidity alongside the larvae experiment. Using a digital thermo-hygrometer, we measured air temperature (°C) and humidity (%) at 5 cm from the ground at the sampling point. We took 20 temperature and humidity measurements per transect (five sampling points x four rounds) and used the average of them in our analyses.

Ant species richness and composition

After the larvae experiment, in the same transect with five sampling points spaced 50 meters apart (totalling 200 m), we installed pitfall traps to assess ant species richness and composition. The traps consisted of plastic pots with a diameter of 12 cm and a depth of 11 cm, installed at ground level. We added an aqueous solution composed of 200 ml of water mixed with salt and detergent to capture and preserve the collected ants. Each trap was left sampling for a period of 48 hours. After this period, the captured ants were stored in 70% alcohol.

Ant species identification

We identified to the genus level based on Baccaro et al. (2015) and morphotyped them based on external morphological characters. Identification and confirmation of species and morphospecies were made by Rodrigo M. Feitosa and Ana Carolina A. Neundorf at the Laboratório de Sistemática e Biologia de Formigas at the Universidade Federal do Paraná

(UFPR). Specific published descriptions were used to identify species in the genera *Acromyrmex* (Gonçalves, 1961), *Acropyga* (LaPolla, 2004), *Apterostigma* (Lattke, 1997), *Basiceros* (Probst & Brandão, 2022), *Brachymyrmex* (Ortiz-Sepúlveda et al., 2019), *Carebara* (Fernández, 2004), *Ectatomma* (Kugler & Brown, 1982), *Gnamptogenys* (Camacho et al., 2020), *Labidus* (Watkins, 1976), *Linepithema* (Wild, 2007), *Neivamyrmex* (Watkins, 1976), *Odontomachus* (Brown, 1976), *Pheidole* (Wilson, 2003), *Strumigenys* (Bolton, 2000), and *Wasmannia* (Longino & Fernández, 2007). Voucher specimens were deposited in the reference collection of Laboratório de Ecologia de Formigas at UFLA and the Coleção Entomológica Padre Jesus Santiago Moure at UFPR (DZUP).

Data analysis

Foraging activity for resources was computed in two distinct ways for nutrients and larvae. For nutrients, we used a measure nutrient preference at each transect (relative resource use; Lasmar et al., 2021). As we are primarily interested in the preference between energy nutrients (carbohydrates and lipids) compared to amino acids, to calculate the nutrient preference, we excluded water (control) and sodium (NaCl) from compute nutrient preference. Moreover, as expected, the control and sodium tubes had lower ant occurrence (Figure S2). Nutrient preference was calculated as the number of tubes visited for a given nutrient at a transect, divided by the total number of tubes visited per transect. Thus, nutrient preference indicates the foraging for a specific nutrient in relation to all others. A nutrient foraging value of 1 indicates that all occurrences were on a single nutrient, and a nutrient foraging value of 0 means that no ant occurrences were recorded for a nutrient (Lasmar et al., 2021). To do this, we measured the nutrient preference between energy and AA, with energy being the combination of carbohydrates and lipids data. We transformed these proportional values using a logit transformation to meet Gaussian assumptions in our analyses (Lasmar et al., 2021; Warton &

242 Hui, 2011). For larvae, foraging was calculated by the number of attacks on larvae, being a
243 count data, and we used the Poisson family (Wilker et al., 2023).

244 To assess (i) whether the species composition is similar across land uses and resources, we
245 calculated Sørensen dissimilarity using the betapart package version 1.6 (Baselga, 2010;
246 Baselga et al., 2023). Sørensen dissimilarity ranges from 0 to 1, where 0 indicates assemblages
247 with identical compositions and 1 indicates assemblages with completely different
248 compositions. We had 32 sites with five resources (amino acids, carbohydrates, lipids, sodium,
249 and larvae), totaling 160 "assemblages". However, in several sites, we collected only one or
250 two ant species per assemblage. Due to the low number of species in each assemblage, we could
251 not compute the dissimilarity between them. As an alternative, we merged the assemblages
252 within the same land use type (woodland savannah, tropical forest, coffee plantation in Atlantic
253 rainforest, and coffee plantation in Cerrado). This reduced our sample size to 20 (five resources
254 X four land use types) but increased the number of species for each sample unit. Moreover, we
255 partitioned βsør-diversity into turnover (βsim) and nestedness (βsne). We used βsør, βsim and
256 βsne to perform three non-metric multidimensional scaling (NMDS) analyses, using the
257 function *metaMDS* (vegan package version 2.6-6; Oksanen et al., 2024). We then tested the
258 difference in community dissimilarity with three permutational analyses of variance
259 (PERMANOVA), using the function a*donis2* (vegan package version 2.6-6; Oksanen et al.,
260 2024) with 9999 permutations. In all models, we used the predictor variables of resources and
261 land use type. As a response variable, we used βsør, βsim and βsne, one for each model. When
262 we found a significant result in PERMANOVA, we used the function *pairwise.adonis2*
263 (pairwiseAdonis package version 0.4; Martinez Arbizu, 2020) to understand which pairs of
264 assemblages were different.

265 To assess (ii) whether foraging for larvae is explained by nutrient preferences, we built two
266 generalized linear model (GLM). As the response variable, we used the number of foraging for

larvae per transect. As predictors we used the nutrient preference per transect (foraging for a specific nutrient in relation to all others). In first model, we used the nutrient preference for energetic nutrients, and in second model the nutrient preference for AA. We considered a result significant if $p < 0.05$. We used the Poisson family because the response variable is count data (number of ants foraging for larvae per transect). We evaluated the normality of the residuals using histograms and quantile-quantile plots and the heteroscedasticity using residuals by fitted value plots. Moreover, because the model was overdispersed, we changed the family to negative binomial, using the MASS package (Venables & Ripley, 2002).

To avoid multicollinearity between microclimate variables, we tested a correlation between temperature and humidity. The Spearman correlation coefficient between these variables was strongly negative ($\rho = -0.86$; $p < 0.001$; Figure S1). For this reason, we used only temperature as a microclimate variable.

To assess (iii) whether changes in foraging activity are explained by ant species richness, land use, and microclimate changes, we calculated three GLMs. In all models, we used ant species richness, land use (natural habitat or coffee plantation) and temperature as predictor variables. We also use biome (Atlantic rainforest and Cerrado) with a predictor variable to assess whether the patterns were consistent across different geographic contexts. In one model, we used foraging for larvae as the response variable. In the other two models, we used nutrient preference for energy and nutrient preference for amino acids. For models with larvae, we used a negative binomial error family because of the overdispersion. For the models with nutrient preference, we used the gaussian family. In all models, we tested the residual normality and homoscedasticity. Moreover, in all models, we used the *dredge* function to select the best models and identified “uninformative parameters” following Leroux (2019).

We used the *dredge* function (MuMIn package version 1.47.5; Bartoń, 2023) to run all possible models. The dredge function ranked the models based on the Akaike information criterion

292 corrected for small sample sizes (AICc). We considered models to be equivalent if ΔAICc < 2
293 (Burnham & Anderson, 2002). However, within our selected models there may be
294 "uninformative parameters", leading to a Type I error (Leroux, 2019). We followed the
295 approach proposed by Leroux (2019) for detecting these "uninformative parameters". We
296 compared the log-likelihoods of the top model and those models within ΔAICc < 2 that had
297 additional parameters not in the top model. If the log likelihoods were different (log-likelihoods
298 > 1), we considered the additional parameters as informative. If the log likelihoods were similar
299 (log-likelihoods < 1), we checked to see if the 95% confidence intervals (CI) of the additional
300 parameters overlapped zero, using the *confint* function (stats package; R Core Team, 2024). If
301 the confidence intervals overlapped zero, we considered the parameters to be uninformative, if
302 they did not overlap zero, we considered them to be informative. When the predictor overlaps
303 zero, it probably does not explain the response variable (Leroux, 2019).

304 All analyses were completed in R 4.3.3 (R Core Team, 2024). All graphs were made with the
305 ggplot2 package (Wickham, 2016).

306 **RESULTS**

307 We sampled 12,346 ant workers and 138 ant species, belonging to 124 ant species for pitfall
308 data, 28 ant species foraging for larvae, and 51 species for nutrient preference (more details in
309 Tables S2-S6). Concerning nutrient preference, we found that ant foraging was higher for
310 carbohydrates (ant presence in carbohydrate tubes: mean ± deviation standard = 0.50 ± 0.50)
311 and lipids (ant presence in lipid tubes: 0.45 ± 0.49), intermediate for amino acids (ant presence
312 in amino acid tubes: 0.19 ± 0.39) and sodium (ant presence in sodium tubes: 0.21 ± 0.41), and
313 low for control tubes (ant presence in control tubes: 0.09 ± 0.29) across all transects (Figure S2;
314 Table S6).

315 Regarding (i) whether the species composition is similar across land uses and resources, we
316 found that the ant species composition differs between land uses (degrees of freedom (d.f.) = 3;

F = 6.373; $p < 0.001$), and the principal beta diversity component is turnover (βsør = 0.918, βsim = 0.883, and βsne = 0.035; Figures S3-S4). However, we did not find a different ant composition across different resources (Figure 2 and Table S7).

Regarding (ii) whether foraging for larvae is explained by nutrient preference, we found that an increase in foraging for energy (carbohydrates and lipids combined), relative to amino acids, positively explained the foraging effort for larvae (d.f. = 30; F = 3.924; p = 0.047; $R^2 = 0.11$; Figure 3). However, we did not find an effect of nutrient preference for amino acids compared to energy (d.f. = 30; F = 0.956; p = 0.328).

Regarding (iii) whether changes in foraging activity are explained by ant species richness, land use, and microclimate changes, we found predictors for both foraging for larvae and nutrient preference for amino acids (Table 1). As ant species richness increased, so did the number of foraging for larvae. Moreover, both foraging for larvae and preference for amino acids were greater in the Atlantic rainforest than in the Cerrado (Table 1; Figure 4A; Figure 5). Additionally, an increase in temperature (°C) reduced the ants' preference for amino acids (Table 1; Figure 4B). On the other hand, we did not find any effect of microclimate or land use on nutrient preference for energetic nutrients (Table 1).

DISCUSSION

In our study, we identified important patterns regarding changes in foraging activity and nutrient preference caused by land use and microclimate changes. We found that ants preferred foraging for carbohydrates and lipids, indicating the ants' preference for energy resources (Lasmar et al., 2021, 2023; Peters et al., 2014). We also found that the ants foraging for different resources had the same species composition, probably due to the presence of generalist ants on the ground. Additionally, we found a positive relationship between ants foraging for energetic nutrients and larvae, suggesting that limitations in energetic resources (carbohydrates and lipids) an increase in ant foraging can contribute to higher insect predation, as it leads to more

342 frequent foraging on larvae. Moreover, both foraging for larvae and preference for amino acids
343 were higher in the Atlantic rainforest than in the Cerrado, suggesting greater predatory ant
344 activity and amino acid consumption in this biome. Thus, although foraging for larvae was
345 associated with amino acid preference in the same biome, it is possible that nutrient limitation
346 for energetic resources leads to increased foraging activity for these nutrients, thereby
347 enhancing predation events.

348 In agreement with other studies, we found that the conversion of natural habitats to coffee
349 systems decreases ant diversity (e.g., De la Mora et al., 2013; Escobar-Ramírez et al., 2020)
350 and changes species composition (Perfecto & Snelling, 1995), making the communities more
351 homogeneous in this type of land use. Sun coffee plantations, as observed in our study, tend to
352 have more intense effects on ant assemblages compared to shaded coffee plantations, which has
353 a more negative impact on ant diversity (Urrutia-Escobar & Armbrecht, 2013). Moreover, ants
354 are important predators in coffee systems, contributing to the reduction of coffee berry borer
355 (Aristizabal & Metzger, 2019; Philpott & Armbrecht, 2006). However, to the best of our
356 knowledge, this is the first study to assess ant nutrient preference in coffee systems, making
357 significant advances in the field, particularly by linking this nutrient search to insect predation,
358 an important ecosystem function in this type of plantation.

359 *(i) How similar is the species composition across land uses and resources?*

360 We found that ant composition differed across land use types but was similar across all
361 resources. At a regional scale, it was expected that species composition would differ between
362 biomes due to distinct species pools and geographic distance (Schmidt et al., 2017). Moreover,
363 with land use changes, there is a loss of sensitive species and a gain of generalist and resistant
364 ones, resulting in species turnover and changes in composition (Queiroz et al., 2020; Wilker et
365 al., 2023). The similarity in ant composition across different resources is likely due to the
366 presence of omnivorous and opportunistic species. Most ants in our study belonged to the genus

Pheidole (Tables S2-S5), which is dominant in Brazilian biomes and forages broadly on the ground (Feitosa et al., 2022; Sarnat et al., 2015). Thus, while ant composition varies across land use types due to species turnover, it remains similar within each land use type because the same opportunistic species exploit available resources.

(ii) Is foraging for larvae explained by nutriente preference?

We found that an increase in foraging for energetic nutrients (carbohydrates and lipids) positively explained foraging for larvae. Energetic nutrients are scarce in prey, leading predators to increase foraging for carbohydrates and lipids despite the low energy gain from amino acids (Jensen et al., 2012; Lasmar et al., 2023; Wilder et al., 2013). Thus, our results suggest a positive link between the search for energetic nutrients (carbohydrates and lipids) and the predatory activity of ants compared to amino acids. Additionally, the lower correlation coefficient ($R^2 = 0.11$) can be explained by the greater number of generalist ants in our experiments, and this pattern could be stronger for strictly predatory animals.

(iii) How are changes in foraging activity explained by ant species richness, land use, and microclimate changes?

Regionally, foraging for larvae and preference for amino acids were higher in the Atlantic rainforest than in the Cerrado. This may be due to a greater limitation of amino acids in Atlantic rainforest ecosystems compared to the Cerrado, leading predatory ants to seek these nutrients more in the bodies of their prey. Cerrado is known for presenting high levels of amino acids that are present in extrafloral nectaries (Leal et al., 2017; Ribas et al., 2010). Although we collected data only from the ground, and extrafloral nectaries are found in arboreal strata, many ground-dwelling ants forage in both strata to search for resources (Passos & Leal, 2019; Rezende et al., 2024). Thus, ants are more limited by resources from nectaries, including amino acids, in the Atlantic rainforest than in the Cerrado, leading to increased predation in this biome.

Therefore, the predatory activity of animals may depend on the biome context, where nutrient limitations can enhance this function.

We also found a positive effect of ant species richness on foraging for larvae. Several studies indicate a positive relationship between ant species richness and predatory activity (e.g., De la Mora et al., 2015; Philpott & Armbrecht, 2006). This occurs because ant predatory activity involves various species, including both specialists and generalists (Wilker et al., 2023). Thus, an increase in the number of species elevates foraging activity and, consequently, insect predation (Frizzo et al., 2020). Therefore, strategies aimed at conserving more species may consequently benefit the conservation of ecosystem functions such as predation.

In addition, we found that increasing temperature decreases the preference for amino acids compared to energetic nutrients. This is likely because, in ants and other ectothermic animals, rising temperatures lead to an increase in metabolic processes (Riemer et al., 2018). As metabolism increases, there is a greater demand for energetic resources such as carbohydrates and lipids, which are essential for energy production and metabolic function (Prather et al., 2018). On the other hand, the consumption of amino acids tends to be higher during periods of lower seasonality and cooler temperatures, which are typically associated with reproduction and body growth (Lasmar et al., 2021).

Study limitations and future directions

In our study, there are some methodological limitations and suggestions. The similarity in ant composition foraging for different resources may be due to our collection being limited to above-ground strata. These strata are dominated by omnivorous and opportunistic species that forage for a wide variety of resources. Therefore, it would be important to assess changes in species composition in other habitat strata, such as subterranean and arboreal (Lasmar et al., 2023). Moreover, we collected our data only during the summer, when temperature and

humidity tend to be higher in the Atlantic rainforest and Cerrado biomes. Therefore, we encourage further studies to evaluate seasonal differences, as they may affect ant communities (Queiroz et al., 2022) and consequently influence the search for and use of resources. Additionally, although we found a positive relationship between foraging for energetic nutrients (carbohydrates and lipids) with larvae, we sampled these nutrients separately. However, arthropod prey typically contains these nutrients together in varying concentrations (Wilder et al., 2013; Wilder & Eubanks, 2010). Therefore, it may be important for future studies to evaluate combinations of these nutrients in relation to predation to understand this relationship more comprehensively (Wilder et al., 2019).

CONCLUSION

Here, we found that land use, species richness, biome, and microclimate changes affect ant foraging activity and nutrient preference. Ant species composition varied with land use type but remained similar across different foraging resources. This suggests that generalist ants may forage on a variety of resources, helping to maintain ecosystem functions. More specifically, we observed a positive relationship between foraging for energetic nutrients (carbohydrates and lipids) and foraging for larvae, indicating that predatory ants are limited by energetic nutrients and forage for these nutrients, which can enhance predation. In addition, we found that both foraging for larvae and preference for amino acids were greater in the Atlantic rainforest than in the Cerrado, which may indicate higher predatory activity aimed at consuming amino acids in environments where these nutrients are less available. Moreover, species richness was positively associated with foraging for larvae, while higher temperatures reduced preference for amino acids. Therefore, we suggest that conserving species richness and mitigating high temperatures could help enhance predatory activity in tropical environments.

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REFERENCES

Adkins, J., Hammill, E., Abdulwahab, U.A., Draper, J.P., Wolf, J.M., McClure et al. (2023) Environmental variables drive spatial patterns of trophic diversity in mammals. *Ecology Letters*, 26, 1940–1950. Available from: https://doi.org/10.1111/ele.14306

Alkama, R. & Cescatti, A. (2016) Biophysical climate impacts of recent changes in global forest cover. *Science*, 351(6273), 600–604. Available from: https://doi.org/10.1126/science.aac8083

463 Andersen, A.N. (2019) Responses of ant communities to disturbance: Five principles for
464 understanding the disturbance dynamics of a globally dominant faunal group. *Journal of Animal*
465 *Ecology*, 88(3), 350–362. Available from: https://doi.org/10.1111/1365-2656.12907

466 Aristizabal, N. & Metzger, J.P. (2019) Landscape structure regulates pest control provided by
467 ants in sun coffee farms. *Journal of Applied Ecology*, 56(1), 21–30. Available from:
468 https://doi.org/10.1111/1365-2664.13283

469 Baccaro, F.B., Feitosa, R.M., Fernandez, F., Fernandes, I.O., Izzo, T.J., Souza, J.L.P. et al.
470 (2015) *Guia para os gêneros de formigas do Brasil*. Editora INPA.

471 Barnes, A.D., Allen, K., Kreft, H., Corre, M.D., Jochum, M., Veldkamp, E. et al. (2017) Direct
472 and cascading impacts of tropical land-use change on multi-trophic biodiversity. *Nature*
473 *ecology & evolution*, 1(10), 1511–1519. Available from: https://doi.org/10.1038/s41559-017-
474 0275-7

475 Bartoń, K. (2023) MuMIn: Multi-Model Inference. R package version 1.47.5,
476 <https://CRAN.R-project.org/package=MuMIn>

477 Baselga, A., Orme, D., Villeger, S., De Bortoli, J., Leprieur, F., Logez, M. et al. (2023) betapart:
478 Partitioning Beta Diversity into Turnover and Nestedness Components. R package version 1.6,
479 <https://CRAN.R-project.org/package=betapart>

480 Baselga, A. (2010) Partitioning the turnover and nestedness components of beta diversity.
481 *Global ecology and biogeography*, 19(1), 134–143. Available from:
482 https://doi.org/10.1111/j.1466-8238.2009.00490.x

483 Biomas, IBGE (2019) *Sistema costeiro-marinho do Brasil: compatível com a escala 1:250.000*.
484 Série Relatórios Metodológicos.

485 Bolton, B. (2000) The ant tribe Dacetini. *Memoirs of the American Entomological Institute*, 65,
486 1–1028.

487 Brown, W.L.Jr. (1976) Contributions toward a reclassification of the Formicidae. Part VI.
488 Ponerinae, tribe Ponerini, subtribe Odontomachiti. Section A. Introduction, subtribal
489 characters. Genus *Odontomachus*. *Studia Entomologica*, 19, 67–171.

490 Burnham, K.P. & Anderson, D.R. (2002) *Model selection and multimodel inference: a practical*
491 *information-theoretic approach*. Springer New York.

492 Camacho, G.P., Franco, W. & Feitosa, R.M. (2020) Additions to the taxonomy of
493 *Gnamptogenys* Roger (Hymenoptera: Formicidae: Ectatomminae) with an updated key to the
494 New World species. *Zootaxa*, 4747(3), 450–476. Available from:
495 https://doi.org/10.11646/zootaxa.4747.3.2

496 Carvalho, R.L., Vieira, J., Melo, C., Silva, A.M., Tolentino, V.C., Neves, K. et al. (2022)
497 Interactions between land use, taxonomic group and aspects and levels of diversity in a
498 Brazilian savanna: Implications for the use of bioindicators. *Journal of Applied Ecology*,
499 59(10), 2642–2653. Available from: https://doi.org/10.1111/1365-2664.14270

500 Castillo-Guevara, C., Cuautle, M., Lara, C. & Juárez-Juárez, B. (2019) Effect of agricultural
501 land-use change on ant dominance hierarchy and food preferences in a temperate oak forest.
502 *PeerJ*, 7, e6255. Available from: https://doi.org/10.7717/peerj.6255

503 Cerdá, X. & Dejean, A. (2011) *Predation by ants on arthropods and other animals*. National
504 Academy of Sciences (US).

505 Corbelli, J.M., Zurita, G.A., Filloy, J., Galvis, J.P., Vespa, N.I. & Bellocq, I. (2015) Integrating
506 taxonomic, functional and phylogenetic beta diversities: Interactive effects with the biome and

507 land use across taxa. *PloS one*, 10(5), e0126854. Available from:
508 https://doi.org/10.1371/journal.pone.0126854

509 De la Mora, A., García-Ballinas, J.A. & Philpott, S.M. (2015) Local, landscape, and diversity
510 drivers of predation services provided by ants in a coffee landscape in Chiapas, Mexico.
511 *Agriculture, Ecosystems & Environment*, 201, 83–91. Available from:
512 https://doi.org/10.1016/j.agee.2014.11.006

513 De la Mora, A., Murnen, C.J. & Philpott, S.M. (2013) Local and landscape drivers of
514 biodiversity of four groups of ants in coffee landscapes. *Biodiversity and conservation*, 22, 871–
515 888. Available from: https://doi.org/10.1007/s10531-013-0454-z

516 Dehling, D.M., Bender, I.M., Blendinger, P.G., Böhning-Gaese, K., Muñoz, M.C., Neuschulz,
517 E.L. et al. (2021) Specialists and generalists fulfil important and complementary functional
518 roles in ecological processes. *Functional Ecology*, 35(8), 1810–1821. Available from:
519 https://doi.org/10.1111/1365-2435.13815

520 Dudley, R., Kaspari, M. & Yanoviak, S.P. (2012) Lust for Salt in the Western Amazon.
521 *Biotropica*, 44(1), 6–9. Available from: https://doi.org/10.1111/j.1744-7429.2011.00818.x

522 Escobar-Ramírez, S., Tscharntke, T., Armbrecht, I., Torres, W. & Grass, I. (2020) Decrease in
523 β-diversity, but not in α-diversity, of ants in intensively managed coffee plantations. *Insect*
524 *Conservation and Diversity*, 13(5), 445–455. Available from:
525 https://doi.org/10.1111/icad.12417

526 Feitosa, R.M., Camacho, G.P., Silva, T.S., Ulysséa, M.A., Ladino, N., Oliveira, A.M. et al.
527 (2022) Ants of Brazil: an overview based on 50 years of diversity studies. *Systematics and*
528 *Biodiversity*, 20(1), 1–27. Available from: https://doi.org/10.1080/14772000.2022.2089268

529 Fernández, F. (2004) The American species of the myrmicine ant genus *Carebara* Westwood
530 (Hymenoptera: Formicidae). *Caldasia,* 26(1), 191–238. Available from:
531 http://www.jstor.org/stable/23641795.

532 Frizzo, T.L., Souza, L.M., Sujii, E.R. & Togni, P.H. (2020) Ants provide biological control on
533 tropical organic farms influenced by local and landscape factors. *Biological Control*, 151,
534 104378. Available from: https://doi.org/10.1016/j.biocontrol.2020.104378

535 Gonçalves, C.R. (1961) O gênero *Acromyrmex* no Brasil (Hym. Formicidae). *Studia*
536 *Entomologica*, 4, 113–180.

537 Google (2024) *Google Satellite Imagery*. Available from: https://www.google.com/maps.

538 Hopmans, J.W., Qureshi, A.S., Kisekka, I., Munns, R., Grattan, S.R., Rengasamy, P. et al.
539 (2021) Critical knowledge gaps and research priorities in global soil salinity. *Advances in*
540 *agronomy*, 169, 1–191. Available from: https://doi.org/10.1016/bs.agron.2021.03.001

541 IBGE (2019) *Biomas e Sistema Costeiro-Marinho do Brasil - 1:250,000*. Instituto Brasileiro de
542 Geografia e Estatística. Available from: https://www.ibge.gov.br/geociencias/informacoes-
543 ambientais/vegetacao/15842-biomas.html.

544 INMET (2024) *Instituto Nacional de Meteorologia*. Banco de Dados Meteorológicos para
545 Ensino e Pesquisa - BDMEP. Brasília, DF, Brazil. Available from: http://www.inmet.gov.br/.

546 Jayathilake, H.M., Prescott, G.W., Carrasco, L.R., Rao, M. & Symes, W.S. (2021) Drivers of
547 deforestation and degradation for 28 tropical conservation landscapes. *Ambio*, 50(1), 215–228.
548 Available from: https://doi.org/10.1007/s13280-020-01325-9

549 Jensen, K., Mayntz, D., Toft, S., Clissold, F.J., Hunt, J., Raubenheimer, D. et al. (2012) Optimal
550 foraging for specific nutrients in predatory beetles. *Proceedings of the Royal Society B:*

551 *Biological Sciences*, 279(1736), 2212–2218. Available from:
552 https://doi.org/10.1098/rspb.2011.2410

553 Kaspari, M. & Yanoviak, S.P. (2001) Bait use in tropical litter and canopy ants—evidence of
554 differences in nutrient limitation. *Biotropica*, 33(1), 207–211. Available from:
555 https://doi.org/10.1646/0006-3606(2001)033[0207:BUITLA]2.0.CO;2

556 Kaspari, M. & Yanoviak, S.P. (2009) Biogeochemistry and the structure of tropical brown food
557 webs. *Ecology*, 90(12), 3342–3351. Available from: https://doi.org/10.1890/08-1795.1

558 Kaspari, M. Donoso, D., Lucas, J.A., Zumbusch, T. & Kay, A.D. (2012) Using nutritional
559 ecology to predict community structure: a field test in Neotropical ants. *Ecosphere*, 3(11), 1–
560 15. Available from: https://doi.org/10.1890/ES12-00136.1

561 Kugler, C. & Brown, W.L.Jr. (1982) Revisionary and other studies on the ant genus *Ectatomma*,
562 including the description of two new species. *Agriculture, 24*, 1–8.

563 LaPolla, J.S. (2004) *Acropyga of the world*. Contributions of the American Entomological
564 Institute, 33, 1–130.

565 Lasmar, C.J., Bishop, T.R., Parr, C.L., Queiroz, A.C., Schmidt, F.A. & Ribas, C.R. (2021)
566 Geographical variation in ant foraging activity and resource use is driven by climate and net
567 primary productivity. *Journal of Biogeography*, 48(6), 1448–1459. Available from:
568 https://doi.org/10.1111/jbi.14089

569 Lasmar, C.J., Bishop, T.R., Parr, C.L., Queiroz, A.C., Wilker, I., Feitosa, R.M et al. (2023)
570 Testing the context dependence of ant nutrient preference across habitat strata and trophic levels
571 in Neotropical biomes. *Ecology*, 104(4), e3975. Available from:
572 https://doi.org/10.1002/ecy.3975

573 Lattke, J.E. (1997) Revisión del género *Apterostigma* Mayr (Hymenoptera: Formicidae). *Arq.*
574 *Zool. (São Paulo)*, 34, 121–22.

575 Leal, I.R., Lopes, A.V., Machado, I.C. & Tabarelli, M. (2017) Plant–animal interactions in the
576 Caatinga: overview and perspectives. In da Silva, J.M.C., Leal, I.R. & Tabarelli, M. (Eds.)
577 *Caatinga: the largest tropical dry forest region in South America*. Springer. pp. 255–278.

578 Leroux, S.J. (2019) On the prevalence of uninformative parameters in statistical models
579 applying model selection in applied ecology. *PloS one*, 14(2), e0206711. Available from:
580 https://doi.org/10.1371/journal.pone.0206711

581 Longino, J.T. & Fernández, F. (2007) Taxonomic review of the genus *Wasmannia*. In Snelling
582 R.R., Fisher B.L. & Ward, P.S. (Eds.) *Advances in ant systematics (Hymenoptera: Formicidae):*
583 *homage to E.O. Wilson – 50 years of contributions.* Memoirs of the American Entomological
584 Institute. pp. 271–289.

585 López-Bedoya, P.A., Bohada-Murillo, M., Ángel-Vallejo, M.C., Audino, L.D., Davis, A.L.,
586 Gurr, G. et al. (2022) Primary forest loss and degradation reduces biodiversity and ecosystem
587 functioning: a global meta-analysis using dung beetles as an indicator taxon. *Journal of Applied*
588 *Ecology*, 59(6), 1572–1585. Available from: https://doi.org/10.1111/1365-2664.14167

589 Machado, N.G., Biudes, M.S., Mützenberg, D.M.D.S. & Angelini, L.P. (2023) Effects of
590 deforestation on microclimate in a Cerrado-Amazonia Transition area. *Ciência Florestal*, 33(2),
591 e70199. Available from: https://doi.org/10.5902/1980509870199

592 Maisey, A.C., Haslem, A., Leonard, S.W. & Bennett, A.F. (2021) Foraging by an avian
593 ecosystem engineer extensively modifies the litter and soil layer in forest ecosystems.
594 *Ecological Applications*, 31(1), e02219. Available from: https://doi.org/10.1002/eap.2219

595 Manlick, P.J. & Newsome, S.D. (2021) Adaptive foraging in the Anthropocene: can individual
596 diet specialization compensate for biotic homogenization?. *Frontiers in Ecology and the*
597 *Environment*, 19(9), 510–518. Available from: https://doi.org/10.1002/fee.2380

598 Martinez Arbizu, P. (2020) pairwiseAdonis: Pairwise multilevel comparison using adonis. R
599 package version 0.4, <https://github.com/pmartinezarbizu/pairwiseAdonis>

600 Mayntz, D., Raubenheimer, D., Salomon, M., Toft, S. & Simpson, S.J. (2005). Nutrient-specific
601 foraging in invertebrate predators. *Science*, 307(5706), 111–113. Available from:
602 https://doi.org/10.1126/science.1105493

603 McKinney, M.L. & Lockwood, J.L. (1999) Biotic homogenization: a few winners replacing
604 many losers in the next mass extinction. *Trends in ecology & evolution*, 14(11), 450–453.
605 Available from: https://doi.org/10.1016/S0169-5347(99)01679-1

606 Moses, J., Peters, M.K., Tiede, Y., Mottl, O., Donoso, D.A., Farwig, N. et al. (2023) Nutrient
607 use by tropical ant communities varies among three extensive elevational gradients: A cross-
608 continental comparison. *Global Ecology and Biogeography*, 32(12), 2212–2229. Available
609 from: https://doi.org/10.1111/geb.13757

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

613 Oksanen, J., Simpson, G., Blanchet, F., Kindt, R., Legendre, P., Minchin, P. et al. (2024) vegan:
614 Community Ecology Package. R package version 2.6-6, <https://CRAN.R-
615 project.org/package=vegan>

616 Ortiz-Sepúlveda, C.M., Van Bocxlaer, B., Meneses, A.D. & Fernández, F. (2019) Molecular
617 and morphological recognition of species boundaries in the neglected ant genus *Brachymyrmex*

(Hymenoptera: Formicidae): Toward a taxonomic revision. *Organisms Diversity & Evolution*, 19, 447–542. Available from: https://doi.org/10.1007/s13127-019-00406-2

Parr, C.L. & Bishop, T.R. (2022) The response of ants to climate change. *Global change biology*, 28(10), 3188–3205. Available from: https://doi.org/10.1111/gcb.16140

Passos, F.C. & Leal, L.C. (2019) Protein matters: ants remove herbivores more frequently from extrafloral nectary-bearing plants when habitats are protein poor. *Biological Journal of the Linnean Society*, 127(2), 407–416. Available from: https://doi.org/10.1093/biolinnean/blz033

Perfecto, I. & Snelling, R. (1995) Biodiversity and the transformation of a tropical agroecosystem: ants in coffee plantations. *Ecological applications*, 5(4), 1084– Available from: 1097. https://doi.org/10.2307/2269356

Peters, M.K., Mayr, A., Röder, J., Sanders, N.J. & Steffan-Dewenter, I. (2014) Variation in nutrient use in ant assemblages along an extensive elevational gradient on Mt Kilimanjaro. *Journal of Biogeography*, 41(12), 2245–2255. Available from: https://doi.org/10.1111/jbi.12384

Philpott, S. M. & Armbrecht, I. (2006) Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecological entomology*, 31(4), 369–377. Available from: https://doi.org/10.1111/j.1365-2311.2006.00793.x

Prather, R. M., Roeder, K. A., Sanders, N. J., & Kaspari, M. (2018). Using metabolic and thermal ecology to predict temperature dependent ecosystem activity: a test with prairie ants. Ecology, 99(9), 2113–2121. https://doi.org/10.1002/ecy.2445

Probst, R.S. & Brandão, C.R.F. (2022) A taxonomic revision of the dirt ants, *Basiceros* Schulz, 1906 (Hymenoptera, Formicidae). *Zootaxa*, 5149 (1), 1–75. Available from: https://doi.org/10.11646/zootaxa.5149.1.1

641 QGIS.org (2023) *QGIS Geographic Information System*. QGIS Association. Available from:
642 http://www.qgis.org

643 Queiroz, A.C., Marques, T.G., Ribas, C.R., Cornelissen, T.G., Nogueira, A., Schmidt, F.A. et
644 al. (2023) Ant diversity decreases during the dry season: A meta-analysis of the effects of
645 seasonality on ant richness and abundance. *Biotropica*, 55(1), 29–39. Available from:
646 https://doi.org/10.1111/btp.13158

647 Queiroz, A.C., Rabello, A.M., Braga, D.L., Santiago, G.S., Zurlo, L.F., Philpott, S.M. et al.
648 (2020) Cerrado vegetation types determine how land use impacts ant biodiversity. *Biodiversity*
649 *and Conservation*, 29, 2017–2034. https://doi.org/10.1007/s10531-017-1379-8

650 Raubenheimer, D. (2011) Toward a quantitative nutritional ecology: the right-angled mixture
651 triangle. *Ecological monographs*, 81(3), 407–427. Available from: https://doi.org/10.1890/10-
652 1707.1

653 R Core Team (2024) *R: A Language and Environment for Statistical Computing*. R Foundation
654 for Statistical Computing, Vienna, Austria. Available from: https://www.R-project.org/

655 Rezende, F.D.M., Schmidt, F.A., Jesus, R.S., Ribas, C.R. & Schoereder, J.H. (2024) Beyond
656 beta: diversity partitioning reveals different underlying patterns in ant assemblages along two
657 small scale gradients in a Brazilian neotropical forest. *International Journal of Tropical Insect*
658 *Science*, 1–10. Available from: https://doi.org/10.1007/s42690-024-01244-2

659 Ribas, C.R., Campos, R.B., Schmidt, F.A. & Solar, R.R. (2012) Ants as indicators in Brazil: a
660 review with suggestions to improve the use of ants in environmental monitoring programs.
661 *Psyche: A Journal of Entomology*, 2012(1), 636749. Available from:
662 https://doi.org/10.1155/2012/636749

663 Ribas, C., Oliveira, P., Sobrinho, T., Schoereder, J. & Madureira, M. (2010) The arboreal ant
664 community visiting extrafloral nectaries in the Neotropical cerrado savanna. *Terrestrial*
665 *Arthropod Reviews*, 3(1), 3–27. Available from: https://doi.org/10.1163/187498310X487785

666 Riemer, K., Anderson-Teixeira, K.J., Smith, F.A., Harris, D.J. & Ernest, S.M. (2018) Body size
667 shifts influence effects of increasing temperatures on ectotherm metabolism. *Global Ecology*
668 *and Biogeography*, 27(8), 958–967. Available from: https://doi.org/10.1111/geb.12757

669 Sarnat, E.M., Fischer, G., Guénard, B. & Economo, E.P. (2015) Introduced *Pheidole* of the
670 world: taxonomy, biology and distribution. *ZooKeys*, (543), 1. Available from:
671 https://doi.org/10.3897/zookeys.543.6050

672 Schmidt, F.A., Ribas, C.R., Sobrinho, T.G., Ubaidillah, R., Schoereder, J.H., Clough, Y. et al.
673 (2017) Similar alpha and beta diversity changes in tropical ant communities, comparing
674 savannas and rainforests in Brazil and Indonesia. *Oecologia*, 185, 487–498. Available from:
675 https://doi.org/10.1007/s00442-017-3960-y

676 Stein, A., Gerstner, K. & Kreft, H. (2014) Environmental heterogeneity as a universal driver of
677 species richness across taxa, biomes and spatial scales. *Ecology letters*, 17(7), 866–880.
678 Available from: https://doi.org/10.1111/ele.12277

679 Tabarelli, M., Peres, C.A. & Melo, F.P. (2012) The 'few winners and many losers' paradigm
680 revisited: emerging prospects for tropical forest biodiversity. *Biological Conservation*, 155,
681 136–140. Available from: https://doi.org/10.1016/j.biocon.2012.06.020

682 Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M.C., Schwager, M. et al. (2004)
683 Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone
684 structures. *Journal of biogeography*, 31(1), 79–92. Available from:
685 https://doi.org/10.1046/j.0305-0270.2003.00994.x

686 Tilman, D., Wedin, D. & Knops, J. (1996) Productivity and sustainability influenced by
687 biodiversity in grassland ecosystems. *Nature*, 379(6567), 718–720. Available from:
688 https://doi.org/10.1038/379718a0

689 Trancoso, R., Syktus, J., Salazar, A., Thatcher, M., Toombs, N., Wong, K.K.H. et al. (2022)
690 Converting tropical forests to agriculture increases fire risk by fourfold. *Environmental*
691 *Research Letters*, 17(10), 104019. Available from: https://doi.org/10.1088/1748-9326/ac8f5c

692 Trew, B.T. & Maclean, I.M. (2021) Vulnerability of global biodiversity hotspots to climate
693 change. *Global Ecology and Biogeography*, 30(4), 768–783. Available from:
694 https://doi.org/10.1111/geb.13272

695 Urrutia-Escobar, M.X. & Armbrecht, I. (2013) Effect of two agroecological management
696 strategies on ant (Hymenoptera: Formicidae) diversity on coffee plantations in southwestern
697 Colombia. *Environmental Entomology*, 42(2), 194–203. Available from:
698 https://doi.org/10.1603/EN11084

699 Venables, W.N. & Ripley, B.D. (2002) *Modern applied statistics with S-PLUS*. Springer
700 Science & Business Media.

701 Warton, D.I. & Hui, F.K. (2011) The arcsine is asinine: the analysis of proportions in ecology.
702 *Ecology*, 92(1), 3–10. Available from: https://doi.org/10.1890/10-0340.1

703 Watkins, J.F. (1976) *The identification and distribution of New World army ants (Dorylinae:*
704 *Formicidae)*. Baylor University Press.

705 Wickham, H. (2016) *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York.

706 Wild, A.L. (2007) *Taxonomic revision of the ant genus Linepithema (Hymenoptera:*
707 *Formicidae)*. University of California Publications in Entomology.

708 Wilder, S.M. & Eubanks, M.D. (2010) Extrafloral nectar content alters foraging preferences of
709 a predatory ant. *Biology letters*, 6(2), 177–179. Available from:
710 https://doi.org/10.1098/rsbl.2009.0736

711 Wilder, S.M., Barnes, C.L. & Hawlena, D. (2019) Predicting predator nutrient intake from prey
712 body contents. *Frontiers in Ecology and Evolution*, 7, 42. Available from:
713 https://doi.org/10.3389/fevo.2019.00042

714 Wilder, S.M., Norris, M., Lee, R.W., Raubenheimer, D. & Simpson, S.J. (2013) Arthropod food
715 webs become increasingly lipid-limited at higher trophic levels. *Ecology letters*, 16(7), *895*–
716 902. Available from: https://doi.org/10.1111/ele.12116

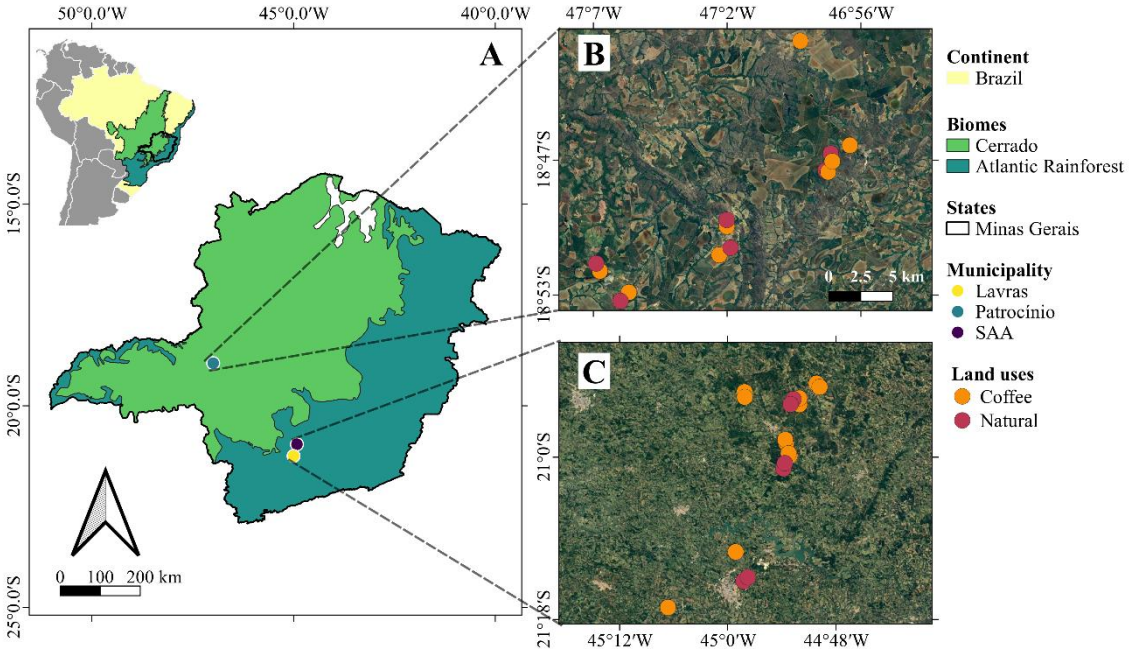
717 Wilker, I., Queiroz, A.C.M., Ribas, C.R., Morini, M.S.C., Lasmar, C.J., Schmidt, F.A. et al.
718 (2024) A systematic review of the land use change effects on ant diversity in Neotropics.
719 *Biological Conservation*, 299, 110778. Available from:
720 https://doi.org/10.1016/j.biocon.2024.110778

721 Wilker, I., Lasmar, C.J., Schmidt, F.A., da Costa, M.M.S., Almeida, D.D.F., Dutra, D.B.D.S.
722 et al. (2023) Land-use change in the Amazon decreases ant diversity but increases ant-mediated
723 predation. *Insect Conservation and Diversity*, 16(3), 379–392. Available from:
724 https://doi.org/10.1111/icad.12632

725 Williams, J.J. & Newbold, T. (2020) Local climatic changes affect biodiversity responses to
726 land use: A review. *Diversity and Distributions*, 26(1), 76–92. Available from:
727 https://doi.org/10.1111/ddi.12999

728 Wilson, E.O. (2003) *Pheidole in the New World. A dominant, hyperdiverse ant genus*. Harvard
729 University Press.

730



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732 **FIGURE 1** The panel A indicates the Brazilian state of Minas Gerais, including its position in
733 South America and the location of the biomes and sampled cities. The panel B indicates some
734 sampling points within the municipality of Patrocínio and panel C indicates the sampling points
735 in municipalities of Lavras and Santo Antônio do Amparo (SAA). The figure was generated
736 using QGIS version 3.32 (QGIS.org, 2023) and adapted biome and state data from Instituto
737 Brasileiro de Geografia e Estatística (IBGE, 2019). The satellite image was from Google
738 Satellite (2024).

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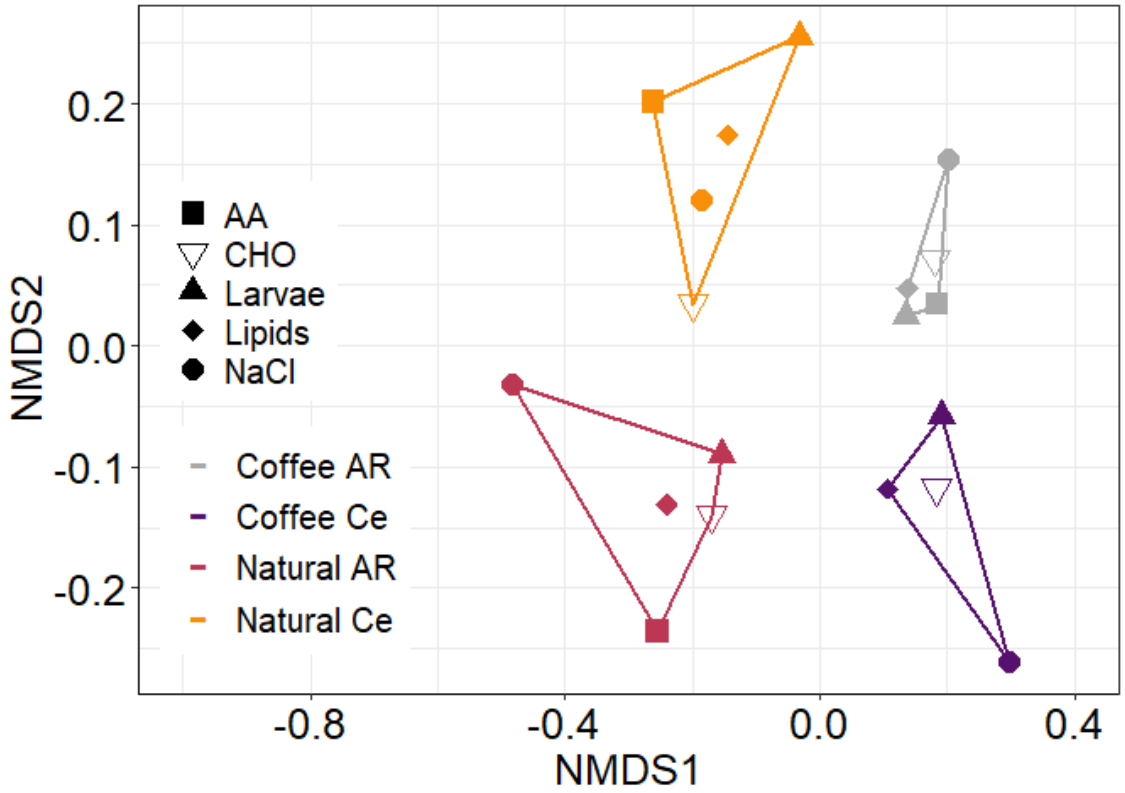

745

746 **FIGURE 2** Ant species composition differs between land use types: Natural AR (forest in the
747 Atlantic rainforest; medium pink), Natural Ce (woodland savannah in Cerrado; orange), Coffee
748 AR (coffee plantation in the Atlantic rainforest; grey), and Coffee Ce (coffee plantation in
749 Cerrado; purple). However, it does not differ significantly with respect to resource types: AA
750 (amino acids; square), CHO (carbohydrates; empty triangle), Lipids (vegetable oil; diamond),
751 NaCl (sodium; circle) and Larvae (predation experiment; full triangle). Species composition
752 was measured using Sørensen dissimilarity (βsør).

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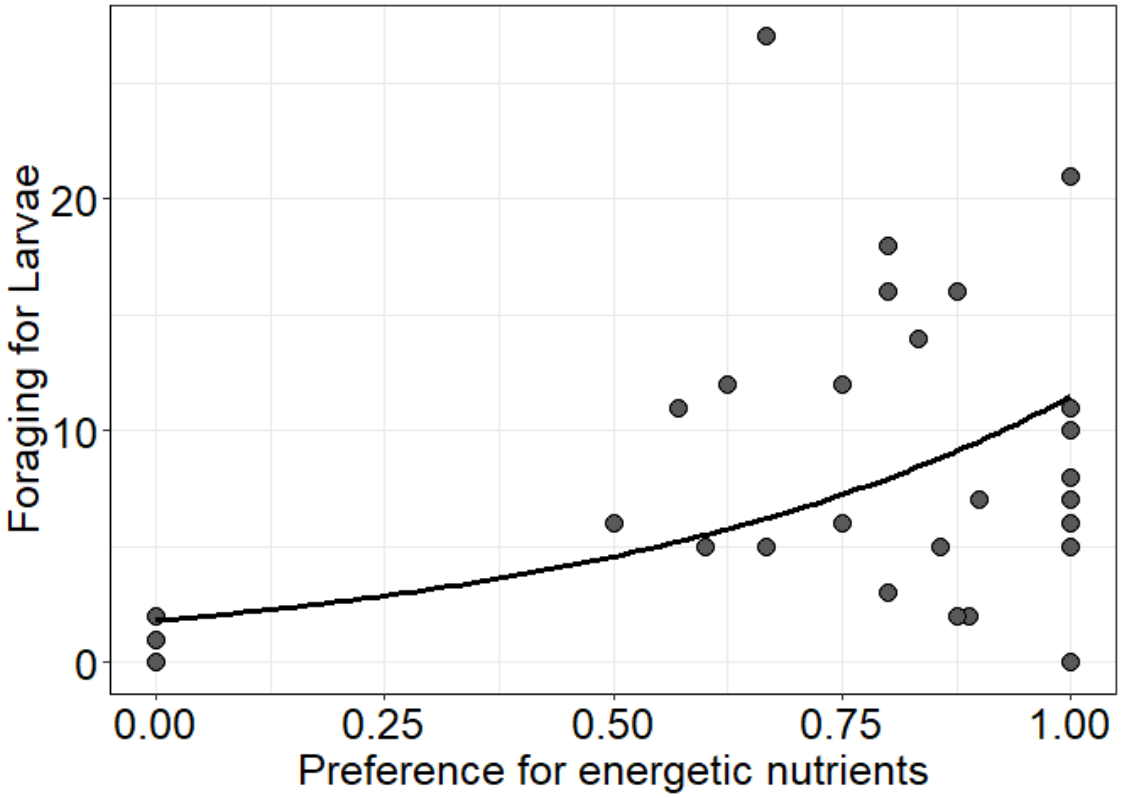

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759 **FIGURE 3** The y-axis indicates the number of foraging for larvae. The x-axis indicates the
760 nutrient preference for energetic nutrients (carbohydrates and lipids) compared to amino acids.
761 The increase in foraging for energetic nutrients, and consequently the decrease in foraging for
762 amino acids, increases larvae foraging.

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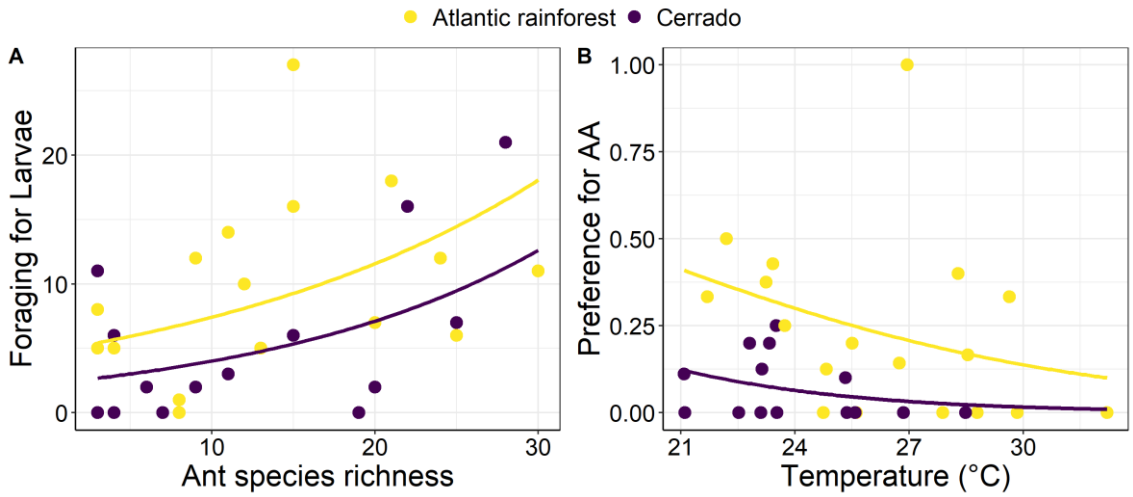
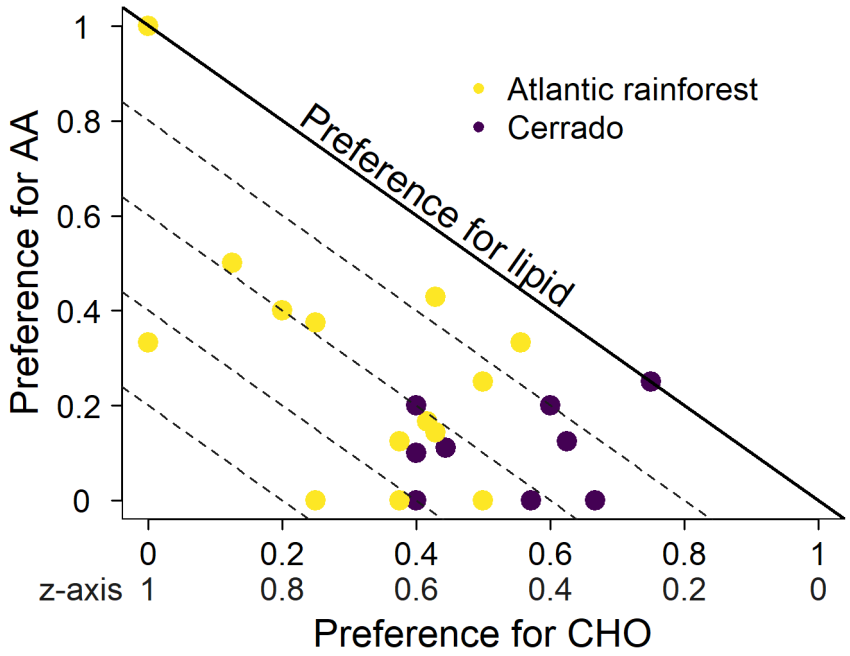


FIGURE 4 Foraging for larvae and preference for amino acids (AA) is greater in Atlantic rainforest than Cerrado. However, ant species richness increases foraging for larvae (panel A), while temperature decreases preference for amino acids (panel B).



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781 **FIGURE 5** Right-angled mixture triangle (Raubenheimer, 2011), for AA (y-axis),
782 carbohydrates (x-axis), and lipids (z-axis). This graph represents relative preference in three
783 nutrients: AA, CHO, and Lipids. For the x-axis, the higher the preference in CHO, the lower
784 the preference in AA and Lipids. For the y-axis, the higher the preference in AA, the lower the
785 preference in CHO and Lipids. For relative lipid preference, the points are graphically
786 represented in relation to the diagonal lines, with the values indicated in relation to the z-axis.
787 The lowest lipid preference occurs when the point touches the diagonal 0, and the highest occurs
788 when the point touches the diagonal 1 for the z-axis. In the Atlantic rainforest, ant assemblages
789 tend to forage more for amino acids than in the Cerrado

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TABLE 1 In the table, "preference for AA" represents the preference for amino acids compared to energetic nutrients (CHO + lipids), while "preference for energy" represents the preference for energetic nutrients compared to amino acid, "Land use" are the land uses (natural habitat and coffee plantation), "Temperature" is the mean of temperature in °C, "Richness" is the ant species richness, and "Biome" are the biomes (Atlantic rainforest and Cerrado). Only models with ΔAICc ≤ 2 were considered. Degrees of freedom of the model (d.f.), differences in AICc values (ΔAICc), Akaike weight (ω), Log Likelihood (LogLik), and Adjusted coefficient of determination (Adj-R^2) were evaluated.

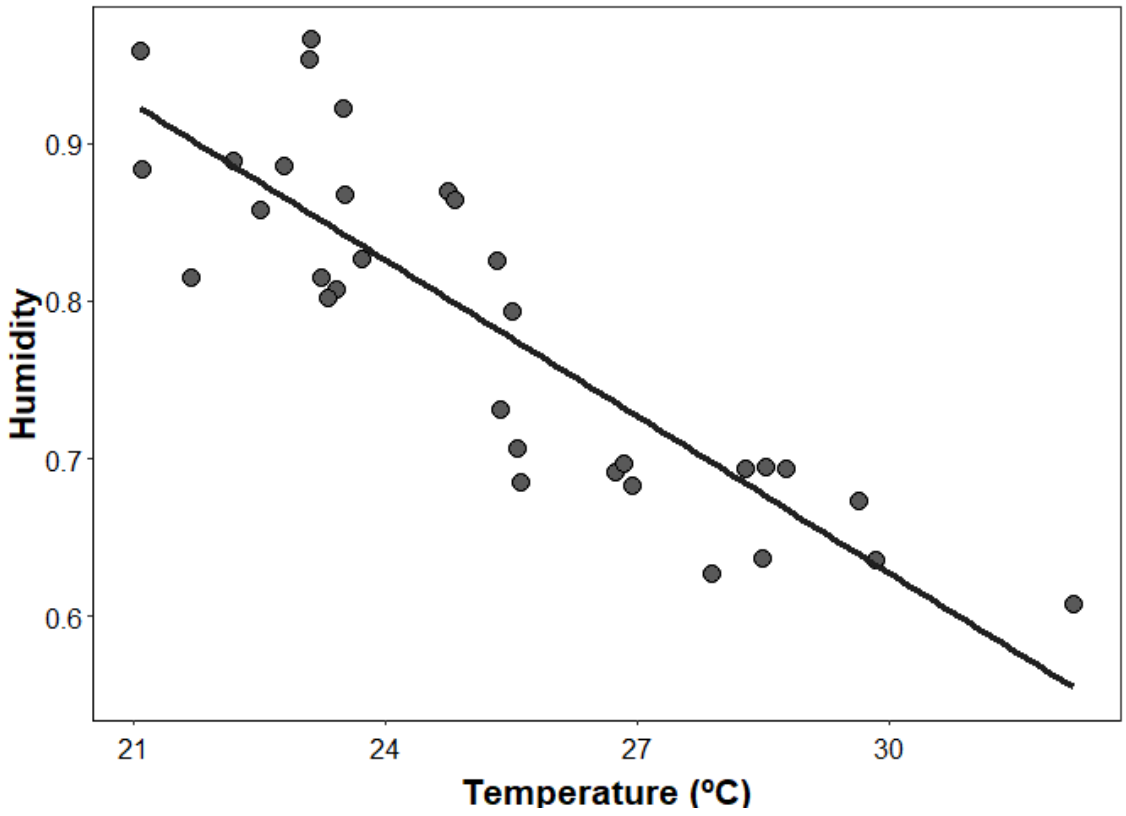
Question 3: How are changes in foraging activity explained by ant species richness, land use, and microclimate changes?						
Model (larvae)	**d.f.**	**AICc**	**ΔAICc**	**ω**	**LogLik**	**Adj-R^2**
Richness	3	198.0	0.00	0.21	-95.59	0.15
Biome + Richness	4	198.1	0.06	0.21	-94.31	0.21
Model (preference for AA)						
Biome + Temperature	4	125.0	0.00	0.31	-57.73	0.31
Temperature	3	126.4	1.47	0.13	-59.78	0.15
Model (preference for energy)						
Null model	2	151.4	0.00	0.22	-73.49	0.00
Biome	3	152.5	1.14	0.12	-72.84	0.04
Land use	3	152.7	1.28	0.11	-72.91	0.03
Temperature	3	152.8	1.42	0.10	-72.98	0.03
Richness	3	153.1	1.75	0.09	-73.14	0.02

SUPPLEMENTARY MATERIAL

Table S1. Table with transect specifications and localization. “Transect” is the name of transect; “City” is the city of transect (SAA: Santo Antônio do Amparo); “Biome” (AR: Atlantic rainforest; Ce: Cerrado); “Land use” is land use collect, natural (Atlantic Forest and Woodland Savannah) and Coffee (coffee plantation); “Altitude” is in meters above the sea level.

Transect	City	Biome	Land use	Latitude	Longitude	Altitude (m)
a1	SAA	AR	Coffee	20°58'25"S	44°53'31"W	1014
a2	SAA	AR	Coffee	20°58'03"S	44°53'37"W	1000
a3	SAA	AR	Coffee	20°52'45"S	44°58'08"W	994
a4	SAA	AR	Coffee	20°53'19"S	44°58'07"W	1025
a5	SAA	AR	Coffee	20°59'48"S	44°53'07"W	1016
a6	SAA	AR	Coffee	20°59'34"S	44°53'15"W	1002
a7	SAA	AR	Coffee	20°54'08"S	44°52'03"W	1078
a8	SAA	AR	Coffee	20°53'26"S	44°52'03"W	1106
a9	SAA	AR	Coffee	20°51'48"S	44°50'09"W	1025
a10	SAA	AR	Coffee	20°52'12"S	44°49'48"W	1009
a11	SAA	AR	Natural	20°53'33"S	44°52'42"W	1102
a12	SAA	AR	Natural	20°54'07"S	44°53'02"W	1039
a13	SAA	AR	Natural	21°01'15"S	44°53'49"W	1055
a14	SAA	AR	Natural	21°00'39"S	44°53'40"W	1039
a15	Lavras	AR	Coffee	21°10'30"S	44°59'07"W	919
a16	Lavras	AR	Coffee	21°16'40"S	45°06'38"W	924
a17	Lavras	AR	Natural	21°13'44"S	44°58'15"W	936
a18	Lavras	AR	Natural	21°13'19"S	44°57'46"W	929
a19	Patrocínio	Ce	Coffee	18°49'49"S	47°01'31"W	902
a20	Patrocínio	Ce	Coffee	18°51'05"S	47°01'51"W	919
a21	Patrocínio	Ce	Coffee	18°52'45"S	47°05'52"W	937
a22	Patrocínio	Ce	Coffee	18°51'48"S	47°07'09"W	995
a23	Patrocínio	Ce	Coffee	18°41'35"S	46°58'15"W	1130
a24	Patrocínio	Ce	Coffee	18°46'13"S	46°56'03"W	1128
a25	Patrocínio	Ce	Natural	18°51'28"S	47°07'19"W	983
a26	Patrocínio	Ce	Natural	18°53'08"S	47°06'14"W	960
a27	Patrocínio	Ce	Natural	18°46'35"S	46°56'54"W	1126
a28	Patrocínio	Ce	Natural	18°47'20"S	46°57'08"W	1121
a29	Patrocínio	Ce	Natural	18°50'46"S	47°01'21"W	868
a30	Patrocínio	Ce	Natural	18°49'32"S	47°01'31"W	933
a31	Patrocínio	Ce	Coffee	18°47'24"S	46°57'01"W	1129
a32	Patrocínio	Ce	Coffee	18°46'56"S	46°56'50"W	1128

813 Figure S1



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815 Figure S1. High negative Spearman correlation between microclimate variables ($\rho = -0.86$; $p <$

816 0.001).

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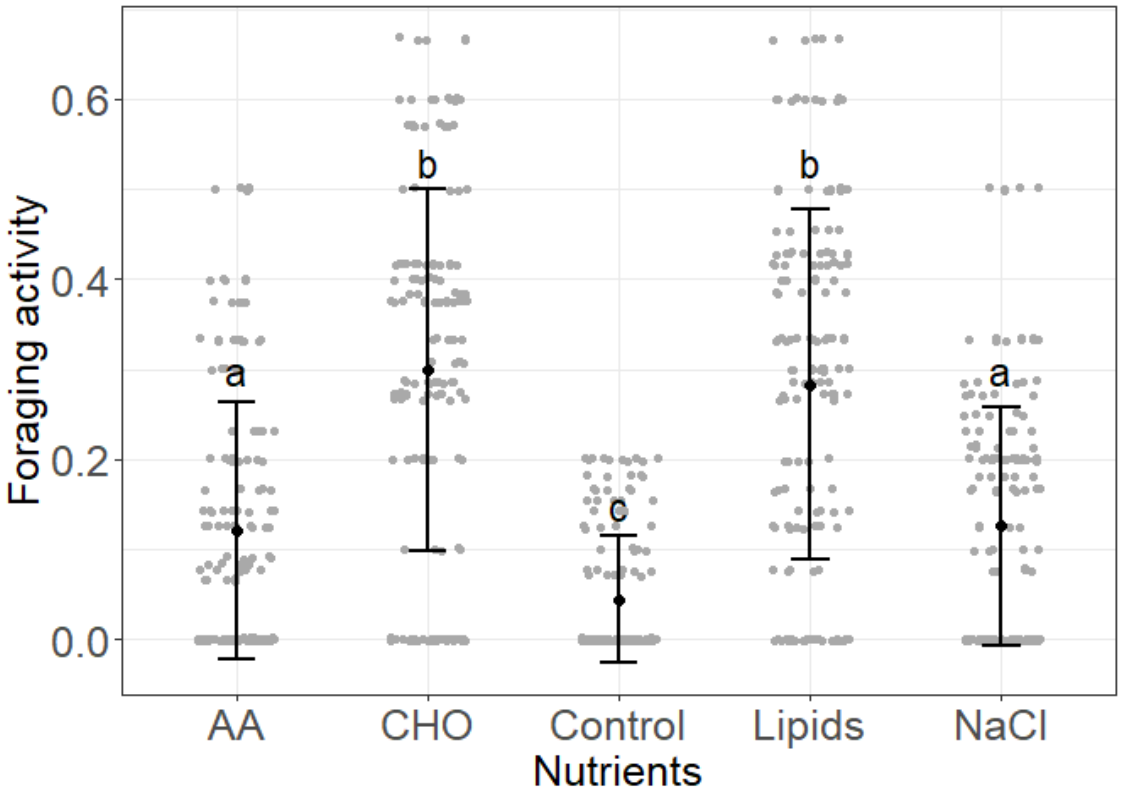
825 Figure S2



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827 Figure S2. General foraging activity between five nutrients (AA: amino acids; CHO:
828 carbohydrates; Control: Water; Lipids: Vegetal oil; and NaCl: Salt). The foraging activity for
829 Control is lower than other nutrients (Gaussian GLM: df = 795; F = 65.091; $p < 0.001$).

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Table S2. Ant species richness and number of workers sampled in natural habitats (forests) in the Atlantic rainforest. “Pitfall” refers to the ants collected in pitfall traps. “Larvae” refers to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae (for larvae, we did not compute the number of workers, only the presence or absence of ants). The other columns refer to the nutrients experiment (CHO: carbohydrates, Lipids: vegetable oil, AA: amino acids/whey protein, NaCl: salt, and Water).

Atlantic rainforest: Natural habitat							
Species	**Pitfall**	**CHO**	**Lipids**	**AA**	**NaCl**	**Water**	**Larvae**
Dolichoderinae							
Linepithema gallardoi (Brèthes, 1914)	1	0	0	0	0	0	0
Linepithema leucomelas (Emery, 1894)	30	0	0	0	0	0	1
Linepithema pulex Wild, 2007	26	1	0	0	0	0	1
Linepithema sp. 2	5	0	0	0	0	0	0
Dorylinae							
Labidus coecus (Latreille, 1802)	2	0	0	0	0	0	0
Ectatomminae							
Ectatomma edentatum Roger, 1863	85	9	2	0	0	0	1
Gnamptogenys sulcata (Smith, 1858)	13	0	0	0	0	0	0
Holcoponera striatula (Mayr, 1884)	48	1	0	0	0	0	1
Formicinae							
Acropyga decedens (Mayr, 1887)	2	0	0	0	0	0	0
Brachymyrmex bruchi Forel, 1912	2	0	0	0	0	0	0
Brachymyrmex cordemoyi Forel, 1895	3	0	0	0	0	0	0
Brachymyrmex minutus Forel, 1893	1	0	0	0	0	0	0
Brachymyrmex pictus Mayr, 1887	1	0	0	0	0	0	0
Brachymyrmex sp. 1	1	0	0	0	0	0	0
Camponotus (Myrmophaenus) sp. 8	1	0	0	0	0	0	0
Camponotus cingulatus Mayr, 1862	140	0	0	0	0	0	1
Camponotus rufipes (Fabricius, 1775)	4	0	0	0	0	0	0
Camponotus lespesii Forel, 1886	37	0	0	0	0	0	0
Camponotus melanoticus Emery, 1894	1	0	0	0	0	0	0
Camponotus (Tanaemyrmex) sp. 1	1	0	0	0	0	0	0
Camponotus (Tanaemyrmex) sp. 4	4	0	0	0	0	0	0
Myrmicinae							
Acromyrmex aspersus (Smith, 1858)	424	0	0	0	0	0	0
Acromyrmex hispidus Santschi, 1925	3	0	0	0	0	0	0
Apterostigma pilosum Mayr, 1865	5	0	0	0	0	0	0
Apterostigma sp. 3	2	0	0	0	0	0	0
Apterostigma wasmannii Forel, 1892	1	0	0	0	0	0	0
Atta sexdens (Linnaeus, 1758)	269	0	0	0	0	0	0

Basiceros disciger (Mayr, 1887)	2	0	0	0	0	0	0
Crematogaster pr. *chodati* Forel, 1921	1	0	0	0	0	0	0
Crematogaster rochai Forel, 1903	1	0	0	0	0	0	0
Cyphomyrmex minutus Mayr, 1862	2	0	0	0	0	0	0
Hylomyrma reitteri (Mayr, 1887)	1	0	0	0	0	0	0
Mycetomoellerius urichii (Forel, 1893)	39	0	0	0	0	0	0
Myrmicocrypta squamosa Smith, 1860	17	0	0	0	1	0	0
Pheidole aper Forel, 1912	10	0	0	1	0	0	1
Pheidole brevicona Mayr, 1887	8	1	0	0	1	0	0
Pheidole fallax Mayr, 1870	38	0	185	0	0	0	1
Pheidole gertrudae Forel, 1886	0	0	0	0	18	0	0
Pheidole oxyops Forel, 1908	0	1	135	0	0	0	0
Pheidole sigillata Wilson, 2003	5	0	12	0	0	0	0
Pheidole sp. 3	18	32	29	15	0	0	0
Pheidole sp. 4	1	0	0	0	0	0	0
Pheidole sp. 12	47	12	12	3	3	0	1
Pheidole sp. 15	0	0	39	0	0	0	0
Pheidole sp. 16	0	0	0	2	0	0	0
Pheidole sp. 27	0	0	43	0	0	0	0
Pheidole sp. 29	0	0	12	0	0	0	0
Pheidole sp. 30	13	0	0	0	0	0	0
Pheidole sp. 46	0	0	5	0	0	0	0
Pheidole sp. 55	22	0	0	0	0	0	0
Pheidole sp. 69	0	23	2	0	0	0	0
Pheidole sp. 71	0	1	0	0	0	0	0
Pheidole sp. 73	65	35	161	17	0	1	1
Pheidole sp. 77	1	0	0	0	0	0	0
Pheidole transversostriata Mayr, 1887	3	0	0	0	0	0	0
Solenopsis sp. 1	1	0	0	0	0	0	0
Solenopsis sp. 3	1	0	0	2	0	0	0
Solenopsis sp. 4	2	18	7	0	0	0	0
Solenopsis sp. 7	3	0	0	0	0	0	0
Solenopsis sp. 8	10	10	2	5	0	0	1
Solenopsis sp. 10	9	0	13	2	1	0	0
Solenopsis sp. 11	10	0	0	0	1	0	0
Strumigenys appretiata (Borgmeier, 1954)	2	0	0	0	0	0	0
Strumigenys denticulata Mayr, 1887	1	0	0	0	0	0	0
Strumigenys subedentata Mayr, 1887	1	0	0	0	0	0	0
Wasmannia affinis Santschi, 1929	10	0	0	0	0	0	0
Wasmannia auropunctata (Roger, 1863)	0	3	0	0	0	0	0
Ponerinae							
Hypoponera sp. 3	2	0	0	0	0	0	0
Neoponera marginata (Roger, 1861)	1	0	0	0	0	0	0
Odontomachus chelifer (Latreille, 1802)	8	0	0	0	0	0	1
Odontomachus meinerti Forel, 1905	3	0	0	0	0	0	0
Pachycondyla harpax (Fabricius, 1804)	1	0	0	0	0	0	0

Pachycondyla striata Smith, 1858	52	0	0	0	0	0	1
Total of ant workers	**1,527**	**147**	**659**	**47**	**25**	**1**	**NA**
Total of ant species	**63**	**11**	**15**	**8**	**6**	**1**	**12**

Table S3. Ant species richness and number of workers sampled in coffee plantations in the Atlantic rainforest. “Pitfall” refers to the ants collected in pitfall traps. “Larvae” refers to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae (for larvae, we did not compute the number of workers, only the presence or absence of ants). The other columns refer to the nutrients experiment (CHO: carbohydrates, Lipids: vegetable oil, AA: amino acids/whey protein, NaCl: salt, and Water).

Atlantic rainforest: Coffee plantation							
Species	**Pitfall**	**CHO**	**Lipids**	**AA**	**NaCl**	**Water**	**Larvae**
Dolichoderinae							
Dorymyrmex brunneus Forel, 1908	17	0	0	0	0	0	0
Linepithema cerradense Wild, 2007	7	4	0	0	1	0	0
Linepithema neotropicum Wild, 2007	359	119	2	130	61	4	1
Linepithema pulex Wild, 2007	25	0	0	0	0	0	0
Linepithema sp. 1	0	0	0	0	2	0	0
Linepithema sp. 4	0	0	0	0	0	0	1
Ectatomminae							
Ectatomma brunneum Smith, 1858	1	0	3	0	0	0	0
Ectatomma permagnum Forel, 1908	2	0	0	0	0	0	0
Holcoponera striatula (Mayr, 1884)	117	1	14	1	0	0	1
Formicinae							
Brachymyrmex cordemoyi Forel, 1895	75	0	0	0	0	0	0
Brachymyrmex pictus Mayr, 1887	4	0	0	0	0	0	0
Brachymyrmex pilipes Mayr, 1887	3	0	0	0	0	0	0
Camponotus melanoticus Emery, 1894	7	4	0	0	25	0	0
Nylanderia sp. 7	2	0	0	0	0	0	0
Myrmicinae							
Atta sexdens (Linnaeus, 1758)	7	0	0	0	0	0	0
Carebara pr. *brasiliana* Fernández, 2004	1	0	0	0	0	0	0
Mycetomoellerius sp. 1	1	0	0	0	0	0	0
Mycocepurus smithii (Forel, 1893)	2	0	0	0	0	0	0
Pheidole fallax Mayr, 1870	6	0	2	0	0	0	0
Pheidole obscurithorax Naves, 1985	52	0	0	0	0	0	1
Pheidole oxyops Forel, 1908	1	56	23	0	0	0	1
Pheidole radoszkowskii Mayr, 1884	102	6	96	1	2	0	1
Pheidole risii Forel, 1892	0	0	5	0	0	0	0
Pheidole subarmata Mayr, 1884	96	209	401	2	50	1	1
Pheidole sp. 5	2	2	0	0	0	0	0
Pheidole sp. 6	0	0	0	0	0	0	1
Pheidole sp. 12	2	0	0	0	0	0	0
Pheidole sp. 65	8	0	0	0	0	0	1

Pheidole sp. 73	1	0	0	0	0	0	1
Pheidole sp. 75	8	13	0	0	2	1	0
Pheidole sp. 99	1	0	0	0	0	0	0
Pogonomyrmex naegelii Emery, 1878	2	0	0	0	0	0	0
Solenopsis gr. saevissima sp. 1	112	237	281	6	1	0	1
Solenopsis sp. 2	1	0	0	0	0	0	0
Solenopsis sp. 3	0	3	0	0	0	0	0
Solenopsis sp. 4	1	0	0	0	0	0	0
Solenopsis sp. 8	9	0	0	0	0	0	0
Strumigenys louisianae Roger, 1863	5	0	0	0	0	0	0
Ponerinae							
Hypoponera sp. 1	1	0	0	0	0	0	0
Hypoponera sp. 2	1	0	0	0	0	0	0
Hypoponera sp. 3	1	0	0	0	0	0	0
Hypoponera sp. 4	9	0	0	0	0	0	0
Hypoponera sp. 5	6	0	0	0	0	0	0
Pachycondyla striata Smith, 1858	13	0	0	0	1	0	1
Total of ant workers	**1,070**	**654**	**827**	**114**	**145**	**6**	**NA**
Total of ant species	**39**	**11**	**9**	**5**	**9**	**3**	**12**

Table S4. Ant species richness and number of workers sampled in natural habitat (woodland savannah) in the Cerrado. “Pitfall” refers to the ants collected in pitfall traps. “Larvae” refers to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae (for larvae, we did not compute the number of workers, only the presence or absence of ants). The other columns refer to the nutrients experiment (CHO: carbohydrates, Lipids: vegetable oil, AA: amino acids/whey protein, NaCl: salt, and Water).

Cerrado: Natural habitat							
Species	**Pitfall**	**CHO**	**Lipids**	**AA**	**NaCl**	**Water**	**Larvae**
Dolichoderinae							
Linepithema neotropicum Wild, 2007	16	0	0	0	0	0	0
Linepithema pulex Wild, 2007	87	3	0	0	1	0	0
Lenepthema sp. 1	9	0	0	0	0	0	0
Lenepthema sp. 3	1	0	0	0	0	0	0
Dorylinae							
Neivamyrmex sp. 1	1	0	0	0	0	0	0
Ectatomminae							
Ectatomma edentatum Roger, 1863	7	6	0	0	0	0	1
Gnamptogenys sulcata (Smith, 1858)	2	0	0	0	0	0	0
Holcoponera striatula (Mayr, 1884)	17	0	0	0	0	0	0
Formicinae							
Brachymyrmex minutus Forel, 1893	2	0	0	0	0	0	0
Brachymyrmex pictus Mayr, 1887	14	0	0	0	0	0	0
Brachymyrmex sp. 2	3	0	0	0	0	0	0
Brachymyrmex sp. 3	6	0	0	0	0	0	0
Brachymyrmex sp. 4	1	0	0	0	0	0	0
Camponotus crassus Mayr, 1862	4	0	0	0	0	0	0
Camponotus fastigatus Roger, 1863	4	0	0	0	0	0	1
Camponotus atriceps (Smith, 1858)	2	0	0	0	0	0	0
Camponotus cingulatus Mayr, 1862	441	7	0	0	0	0	0
Camponotus ager (Smith, 1858)	19	0	0	0	0	0	0
Camponotus lespesii Forel, 1886	19	0	0	0	0	0	1
Camponotus melanoticus Emery, 1894	0	19	0	0	0	0	0
Camponotus (Tanaemyrmex) sp. 1	2	0	0	0	0	0	0
Nylanderia docilis (Forel, 1908)	18	11	0	1	0	0	0
Nylanderia sp. 7	1	0	0	0	0	0	0
Nylanderia steinheili (Forel, 1893)	35	20	0	1	0	1	0
Myrmicinae							
Acromyrmex aspersus (Smith, 1858)	206	0	0	0	0	0	0
Acromyrmex hispidus Santschi, 1925	19	0	0	0	0	0	0
Acromyrmex subterraneus (Forel, 1893)	716	0	0	0	0	0	0

Atta sexdens (Linnaeus, 1758)	1,196	0	0	0	0	0	0
Carebara brevipilosa Fernández, 2004	4	0	0	0	0	0	0
Crematogaster corticicola Mayr, 1887	0	0	0	0	0	0	1
Cyphomyrmex minutus Mayr, 1862	2	0	0	0	0	0	0
Mycetomoellerius urichii (Forel, 1893)	1	0	0	0	0	0	0
Mycetomoellerius sp. 1	1	0	0	0	0	0	0
Mycetophylax lectus (Forel, 1911)	1	0	0	0	0	0	0
Ochetomyrmex sp. 1	1	0	0	0	0	0	0
Pheidole aberrans Mayr, 1868	2	0	0	0	0	0	0
Pheidole fallax Mayr, 1870	15	16	1	0	9	0	1
Pheidole gertrudae Forel, 1886	0	3	23	0	0	0	0
Pheidole jelskii Mayr, 1884	6	0	8	0	0	0	1
Pheidole oxyops Forel, 1908	2	0	0	0	0	0	1
Pheidole pr. deima Wilson, 2003	1	0	0	0	0	0	0
Pheidole pr. radoszkowskii Mayr, 1884	0	0	2	0	0	0	0
Pheidole radoszkowskii Mayr, 1884	408	158	222	3	74	3	1
Pheidole sarcina Forel, 1912	3	0	0	0	0	0	0
Pheidole sigillata Wilson, 2003	0	0	3	0	0	0	0
Pheidole sp. 12	60	32	3	4	1	2	0
Pheidole sp. 15	4	2	32	0	0	0	0
Pheidole sp. 19	4	0	0	0	0	0	0
Pheidole sp. 22	0	5	10	0	8	0	0
Pheidole sp. 41	5	0	0	0	0	0	0
Pheidole sp. 55	3	0	0	0	0	0	1
Pheidole sp. 65	18	0	0	0	0	0	0
Pheidole sp. 69	0	23	0	0	0	0	0
Pheidole sp. 71	5	1	5	0	0	0	0
Pheidole sp. 73	0	32	0	0	0	0	0
Rogeria lirata Kugler, 1994	1	0	0	0	0	0	0
Sericomyrmex saussurei Emery, 1894	382	0	0	0	0	1	0
Solenopsis sp. 3	1	0	0	0	0	0	0
Solenopsis sp. 4	1	0	0	0	0	0	0
Solenopsis sp. 10	1	0	0	0	0	0	0
Solenopsis sp. 11	5	0	0	0	0	0	0
Solenopsis sp. 21	0	0	0	0	0	1	0
Wasmannia auropunctata (Roger, 1863)	14	15	26	0	0	0	0
Ponerinae							
Hypoponera sp. 2	1	0	0	0	0	0	0
Neoponera sp. 1	1	0	0	0	0	0	0
Odontomachus chelifer (Latreille, 1802)	8	0	0	0	0	0	0
Pachycondyla striata Smith, 1858	51	0	2	0	0	0	1
Pseudomyrmecinae							
Pseudomyrmex gr. pallidus sp. 1	1	0	0	0	0	0	0
Pseudomyrmex phyllophilus (Smith, 1858)	1	0	0	0	0	0	0
Total of ant workers	**3,862**	**353**	**337**	**9**	**93**	**8**	**NA**
Total of ant species	**60**	**16**	**12**	**4**	**5**	**5**	**10**

Table S5. Ant species richness and number of workers sampled in coffee plantations in the Cerrado. “Pitfall” refers to the ants collected in pitfall traps. “Larvae” refers to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae (for larvae, we did not compute the number of workers, only the presence or absence of ants). The other columns refer to the nutrients experiment (CHO: carbohydrates, Lipids: vegetable oil, AA: amino acids/whey protein, NaCl: salt, and Water).

Cerrado: Coffee plantation							
Species	**Pitfall**	**CHO**	**Lipids**	**AA**	**NaCl**	**Water**	**Larvae**
Dolichoderinae							
Dorymyrmex brunneus Forel, 1908	50	13	0	0	4	0	1
Linepithema neotropicum Wild, 2007	28	2	0	0	1	0	0
Ectatomminae							
Holcoponera striatula (Mayr, 1884)	70	43	12	0	0	0	1
Formicinae							
Brachymyrmex cordemoyi Forel, 1895	28	0	0	0	0	0	0
Brachymyrmex pilipes Mayr, 1887	3	0	0	0	0	0	0
Camponotus cingulatus Mayr, 1862	1	0	0	0	0	0	0
Camponotus melanoticus Emery, 1894	1	0	0	0	1	0	0
Myrmicinae							
Cardiocondyla minutior Forel, 1899	1	0	0	0	0	0	0
Mycocepurus smithii (Forel, 1893)	1	0	0	0	0	0	0
Pheidole aberrans Mayr, 1868	1,491	0	0	0	0	0	0
Pheidole fallax Mayr, 1870	50	5	31	0	0	1	1
Pheidole gertrudae Forel, 1886	12	0	9	0	0	1	0
Pheidole obscurithorax Naves, 1985	0	0	133	0	0	1	0
Pheidole oxyops Forel, 1908	1	0	0	0	0	0	0
Pheidole radoszkowskii Mayr, 1884	35	0	0	0	0	0	0
Pheidole sp. 5	0	0	0	0	0	0	1
Pheidole sp. 6	0	0	0	1	0	0	1
Pheidole sp. 7	0	7	0	0	0	0	0
Pheidole sp. 65	0	0	80	1	0	0	0
Pheidole sp. 75	35	0	0	0	0	0	0
Pheidole subarmata Mayr, 1884	41	25	96	0	0	0	1
Pheidole vallifica Forel, 1901	7	35	5	0	1	0	0
Solenopsis gr. *saevissima* sp. 1	21	0	0	1	0	0	1
Solenopsis sp. 17	1	0	0	0	0	0	0
Solenopsis sp. 18	76	0	0	0	0	0	0
Total of ant workers	**1,953**	**130**	**366**	**3**	**7**	**3**	**NA**
Total of ant species	**20**	**7**	**7**	**2**	**4**	**3**	**7**

889 Table S6. Mean and sd (standard deviation) for ant foraging in different resources (presence of
890 ants). “Biome” refers to the biome sampled (AR: Atlantic rainforest and Cerrado); “Habitat”
891 refers to the land use sampled (Natural: Forest in Atlantic rainforest and woodland savannah in
892 Cerrado; Coffee: coffee plantation in both biomes); “n” indicates the number of transects;
893 “Param.” indicates mean and sd parameters; “Pitfall” is the number of ant species. “Larvae” is
894 the number of insect predation by ants; and five nutrients (CHO: carbohydrates, Lipids:
895 vegetable oil, AA: amino acids/whey protein, NaCl: salt, and Water).

Biome	**Habitat**	**n**	**Param.**	**Pitfall**	**Larvae**	**CHO**	**Lipids**	**AA**	**NaCl**	**Water**
AR	Natural	6	mean	20	11.12	0.53	0.53	0.40	0.20	0.03
AR	Natural	6	sd	6.54	4.79	0.50	0.50	0.49	0.40	0.18
AR	Coffee	12	mean	11.68	9.06	0.35	0.38	0.20	0.23	0.08
AR	Coffee	12	sd	6.65	7.27	0.48	0.49	0.40	0.42	0.27
Cerrado	Natural	6	mean	21.66	8.66	0.80	0.66	0.16	0.33	0.20
Cerrado	Natural	6	sd	5.04	8.18	0.40	0.47	0.37	0.47	0.40
Cerrado	Coffee	8	mean	12.71	5.42	0.47	0.32	0.05	0.12	0.07
Cerrado	Coffee	8	sd	8.93	6.48	0.50	0.47	0.22	0.33	0.26

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Table S7. The first column presents the comparison of ant composition between land use types: Natural AR (forest in the Atlantic rainforest), Natural Ce (woodland savannah in Cerrado), Coffee AR (coffee plantation in the Atlantic rainforest), and Coffee Ce (coffee plantation in Cerrado); and resource types: AA (amino acids), CHO (carbohydrates), Lipids (vegetable oil), NaCl (sodium) and Larvae (predation experiment). The table includes degrees of freedom (d.f.), sums of squares (SumOfSqs), coefficient of determination (R^2), F value (F), and P value (p-value; significant values are < 0.05).

Question 1: How similar is the species composition across land uses and resources?					
Natural AR *vs* Natural Ce	**d.f.**	**SumOfSqs**	**R^2**	**F**	**p-value**
Land use type	1	0.74	0.29	4.50	0.002
Resource type	4	1.08	0.45	1.64	0.054
Natural AR *vs* Coffee AR					
Land use type	1	1.49	0.54	12.47	0.002
Resource type	4	0.77	0.28	1.62	0.231
Natural AR *vs* Coffee Ce					
Land use type	1	1.25	0.38	5.77	0.003
Resource type	4	1.11	0.34	1.27	0.280
Natural Ce *vs* Coffee AR					
Land use type	1	1.12	0.48	9.02	0.002
Resource type	4	0.71	0.30	1.42	0.235
Natural Ce *vs* Coffee Ce					
Land use type	1	1.21	0.38	5.34	0.006
Resource type	4	1.03	0.32	1.13	0.374
Coffee AR *vs* Coffee Ce					
Land use type	1	0.51	0.26	3.62	0.003
Resource type	4	0.88	0.45	1.56	0.132

Figure S3

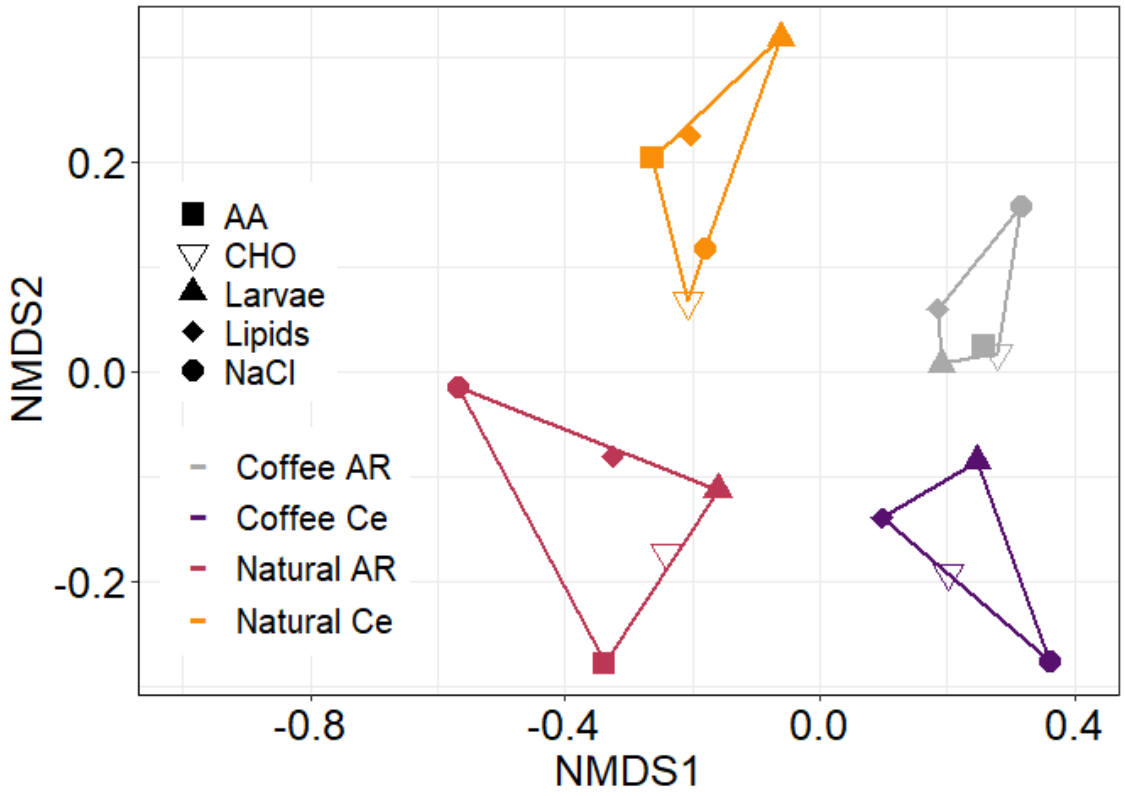

Figure S3. Ant species composition differs between land use types: Natural AR (forest in the Atlantic rainforest; medium pink), Natural Ce (woodland savannah in Cerrado; orange), Coffee AR (coffee plantation in the Atlantic rainforest; grey), and Coffee Ce (coffee plantation in Cerrado; purple). However, it does not differ significantly with respect to resource types: Larvae (predation experiment; full triangle), CHO (carbohydrates; empty triangle), Lipids (vegetable oil; diamond), AA (amino acids; square), and NaCl (salt; circle). The species composition used was measured using the turnover component of Sørensen dissimilarity (βsim).

Figure S4

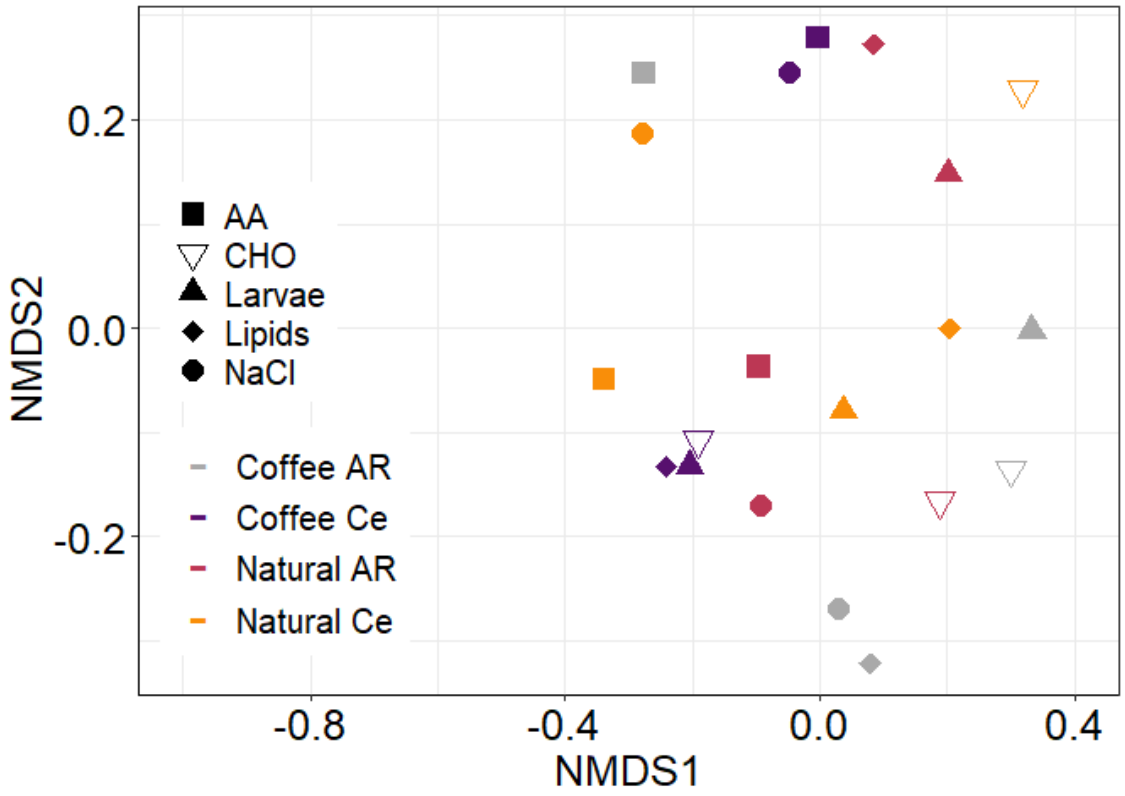

Figure S4. Ant species composition differs between land use types: Natural AR (forest in the Atlantic rainforest; medium pink), Natural Ce (woodland savannah in Cerrado; orange), Coffee AR (coffee plantation in the Atlantic rainforest; grey), and Coffee Ce (coffee plantation in Cerrado; purple). However, it does not differ significantly with respect to resource types: Larvae (predation experiment; full triangle), CHO (carbohydrates; empty triangle), Lipids (vegetable oil; diamond), AA (amino acids; square), and NaCl (salt; circle). The species composition used was measured using nestedness component of Sørensen dissimilarity (βsne).

ARTIGO 2 - Land use changes have direct and indirect negative effects on ant species richness and predation

Versão preliminar para submissão e nas normas da revista *Biodiversity and Conservation*

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Abstract

Land use change is the primary driver of biodiversity decline in tropical terrestrial ecosystems. However, the direct and indirect effects of land use changes on other environmental variables and biodiversity remain largely unexplored. Here, our aim was to evaluate the direct and indirect effects of land use changes on microclimate, species richness, and ecosystem function. To achieve this, we sampled ants in natural sites and coffee plantations in two Neotropical biomes: the Atlantic rainforest and Cerrado. We assessed microclimate (temperature and humidity) using a thermohygrometer. Species richness was measured using pitfall traps to collect ants. Ecosystem function was evaluated using insect predation, which we assessed through experiments with *Tenebrio molitor* larvae. For these measurements, we conducted 32 replicates (n = 32). Our results showed that land use changes directly increased temperature, likely due to reduced vegetation cover and higher solar radiation. However, we did not find an effect of microclimate on species richness or ecosystem function. Additionally, we found that land use changes directly decreased ant species richness. This is likely because land use changes severely impact most ant species, excluding a greater number of sensitive species and favouring only generalist species. Furthermore, the reduction in ant species richness led to a decline in predatory ants. A highly diverse ant assemblage can support a greater number of species across different guilds and functional groups. Finally, we found an indirect effect of land use change on insect predation, mediated by the reduction in predatory ants, which resulted in a decline in insect predation, likely due to a smaller number of different species performing this function. In conclusion, we found both direct and indirect effects of land use change on microclimate, ant species richness, and predation function in anthropized regions, likely due to alterations in vegetation structure. Therefore, we recommend maintaining vegetation structure in anthropized sites similar to the original vegetation to minimize changes in microclimate, species richness, and, consequently, ecosystem functions.

Keywords: Microclimate, Neotropical, insect predation, ecosystem function, structural equation model, coffee plantation

Introduction

Tropical habitats host a large portion of global biodiversity, which is threatened by land use changes for supposed economic development (Jayathilake et al. 2021; Raven et al. 2020). Although land use changes primarily impact biodiversity by removing natural habitats, it also generates a series of modifications on ecosystems (Barnes et al. 2017). First, land uses can cause changes in the resources that are available to species (Stein et al. 2014) and in the microclimate that they are exposed to, such as temperature and humidity (Machado et al. 2023). These changes can lead to a decrease in species diversity that can ultimately alter ecosystem functioning (Newbold et al. 2020; Wu et al. 2023), consequently, affecting the stability of natural ecosystems and the provision of ecosystem services in anthropized land uses (Le Provost et al. 2023). Therefore, understanding the direct and indirect effects of how land use changes affect community structure can enhance our knowledge of how ecosystem functions are maintained in human-altered habitats.

The conversion of tropical forests to anthropogenic land uses causes a drastic shift in conditions and resources, resulting in negative impacts on species (Manlick and Newsome 2021). The loss of plant abundance and diversity tends to decrease resources available for species (Stein et al. 2014), excluding most specialists and favouring just a few generalist and opportunist species (Filgueiras et al. 2021). Moreover, the loss of vegetation cover causes an increases in solar radiation, raising average temperatures and decreasing humidity (Machado et al. 2023; Senior et al. 2017). More specifically, in open anthropogenic habitats, there is an increase in maximum temperature (hot extremes), mean temperature, and minimum temperature (cold extremes) compared to closed natural habitats (Alkama and Cescatti 2016; Medvigy et al. 2012). These drastic alterations in microclimate exclude most tropical species that are sensitive to temperature changes, favouring a few thermally resistant species that are better adapted to extreme conditions (Outhwaite et al. 2022). Thus, drastic changes in

microclimate caused by land use changes can decrease the diversity of most tropical species and favour a few generalist and resistant species.

Changes in microclimate can also affect ecosystem functioning through alternative mechanisms. In general, an increase in temperature can have a positive effect on species activity (Lasmar et al. 2021) and, consequently, on ecosystem functions. This increase in activity may occur due to the rise in metabolic rates at higher temperatures (González-Tokman et al. 2020). However, with higher and more variable temperatures, ecosystem functions may also be negatively affected, due to the reduced activity of organisms during very hot periods, as they avoid thermal and desiccation risks (Parr and Bishop 2022). Thus, although extreme microclimate may favour more resistant species in anthropogenic land uses, higher temperatures can have a negative impact on the activity of these species and their ecosystem functions.

Complementary to the effects of microclimate on ecosystem functions, species richness can also alter ecosystem functions in different ways (Le Provost et al. 2023). First, the maintenance of species diversity can favour ecosystem functions (Le Provost et al. 2023). This can occur through functional redundancy (Biggs et al. 2020), where species perform the same function, and functional complementarity (Loreau and Hector 2001), where species perform different functions. In this way, a loss of species can consequently lead to a loss of functions due to fewer species acting in the ecosystem. However, in some cases, ecosystem functions can still be preserved even when the environment loses species. This can occur due to ecological release, caused by the reduction in competition resulting from the loss of specialist species, leading to increased activity of generalist and opportunistic species in anthropogenic land use (Manlick and Newsome 2021). Therefore, even though land use reduces species richness, ecosystem functions can still be maintained by generalist species. Thus, assessing whether species richness

77 is directly related to ecosystem functions is important for a better understanding of the role of
78 species diversity in anthropogenic ecosystems.

79 Land use can affect species richness and their ecosystem functions due to microclimatic
80 changes, however, the indirect effects and the mechanisms through which these impacts occur
81 are still poorly explored (Ceresa et al. 2021). Land use changes directly affect species richness
82 and ecosystem functions; however, these changes can vary depending on microclimatic
83 conditions. Moreover, regarding ecosystem functions, a decrease in species richness can help
84 explain alterations in these functions. However, despite several studies assessing these
85 variables, the direct and indirect effects along with indirect mechanisms, remains
86 underexplored. Therefore, understanding the direct and indirect effects of land use on
87 microclimate, species richness, and, consequently, ecosystem functions is crucial for species
88 conservation and for understanding their interactions and roles in anthropized regions (Barnes
89 et al. 2017).

90 Here, we aimed to assess the direct and indirect effects of land use change (conversion from
91 forest to agriculture) on microclimate, species richness and ecosystem functions. We used ants
92 and their predation activity as a model to study land use in tropical environments because ants
93 are sensitive to anthropogenic impacts and are among the main arthropod predators in tropical
94 forests and agricultural systems (Anjos et al. 2022; Philpott and Armbrecht 2006; Philpott et al.
95 2004; Wilker et al. 2023). More specifically, we constructed a structural equation model (SEM)
96 to test the direct and indirect effects among land use, microclimate and species richness, and
97 ultimately on ecosystem functions following these hierarchical predictions: (i) land use change
98 increases air temperature but decreases air humidity; (ii) land use changes and increase in
99 temperature decreases ant species richness; (iii) the decrease in ant species richness decreases
100 the species richness of predatory ants; and (iv) the decrease in the species richness of predatory
101 ants decreases insect predation.

Methods

Study site

We collected data on ant diversity and insect predation in three regions of the state of Minas Gerais, Brazil, covering two Neotropical biomes: the Atlantic rainforest and the Cerrado (Fig. 1). We sampled four sites in rural areas of the municipality of Lavras (21°14’43”S, 44°59’ 59”W) and 14 sites in rural areas of the municipality of Santo Antônio do Amparo (SAA; 20°57’19”S, 44°55’0”W), both in the Atlantic rainforest. We also sampled 14 sites in rural areas of the municipality of Patrocínio (18°56’38”S, 46°59’34”W), located in the Cerrado. In total, we sampled 32 sites, comprising 12 natural habitats and 20 anthropogenic land uses. In each site, we created a transect with five sampling points spaced 50 meters apart, totalling 200 meters.

The Atlantic rainforest is a tropical forest, while the Cerrado features various vegetation types, ranging from open habitats to closed forests. In all regions, we collected data in forest vegetation (tropical forest and woodland savanna) within a natural habitat, and coffee plantation with an anthropogenic land use. We sampled between January and March of 2022 and 2023, during the rainy season. In the rainy season, the Atlantic rainforest has an average precipitation of 134.54 mm and an average temperature of 20.41 °C (INMET 2024), while the Cerrado has an average precipitation of 212.87 mm and an average temperature of 22.16 °C.

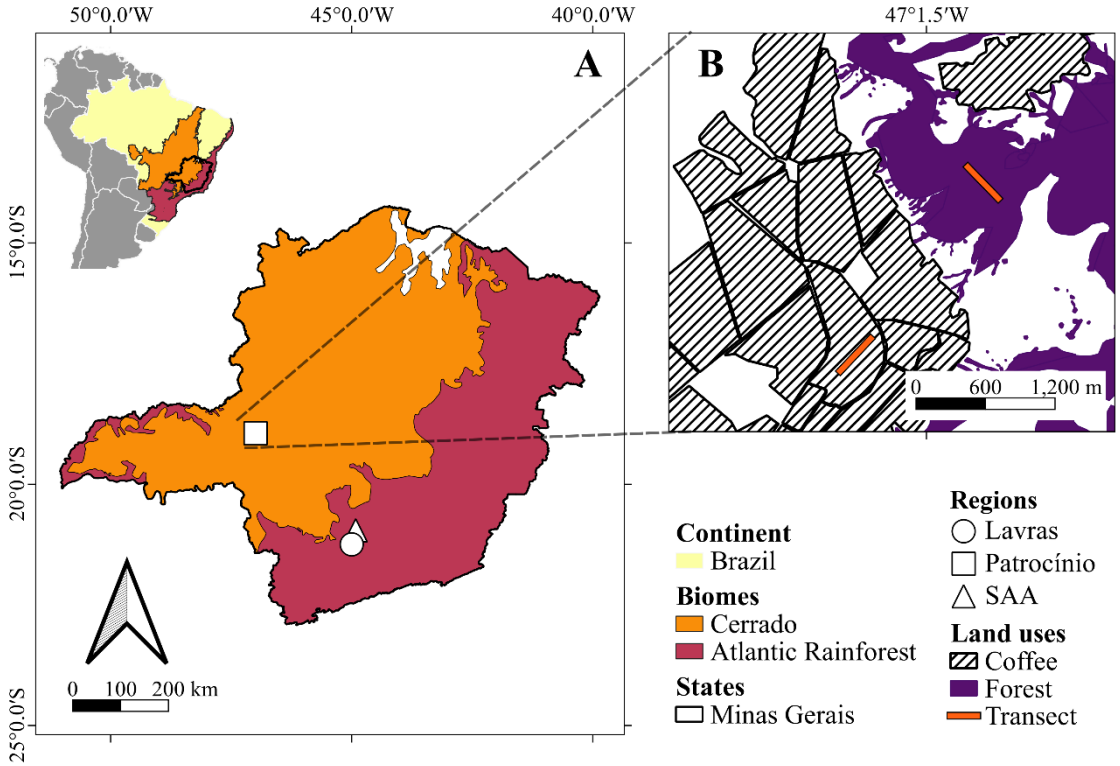


Fig. 1 The panel A indicates the Brazilian state of Minas Gerais, including its position in South America and the location of the biomes and sampled regions. The panel B indicates two transects within the region of Patrocínio. The figure was generated using QGIS version 3.32 (QGIS.org 2023) and adapted biome and state data from Instituto Brasileiro de Geografia e Estatística (IBGE 2019). The panel B was adapted by satellite image from Google Satellite (2024).

Insect predation by ants

We assessed insect predation by ants placing beetle larvae (*Tenebrio molitor* Linnaeus, 1758) along a transect with five sampling points spaced 50 meters apart. At each sampling point, we placed two beetle larvae. The larvae were attached with touch fastener to an ethylene-vinyl acetate (EVA) surface to prevent them from escaping (Figure S1). At each sampling point, between 8 a.m. and 12 p.m. (after the baited tubes), we observed insect predation by ants in four rounds of five minutes each. At the beginning of the experiment, we attached the larvae to the ground at the first sampling point and immediately observed the ants' attack for five minutes. Then, we attached the larvae at the second sampling point and observed them for five minutes. We repeated this process until completing the transect, and then started again for the second, third, and fourth rounds. This totalled 20 minutes per sampling point and 100 minutes

per transect. The ants that engaged in predation were collected and stored in 70% alcohol for later identification. We considered “predatory ants” as the number of ant species collected per transect in this predation experiment and “predation” was measured by the number of larvae attacked per transect. In this way, each of the 32 transects (n = 32) has a measure of predatory ants and a measure of insect predation.

Microclimate measurements

Alongside the insect predation experiment, we measured temperature and relative humidity. We measured at each sampling point for each of the four rounds of the predation experiment. We used a digital thermo-hygrometer to measure air temperature (°C) and humidity (%) at 5 cm above the ground at each sampling point. We used the mean temperature and humidity per transect.

Ant species richness

After insect predation experiment, in the same transect with five pitfall traps spaced 50 meters apart, we installed pitfall traps. The traps consisted of plastic pots with a diameter of 12 cm and a depth of 11 cm, installed in the ground. We added a solution composed of 200 ml of water mixed with salt and detergent to capture and preserve the collected ants. Each trap operated for a period of 48 hours. After this period, the captured ants were stored in 70% alcohol. We considered “ant species richness” as the number of ant species collected per transect (n = 32).

Ant species identification

We identified all ants collected from the pitfall and predation experiments to the genus level based on Baccaro et al. (2015) and morphotyped them according to external morphological characters. Identification and confirmation of species and morphospecies were made by Rodrigo M. Feitosa and Ana Carolina A. Neundorf at the Laboratório de Sistemática e Biologia de Formigas at the Universidade Federal do Paraná (UFPR). Specific published descriptions were used to identify species in the genera *Acromyrmex* (Gonçalves 1961), *Acropyga* (LaPolla

2004), *Apterostigma* (Lattke 1997), *Basiceros* (Probst and Brandão 2022), *Brachymyrmex* (Ortiz-Sepúlveda et al. 2019), *Carebara* (Fernández 2004), *Ectatomma* (Kugler and Brown 1982), *Gnamptogenys* (Camacho et al. 2020), *Labidus* (Watkins 1976), *Linepithema* (Wild 2007), *Neivamyrmex* (Watkins 1976), *Odontomachus* (Brown 1976), *Pheidole* (Wilson 2003), *Strumigenys* (Bolton 2000), and *Wasmannia* (Longino and Fernández 2007). Voucher specimens were deposited in the reference collection of Laboratório de Ecologia de Formigas at UFLA and the Coleção Entomológica Padre Jesus Santiago Moure at UFPR (DZUP).

Data analysis

Before the analyses, we tested for a correlation between the microclimate variables of temperature and humidity. We found that these variables were strongly negatively correlated ($\rho = -0.86$; $p < 0.001$), and we decided to use only temperature as a microclimate variable in subsequent analyses. After these steps, we constructed five generalized linear mixed models (GLMM) to test our predictions. For normalized assumptions, we square root transformed the data for ant species richness and insect predation. In all models, we included the regions as a random variable to control for the effects of different regions and biomes (Bates et al. 2015), as different regions can support distinct regional species pools, and different biomes have intrinsic abiotic and biotic characteristics that can generate partially context-dependent patterns (Lasmar et al. 2023). For detailed data, see Supplementary Material, Table S1.

Our structural equation modelling (SEM) was based in four models. For the first model, (i) testing whether the conversion from natural habitat to coffee plantation (land use change) alters microclimate variables, we used temperature as the response variable and land use change as the predictor. For the second model, (ii) testing whether land use changes and an increase in temperature decrease ant species richness, we used ant species richness as the response variable and land use change and temperature as predictors. For the third model, (iii) testing whether the decrease in ant species richness decreases the number of predatory ants, we used the predatory

ants as the response variable and land use change, temperature, and ant species richness as predictors. For the fourth model, (iv) testing whether the decrease in the predatory ants decreases insect predation, we used the number of insect predations by ants as the response variable and land use change, temperature, ant species richness, and predatory ants as predictors. For models with normalized response variable, we analysed with *lmer* function. For models with count response variable, we analysed with *glmer.nb* function. We used Negative Binomial for count due overdispersion. All GLMMs were made with 'lme4' R package version 1.1.35.5 (Bates et al. 2015). For detailed models, see Supplementary Material, Full models.

To avoid overfitting in SEM analyses in our models, we used the *dredge* function ('MuMIn' package version 1.47.5; Bartoń 2023) for selected the best predictors in each model, based on the Akaike information criterion corrected for small sample sizes (AICc). We selected the variables in models with $\Delta AICc < 2$ (Burnham and Anderson 2002). When more than one variable was selected, we used the function *model.avg* (package 'MuMIn', version 1.47.5; Bartoń 2023) to detect uninformative parameters and avoid Type I errors (Leroux 2019). Uninformative parameters are predictors selected in good models but that do not have a significant effect on the response variable (false positive). For detailed selected models, see Supplementary Material, Tables S2-S6.

For testing the direct and indirect effects of land use and microclimate changes on ecosystem function, we used the best predictors in each model for conducted structural equation modelling analyses (SEM). For this, we used the *psem* function of the 'piecewiseSEM' R package version 2.3.0 (Lefcheck 2016). We construct the model connecting the mixed models (i) to (iv), following the hypothetical cascade effect starting from changes in land use and temperature affecting ant species, which, in turn, affects predatory ants, and consequently insect predation (details of model in Supplementary material - *psem model*). For the *psem* function, we assess the Global goodness-of-fit through Fisher's C, considering it a good fit if $p > 0.05$. We also

assess the independence of the variables through Tests of Directed Separation, considering them independent if $p > 0.05$ and to assure that there were no missing paths in our SEM. In addition, we ensure that all predictors influenced the response variables within the *psem* model, considering significative if $p < 0.05$.

To assess direct, mediator, indirect, and total effects for the response variables, we used the function *bootEff* with 1,000 permutations to compute SEM correlated errors and the *semEff* function. Both functions are in 'semEff' R package version 0.7.2 (Murphy 2024). The direct effect is the immediate relationship between a predictor and a response variable, for example, an increase in temperature (direct effect) increases insect predation (response variable). However, the effect of a predictor on a response variable can also be mediated by an intermediate variable known as a mediator. In this context, the effect of the predictor variable through the mediator is referred to as the indirect effect. The mediator clarifies how the predictor indirectly affects the response variable. For example, an increase in temperature (predictor) increases ant species richness (mediator), which consequently leads to increased insect predation by ants (response variable). Finally, the sum of the direct and indirect effects is referred to as the total effect of a predictor on a response variable.

All analyses were completed in R 4.3.3 (R Core Team 2024). All graphs were made with the ggplot2 R package version 3.5.1 (Wickham 2016).

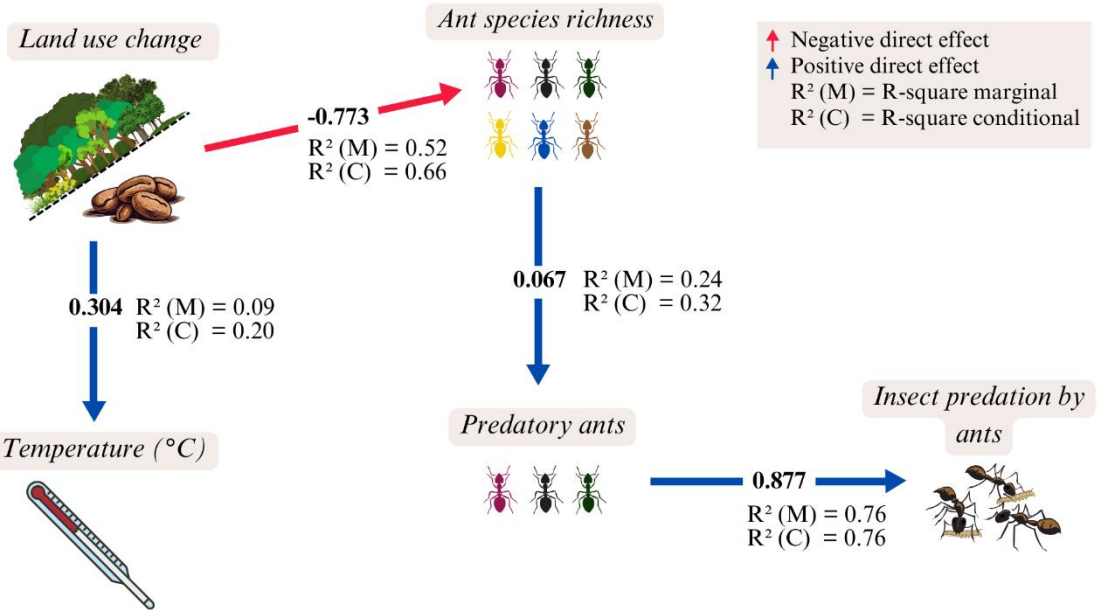
Results

We sampled 127 ant species, belonging to 124 ant species for pitfall data, and 28 ant species for predation (more details in Tables S7-S10). We sampled seven of 12 ant subfamilies from Brazil. According to Feitosa et al. (2022), we found the following percentage of species within each subfamily for Atlantic Rainforest and Cerrado biomes: Dolichoderinae (10 species; 12% of species for both biomes), Dorylinae (2; 5%), Ectatomminae (5; 7%), Formicinae (24; 17%), Myrmicinae (73; 13%), Ponerinae (11; 9%), and Pseudomyrmecinae (2; 3%).

We found direct and indirect effects initiated by land use change, which altered ant species richness and, ultimately, ecosystem function (Fisher's C = 12.541; AIC = 442.530; d.f. = 12; p = 0.403; Fig. 2). First, we found that land use change directly affects temperature and ant species richness, increasing temperature (Table 1; Fig. 3A; Table S2) but decreasing species richness (Table 1; Fig. 3B; Table S3). Temperature, which we hypothesized would impact other variables, had no effect on any response variable (Fig. 2; Tables S4-S6). Ant species richness had a direct and positive effect on predatory ants (Table 1; Fig. 3C; Tables S4-S5). In turn, predatory ants had a direct and positive effect on insect predation (Table 1; Fig. 3D; Table S6). However, land use change had an indirect and negative effect on insect predation (Table 1). This occurs through the mechanism whereby land use change reduces the number of predatory ants, which in turn has a negative effect on insect predation (Table 1).

Table 1 Table of direct, indirect, total, and mediator effects on the response variable in the structural equation model (SEM). "Effect" denotes the effect of the predictor on the response variable. "Std. Err." provides the standard errors. "Lower CI" and "Upper CI" are the lower and upper confidence intervals, respectively. No confidence intervals overlapped with zero, indicating that all effects were significant.

(i) Temperature response					
Relationship	*Predictor*	*Effect*	*Std. Err.*	*Lower CI*	*Upper CI*
Direct	Land use	0.304	0.201	0.033	0.665
Total	Land use	0.304	0.201	0.033	0.665
(ii) Ant species response					
Relationship	*Predictor*	*Effect*	*Std. Err.*	*Lower CI*	*Upper CI*
Direct	Land use	-0.773	0.017	-0.775	-0.754
Total	Land use	-0.773	0.017	-0.775	-0.754
(iii) Predatory ants response					
Relationship	*Predictor*	*Effect*	*Std. Err.*	*Lower CI*	*Upper CI*
Direct	Ant species	0.067	0.017	0.030	0.084
Total	Ant species	0.067	0.017	0.030	0.084
(iv) Insect predation response					
Relationship	*Predictor*	*Effect*	*Std. Err.*	*Lower CI*	*Upper CI*
Direct	Predatory ants	0.877	0.047	0.770	0.924
Indirect	Land use	-0.045	0.012	-0.057	-0.020
Total	Land use	-0.045	0.012	-0.057	-0.020
Total	Predatory ants	0.877	0.047	0.770	0.924
Mediator	Predatory ants	-0.045	0.012	-0.057	-0.020



255

256 **Fig. 2** Direct effects of land use changes on insect predation by ants by Structural Equation
257 Model (SEM). Blue arrows indicate direct positive effects, while red arrows indicate direct
258 negative effects. The effects are represented as overlays on each arrow. R^2 marginal is the
259 coefficient of determination considering only the predictors, while R^2 conditional considers
260 both the predictors and the random variable.

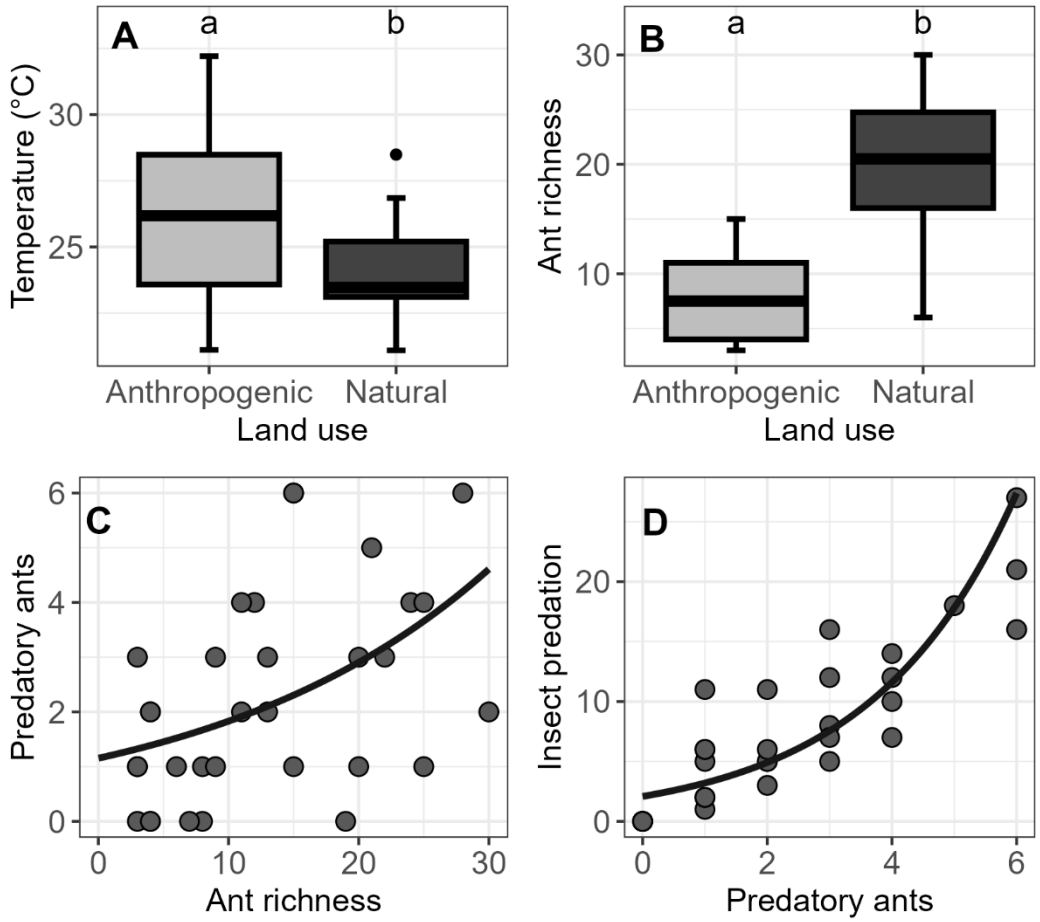


Fig. 3 Panel A shows the increase in temperature (°C) caused by land use changes. Panel B shows the decrease in the number of ant species caused by land use changes. Panel C shows the increase in predatory ants with the increase in ant species richness. Panel D shows the increase in insect predation by ants with the increase in predatory ants.

Discussion

In our study, we identified the hierarchical mechanism through which the land use affects ant species richness and ultimately impact their ecosystem function. First, we found that land use change increases air temperature. However, we did not find support indicating that microclimate affect ant species richness and their predation function. We also identified a negative direct effect of land use change on ant species richness, which, in turn, has a positive direct effect on predatory species. Finally, we identified an indirect effect of land use change on insect predation, mediated by changes in predatory species. This occurs due to the reduction in the number of predatory species caused by land use, leading to a decline in predation activity.

Thus, our findings on the direct and indirect effects of land use change on species and ecosystem function, particularly highlighting the importance of species richness for predation, can contribute to understanding the mechanisms driving alterations in ecosystem functions in anthropized environments.

We found that the conversion of natural habitats to anthropogenic land uses directly increases temperature. However, contrary to our expectations, we did not find an effect of microclimate on species richness and ecosystem function. This is probably related to the low temperature variation observed between natural habitats (mean = 24.16°C; standard deviation = 1.94) and anthropogenic land uses (mean = 26.18°C; standard deviation = 3.10) in our study system. Additionally, the agricultural system studied was a coffee plantation, which is also a tree, acting as an intermediate between closed environments (such as forests or agroforests) and open areas (such as pastures), which may have contributed to the lower variation in the microclimate. Although we detected a significant increase in temperature in anthropogenic land uses, this air temperature variation may have been too small to detect changes in ant species and predatory activity. Moreover, land use changes themselves tend to have a very large negative effect on animals (discussed below), making that small temperature variations almost insignificant in these cases (Englmeier et al. 2023). In addition, ground ants and other ectotherms may find cooler habitats for foraging and nesting, contributing to their thermal plasticity (Parr and Bishop 2022). Thus, although we found an increase in temperature in anthropogenic land uses, microclimatic changes were not a significant predictor of changes in diversity and predation function. This is probably due to the low variability between natural habitats and anthropogenic land uses, as well as the high impact of land use changes themselves.

Land use change decreases species richness, which is consistent with what is widely documented in the literature (e.g., Davison et al. 2021; Newbold et al. 2015). In tropical regions, land use change is the principal driver of biodiversity loss (Jaureguiberry et al. 2022).

Moreover, the conversion of forests to perennial agriculture, such as coffee plantations, tends to decrease ant species richness (Wilker et al. 2024). Although we did not find an effect of microclimate, other important not measured environmental conditions in agricultural land uses, such as increased soil compaction (Zhang et al. 2024) and changes in nutrient deposition (Cappelli et al. 2022), may decrease the sensitive species adapted to the original conditions. In addition, the quantity and diversity of resources decrease, excluding most specialist species (Miao et al. 2022; Ribas et al. 2003). This reduction in species richness tends to increase the presence of generalist and opportunistic species (winners and losers; McKinney and Lockwood 1999; Tabarelli et al. 2012). Thus, land use changes cause drastic alterations in species richness and community structure.

A decrease in species richness leads to a reduction in the number of predatory ants. Predatory ants are a group composed of species that prey on other animals, thus playing an important role in the ecosystem function of predation (Cerdá and Dejean 2011). Several studies have demonstrated a positive relationship between overall species richness and the number of species within a functional group (e.g., Laliberte et al. 2010; Mori et al. 2017), including functional groups such as predatory ants (Wilker et al. 2023). Communities with greater species richness tend to exhibit higher functional redundancy (Biggs et al. 2020), which enhances the stability and resilience of ecosystems (Sadeghinia et al. 2023). This redundancy ensures that if some species are excluded, others can continue performing the same function, maintaining the ecosystem balance (Biggs et al. 2020). Thus, land use changes lead to a decrease in species richness and, consequently, in specific groups such as predators, which can in turn affect ecosystem functions.

Finally, we found a direct and positive effect of predatory ants on insect predation. The positive relationship between ant species richness and insect predation is reported in the literature (Wilker et al. 2023). This occurs due to the greater number of species performing the

same function (Biggs et al. 2020). Furthermore, we found that predatory ants are the mediator through which land use changes reduce insect predation. Thus, as with general species richness, predatory species are also negatively affected by land use changes, leading to a decrease in predation activity (Barnes et al. 2017). Therefore, one way to conserve and promote higher levels of insect predation in anthropogenic land uses is to maintain a higher similarity to natural tropical habitats (e.g., shaded coffee plantations; Manson et al. 2024), which would conserve species richness and, consequently, the functions they perform.

Conclusion

In our study, we identified important direct and indirect effects of land use changes on ecosystem functions, with indirect mediator effects by species richness and predatory species. We found that land use changes increase temperature, but the microclimate did not affect ant species or predation function. This is likely because ground ants can find cooler microhabitats or due to the small temperature differences between natural environments and anthropogenic land uses. For this reason, we suggest further research where microclimate is assessed over longer time scales, such as variations during the day and night (Liu et al. 2020), and even seasonal changes (Queiroz et al. 2022). We found that land use has a direct negative effect on species richness, probably due to ecological filters that exclude most tropical ant species. In turn, overall species richness is directly linked to predator richness, indicating that conserving more species may likely contribute to the preservation of ecosystem functions beyond insect predation. Therefore, we recommend conservation strategies that maintain land uses as similar to natural conditions as possible, as this can enhance species richness and, consequently, the functions and services they provide.

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References

Alkama R, Cescatti A (2016) Biophysical climate impacts of recent changes in global forest cover. Science 351(6273):600–604. https://doi.org/10.1126/science.aac8083

Anjos DV, Tena A, Viana-Junior AB et al. (2022) The effects of ants on pest control: a meta-analysis. Proceedings of the Royal Society B 289(1981):20221316. https://doi.org/10.1098/rspb.2022.1316

Baccaro FB, Feitosa RM, Fernandez F et al (2015) Guia para os gêneros de formigas do Brasil. Editora INPA.

Barnes AD, Allen K, Kreft H et al (2017) Direct and cascading impacts of tropical land-use change on multi-trophic biodiversity. Nature ecology & evolution 1(10):1511–1519. https://doi.org/10.1038/s41559-017-0275-7

Bartoń K (2023) MuMIn: Multi-Model Inference. R package version 1.47.5, <https://CRAN.R-project.org/package=MuMIn>

Bates D, Maechler M, Bolker B et al (2015) Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1–48. doi:10.18637/jss.v067.i01

Biggs CR, Yeager LA, Bolser DG et al (2020) Does functional redundancy affect ecological stability and resilience? A review and meta-analysis. Ecosphere 11(7):e03184. https://doi.org/10.1002/ecs2.3184

Bolton B (2000) The ant tribe Dacetini. Memoirs of the American Entomological Institute 65:1–1028.

Brown WLJr (1976) Contributions toward a reclassification of the Formicidae. Part VI. Ponerinae, tribe Ponerini, subtribe Odontomachiti. Section A. Introduction, subtribal characters. Genus *Odontomachus*. Studia Entomologica 19:67–171.

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach. Springer New York.

Camacho GP, Franco W, Feitosa RM (2020) Additions to the taxonomy of *Gnamptogenys* Roger (Hymenoptera: Formicidae: Ectatomminae) with an updated key to the New World species. Zootaxa 4747(3):450–476. https://doi.org/10.11646/zootaxa.4747.3.2

Cappelli SL, Domeignoz-Horta LA, Loaiza V et al (2022) Plant biodiversity promotes sustainable agriculture directly and via belowground effects. Trends in Plant Science 27(7):674–687. https://doi.org/10.1016/j.tplants.2022.02.003

Cerdá, X., & Dejean, A. (2011). Predation by ants on arthropods and other animals. National Academy of Sciences (US).

Ceresa F, Kranebitter P, Monrós JS et al (2021) Disentangling direct and indirect effects of local temperature on abundance of mountain birds and implications for understanding global change impacts. PeerJ 9:e12560. https://doi.org/10.7717/peerj.12560

Davison CW, Rahbek C, Morueta-Holme N (2021) Land-use change and biodiversity: Challenges for assembling evidence on the greatest threat to nature. Global Change Biology 27(21):5414–5429. https://doi.org/10.1111/gcb.15846

Englmeier J, Rieker D, Mitesser O et al (2023) Diversity and specialization responses to climate and land use differ between deadwood fungi and bacteria. Ecography 2023(11):e06807. https://doi.org/10.1111/ecog.06807

Feitosa RM, Camacho GP, Silva TS et al (2022) Ants of Brazil: an overview based on 50 years of diversity studies. Systematics and Biodiversity 20(1):1–27. https://doi.org/10.1080/14772000.2022.2089268

419 Fernández F (2004) The American species of the myrmicine ant genus *Carebara* Westwood
420 (Hymenoptera: Formicidae). Caldasia 26(1):191–238.
421 http://www.jstor.org/stable/23641795

422 Filgueiras BK, Peres CA, Melo FP et al (2021) Winner–loser species replacements in human-
423 modified landscapes. Trends in Ecology & Evolution 36(6):545–555.
424 https://doi.org/10.1016/j.tree.2021.02.006

425 Gonçalves CR (1961) O gênero *Acromyrmex* no Brasil (Hym. Formicidae). Studia
426 Entomologica 4:113–180.

427 González-Tokman D, Córdoba-Aguilar A, Dáttilo W et al (2020) Insect responses to heat:
428 physiological mechanisms, evolution and ecological implications in a warming world.
429 Biological Reviews 95(3):802–821. https://doi.org/10.1111/brv.12588

430 Google (2024) Google Satellite Imagery. Available in: https://www.google.com/maps.
431 (accessed 28 May 2024).

432 IBGE (2019) Biomas e Sistema Costeiro-Marinho do Brasil - 1:250,000. Instituto Brasileiro de
433 Geografia e Estatística. Available in:
434 https://www.ibge.gov.br/geociencias/informacoes-ambientais/vegetacao/15842-
435 biomas.html. (Accessed 28 May 2024).

436 INMET (2024) Instituto Nacional de Meteorologia. Banco de Dados Meteorológicos para
437 Ensino e Pesquisa - BDMEP. Brasília, DF, Brazil. Available in:
438 http://www.inmet.gov.br/. (Accessed 30 May 2024).

439 Jaureguiberry P, Titeux N, Wiemers M et al (2022) The direct drivers of recent global
440 anthropogenic biodiversity loss. Science advances 8(45):eabm9982.
441 https://doi.org/10.1126/sciadv.abm9982

442 Jayathilake HM, Prescott GW, Carrasco LR et al (2021) Drivers of deforestation and
443 degradation for 28 tropical conservation landscapes. Ambio 50(1):215–228.
444 https://doi.org/10.1007/s13280-020-01325-9

445 Kugler C, Brown WLJr (1982) Revisionary and other studies on the ant genus *Ectatomma*,
446 including the description of two new species. Agriculture 24:1–8.

447 Laliberte E, Wells JA, DeClerck F et al (2010) Land-use intensification reduces functional
448 redundancy and response diversity in plant communities. Ecology letters 13(1):76–86.
449 https://doi.org/10.1111/j.1461-0248.2009.01403.x

450 LaPolla JS (2004) Acropyga of the world. Contributions of the American Entomological
451 Institute 33:1–130.

452 Lasmar CJ, Bishop TR, Parr CL et al (2021) Geographical variation in ant foraging activity and
453 resource use is driven by climate and net primary productivity. Journal of Biogeography
454 48(6):1448–1459. https://doi.org/10.1111/jbi.14089

455 Lasmar CJ, Bishop TR, Parr CL et al (2023) Testing the context dependence of ant nutrient
456 preference across habitat strata and trophic levels in Neotropical biomes. Ecology
457 104(4):e3975.

458 Lattke JE (1997) Revisión del género *Apterostigma* Mayr (Hymenoptera: Formicidae). Arq.
459 Zool. (São Paulo) 34:121–22.

460 Le Provost G, Schenk NV, Penone C et al (2023) The supply of multiple ecosystem services
461 requires biodiversity across spatial scales. Nature ecology & evolution 7(2):236–249.
462 https://doi.org/10.1038/s41559-022-01918-5

463 Lefcheck JS (2016) piecewiseSEM: Piecewise structural equation modeling in R for ecology,
464 evolution, and systematics. Methods in Ecology and Evolution 7(5):573–579.
465 https://doi.org/10.1111/2041-210X.12512

466 Leroux SJ (2019) On the prevalence of uninformative parameters in statistical models applying
467 model selection in applied ecology. PloS one 14(2):e0206711.
468 https://doi.org/10.1371/journal.pone.0206711

469 Liu X, Wang Z, Huang C et al (2020) Ant assemblage composition explains high predation
470 pressure on artificial caterpillars during early night. Ecological Entomology 45(3):547–
471 554. https://doi.org/10.1111/een.12826

472 Longino JT, Fernández F (2007) Taxonomic review of the genus Wasmannia. In R. R. Snelling,
473 B. L. Fisher, & P. S. Ward, (Eds.), Advances in ant systematics (Hymenoptera:
474 Formicidae): homage to E.O. Wilson – 50 years of contributions. (pp. 271–289).
475 Memoirs of the American Entomological Institute.

476 Loreau M, Hector A (2001) Partitioning selection and complementarity in biodiversity
477 experiments. Nature 412(6842):72–76. https://doi.org/10.1038/35083573

478 Machado NG, Biudes MS, Mützenberg DMDS et al (2023) Effects of deforestation on
479 microclimate in a Cerrado-Amazonia Transition area. Ciência Florestal 33(2):e70199.
480 https://doi.org/10.5902/1980509870199

481 Manlick PJ, Newsome SD (2021) Adaptive foraging in the Anthropocene: can individual diet
482 specialization compensate for biotic homogenization?. Frontiers in Ecology and the
483 Environment 19(9):510–518. https://doi.org/10.1002/fee.2380

Manson S, Nekaris KAI, Nijman V et al (2024). Effect of shade on biodiversity within coffee farms: A meta-analysis. Science of the Total Environment 169882. https://doi.org/10.1016/j.scitotenv.2024.169882

McKinney ML, Lockwood JL (1999) Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in ecology & evolution 14(11):450–453. https://doi.org/10.1016/S0169-5347(99)01679-1

Medvigy D, Walko RL, Avissar R (2012) Simulated links between deforestation and extreme cold events in South America. Journal of climate 25(11):3851–3866. https://doi.org/10.1175/JCLI-D-11-00259.1

Miao BG, Peng YQ, Yang DR et al (2022). Diversity begets diversity: Low resource heterogeneity reduces the diversity of nut-nesting ants in rubber plantations. Insect Science 29(3):932–941. https://doi.org/10.1111/1744-7917.12964

Mori AS, Lertzman KP, Gustafsson L (2017) Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. Journal of Applied Ecology 54(1):12–27. https://doi.org/10.1111/1365-2664.12669

Murphy MV (2024) semEff: Automatic Calculation of Effects for Piecewise Structural Equation Models. R package version 0.7.2. <https://CRAN.R-project.org/package=semEff>

Newbold T, Hudson LN, Hill SL et al (2015) Global effects of land use on local terrestrial biodiversity. Nature 520(7545):45–50. https://doi.org/10.1038/nature14324

Newbold T, Oppenheimer P, Etard A et al (2020) Tropical and Mediterranean biodiversity is disproportionately sensitive to land-use and climate change. Nature Ecology & Evolution 4(12):1630–1638. https://doi.org/10.1038/s41559-020-01303-0

507 Ortiz-Sepúlveda CM, Van Bocxlaer B, Meneses AD et al (2019) Molecular and morphological
508 recognition of species boundaries in the neglected ant genus *Brachymyrmex*
509 (Hymenoptera: Formicidae): Toward a taxonomic revision. Organisms Diversity &
510 Evolution 19:447–542. https://doi.org/10.1007/s13127-019-00406-2

511 Outhwaite CL, McCann P, Newbold T (2022) Agriculture and climate change are reshaping
512 insect biodiversity worldwide. Nature 605(7908):97–102.
513 https://doi.org/10.1038/s41586-022-04644-x

514 Parr CL. Bishop TR (2022) The response of ants to climate change. Global change biology
515 28(10):3188–3205. https://doi.org/10.1111/gcb.16140

516 Philpott SM, Armbrecht I (2006) Biodiversity in tropical agroforests and the ecological role of
517 ants and ant diversity in predatory function. Ecological entomology 31(4):369–377.
518 https://doi.org/10.1111/j.1365-2311.2006.00793.x

519 Philpott SM, Greenberg R, Bichier P et al (2004) Impacts of major predators on tropical
520 agroforest arthropods: comparisons within and across taxa. Oecologia 140:140–149.
521 https://doi.org/10.1007/s00442-004-1561-z

522 Probst RS, Brandão CRF (2022) A taxonomic revision of the dirt ants, *Basiceros* Schulz, 1906
523 (Hymenoptera, Formicidae). Zootaxa 5149(1):1–75.
524 https://doi.org/10.11646/zootaxa.5149.1.1

525 QGIS.org (2023) QGIS Geographic Information System. QGIS Association. Available in:
526 http://www.qgis.org. (Accessed 28 May 2024).

527 Queiroz AC, Marques TG, Ribas CR et al (2023) Ant diversity decreases during the dry season:
528 A meta-analysis of the effects of seasonality on ant richness and abundance. Biotropica
529 55(1):29–39. https://doi.org/10.1111/btp.13158

R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>

Raven PH, Gereau RE, Phillipson PB et al (2020) The distribution of biodiversity richness in the tropics. Science Advances 6(37):eabc6228. https://doi.org/10.1126/sciadv.abc6228

Ribas CR, Schoereder JH, Pic M et al (2003) Tree heterogeneity, resource availability, and larger scale processes regulating arboreal ant species richness. Austral Ecology 28(3):305–314. https://doi.org/10.1046/j.1442-9993.2003.01290.x

Sadeghinia M, Kargar M, Jafarian Z (2023) The relationship between the functional diversity, functional redundancy and community stability in mountain rangelands. Community Ecology 24(1):1–8. https://doi.org/10.1007/s42974-022-00128-0

Senior RA, Hill JK, González del Pliego P et al (2017) A pantropical analysis of the impacts of forest degradation and conversion on local temperature. Ecology and evolution 7(19):7897–7908. https://doi.org/10.1002/ece3.3262

Stein A, Gerstner K, Kreft H (2014) Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. Ecology letters 17(7):866–880. https://doi.org/10.1111/ele.12277

Tabarelli M, Peres CA, Melo FP (2012) The ‘few winners and many losers’ paradigm revisited: emerging prospects for tropical forest biodiversity. Biological Conservation 155:136–140. https://doi.org/10.1016/j.biocon.2012.06.020

Watkins JF (1976) The identification and distribution of New World army ants (Dorylinae: Formicidae). Baylor University Press.

Wickham H (2016) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

552 Wild AL (2007) Taxonomic revision of the ant genus *Linepithema* (Hymenoptera: Formicidae).
553 University of California Publications in Entomology.

554 Wilker I, Lasmar CJ, Schmidt FA et al (2023) Land-use change in the Amazon decreases ant
555 diversity but increases ant-mediated predation. Insect Conservation and Diversity
556 16(3):379–392. https://doi.org/10.1111/icad.12632

557 Wilker I, Queiroz AC, Ribas CR et al (2024) A systematic review of the land use change effects
558 on ant diversity in Neotropics. Biological Conservation 299:110778.
559 https://doi.org/10.1016/j.biocon.2024.110778

560 Wilson EO (2003) *Pheidole* in the New World. A dominant, hyperdiverse ant genus. Harvard
561 University Press.

562 Wu L, Chen H, Chen D et al (2023) Soil biota diversity and plant diversity both contributed to
563 ecosystem stability in grasslands. Ecology Letters 26(6):858–868.
564 https://doi.org/10.1111/ele.14202

565 Zhang B, Jia Y, Fan H et al (2024) Soil compaction due to agricultural machinery impact: A
566 systematic review. Land Degradation & Development 35(10):3256–3273.
567 https://doi.org/10.1002/ldr.5144

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577 **Supplementary material**

578

579 **Figure S1** For the predation experiment, two beetle larvae were attached with touch fastener to

580 an ethylene-vinyl acetate (EVA) surface to prevent them from escaping.

581 **Table S1** Ecological data for 32 sites across three regions (SAA: Santo Antônio do Amparo;
582 LA: Lavras; PA: Patrocínio) and two biomes (AR: Atlantic rainforest; CE: Cerrado).
583 Temperature was measured in degrees Celsius and humidity in percentage. Richness refers to
584 the number of ant species collected in pitfalls. Predatory ants represent the number of ant
585 species that preyed on insects. Pred. refers to the number of insect predation events.

Site	Region	Biome	Land use	Temperature	Humidity	Richness	Predatory ants	Pred.
A1	SAA	AR	Coffee	26.95	68.30	04	0	00
A2	SAA	AR	Coffee	28.29	69.35	04	2	05
A3	SAA	AR	Coffee	29.64	67.35	03	1	05
A4	SAA	AR	Coffee	27.89	62.70	03	3	08
A5	SAA	AR	Coffee	25.61	68.45	08	0	00
A6	SAA	AR	Coffee	29.85	63.60	08	1	01
A7	SAA	AR	Coffee	23.73	82.72	09	3	12
A8	SAA	AR	Coffee	21.70	81.45	15	6	27
A9	SAA	AR	Coffee	32.21	60.71	12	4	10
A10	SAA	AR	Coffee	26.75	69.15	13	2	05
A11	SAA	AR	Forest	23.24	81.52	24	4	12
A12	SAA	AR	Forest	24.75	87.00	20	3	07
A13	SAA	AR	Forest	25.51	79.35	21	5	18
A14	SAA	AR	Forest	24.83	86.40	15	6	16
A15	LA	AR	Coffee	28.79	69.41	13	3	05
A16	LA	AR	Coffee	28.55	69.43	11	4	14
A17	LA	AR	Forest	23.42	80.78	30	2	11
A18	LA	AR	Forest	22.20	88.91	25	1	06
A19	PA	Ce	Coffee	25.58	70.60	04	2	06
A20	PA	Ce	Coffee	23.53	86.81	03	0	00
A21	PA	Ce	Coffee	22.52	85.77	04	0	00
A22	PA	Ce	Coffee	21.11	88.40	03	1	11
A23	PA	Ce	Coffee	25.37	73.15	07	0	00
A24	PA	Ce	Coffee	23.33	80.20	11	2	03
A25	PA	Ce	Forest	22.81	88.57	22	3	16
A26	PA	Ce	Forest	21.09	95.90	20	1	02
A27	PA	Ce	Forest	23.10	95.31	19	0	00
A28	PA	Ce	Forest	23.51	92.24	15	1	06
A29	PA	Ce	Forest	26.85	69.68	28	6	21
A30	PA	Ce	Forest	25.33	82.61	25	4	07
A31	PA	Ce	Forest	28.49	63.65	06	1	02
A32	PA	Ce	Forest	23.13	96.62	09	1	02

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587

Full models and model selection by AIC

Model1 <- lmer(Temperature ~ Land_use + (1|Region), data = data)

Model selection by dread (MuMIn package version 1.47.5)

Table S2. The first column (Int) is the intercept. The columns in blue are the predictors. Df represents the degrees of freedom. logLik is the log-likelihood. AICc is the Akaike information criterion corrected for small sample sizes. Delta is the AICc difference between the selected model and the top model. Weight is the Akaike weight, indicating the relative probability that the model is the best. The table show only models with AICc < 2.

(Int)	Land	Df	logLik	AICc	Delta	Weight
26.10	+	4	-74.160	157.8	0.00	0.753

Model selected

Model1 <- lmer(Temperature ~ Land_use + (1|Region), data = data)

Model2 <- lmer(sqrt(Richness) ~ Temperature + Land_use + (1|Region), data = data)

Model selection by dread (MuMIn package version 1.47.5)

Table S3. The first column (Int) is the intercept. The columns in blue are the predictors. Df represents the degrees of freedom. logLik is the log-likelihood. AICc is the Akaike information criterion corrected for small sample sizes. Delta is the AICc difference between the selected model and the top model. Weight is the Akaike weight, indicating the relative probability that the model is the best. The table show only models with AICc < 2.

(Int)	Land	Temp	Df	logLik	AICc	Delta	Weight
2.74	+		4	-37.76	85.0	0.00	0.95

Model selected

Model2 <- lmer(sqrt(Richness) ~ Land_use + (1|Region), data = data)

Model3 <- glmer.nb (Predatory_ants ~ + sqrt(Richness) + Temperature + Land_use + (1|Region), data = data)

Model selection by dread (MuMIn package version 1.47.5)

Table S4. The first column (Int) is the intercept. The columns in blue are the predictors. Df represents the degrees of freedom. logLik is the log-likelihood. AICc is the Akaike information criterion corrected for small sample sizes. Delta is the AICc difference between the selected model and the top model. Weight is the Akaike weight, indicating the relative probability that the model is the best. The table show only models with AICc < 2.

(Int)	Land	Temp	Rich	Df	logLik	AICc	Delta	Weight
-2.97		0.083	0.44	5	-55.09	122.5	0.00	0.35
-0.61			0.37	4	-56.58	122.6	0.15	0.32
-1.02	+		0.56	5	-55.73	123.8	1.28	0.18

Predictors selection by model.avg (MuMIn package version 1.47.5)

Table S5. The first column indicates the intercept and predictors selected in the *dredge* function. The other columns are the estimate, standard error, adjusted standard error, z-value, and p-value. The best predictors were selected based on p < 0.05.

	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)	-1.664	1.471	1.502	1.108	0.267
Temp	0.083	0.046	0.048	1.717	0.085
Rich	0.444	0.148	0.154	2.878	0.004*
Land	-0.524	0.403	0.422	1.242	0.214

Model selected

Model3 <- glmer.nb (Predatory_ants ~ sqrt(Richness) + (1|Region), data = data)

628 Model4 <- lmer(sqrt(Predation) ~ Predatory_ants + sqrt(Richness) + Temperature + Land_use
629 + (1|Region), data = data)

630

631 *Model selection by dread (MuMIn package version 1.47.5)*

632 Table S6. The first column (Int) is the intercept. The columns in blue are the predictors. Df
633 represents the degrees of freedom. logLik is the log-likelihood. AICc is the Akaike information
634 criterion corrected for small sample sizes. Delta is the AICc difference between the selected
635 model and the top model. Weight is the Akaike weight, indicating the relative probability that
636 the model is the best. The table show only models with AICc < 2.

(Int)	Land	Temp	Pr.ant	Rich	Df	logLik	AICc	Delta	Weight
0.74			0.69		4	-36.77	83.0	0.00	0.70

637

638 *Model selected*

639 Model4 <- lmer(sqrt(Predation) ~ Predatory_ants + (1|Region), data = data)

psem model

```
SEMmodel <- psem(
lmer(Temperature ~ Land_use + (1|Region), na.action = na.omit, data = data),
lmer(sqrt(Richness) ~ Land_use + (1|Region), na.action = na.omit, data = data),
glmer.nb(Predatory_ants ~ sqrt(Richness) + (1|Region), na.action = na.omit, data = data),
lmer(sqrt(Predation) ~ Predatory_ants + (1|Region), na.action = na.omit, data = data))
```

646 **Table S7** Presence or absence of ants and ant species richness in natural habitats (forests) in the
647 Atlantic rainforest. “Pitfall” refers to the ants collected in pitfall traps. “Predation” refers to ants
648 collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae.

Atlantic rainforest: Natural habitat		
Species	**Pitfall**	**Predation**
Dolichoderinae		
Linepithema gallardoi (Brèthes, 1914)	1	0
Linepithema leucomelas (Emery, 1894)	1	1
Linepithema pulex Wild, 2007	1	1
Linepithema sp. 2	1	0
Dorylinae		
Labidus coecus (Latreille, 1802)	1	0
Ectatomminae		
Ectatomma edentatum Roger, 1863	1	1
Gnamptogenys sulcata (Smith, 1858)	1	0
Holcoponera striatula (Mayr, 1884)	1	1
Formicinae		
Acropyga decedens (Mayr, 1887)	1	0
Brachymyrmex bruchi Forel, 1912	1	0
Brachymyrmex cordemoyi Forel, 1895	1	0
Brachymyrmex minutus Forel, 1893	1	0
Brachymyrmex pictus Mayr, 1887	1	0
Brachymyrmex sp. 1	1	0
Camponotus (Myrmophaenus) sp. 8	1	0
Camponotus cingulatus Mayr, 1862	1	1
Camponotus rufipes (Fabricius, 1775)	1	0
Camponotus lespesii Forel, 1886	1	0
Camponotus melanoticus Emery, 1894	1	0
Camponotus (Tanaemyrmex) sp. 1	1	0
Camponotus (Tanaemyrmex) sp. 4	1	0
Myrmicinae		
Acromyrmex aspersus (Smith, 1858)	1	0
Acromyrmex hispidus Santschi, 1925	1	0
Apterostigma pilosum Mayr, 1865	1	0
Apterostigma sp. 3	1	0
Apterostigma wasmannii Forel, 1892	1	0
Atta sexdens (Linnaeus, 1758)	1	0
Basiceros disciger (Mayr, 1887)	1	0
Crematogaster pr. *chodati* Forel, 1921	1	0
Crematogaster rochai Forel, 1903	1	0
Cyphomyrmex minutus Mayr, 1862	1	0
Hylomyrma reitteri (Mayr, 1887)	1	0
Mycetomoellerius urichii (Forel, 1893)	1	0

Myrmicocrypta squamosa Smith, 1860	1	0
Pheidole aper Forel, 1912	1	1
Pheidole brevicona Mayr, 1887	1	0
Pheidole fallax Mayr, 1870	1	1
Pheidole sigillata Wilson, 2003	1	0
Pheidole sp. 3	1	0
Pheidole sp. 4	1	0
Pheidole sp. 12	1	1
Pheidole sp. 30	1	0
Pheidole sp. 55	1	0
Pheidole sp. 73	1	1
Pheidole sp. 77	1	0
Pheidole transversostriata Mayr, 1887	1	0
Solenopsis sp. 1	1	0
Solenopsis sp. 3	1	0
Solenopsis sp. 4	1	0
Solenopsis sp. 7	1	0
Solenopsis sp. 8	1	1
Solenopsis sp. 10	1	0
Solenopsis sp. 11	1	0
Strumigenys appretiata (Borgmeier, 1954)	1	0
Strumigenys denticulata Mayr, 1887	1	0
Strumigenys subedentata Mayr, 1887	1	0
Wasmannia affinis Santschi, 1929	1	0
Ponerinae		
Hypoponera sp. 3	1	0
Neoponera marginata (Roger, 1861)	1	0
Odontomachus chelifer (Latreille, 1802)	1	1
Odontomachus meinerti Forel, 1905	1	0
Pachycondyla harpax (Fabricius, 1804)	1	0
Pachycondyla striata Smith, 1858	1	1
Total of ant species	**63**	**12**

649

650 **Table S8** Presence or absence of ants and ant species richness in coffee plantations in the
651 Atlantic rainforest. “Pitfall” refers to the ants collected in pitfall traps. “Predation” refers to ants
652 collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae.

Atlantic rainforest: Coffee plantation		
Species	**Pitfall**	**Predation**
Dolichoderinae		
Dorymyrmex brunneus Forel, 1908	1	0
Linepithema cerradense Wild, 2007	1	0
Linepithema neotropicum Wild, 2007	1	1
Linepithema pulex Wild, 2007	1	0
Linepithema sp. 4	0	1
Ectatomminae		
Ectatomma brunneum Smith, 1858	1	0
Ectatomma permagnum Forel, 1908	1	0
Holcoponera striatula (Mayr, 1884)	1	1
Formicinae		
Brachymyrmex cordemoyi Forel, 1895	1	0
Brachymyrmex pictus Mayr, 1887	1	0
Brachymyrmex pilipes Mayr, 1887	1	0
Camponotus melanoticus Emery, 1894	1	0
Nylanderia sp. 7	1	0
Myrmicinae		
Atta sexdens (Linnaeus, 1758)	1	0
Carebara pr. *brasiliana* Fernández, 2004	1	0
Mycetomoellerius sp. 1	1	0
Mycocepurus smithii (Forel, 1893)	1	0
Pheidole fallax Mayr, 1870	1	0
Pheidole obscurithorax Naves, 1985	1	1
Pheidole oxyops Forel, 1908	1	1
Pheidole radoszkowskii Mayr, 1884	1	1
Pheidole subarmata Mayr, 1884	1	1
Pheidole sp. 5	1	0
Pheidole sp. 6	0	1
Pheidole sp. 12	1	0
Pheidole sp. 65	1	1
Pheidole sp. 73	1	1
Pheidole sp. 75	1	0
Pheidole sp. 99	1	0
Pogonomyrmex naegelii Emery, 1878	1	0
Solenopsis gr. saevissima sp. 1	1	1
Solenopsis sp. 2	1	0
Solenopsis sp. 4	1	0
Solenopsis sp. 8	1	0

Strumigenys louisianae Roger, 1863	1	0
Ponerinae		
Hypoponera sp. 1	1	0
Hypoponera sp. 2	1	0
Hypoponera sp. 3	1	0
Hypoponera sp. 4	1	0
Hypoponera sp. 5	1	0
Pachycondyla striata Smith, 1858	1	1
Total of ant species	**39**	**12**

653

654 **Table S9** Presence or absence of ants and ant species richness in natural habitat (woodland
655 savannah) in the Cerrado. "Pitfall" refers to the ants collected in pitfall traps. "Predation" refers
656 to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae.

Cerrado: Natural habitat		
Species	**Pitfall**	**Predation**
Dolichoderinae		
Linepithema neotropicum Wild, 2007	1	0
Linepithema pulex Wild, 2007	1	0
Lenepthema sp. 1	1	0
Lenepthema sp. 3	1	0
Dorylinae		
Neivamyrmex sp. 1	1	0
Ectatomminae		
Ectatomma edentatum Roger, 1863	1	1
Gnamptogenys sulcata (Smith, 1858)	1	0
Holcoponera striatula (Mayr, 1884)	1	0
Formicinae		
Brachymyrmex minutus Forel, 1893	1	0
Brachymyrmex pictus Mayr, 1887	1	0
Brachymyrmex sp. 2	1	0
Brachymyrmex sp. 3	1	0
Brachymyrmex sp. 4	1	0
Camponotus crassus Mayr, 1862	1	0
Camponotus fastigatus Roger, 1863	1	1
Camponotus atriceps (Smith, 1858)	1	0
Camponotus cingulatus Mayr, 1862	1	0
Camponotus ager (Smith, 1858)	1	0
Camponotus lespesii Forel, 1886	1	1
Camponotus (Tanaemyrmex) sp. 1	1	0
Nylanderia docilis (Forel, 1908)	1	0
Nylanderia sp. 7	1	0
Nylanderia steinheili (Forel, 1893)	1	0
Myrmicinae		
Acromyrmex aspersus (Smith, 1858)	1	0
Acromyrmex hispidus Santschi, 1925	1	0
Acromyrmex subterraneus (Forel, 1893)	1	0
Atta sexdens (Linnaeus, 1758)	1	0
Carebara brevipilosa Fernández, 2004	1	0
Crematogaster corticicola Mayr, 1887	0	1
Cyphomyrmex minutus Mayr, 1862	1	0
Mycetomoellerius urichii (Forel, 1893)	1	0
Mycetomoellerius sp. 1	1	0
Mycetophylax lectus (Forel, 1911)	1	0

Ochetomyrmex sp. 1	1	0
Pheidole aberrans Mayr, 1868	1	0
Pheidole fallax Mayr, 1870	1	1
Pheidole jelskii Mayr, 1884	1	1
Pheidole oxyops Forel, 1908	1	1
Pheidole pr. deima Wilson, 2003	1	0
Pheidole radoszkowskii Mayr, 1884	1	1
Pheidole sarcina Forel, 1912	1	0
Pheidole sp. 12	1	0
Pheidole sp. 15	1	0
Pheidole sp. 19	1	0
Pheidole sp. 41	1	0
Pheidole sp. 55	1	1
Pheidole sp. 65	1	0
Pheidole sp. 71	1	0
Rogeria lirata Kugler, 1994	1	0
Sericomyrmex saussurei Emery, 1894	1	0
Solenopsis sp. 3	1	0
Solenopsis sp. 4	1	0
Solenopsis sp. 10	1	0
Solenopsis sp. 11	1	0
Wasmannia auropunctata (Roger, 1863)	1	0
Ponerinae		
Hypoponera sp. 2	1	0
Neoponera sp. 1	1	0
Odontomachus chelifer (Latreille, 1802)	1	0
Pachycondyla striata Smith, 1858	1	1
Pseudomyrmecinae		
Pseudomyrmex gr. pallidus sp. 1	1	0
Pseudomyrmex phyllophilus (Smith, 1858)	1	0
Total of ant species	**60**	**10**

657

Table S10 Presence or absence of ants and ant species richness in coffee plantations in the Cerrado. "Pitfall" refers to the ants collected in pitfall traps. "Predation" refers to ants collected in predation experiments using *Tenebrio molitor* Linnaeus, 1758 larvae.

Cerrado: Coffee plantation		
Species	**Pitfall**	**Predation**
Dolichoderinae		
Dorymyrmex brunneus Forel, 1908	1	1
Linepithema neotropicum Wild, 2007	1	0
Ectatomminae		
Holcoponera striatula (Mayr, 1884)	1	1
Formicinae		
Brachymyrmex cordemoyi Forel, 1895	1	0
Brachymyrmex pilipes Mayr, 1887	1	0
Camponotus cingulatus Mayr, 1862	1	0
Camponotus melanoticus Emery, 1894	1	0
Myrmicinae		
Cardiocondyla minutior Forel, 1899	1	0
Mycocepurus smithii (Forel, 1893)	1	0
Pheidole aberrans Mayr, 1868	1	0
Pheidole fallax Mayr, 1870	1	1
Pheidole gertrudae Forel, 1886	1	0
Pheidole oxyops Forel, 1908	1	0
Pheidole radoszkowskii Mayr, 1884	1	0
Pheidole sp. 5	0	1
Pheidole sp. 6	0	1
Pheidole sp. 75	1	0
Pheidole subarmata Mayr, 1884	1	1
Pheidole vallifica Forel, 1901	1	0
Solenopsis gr. *saevissima* sp. 1	1	1
Solenopsis sp. 17	1	0
Solenopsis sp. 18	1	0
Total of ant species	**20**	**7**

ARTIGO 3 - A systematic review of the land use change effects on ant diversity in Neotropics

Artigo publicado na revista *Biological Conservation*

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Abstract

Land use changes represent one of the leading causes of terrestrial biodiversity loss, particularly in tropical ecosystems. In Brazil, a country that encompasses six distinct biomes and one of the world's highest ant diversities, the increasing land use changes are having detrimental effects on biodiversity. Our aim in this study is to summarize the impact of land use changes on ants in Brazil through a systematic review. We adhered to the PRISMA Eco-Evo methodology and conducted a qualitative review of studies, as well as a meta-analysis focusing on ant species richness and abundance. Especially, we observe a more pronounced negative effect in more contrasting conversions, such as from tropical forest to open anthropogenic land uses. We associate the decrease in richness with drastic changes in the vegetation structure. Consequently, this leads to extreme temperature variations, reduced humidity, and a decline in both the variety and quantity of food resources and nesting sites. Our findings provide a foundation for the conservation and management of anthropogenic land uses in human-impacted regions. More specifically, we highlight that future management plans should aim for anthropogenic land uses that more closely resemble the original natural vegetation, to maintain conditions and increase resource availability for biodiversity in the new habitats. Additionally, avoiding intensive management practices, such as the use of fertilizers and pesticides in agricultural systems, can also support the conservation of entomofauna in terms of species richness and abundance, and potentially benefit ecosystem services.

Keywords: Formicidae; Brazil; meta-analysis; biodiversity; Biomes

1. Introduction

Land use changes, like the conversion of natural habitats into anthropogenic land uses, significantly drive the decline in global biodiversity, potentially hampering ecosystem functioning (de Chazal and Rounsevell, 2009; Newbold et al., 2015, 2019). While these changes occur worldwide, they have more pronounced impacts in tropical regions (Magnusson et al., 2018; Nunes et al., 2022; Sala et al., 2000), which is of concern because tropical areas host the highest terrestrial biodiversity (Antonelli et al., 2018; Gardner et al., 2009). In tropical ecosystems, land use changes often create strong contrasts between natural habitats and altered anthropogenic land use, primarily due to the expansion of the agricultural frontier (Gibbs et al., 2010; Song et al., 2018). For example, in the Brazilian Amazon biome, most conversions involve conversion from forest to soy monoculture and extensive pasture, representing open land uses that significantly differ from the original habitat (FAO, 2016; Nunes et al., 2022; Parente et al., 2021). Anthropogenic land uses, such as agricultural crops and pastures, typically exhibit low environmental heterogeneity, leading to reduced resource quantity and diversity, and more severe alterations to local conditions (Priyadarshana et al., 2024; Stein and Kreft, 2015). In addition, the use of synthetic pesticides can increase the negative effects of land use on several species (Sánchez-Bayo and Wyckhuys, 2019). Similarly, agricultural practices such as the use of fertilizers can alter nutrient deposition (*e.g.*, salinization), impacting species richness and ecosystem processes (Hopmans et al., 2021; Lasmar et al., 2021a). Thus, these impacts on habitat structure and quality result in a substantial loss of specialist species and an increase in generalist ones (Filgueiras et al., 2021; Martins et al., 2022; Tabarelli et al., 2012).

The adverse impacts of land use changes on biodiversity have been extensively researched across various terrestrial organisms, encompassing vertebrates (Newbold, 2018), plants (Laliberté et al., 2010), soil microbiomes (Díaz-Vallejo et al., 2021), and arthropods (Attwood et al., 2008). Among arthropods, ants are regarded as excellent model organisms for

investigating the consequences of land use changes in tropical regions (Andersen et al., 2002; Ribas et al., 2012). This recognition is due to their high species richness (Feitosa et al., 2022) and their significant ecological roles, including seed dispersal, bioturbation, and predation (Folgarait, 1998; Lach et al., 2010). Ants exhibit a high sensitivity to anthropogenic land uses (*e.g.*, Queiroz et al., 2020; Rabello et al., 2018; Wilker et al., 2023).

Within the Neotropical Region, Brazil encompasses an extensive spatial expanse that includes six biomes: Amazon (tropical forest), Atlantic Forest (tropical forest), Caatinga (xeric shrubland), Cerrado (savannah), Pampa (grassland), and Pantanal (flooded grasslands). Furthermore, within the same biome, multiple vegetation types can coexist. For example, in the Cerrado biome, comprising forested vegetation (cerradão or woodland savannah), savannah, and open vegetation (grasslands). However, despite the high biodiversity found in these biomes, they undergo significant land use changes, with the Cerrado and the Atlantic Forest biomes considered global biodiversity hotspots (Trew and Maclean, 2021). Indeed, currently all Brazilian biomes are under severe threat due to land use changes (Magnusson et al., 2018; Projeto MapBiomas, 2022).

While some general patterns have indicated that anthropogenic impacts can reduce ant assemblage diversity (*e.g.*, fire effects: Vasconcelos et al., 2017) and ecosystem functions, such as the reduced removal of diaspores by ants (Bona et al., 2023), the intensity of these impacts is largely determined by their association with habitat openness (Andersen, 2019). Therefore, ant assemblages from closed-forested vegetation types are more sensitive to the impacts promoted by the establishment of pastures and agricultural land uses (Costa and Schmidt, 2022; Lasmar et al., 2021b; Queiroz et al., 2020) than ant assemblages in open vegetation types (*e.g.*, grasslands; Queiroz et al., 2020). Furthermore, ant assemblages from closed-forested vegetation types require more time to recover from anthropogenic impacts than those from open vegetation types (Casimiro et al., 2019). Considering Brazil's significance in global ant diversity (Feitosa

et al., 2022; Schmidt et al., 2022) and the escalating threats faced by its biodiversity, such as agricultural frontiers and mining projects (Pereira et al., 2020), the country serves as an excellent model for studying the effects of land use changes on biodiversity.

Thus, we conducted a systematic review, including both a qualitative review and a meta-analysis, with the aim of assessing the impact of land use changes on ant assemblages in Brazil. We conducted a qualitative review examining studies that evaluated the effects of land use changes on ants in Brazil, identifying knowledge gaps and proposing new approaches for future studies. We also conducted a meta-analysis to determine if the negative effects on species richness and abundance of ants resulting from land use change are associated with the biome and land use change type. Specifically, we predict that (i) the negative impacts of land use changes in species richness and abundance will be more significant in tropical forest biomes (*e.g.*, Amazon and Atlantic Forest) compared to grassland biomes (*e.g.*, Pampa and Pantanal), and (ii) these negative effects in species richness and abundance will be more pronounced in cases of intense conversion, such as the conversion from forests habitat to pasture or mining anthropogenic land uses.

2. Methods

2.1. Data collection

We followed the PRISMA-EcoEvo methodology (O'Dea et al., 2021). First, we conducted a search for studies on the effects of land use change on ants in Brazil using the Ants of Brazil Project database (Feitosa et al., 2022; Schmidt et al., 2022). We also performed a preliminary search (naïve search) for relevant studies in the "Web of Science databases - Main Collection (Clarivate Analytics)" (www.webofscience.com), "Scopus" (www.scopus.com), and "SciELO.ORG" (www.scielo.org). Initially, we carried out a preliminary search using pertinent keywords related to the topic (Grames et al., 2019). To achieve this, we categorized the keywords into four sections, following the PICO/PECO model (population,

intervention/exposure, comparator, outcome; Haddaway et al., 2016). The “Population” section pertained to the specific population under study (*e.g.,* Ants), the “Intervention/Exposure” section referred to various exposure or environmental factors (*e.g.*, Land use), the “Comparator” section related to what the exposure would be compared to (*e.g.*, Biomes), and the “Outcome” encompassed the measured variables (*e.g.*, Diversity). The naïve search conducted in November 2023. The titles, abstracts, and keywords of these studies were exported, and additional keywords were identified using the “litsearchr” package (Grames et al., 2019), within the R software (R Core Team, 2021). In the analysis of the new keywords, we included the term 'species composition' as an outcome and performed a subsequent search. In addition to the search using English terms, we also conducted searches in Portuguese and Spanish in the same databases (see Appendix A: Keywords). The new search returned 3,488 studies in Web of Science, 1,573 in Scopus, and 16 in SciELO.ORG. We also included an additional 72 studies from the Ants of Brazil Project, bringing the total to 5,149.

2.2. Exclusion and inclusion criteria

We removed duplicate studies and conducted a screening of titles, abstracts, and full articles. Our inclusion criteria focused on studies that specifically assessed the impact of land use changes on ant assemblages in Brazil. We applied exclusion criteria, including: (1) studies conducted outside Brazil; (2) studies unrelated to ant communities or assemblages; (3) studies not addressing the effects of land use changes; (4) studies lacking a comparison between natural habitat and anthropogenic land use. We also excluded non-case studies (*e.g.*, reviews) and studies dealing with anthropogenic disturbances not related to land use categorization (*e.g.*, chronic disturbances like logging or non-timber forest product extraction). Furthermore, we omitted studies focusing on ecological succession (*e.g.*, succession or restoration) and those where it was impossible to separate the impact on ant assemblages from other evaluated organisms (*e.g.*, macrofauna). Out of the initial pool of 5,149 studies, 128 remained for the

qualitative review (Fig. 1A), and 42 were eligible for the meta-analysis. Detailed information is available in Appendix B (PRISMA-EcoEvo). A list of data sources used in the study are provided in the Appendix A: Data sources.

Fig. 1

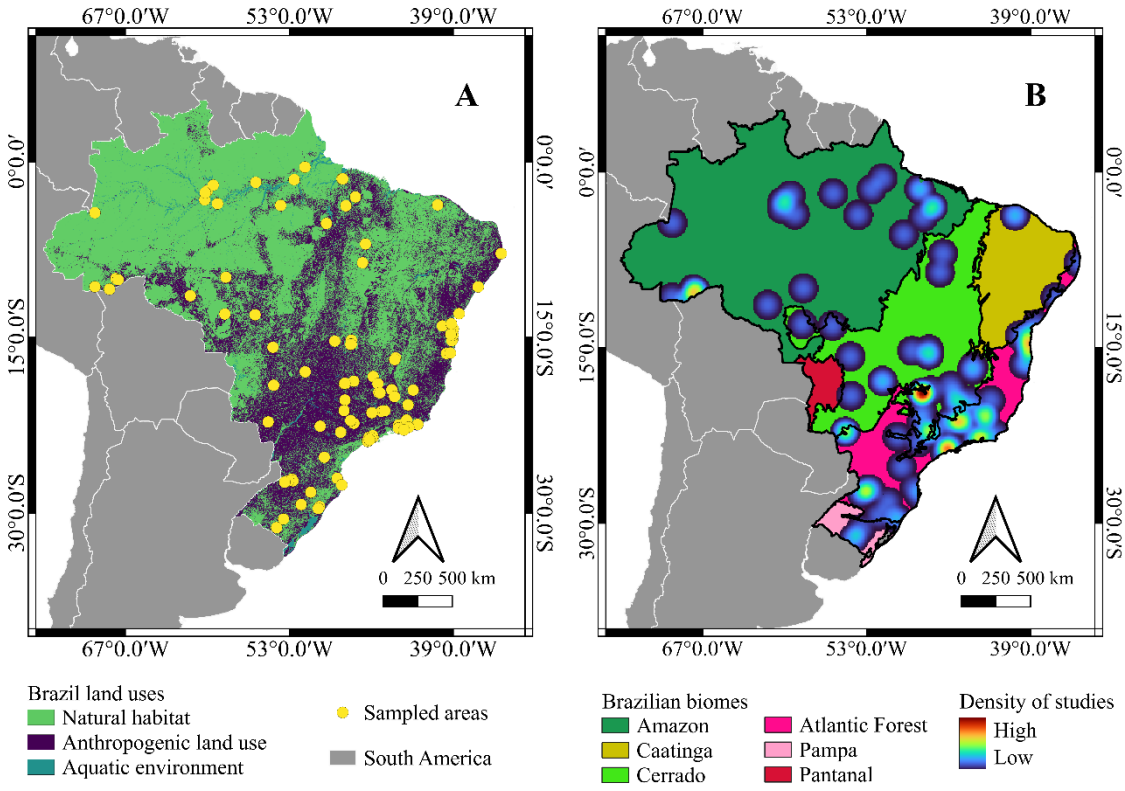


Fig. 1. Study sites extracted from the 128 studies concerning the effects of land use changes on ants in Brazil. The figure 1A indicates the concentration of study sites in regions with a high degree of land use changes, and figure 1B indicates the concentration of studies in the Brazilian biomes Atlantic Forest and Cerrado. The figure was generated using QGIS.org version 3.32 (QGIS.org, 2023) and adapted from the land use and land cover map for the year 2021 provided by MapBiomas (Projeto MapBiomas, 2022) and biome data from Instituto Brasileiro de Geografia e Estatística (IBGE, 2019).

2.3. Qualitative review

From the 128 studies, we extracted qualitative data including the study ID (citation), publication year, language, journal, impact factor, biome, sampling season, vegetation type, anthropogenic land use, sampling methods, sampled strata (epigeic, leaf-litter, subterranean, and arboreal), and response variable, such as species richness and abundance. We are counting votes for qualitative data from the studies and assessed whether land use affects species compositions. Species composition refers to the differences in the identity of ant species between natural habitats and anthropogenic land uses, extracted from analyses such as PERMANOVA (Permutational Multivariate Analysis of Variance) and ANOSIM (Analysis of Similarities) (Anderson, 2001; Clarke, 1993; Warton et al., 2012).

2.4. Extracting and calculating effect sizes

For the meta-analysis, we gathered data on the most frequently assessed response variable, including species richness and abundance. Species richness was reported in studies as either observed species richness or estimators (*e.g.*, Chao1, Chao2, Jackknife1, individual-based rarefaction, and sample-based rarefaction). Abundance was reported in studies as number of ant workers and species frequency. For these response variables, we collected mean values, sample size, and dispersion metrics such as variance, standard deviation, standard error, and 95% confidence intervals. We extracted these data from the text, tables, and figures of the studies. When the data was solely presented in figures, we utilized WebPlotDigitizer version 4.6 to extract the mean and dispersion metrics (www.automeris.io/WebPlotDigitizer/). We standardized all the dispersion metrics into standard deviation. We also obtained data regarding vegetation type and anthropogenic land uses. Vegetation types were classified into various categories, encompassing forest types such as primary and secondary forests, riparian forests, and woodland savannah, as well as grassland, “restinga”, savannah, “vereda”, mangrove, and “canga”. The anthropogenic land use data were classified into agriculture and pasture categories when these two anthropogenic uses were sampled jointly, annual agriculture (*e.g.*,

164 soybean plantation), perennial agriculture (*e.g.*, coffee plantation), mining, pasture, silviculture
165 (*e.g.*, *Eucalyptus* spp. plantation), and urbanization.

166 We analyzed a total of 42 studies and 212 comparisons for the meta-analysis, which were
167 categorized according to the response variable: species richness (studies: n = 36; comparisons:
168 n = 171) and abundance (studies: n = 14; comparisons: n = 41). For this, we determined an
169 effect size that could be summarized across all studies. The effect size is a metric that quantifies
170 the relationship between two entities, capturing the direction and magnitude of this relationship
171 (Harrer et al., 2021). In our case, the effect size indicated the effects of land use change on the
172 richness and abundance of ants. To calculate the effect size (Hedges' g), we used the
173 standardized mean difference (SMD) metric corrected for small sample sizes (J-corrected form;
174 Goulet-Pelletier and Cousineau, 2018; Hedges, 1981) and utilized the "escalc" function of the
175 "metafor" R package (Viechtbauer, 2010). A negative Hedges' g indicates an adverse effect of
176 a given response variable resulting from the land use change, while a positive value indicates
177 the opposite. The zero value represents the absence of an effect size. We only analyzed
178 comparisons involving three or more elements. For instance, we excluded the conversion from
179 "canga" to mining because we found only one comparison in this case.

180 *2.5. Meta-analysis*

181 We analysed nine multilevel linear (mixed-effects) models using the "rma.mv" function from
182 the "metafor" R package (Viechtbauer, 2010). In all models, we used the study ID as a random
183 variable due to the non-independence of the effect sizes found in the same study. We constructed
184 three general models with no fixed moderators (only with the random variable): one with all
185 effect sizes for the general model (n = 212), one for species richness (n = 171), and one for
186 abundance (n = 41). Additionally, we established six models with moderators to test our two
187 predictions, both for richness and abundance. To test our prediction that (i) the negative impacts
188 of land use changes in species richness and abundance will be more significant in tropical forest

biomes, we created two models with the biome as the moderator. To test our prediction that (ii) the negative impacts of land use changes in species richness and abundance will be more pronounced in cases of intense conversion, we built two models with the land use conversion type as the moderator.

For each model, we assessed Cochran's Q. In these statics, using the chi-square distribution with n-1 degrees of freedom, significant results ($p < 0.05$) indicate heterogeneity, suggesting substantial variability among the effect sizes. We evaluated both total heterogeneity (Q_T) and moderator heterogeneity (Q_W). Additionally, we examined publication bias through funnel plots. Publication bias refers to the tendency to publish studies with significant results (Rosenthal, 1979), which can introduce bias into the effect sizes available for meta-analyses. Identifying publication bias is a critical aspect of meta-analyses, as it facilitates the validation of these findings through additional investigations (Nakagawa and Santos, 2012). The figures were generated using the R package "ggplot2" (Wickham, 2016).

3. Results

3.1. Qualitative review

The first study found was published in 1995, and since then, there has been a growth trend over the years, with a peak of 12 studies in 2013 and 2018. Most of the studies evaluated were published in English (101 studies; 79%) and Portuguese (26 studies; 20%). Studies were published in 71 journals, with Sociobiology (13 studies; 10%) and Neotropical Entomology (10 studies; 08%) having the highest publication numbers. Of the journals with impact factors, the values ranged from 0.271 to 13.211, with a mean ($\bar{x}$) and standard deviation ($\pm$ SD) of 4.126 and 2.671, respectively. The most sampled biomes included the Atlantic Forest (53 studies; 41%), Cerrado (29 studies; 23%), and Amazon (28 studies; 22%) (Fig. 1B).

Most studies sampled ants during both the dry and rainy seasons (45 studies; 35%) or solely in the rainy season (45 studies; 35%). In line with the trend of the most frequently sampled biomes,

214 the vegetation types most studied were forests (106 studies; 83%) and savannahs (25 studies;
215 19%). The most studied anthropogenic land uses were pasture (51 studies; 40%), silviculture
216 (46 studies; 36%), and annual agriculture (41 studies; 32%). Pitfall traps (68 studies; 53%) were
217 the most used sampling method, and the most studied habitat stratum was the epigeic stratum
218 (82 studies; 64%). Most studies assessed the effects on species richness (114 studies; 89%),
219 diversity indices (65 studies; 51%), species composition (64 studies; 50%), and abundance (62
220 studies; 48%). Of the 64 studies that evaluated species composition, 56 studies (87%) reported
221 differences in composition between ant assemblages from natural habitats and those from
222 anthropogenic land uses. In addition, few studies have evaluated ecosystem functions and
223 functional groups, making it impossible to find general patterns among them. For qualitative
224 review graphs, see Appendix A, Fig. A.1-A.14.

225 *3.2. Meta-analysis*

226 We identified a detrimental impact on ants due to land use change (E++ = -0.763, CI = -1.079
227 to -0.447, df = 211; where E++ represents Hedges' g (effect size), CI represents confidence
228 interval, and df represents degrees of freedom). Furthermore, we observed that the land use
229 change reduces ant species richness (E++ = -0.962, CI = -1.286 to -0.638, df = 170; Fig. 2), but
230 we did not detect any significant impact on ant abundance (E++ = -0.188, CI = -0.803 to 0.427,
231 df = 40; Fig. 2).

232

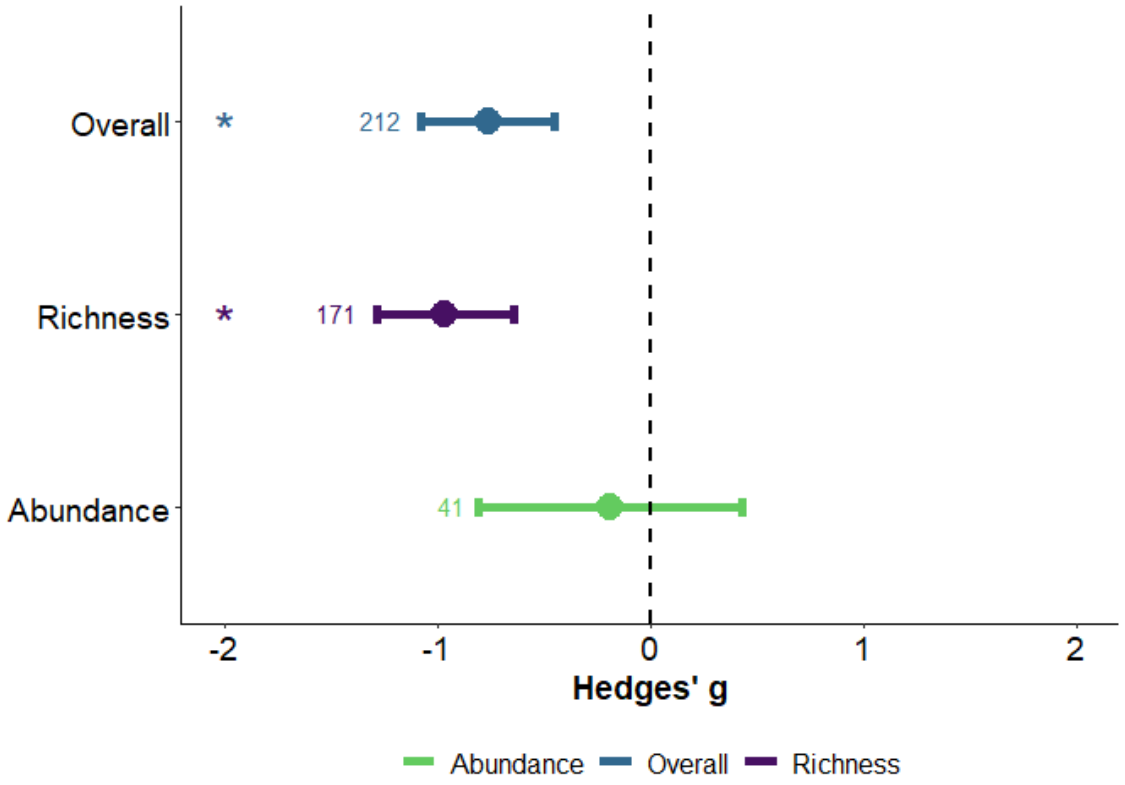
233

234

235

236

237 Fig. 2



238

239 Fig. 2. Negative impacts were observed on ant species richness due to land use changes, but we
240 did not find an effect for abundance. The numbers adjacent to the confidence interval denote
241 the quantity of effect sizes analyzed. The data points represent the estimated mean effect size
242 (Hedges' g), and the bars indicate the 95% confidence interval. The asterisk indicates a
243 significant result.

244 For our first prediction, we found that land use changes lead to a more pronounced decrease in
245 ant species richness in the Amazon, Atlantic Forest, and Cerrado biomes (Fig. 3, Table A.1).
246 However, no significant impact was observed on ant abundance (Fig. 3, Table A.1). For our
247 second prediction, we observed that land use changes, mainly from forests and savannahs to
248 open anthropogenic land uses, resulted in a reduction in ant species richness and ant abundance
249 (Fig. 4, Table A.2).

250

Fig. 3

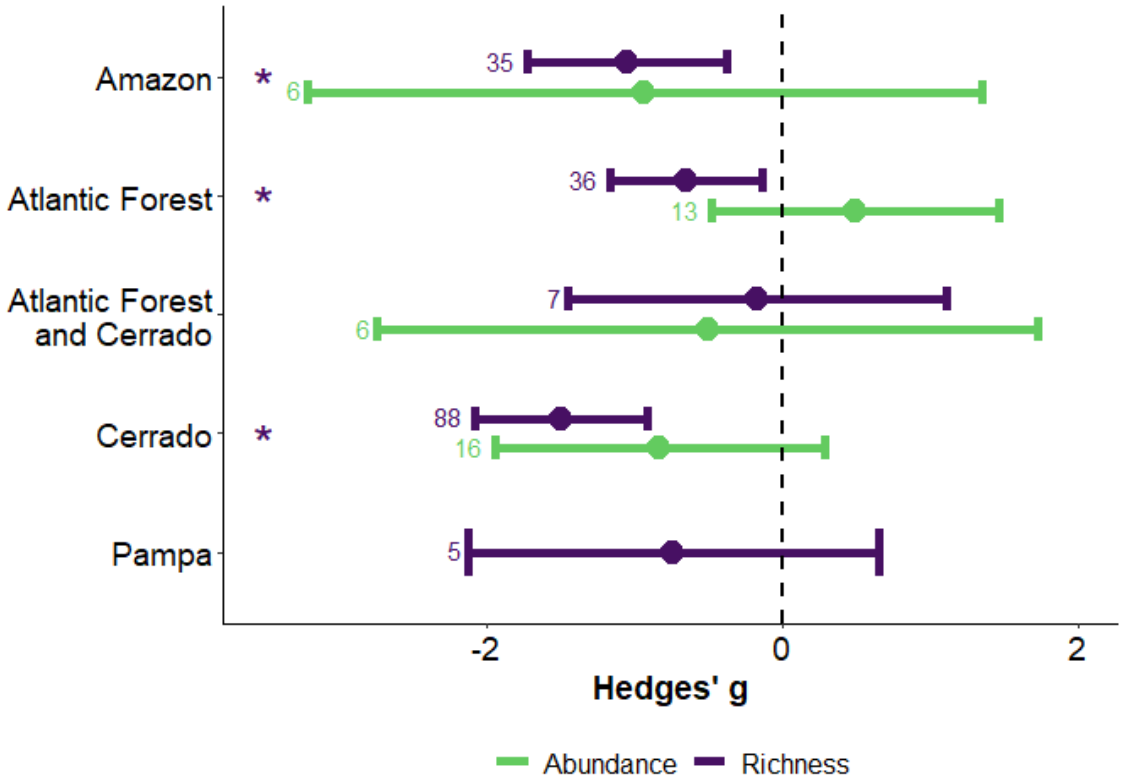
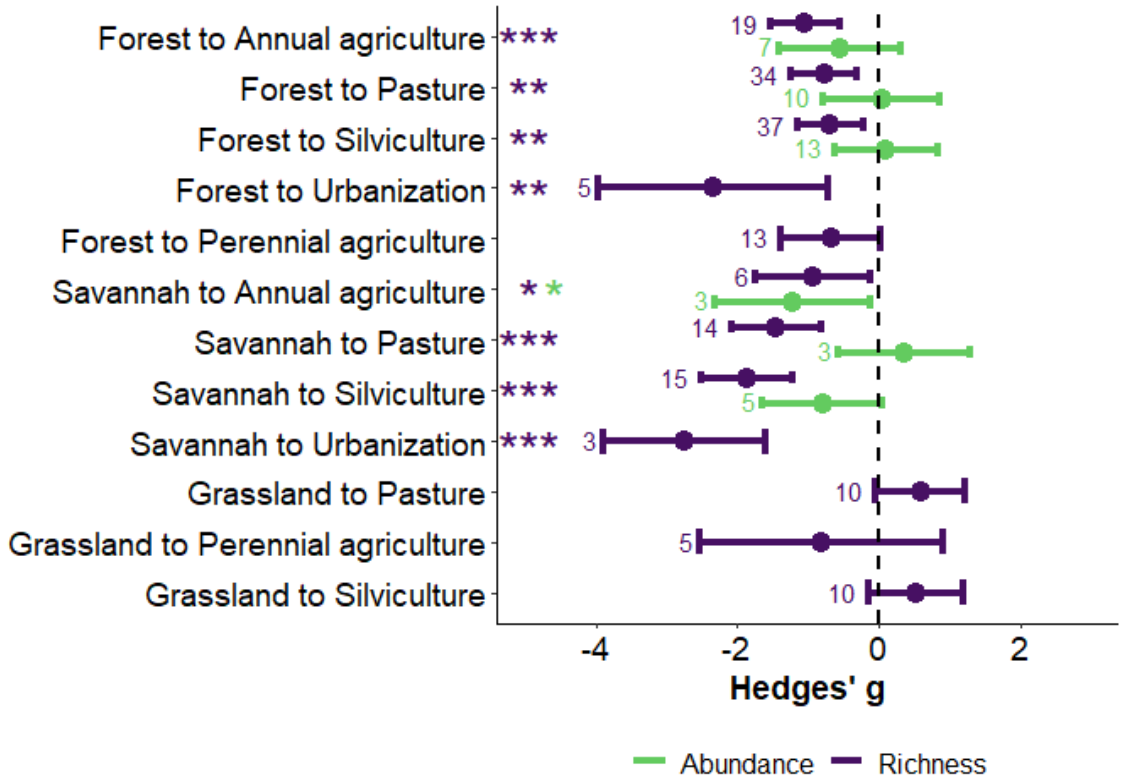


Fig. 3. Negative effects of land use changes (biome moderator) on ant species richness, but we did not find an effect for abundance. The “Atlantic Forest and Cerrado” indicates the presence of effect sizes for both biomes in the study. Biomes that are not shown in the figures lacked effect sizes for inclusion in the meta-analysis. The numbers adjacent to the confidence interval denote the quantity of effect sizes analyzed. The data points represent the estimated mean effect size (Hedges’ g), and the bars indicate the 95% confidence interval. The asterisk indicates a significant result.

264 Fig. 4



265

266 Fig. 4. Negative and null effects of land use (conversion type moderator) changes on ant species
267 richness and abundance. Points represent the estimated mean effect size (Hedges' g), and the
268 lines represent the 95% confidence interval. Numbers next to the confidence interval indicate
269 the number of effect sizes analyzed. The asterisk indicates a significant result.

270 *3.3. Heterogeneity and publication bias*

271 We found high heterogeneity in the overall model without moderators (Q_T = 1 591.202, p <
272 0.001, df = 211). For species richness, we also observed high heterogeneity (Q_T = 1 467.317, p
273 < 0.001, df = 170), which was partially explained by biome (Q_W = 41.915, p < 0.001, df = 5)
274 and conversion type (Q_W = 117.463, p < 0.001, df = 12). For abundance, we similarly found
275 high heterogeneity (Q_T = 102.095, p < 0.001, df = 40), which was not explained by biome (Q_W
276 = 3.971, p = 0.409, df = 4), but yes for the conversion type (Q_W = 17.532, p = 0.007, df = 6).

We evaluated publication bias using funnel plots, which revealed asymmetry and the presence of bias in the articles evaluated, indicating that studies with smaller samples (larger standardized error) tend to be published if the result found is negative (Appendix A, Fig. A.15-A.17).

4. Discussion

Here, we synthesized the negative and neutral effects of land use changes on ants in Brazil, a significant part of the Neotropical space. In general, land use changes decrease ant diversity, mainly ant richness. Additionally, this decrease in richness is more pronounced in tropical forests and tropical savannahs. More specifically, the more significant changes in land use, such as the conversion from closed tropical forests to open agricultural systems, excluded a larger proportion of ants, decreasing richness and altering species compositions. These patterns highlight the negative impact of land use changes in tropical ecosystems, where the primary land use changes are often from closed habitats to open anthropogenic habitats, as we found. On the other hand, we only found a negative effect of conversion from savannah to annual agriculture on ant abundance. This may have occurred due to the management of these areas, due use of synthetic fertilizers and pesticides, causing negative effects on the diversity of entomofauna. Moreover, few studies have assessed the effects of land use changes on ecosystem functions and interactions. As a result, despite the decrease in species richness in anthropogenic land uses, the different effects on ecosystem functioning remain unknown. Thus, our results suggest that, to conserve most of the species' diversity, it may be important to implement management plans aimed at maintaining habitat similarity in anthropogenic land uses similar to the original habitats, also avoiding use of pesticides in agriculture systems.

Studies about land use change effects on ants in Brazil have focus on the three major Brazilian biomes and primary land use conversions, aiming to grasp ant diversity responses in these prevalent changes. However, certain biomes, vegetation types, and land uses lack adequate research and documentation, necessitating further exploration, like Caatinga (xeric shrublands),

Pantanal (flooded grasslands), and mining activities. Most of the sampling was carried out within the epigeic strata (epigeic and leaf-litter). This was primarily accomplished using pitfall traps and mini-Winkler extractors, as they provide the highest ant diversity and foraging activity (Lasmar et al. 2021a, 2023). Pitfall traps are cost-effective and simple sampling methods, applicable across diverse vegetation types and human-altered land uses (Schmidt et al., 2022). Furthermore, most samples were collected during both the rainy and dry seasons, or only during the rainy season, when ant diversity is higher (Queiroz et al., 2023). Our results show that although the sampling effort maximize ant diversity and activity, moreover the focus relies on the most common land use changes in Brazil. However, there is still a need for more studies in other biomes, vegetation types, and anthropogenic land uses, as the effects of land use changes may differ in these cases.

We observed marked species richness loss likely attributable to the presence of ecological filters (Diamond et al., 2012; Ribas et al., 2003). When forested and savannah vegetation types are transformed into open anthropogenic land uses, there is a change in conditions, such as greater temperature variation and decreased humidity, as well as a decrease in the quantity and diversity of food and nesting resources (da Silva et al., 2022; Mathieu et al., 2005; Pacheco and Vasconcelos, 2007). This change tends to favour only a few more resilient and generalist ant species, allowing them to increase their numbers if they were already present in natural habitats or invade these anthropogenic land uses (Andersen, 2019; McKinney and Lockwood, 1999). When the vegetation structure is still maintained, as in the case of converting forest to silviculture, there can still be ecological filters. Even though the conditions remain similar (*e.g.*, high forest cover), a significant portion of the resources is lost with the conversion to monoculture (Simberloff et al., 2010). For ant abundance, we only found a negative effect of the conversion from savannah to annual agriculture. This could be due to land use management, such as the use of fertilizers and insecticides, which are usual procedures in conventional

agriculture in Brazil (Dalle Laste et al., 2019). Insecticides are the second-largest driver of entomofauna loss, behind land use change (Sánchez-Bayo and Wyckhuys, 2019). Therefore, maintaining the similarity of the original habitat in anthropogenic land uses can promote the conservation of diversity. However, in some cases where the higher vegetation structure is maintained, diversity can still decrease, highlighting the importance of plant diversity for resource availability in these new habitats. Additionally, avoiding intensive management practices, such as the use of fertilizers and pesticides in agricultural systems, can also promote the conservation of diversity.

We observed no effects on species richness and abundance across various biomes and land use change types. In many instances, these outcomes might be attributed to the limited number of comparisons. Furthermore, certain anthropogenic land uses maintain conditions and resource diversity like those of biomes and vegetation types, potentially bolstering ant richness and abundance, such as conversion from grassland to pasture and from forest to perennial agriculture (Bos et al., 2007; Delabie et al., 2021; Lassau and Hochuli, 2004; Queiroz et al., 2020; Solar et al., 2015; Vasconcelos et al., 2017). Additionally, in some anthropogenic land uses, the survival of generalist ants may lead to increased abundance, resulting in a no effect of land use change on overall ant abundance (Wilker et al., 2023). Moreover, these areas often exhibit a higher presence of invasive ant species (Baidya and Bagchi, 2022; Holway et al., 2002), which tend to have higher abundances (Lester and Gruber, 2016) and may also contribute to the null effect we observed in ant abundance.

Regarding the assessment of ant abundance, it is important to consider that the term “ant abundance” may not directly reflect the actual number of individuals, but rather the foraging activity. In ants, where the colony is regarded as the individual (Wilson, 1987), the present ants are part of this collective organism. Therefore, when using methods such as “ant trapping or area-based ant counting”, it is crucial to understand that this might indicate more about foraging

activity than the true abundance of ants. Despite observing a decrease in species diversity, the quantity of ants engaged in foraging activities remained no effect in most of the comparisons, suggesting the necessity for further studies to comprehend the ecosystem functions and interactions of these ants in anthropogenic land uses. Moreover, colony counting as a method to evaluate ant abundance still poses a challenge in diversity studies, particularly due to difficulties in nest counting, especially in polydomous species. Only six studies opted to use species occurrence frequency per trap as a viable alternative to circumvent issues related to ant foraging and colony size (Brandão et al., 2011; Rizzotto et al., 2019). Moreover, it is important to acknowledge that our data might have certain biases, as there is a tendency to publish articles that report negative effects on ant assemblages, while smaller articles with null or positive results might go unpublished. This pattern of bias toward publishing articles that support our hypotheses is also found in other scientific fields, and the publication and citation of studies with neutral effects are encouraged (Mlinarić et al., 2017).

Contrary to responses related to taxonomic metrics, the impacts of land use changes on functional ecology and interactions remain uncertain. Outcomes for ecosystem functions are contingent upon the function type, vegetation type, and land use type. They may reveal a negative effect (*e.g.*, reduced seed removal when changes from grassland to silviculture; Rabello et al., 2018), a positive effect (*e.g.*, increased seed removal and insect predation when shifting from forest to pasture; Fontenele and Schmidt, 2021; Wilker et al., 2023), or null effect (*e.g.*, unchanged seed removal when changing from savannah to pasture, Rabello et al., 2018). Thus, ecosystem functions may exhibit effects different from those found for species richness (Queiroz et al., 2021; Wilker et al., 2023). Moreover, the frequent increase in invasive ants in anthropogenic land uses (Baidya and Bagchi, 2022) has a high impact on interactions with other species, increasing competition with other ants (Neumann and Pinter-Wollman, 2022) and decreasing pollinators' activity (Unni et al., 2021). Along with the decrease in pollination and

seed dispersal (Bona et al., 2023), other ant-plant interactions may also decline due to land use changes. For instance, a few ants are involved with several plant species and multiple ecosystem functions (Costa et al., 2016), which can decrease due to reduced stability caused by anthropogenic disturbance (Câmara et al., 2019) or the loss of plant resource availability (Fagundes et al., 2016). Thus, this knowledge gap regarding ecosystem functions and interactions must be addressed, given the vital role played by ants in various biomes, vegetation types, and anthropogenic land uses.

5. Conclusions

Here, we identified the negative effects of land use changes on ant diversity in Brazil, a vast Neotropical country. Although we found a greater number of studies in biomes, vegetation types, and anthropogenic land uses with a higher frequency of land use changes, we recommend more efforts in less-explored areas, such as the xeric shrublands of the Caatinga and land uses associated with mining. However, despite some biomes being underexplored, like the Pampa and Pantanal, their vegetation types can be found in more studied biomes, like the Cerrado, and can therefore serve as references for possible effects. Our meta-analysis revealed that land uses that significantly alter vegetation structure lead to a reduction in species richness, but largely maintain abundance, with a decrease in abundance occurring only in certain conversions to agriculture. From this, we emphasize the importance of management plans in areas of anthropogenic land use, maintaining habitat-specific environmental similarity (Arroyo-Rodríguez et al., 2020), supporting higher vegetation diversity to ensure resource availability and avoiding intensive use of pesticides in agricultural systems. Additionally, we suggest that future research on land use effects also focus on ecosystem functions, traits, guilds, and interactions to assess possible changes in the functioning of these new ecosystems, as well as the ecosystem services provided by species that remain in anthropogenic land uses.

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426 **References**

427 Andersen, A.N., 2019. Responses of ant communities to disturbance: Five principles for
428 understanding the disturbance dynamics of a globally dominant faunal group. J. Anim.
429 Ecol. 88, 350–362. https://doi.org/10.1111/1365-2656.12907.

430 Andersen, A.N., Hoffmann, B.D., Müller, W.J., et al., 2002. Using ants as bioindicators in land
431 management: Simplifying assessment of ant community responses. J. Appl. Ecol. 39(1),
432 8–17. https://doi.org/10.1046/j.1365-2664.2002.00704.x.

433 Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance.
434 Austral Ecol. 26, 32–46. https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x.

435 Antonelli, A., Zizka, A., Carvalho, F.A., et al., 2018. Amazonia is the primary source of
436 Neotropical biodiversity. Proc. Natl. Acad. Sci. USA. 115(23), 6034–6039.
437 https://doi.org/10.1073/pnas.1713819115.

438 Arroyo-Rodríguez, V., Fahrig, L., Tabarelli, M., et al., 2020. Designing optimal human-
439 modified landscapes for forest biodiversity conservation. Ecol. Lett. 23(9), 1404–1420.
440 https://publons.com/publon/10.1111/ele.13535.

441 Attwood, S.J., Maron, M., House, A.P.N., et al., 2008. Do arthropod assemblages display
442 globally consistent responses to intensified agricultural land use and management?.
443 Global Ecol. Biogeogr. 17(5), 585–599. https://doi.org/10.1111/j.1466-
444 8238.2008.00399.x.

445 Baidya, P., Bagchi, S., 2022. Influence of human land use and invasive species on beta diversity
446 of tropical ant assemblages. Insect Conserv. Diver. 15(1), 73–85.
447 https://doi.org/10.1111/icad.12536.

448 Bona, K., Delabie, J.H.C., Cazetta, E., 2023. Effects of anthropogenic disturbances on diaspore
449 removal by ants: A meta-analysis. Acta Oecol. 118.
450 https://doi.org/10.1016/j.actao.2023.103893.

451 Bos, M.M., Steffan-Dewenter, I., Tscharntke, T., 2007. The contribution of cacao agroforests to
452 the conservation of lower canopy ant and beetle diversity in Indonesia. Biodivers.
453 Conserv. 16(8), 2429–2444. https://doi.org/10.1007/s10531-007-9196-0.

454 Brandão, C.R.F., Silva, R.R., Feitosa, R.M., 2011. Cerrado ground-dwelling ants
455 (Hymenoptera: Formicidae) as indicators of edge effects. Zoologia-Curitiba 28, 379–387.
456 https://doi.org/10.1590/S1984-46702011000300012.

457 Câmara, T., Leal, I.R., Blüthgen, N. 2019. Anthropogenic disturbance and rainfall variation
458 threaten the stability of plant–ant interactions in the Brazilian Caatinga. Ecography.
459 42(11), 1960–1972. https://doi.org/10.1111/ecog.04531.

460 Casimiro, M.S., Sansevero, J.B.B., Queiroz, J.M., 2019. What can ants tell us about ecological
461 restoration? A global meta-analysis. Ecol. Indic. 102, 593–598.
462 https://doi.org/10.1016/j.ecolind.2019.03.018.

463 Clarke, K.R., 1993. Non-parametric multivariate analysis of changes in community structure.
464 Aust. J. Ecol. 18, 117–143. https://doi.org/10.1111/j.1442-9993.1993.tb00438.x.

465 Costa, F.V., Mello, M.A., Bronstein, J.L. 2016. Few ant species play a central role linking
466 different plant resources in a network in rupestrian grasslands. PloS one. 11(12),
467 e0167161. https://doi.org/10.1371/journal.pone.0167161.

468 Costa, M.M.S.D., Schmidt, F.A., 2022. Gamma, alpha, and beta diversity of ant assemblages
469 response to a gradient of forest cover in human-modified landscape in Brazilian Amazon.
470 Biotropica 54(2), 515–524. https://doi.org/10.1111/btp.13073.

471 da Silva, W.B., Cajaiba, R.L., Santos, M., et al., 2022. Effectiveness of ant communities to
472 detect anthropogenic disturbance in Neotropical forest landscapes: a case study in the
473 Brazilian Amazon. Biodivers. Conserv. 31(1), 211–226. https://doi.org/10.1007/s10531-
474 021-02329-x.

475 Dalle Laste, K.C., Durigan, G., Andersen, A.N., 2019. Biodiversity responses to land-use and
476 restoration in a global biodiversity hotspot: Ant communities in Brazilian Cerrado.
477 Austral Ecol. 44(2), 313–326. https://doi.org/10.1111/aec.12676.

478 de Chazal, J., Rounsevell, M.D.A., 2009. Land-use and climate change within assessments of
479 biodiversity change: A review. Glob. Environ. Change 19(2), 306–315.
480 https://doi.org/10.1016/j.gloenvcha.2008.09.007.

481 Delabie, J., Koch, E., Dodonov, P., et al., (2021). Sampling and Analysis Methods for Ant
482 Diversity Assessment, in Santos, J.C., Fernandes, W.G. (Eds.), Measuring Arthropod
483 Biodiversity: A Handbook of Sampling Methods. Springer International Publishing. pp.
484 13–54. https://doi.org/10.1007/978-3-030-53226-0_2.

485 Diamond, S.E., Sorger, D.M., Hulcr, J., et al., 2012. Who likes it hot? A global analysis of the
486 climatic, ecological, and evolutionary determinants of warming tolerance in ants. Glob.
487 Change Biol. 18(2), 448–456. https://doi.org/10.1111/j.1365-2486.2011.02542.x.

488 Díaz-Vallejo, E.J., Seeley, M., Smith, A.P., et al., 2021. A meta-analysis of tropical land-use
489 change effects on the soil microbiome: Emerging patterns and knowledge gaps.
490 Biotropica 53, 738–752. https://doi.org/10.1111/btp.12931.

491 Fagundes, R., Dáttilo, W., Ribeiro, S.P. 2016. Food source availability and interspecific
492 dominance as structural mechanisms of ant-plant-hemipteran multitrophic networks.
493 Arthropod Plant Interact. 10, 207–220. https://doi.org/10.1007/s11829-016-9428-x.

494 FAO, 2016. State of the World's Forests 2016. Forests and agriculture: land-use challenges and
495 opportunities. Rome.

496 Feitosa, R.M., Camacho, G.P., Silva, T.S.R., et al., 2022. Ants of Brazil: an overview based on
497 50 years of diversity studies. Syst. Biodivers. 20(1), 1–27.
498 https://doi.org/10.1080/14772000.2022.2089268.

499 Filgueiras, B.K., Peres, C.A., Melo, F.P., et al., 2021. Winner–loser species replacements in
500 human-modified landscapes. Trends Ecol. Evol. 36(6), 545–555.
501 https://doi.org/10.1016/j.tree.2021.02.006.

502 Folgarait, P.J., 1998. Ant biodiversity and its relationship to ecosystem functioning: a review.
503 Biodivers. Conserv. 7, 1221–1244. https://doi.org/10.1023/A:1008891901953.

504 Fontenele, L.K., Schmidt, F.A., 2021. Forest-pasture shifting alters the assemblages of seed-
505 removing ants in southwestern Brazilian Amazon. J. Insect Conserv. 25(2), 213–220.
506 https://doi.org/10.1007/s10841-021-00295-x.

507 Gardner, T.A., Barlow, J., Chazdon, R., et al., 2009. Prospects for tropical forest biodiversity in
508 a human-modified world. Ecol. Lett. 12, 561–582. https://doi.org/10.1111/j.1461-
509 0248.2009.01294.x.

510 Gibbs, H.K., Ruesch, A.S., Achard, F., et al., 2010. Tropical forests were the primary sources
511 of new agricultural land in the 1980s and 1990s. Proc. Natl. Acad. Sci. USA. 107(38),
512 16732–16737. https://doi.org/10.1073/pnas.0910275107.

513 Goulet-Pelletier, J.C., Cousineau, D., 2018. A review of effect sizes and their confidence
514 intervals, Part I: The Cohen's d family. The Quantitative Methods for Psychology 14(4),
515 242–265. https://doi.org/10.20982/tqmp.14.4.p242.

516 Grames, E.M., Stillman, A.N., Tingley, M.W., et al., 2019. An automated approach to
517 identifying search terms for systematic reviews using keyword co-occurrence networks.
518 Methods Ecol. Evol. 10(10), 1645–1654. https://doi.org/10.1111/2041-210X.13268.

519 Haddaway, N.R., Bernes, C., Jonsson, B.G., et al., 2016. The benefits of systematic mapping to
520 evidence-based environmental management. Ambio 45(5), 613–620.
521 https://doi.org/10.1007/s13280-016-0773-x.

522 Harrer, M., Cuijpers, P., Furukawa, T., et al., 2021. Doing meta-analysis with R: A hands-on
523 guide. Chapman and Hall/CRC.

524 Hedges, L.V., 1981. Distribution theory for Glass's estimator of effect size and related
525 estimators. J. Educ. Stat. 6(2), 107–128. https://doi.org/10.3102/10769986006002107.

526 Holway, D.A., Lach, L., Suarez, A.V., et al., 2002. The causes and consequences of ant
527 invasions. Annu. Rev. Ecol. Syst. 33(1), 181–233.
528 https://doi.org/10.1146/annurev.ecolsys.33.010802.150444.

529 Hopmans, J.W., Qureshi, A.S., Kisekka, I., et al., 2021. Critical knowledge gaps and research
530 priorities in global soil salinity. Adv. Agron. 169, 1–191.
531 https://doi.org/10.1016/bs.agron.2021.03.001.

532 IBGE, 2019. Biomas e Sistema Costeiro-Marinho do Brasil - 1:250,000. Instituto Brasileiro de
533 Geografia e Estatística. https://www.ibge.gov.br/geociencias/informacoes-
534 ambientais/vegetacao/15842-biomas.html (accessed 28 May 2024).

535 Lach, L., Parr, C., Abbott, K., 2010. Ant ecology. Oxford University Press.

536 Laliberté, E., Wells, J.A., Declerck, F., et al., 2010. Land-use intensification reduces functional
537 redundancy and response diversity in plant communities. Ecol. Lett. 13(1), 76–86.
538 https://doi.org/10.1111/j.1461-0248.2009.01403.x.

539 Lasmar, C.J., Bishop, T.R., Parr, C.L., et al., 2021a. Geographical variation in ant foraging
540 activity and resource use is driven by climate and net primary productivity. J. Biogeogr.
541 48(6), 1448–1459. https://doi.org/10.1111/jbi.14089.

542 Lasmar, C.J., Bishop, T.R., Parr, C.L., et al., 2023. Testing the context dependence of ant
543 nutrient preference across habitat strata and trophic levels in Neotropical biomes. Ecology
544 104(4), e3975. https://doi.org/10.1002/ecy.3975.

545 Lasmar, C.J., Queiroz, A.C., Rosa, C., et al., 2021b. Contrasting edge and pasture matrix effects
546 on ant diversity from fragmented landscapes across multiple spatial scales. Landscape
547 Ecol. 36(9), 2583–2597. https://doi.org/10.1007/s10980-021-01258-y.

548 Lassau, S.A., Hochuli, D.F., 2004. Effects of habitat complexity on ant assemblages. Ecography
549 27(2), 157–164. https://doi.org/10.1111/j.0906-7590.2004.03675.x.

550 Lester, P.J., Gruber, M.A.M., 2016. Booms, busts and population collapses in invasive ants.
551 Biol. Invasions 18(11), 3091–3101. https://doi.org/10.1007/s10530-016-1214-2.

552 Magnusson, W.E., Grelle, C.E., Marques, M.C., et al., 2018. Effects of Brazil's political crisis
553 on the science needed for biodiversity conservation. Front. Ecol. Evol. 6, 163.
554 https://doi.org/10.3389/fevo.2018.00163.

555 Martins, I.S., Ortega, J.C.G., Guerra, V., et al., 2022. Ant taxonomic and functional beta-
556 diversity respond differently to changes in forest cover and spatial distance. Basic Appl.
557 Ecol. 60, 89–102. https://doi.org/10.1016/j.baae.2022.02.008.

558 Mathieu, J., Rossi, J.P., Mora, P., et al., 2005. Recovery of soil macrofauna communities after
559 forest clearance in Eastern Amazonia, Brazil. Conserv. Biol. 19(5), 1598–1605.
560 https://doi.org/10.1111/j.1523-1739.2005.00200.x.

561 McKinney, M.L., Lockwood, J.L., 1999. Biotic homogenization: a few winners replacing many
562 losers in the next mass extinction. Trends Ecol. Evol. 14(11), 450–453.
563 https://doi.org/https://doi.org/10.1016/S0169-5347(99)01679-1.

564 Mlinarić, A., Horvat, M., Šupak Smolčić, V., 2017. Dealing with the positive publication bias:
565 Why you should really publish your negative results. Biochem. medica (3), 447–52.
566 https://doi.org/10.11613/BM.2017.030201.

567 Nakagawa, S., Santos, E.S.A., 2012. Methodological issues and advances in biological meta-
568 analysis. Evol. Ecol. 26, 1253–1274. https://doi.org/10.1007/s10682-012-9555-5.

569 Neumann, K., Pinter-Wollman, N., 2022. The effect of resource availability on interspecific
570 competition between a native and an invasive ant. Philos. Trans. R. Soc. B. 377(1851),
571 20210146. https://doi.org/10.1098/rstb.2021.0146.

572 Newbold, T., 2018. Future effects of climate and land-use change on terrestrial vertebrate
573 community diversity under different scenarios. P. Roy. Soc. B-Biol. Sci. 285(1881).
574 https://doi.org/10.1098/rspb.2018.0792.

575 Newbold, T., Adams, G.L., Robles, G.A., et al., 2019. Climate and land-use change homogenise
576 terrestrial biodiversity, with consequences for ecosystem functioning and human well-
577 being. Emerg. Top. Life Sci. 3(2), 207–219. https://doi.org/10.1042/ETLS20180135.

578 Newbold, T., Hudson, L.N., Hill, S.L.L., et al., 2015. Global effects of land use on local
579 terrestrial biodiversity. Nature 520(7545), 45–50. https://doi.org/10.1038/nature14324.

580 Nunes, C.A., Berenguer, E., França, F., et al., 2022. Linking land-use and land-cover transitions
581 to their ecological impact in the Amazon. Proc. Natl. Acad. Sci. USA. 119(27),
582 e2202310119. https://doi.org/10.1073/pnas.2202310119.

583 O'Dea, R.E., Lagisz, M., Jennions, M.D., et al., 2021. Preferred reporting items for systematic
584 reviews and meta-analyses in ecology and evolutionary biology: a PRISMA extension.
585 Biol. Rev. 96(5), 1695–1722. https://doi.org/10.1111/brv.12721.

586 Pacheco, R., Vasconcelos, H.L., 2007. Invertebrate conservation in urban areas: Ants in the
587 Brazilian Cerrado. Landscape Urban Plan. 81(3), 193–199.
588 https://doi.org/10.1016/j.landurbplan.2006.11.004.

589 Parente, L., Nogueira, S., Baumann, L., et al., 2021. Quality assessment of the PRODES
590 Cerrado deforestation data. Remote Sens. Appl. Soc. Environ. 21, 100444.
591 https://doi.org/10.1016/j.rsase.2020.100444.

592 Pereira, E.J.A.L, de Santana Ribeiro, L.C., da Silva Freitas, L.F., et al., 2020. Brazilian policy
593 and agribusiness damage the Amazon rainforest. Land Use Policy, 92.
594 https://doi.org/10.1016/j.landusepol.2020.104491.

595 Priyadarshana, T.S., Martin, E.A., Sirami, C., et al., 2024. Crop and landscape heterogeneity
596 increase biodiversity in agricultural landscapes: A global review and meta-analysis. Ecol.
597 Lett. 27(3), e14412. https://doi.org/10.1111/ele.14412.

598 Projeto MapBiomas, 2022. Coleção 7 da Série Anual de Mapas de Uso e Cobertura da Terra do
599 Brasil. https://storage.googleapis.com/mapbiomas-public/brasil/collection-
600 7/lclu/coverage/brasil_coverage_2021.tif (accessed 28 May 2024).

601 QGIS.org, 2023. QGIS Geographic Information System. QGIS Association.
602 http://www.qgis.org (accessed 28 May 2024).

603 Queiroz, A.C. M., Marques, T.G., Ribas, C.R., et al., 2023. Ant diversity decreases during the
604 dry season: A meta-analysis of the effects of seasonality on ant richness and abundance.
605 Biotropica 55(1), 29–39. https://doi.org/10.1111/btp.13158.

606 Queiroz, A.C.M., Rabello, A.M., Braga, D.L., et al., 2020. Cerrado vegetation types determine
607 how land use impacts ant biodiversity. Biodivers. Conserv. 29(6), 2017–2034.
608 https://doi.org/10.1007/s10531-017-1379-8.

609 Queiroz, A.C.M., Rabello, A.M., Lasmar, C.J., et al., 2021. Diaspore Removal by Ants Does
610 Not Reflect the Same Patterns of Ant Assemblages in Mining and Rehabilitation
611 Areas. Neotrop. Entomol. 50, 335–348. https://doi.org/10.1007/s13744-021-00861-7.

612 R Core Team, 2021. R: a language and environment for statistical computing. R foundation for
613 statistical computing. https://www.R-project.org/ (accessed 28 May 2024).

614 Rabello, A.M., Parr, C.L., Queiroz, A.C.M., et al., 2018. Habitat attribute similarities reduce
615 impacts of land-use conversion on seed removal. Biotropica 50(1), 39–49.
616 https://doi.org/10.1111/btp.12506.

617 Ribas, C.R., Campos, R.B., Schmidt, F.A., et al., 2012. Ants as indicators in Brazil: a review
618 with suggestions to improve the use of ants in environmental monitoring programs.
619 Psyche 2012:636749. https://doi.org/10.1155/2012/636749.

620 Ribas, C.R., Schoereder, J.H., Pic, M., et al., 2003. Tree heterogeneity, resource availability,
621 and larger scale processes regulating arboreal ant species richness. Austral Ecol. 28(3),
622 305–314. https://doi.org/10.1046/j.1442-9993.2003.01290.x.

623 Rizzotto, A.M., Roani, A.H., Guarda, C., et al., 2019. Ant fauna in permanent preservation areas
624 and in forest plantations in the northwestern region of Rio Grande do Sul state. Ciência
625 Florestal, 29, 1227–1240. https://doi.org/10.5902/1980509836279.

626 Rosenthal, R., 1979. The file drawer problem and tolerance for null results. Psychol. bull. 86(3),
627 638–641. https://psycnet.apa.org/doi/10.1037/0033-2909.86.3.638.

628 Sala, O.E., Stuart Chapin, F.I.I.I., Armesto, J.J., et al., 2000. Global biodiversity scenarios for
629 the year 2100. Science 287(5459), 1770–1774.
630 https://doi.org/10.1126/science.287.5459.1770.

631 Sánchez-Bayo, F., Wyckhuys, K.A., 2019. Worldwide decline of the entomofauna: A review of
632 its drivers. Biol. Conserv. 232, 8–27. https://doi.org/10.1016/j.biocon.2019.01.020.

633 Schmidt, F.A., Ribas, C.R., Feitosa, R.M., et al., 2022. Ant diversity studies in Brazil: an
634 overview of the myrmecological research in a megadiverse country. Insect. Soc. 69(1),
635 105–121. https://doi.org/10.1007/s00040-022-00848-6.

636 Simberloff, D., Nuñez, M.A., Ledgard, N.J., et al., 2010. Spread and impact of introduced
637 conifers in South America: Lessons from other southern hemisphere regions. Austral
638 Ecol. 35(5), 489–504. https://doi.org/10.1111/j.1442-9993.2009.02058.x.

639 Solar, R.R., Barlow, J., Ferreira, J., et al., 2015. How pervasive is biotic homogenization in
640 human-modified tropical forest landscapes?. Ecol. Lett. 18(10):1108–18.
641 https://doi.org/10.1111/ele.12494.

642 Song, X.P., Hansen, M.C., Stehman, S.V., et al., 2018. Global land change from 1982 to 2016.
643 Nature 560(7720), 639–643. https://doi.org/10.1038/s41586-018-0411-9.

644 Stein, A., Kreft, H., 2015. Terminology and quantification of environmental heterogeneity in
645 species-richness research. Biol. Rev. 90(3), 815–836. https://doi.org/10.1111/brv.12135.

646 Tabarelli, M., Peres, C.A., Melo, F.P., 2012. The ‘few winners and many losers’ paradigm
647 revisited: emerging prospects for tropical forest biodiversity. Biol. Conserv. 155, 136–
648 140. https://doi.org/10.1016/j.biocon.2012.06.020.

649 Trew, B.T., Maclean, I.M., 2021. Vulnerability of global biodiversity hotspots to climate
650 change. Global Ecol. Biogeogr. 30(4), 768–783. https://doi.org/10.1111/geb.13272.

651 Unni, A.P., Mir, S.H., Rajesh, T.P., 2021. Native and invasive ants affect floral visits of
652 pollinating honey bees in pumpkin flowers (Cucurbita maxima). Sci. Rep. 11(1), 4781.
653 https://doi.org/10.1038/s41598-021-83902-w.

654 Vasconcelos, H.L., Maravalhas, J.B., Cornelissen, T., 2017. Effects of fire disturbance on ant
655 abundance and diversity: a global meta-analysis. Biodivers. Conserv. 26, 177–188.
656 https://doi.org/10.1007/s10531-016-1234-3.

657 Viechtbauer, W., 2010. Conducting meta-analyses in R with the metafor package. J. Stat Softw.
658 36, 1–48. https://doi.org/10.18637/jss.v036.i03.

659 Warton, D.I., Wright, T.W., Wang, Y., 2012. Distance-based multivariate analyses confound
660 location and dispersion effects. Methods Ecol. Evol. 3, 89–101.
661 https://doi.org/10.1111/j.2041-210X.2011.00127.x.

662 Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

663 Wilker, I., Lasmar, C.J., Schmidt, F.A., et al., 2023. Land-use change in the Amazon decreases
664 ant diversity but increases ant-mediated predation. Insect Conserv. Diver. 16(3), 379–392.
665 https://doi.org/10.1111/icad.12632.

666 Wilson, E.O. 1987. Causes of ecological success: the case of the ants. J. Anim. Ecol. 56(1), 1–
667 9. https://doi.org/10.2307/4795.

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676 **Appendix A**

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678 **Keywords**

679 ***English***

680 **population** (Ants OR Formicidae AND Brazil OR Brazilian); **intervention/exposure** (Land
681 use OR Farming OR Pasture OR Agriculture OR Forest plantation OR Silviculture OR Urban
682 area OR Urbanization OR Mining); **comparator** (Biomes OR Amazon OR Atlantic Forest OR
683 Pampa OR Caatinga OR Cerrado OR Forest OR Savanna OR Mangrove OR Wetland OR
684 Grassland); **outcome** (Diversity OR Richness OR Abundance OR α-diversity OR β-diversity
685 OR Community OR Assemblage OR Ecosystem function OR Ecosystem services OR
686 Ecological role OR Functional groups OR Harvester OR Seed dispersal OR Seed removal OR
687 Myrmecochory OR Diaspore dispersal OR Diaspore removal OR Bioturbation OR Predation
688 OR Scaveng* OR Predator*)

689

690 ***Portuguese***

691 **population** (Formiga* OR Formicidae AND Brasil OR Brasileir*); **intervention/exposure**
692 (Uso do solo OR Cultivo* OR Pastage* OR Pasto* OR Agricultura OR Plantaç* florestal OR
693 Silvicultura OR Área* urbana* OR Urbanizaç* OR Mineraç*); **comparator** (Bioma* OR
694 Amazônia OR Mata Atlântica OR Pampa OR Caatinga OR Cerrado OR Floresta* OR Savanna*
695 OR Mangue* OR Várzea* OR Campo*); **outcome** (Diversidade OR Riqueza OR Abundância
696 OR α-diversidade OR β-diversidade OR Comunidade* OR Assembleia* OR Funç*
697 ecossistêmica* OR Serviço* ecossistêmica* OR Pape* ecológico* OR Grupo* funciona* OR
698 Granívora* OR Dispersão de semente* OR Remoção de semente* OR Mirmecocoria OR
699 Dispersão de diásporo* OR Remoção de diásporo* OR Bioturbação OR Predação OR
700 Detritívora* OR Predador* OR Composição de espécie*)

701

702 ***Spanish***

703 **population** (Hormiga* OR Formicidae AND Brasil OR Brasileñ*); **intervention/exposure**
704 (Uso del suelo OR Cultivo* OR Pasto* OR Agricultura OR Plantaci* forestal* OR Silvicultura
705 OR Zona* urbana* OR Urbanizacion* OR Minería*); **comparator** (Biomas OR Amazonía OR
706 Bosque Atlántico OR Pampa OR Caatinga OR Cerrado OR Bosque OR Savanna OR Manglar
707 OR Humedal OR Campo*); **outcome** (Diversidad OR Riqueza OR Abundancia OR α-
708 diversidad OR β-diversidad OR Comunidad OR Ensamblaje OR Función ecosistémica OR
709 Servicio ecosistémico OR Rol ecológico OR Grupo* funcional* OR Cosechador* OR
710 Dispersión de semilla* OR Transporte de semilla* OR Mirmecocoria OR Dispersión de
711 diáspora* OR Transporte de diáspora* OR Bioturbaci* OR Depredación OR Carroñer* OR
712 Depredador* OR Composición)

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Data sources

Almeida, F. S., Mayhe-Nunes, A. J., & Queiroz, J. M. (2013). The importance of poneromorph ants for seed dispersal in altered environments. *Sociobiology*, *60(3)*, 229-235. https://doi.org/10.13102/sociobiology.v60i3.229-235

Amaral, G. C. D., Vargas, A. B., & Almeida, F. S. (2019). Effects of environmental attributes on the biodiversity of ants under different land uses. *Ciência Florestal*, *29*, 660-672. https://doi.org/10.5902/1980509833811

Apolinário, L. D. C. M. H., Almeida, Â. A. D., Queiroz, J. M., Vargas, A. B., & Almeida, F. S. (2019). Diversity and guilds of ants in different land-use systems in Rio de Janeiro State, Brazil. *Floresta e Ambiente*, *26(4),* e20171152. https://doi.org/10.1590/2179-8087.115217

Assis, D. S., Dos Santos, I. A., Ramos, F. N., Barrios-Rojas, K. E., Majer, J. D., & Vilela, E. F. (2018a). Agricultural matrices affect ground ant assemblage composition inside forest fragments. *PLoS One*, *13(5),* e0197697. https://doi.org/10.1371/journal.pone.0197697

Assis, V. C. B. D., Chagas, P. G., Marinho, C. G. S., Fadini, M. A. M., Delabie, J. H. C., & Mendes, S. M. (2018b). Transgenic Bt maize does not affect the soil ant community. *Pesquisa Agropecuária Brasileira, 53,* 152-162. https://doi.org/10.1590/S0100-204X2018000200003

Barros, E., Grimaldi, M., Sarrazin, M., Chauvel, A., Mitja, D., Desjardins, T., & Lavelle, P. (2004). Soil physical degradation and changes in macrofaunal communities in Central Amazon. *Applied Soil Ecology*, *26(2),* 157-168. https://doi.org/10.1016/j.apsoil.2003.10.012

736 Benito, N. P., Brossard, M., Pasini, A., de Fátima Guimarães, M., & Bobillier, B. (2004).
737 Transformations of soil macroinvertebrate populations after native vegetation conversion
738 to pasture cultivation (Brazilian Cerrado). *European journal of soil biology, 40(3-4),* 147-
739 154. https://doi.org/10.1016/j.ejsobi.2005.02.002

740 Braga, D. L., Louzada, J. N., Zanetti, R., & Delabie, J. (2010). Rapid evaluation of ant diversity
741 in land use systems in southern Bahia, Brazil. *Neotropical Entomology*, *39,* 464-469.
742 https://doi.org/10.1590/S1519-566X2010000400002

743 Brandão, C. R. F., Silva, R. R., & Feitosa, R. M. (2011). Cerrado ground-dwelling ants
744 (Hymenoptera: Formicidae) as indicators of *edge* effects. *Zoologia (*Curitiba), 28, 379-
745 387. https://doi.org/10.1590/S1984-46702011000300012

746 Camara, R., Correia, M. E. F., & Villela, D. M. (2012). Effects of eucalyptus plantations on soil
747 arthropod communities in a Brazilian Atlantic Forest conservation unit. *Bioscience*
748 *Journal, 28(3),* 445-455.

749 Campbell, A. J., Carvalheiro, L. G., Maués, M. M., Jaffé, R., Giannini, T. C., Freitas, M. A. B.,
750 ... & Menezes, C. (2018). Anthropogenic disturbance of tropical forests threatens
751 pollination services to açaí palm in the Amazon river delta. *Journal of Applied Ecology,*
752 *55(4),* 1725-1736. https://doi.org/10.1111/1365-2664.13086

753 Cantarelli, E. B., Fleck, M. D., Granzotto, F., Corassa, J. D. N., & d'Avila, M. (2015). Diversity
754 of ants (Hymenoptera: Formicidae) of litter in different systems of soil use. *Ciência*
755 *Florestal, 25(3),* 607-616.

756 Carneiro, M. A. F., Gaglioti, A. L., Carvalho, K. S., Nascimento, I. C., & Zina, J. (2018). The
757 Habitat Affects the Ecological Interactions between Azteca Forel (Hymenoptera:
758 Formicidae) and Cecropia Loefl. (Urticaceae Juss.). *Sociobiology*, *65(2),* 177-184.
759 https://doi.org/10.13102/sociobiology.v65i2.2044

760 Carvalho, R. L., Vieira, J., Melo, C., Silva, A. M., Tolentino, V. C., Neves, K., ... & Vasconcelos,
761 H. L. (2022). Interactions between land use, taxonomic group and aspects and levels of
762 diversity in a Brazilian savanna: Implications for the use of bioindicators. *Journal of*
763 *Applied Ecology, 59(10),* 2642-2653. https://doi.org/10.1111/1365-2664.14270

764 Corassa, J. D. N., Faixo, J. G., Andrade Neto, V. R., & Santos, I. B. (2015). Biodiversity of the
765 ant fauna in different soil uses in North Mato Grosso. *Comunicata Scientiae*, *6(2),* 154-
766 163.

767 Costa-Milanez, C. B., Lourenço-Silva, G., Castro, P. T. A., Majer, J. D., & Ribeiro, S. P. (2014).
768 Are ant assemblages of Brazilian veredas characterised by location or habitat type?.
769 *Brazilian Journal of Biology, 74,* 89-99. https://doi.org/10.1590/1519-6984.17612

770 Crepaldi, R. A., Portilho, I. I. R., Silvestre, R., & Mercante, F. M. (2014). Ants as bioindicators
771 of soil quality in integrated crop-livestock system/Formigas como bioindicadores da
772 qualidade do solo em sistema integrado lavoura-pecuaria. *Ciência Rural, 44(5),* 781-788.

773 da Rocha, P. L. B., Viana, B. F., Cardoso, M. Z., de Melo, A. M. C., Costa, M. G. C., de
774 Vasconcelos, R. N., & Dantas, T. B. (2013). What is the value of eucalyptus monocultures
775 for the biodiversity of the Atlantic forest? A multitaxa study in southern Bahia, Brazil.
776 *Journal of Forestry Research, 24,* 263-272. https://doi.org/10.1007/s11676-012-0311-z

777 da Silva, R. F. da., Aquino, A. M. de., Mercante, F. M., & de Fatima Guimaraes, M. (2008). Soil
778 invertebrate macrofauna in an integrated livestock production system in the Brazilian
779 savanna/Macrofauna invertebrada do solo em sistema integrado de producao
780 agropecuaria no Cerrado. *Acta Scientiarum. Agronomy, 30(4),* 725-732.

781 da Silva, W. B., Cajaiba, R. L., Santos, M., & Périco, E. (2022). Effectiveness of ant
782 communities to detect anthropogenic disturbance in Neotropical forest landscapes: a case

783 study in the Brazilian Amazon. *Biodiversity and Conservation, 31(1),* 211-226.
784 https://doi.org/10.1007/s10531-021-02329-x

785 Dalle Laste, K. C., Durigan, G., & Andersen, A. N. (2019). Biodiversity responses to land-use
786 and restoration in a global biodiversity hotspot: Ant communities in Brazilian Cerrado.
787 *Austral Ecology, 44(2),* 313-326. https://doi.org/10.1111/aec.12676

788 DaRocha, W. D., Neves, F. S., Dáttilo, W., & Delabie, J. H. (2016). Epiphytic bromeliads as
789 key components for maintenance of ant diversity and ant–bromeliad interactions in
790 agroforestry system canopies. *Forest Ecology and Management, 372,* 128-136.
791 https://doi.org/10.1016/j.foreco.2016.04.011

792 DaRocha, W., Antoniazzi, R., Delabie, J. H., Schroth, G., Fernandes, G. W., & Neves, F. S.
793 (2021). Disentangling the factors that shape bromeliad and ant communities in the
794 canopies of cocoa agroforestry and preserved Atlantic Forest. *Biotropica, 53(6),* 1698-
795 1709. https://doi.org/10.1111/btp.13018

796 de Faria, L. S., Paseto, M. L., Couri, M. S., Mello-Patiu, C. A., & Mendes, J. (2018). Insects
797 associated with pig carrion in two environments of the Brazilian Savanna. *Neotropical*
798 *Entomology, 47,* 181-198. https://doi.org/10.1007/s13744-017-0518-y

799 de Souza, D. R., Fernandes, T. T., Nascimento, J. R. D. O., Suguituru, S. S., & Morini, M. S.
800 D. C. (2012). Characterization of ant communities (Hymenoptera: Formicidae) in twigs
801 in the leaf litter of the Atlantic rainforest and eucalyptus trees in the southeast region of
802 Brazil. *Psyche: A Journal of Entomology, 2012,* 1-12.
803 https://doi.org/10.1155/2012/532768

804 de Souza-Campana, D. R., Silva, R. R., Fernandes, T. T., Silva, O. G. D. M., Saad, L. P., &
805 Morini, M. S. D. C. (2017). Twigs in the leaf litter as ant habitats in different vegetation

habitats in southeastern Brazil. *Tropical conservation science, 10,* 1940082917710617. https://doi.org/10.1177/1940082917710617

Delabie, J. H., Jahyny, B., do Nascimento, I. C., Mariano, C. S., Lacau, S., Campiolo, S., ... & Leponce, M. (2007). Contribution of cocoa plantations to the conservation of native ants (Insecta: Hymenoptera: Formicidae) with a special emphasis on the Atlantic Forest fauna of southern Bahia, Brazil. *Biodiversity and Conservation, 16,* 2359-2384. https://doi.org/10.1007/s10531-007-9190-6

Delabie, J. H., Paim, V. R. D. M., Nascimento, I. C. D., Campiolo, S., & Mariano, C. D. S. (2006). Ants as biological indicators of human impact in mangroves of the southeastern coast of Bahia, Brazil. *Neotropical Entomology, 35,* 602-615. https://doi.org/10.1590/S1519-566X2006000500006

Demetrio, W. C., Conrado, A. C., Acioli, A. N., Ferreira, A. C., Bartz, M. L., James, S. W., ... & Cunha, L. (2021). A “dirty” footprint: Macroinvertebrate diversity in Amazonian anthropic soils. *Global Change Biology, 27(19),* 4575-4591. https://doi.org/10.1111/gcb.15752

Demolin-Leite, G. L., Von dos Santos-Veloso, R., Alvarenga-Soares, M., Fernandes, G. W., Cola-Zanuncio, J., Alves-Oliveira, N., & dos Santos Junior, V. C. (2020). Does environmental diversity affect hymenopteran galling insects and their natural enemies on Caryocar brasiliense trees (Caryocaraceae)?. *Revista Colombiana de Entomologia, 46(1).* e8546. https://doi.org/10.25100/socolen.v46i1.8546

Dias, N. D. S., Zanetti, R., Santos, M. S., Peñaflor, M. F. G. V., Broglio, S. M. F., & Delabie, J. H. C. (2013). The impact of coffee and pasture agriculture on predatory and omnivorous leaf-litter ants. *Journal of Insect Science, 13(1),* 29. https://doi.org/10.1673/031.013.2901

829 Dias, N. S., Zanetti, R., Santos, M. S., Louzada, J., & Delabie, J. (2008). Interaction between
830 forest fragments and adjacent coffee and pasture agroecosystems: responses of the ant
831 communities (Hymenoptera, Formicidae). *Iheringia. Série Zoologia, 98,* 136-142.
832 https://doi.org/10.1590/S0073-47212008000100017

833 Diehl, E., Sanhudo, C. E. D., & Diehl-Fleig, E. (2004). Ground-dwelling ant fauna of sites with
834 high levels of copper. *Brazilian Journal of Biology, 64,* 33-39.
835 https://doi.org/10.1590/S1519-69842004000100005

836 Dolabela, B. M., Antonini, Y., Pinto, V. D., Onésimo, C., Brito, M. F., & Costa, F. V. (2020).
837 The importance of Forest simplification and litter disturbance in Defining the Assembly
838 of Ground-Foraging ants. *Neotropical Entomology, 49(6),* 832-839.
839 https://doi.org/10.1007/s13744-020-00815-5

840 Falcão, J. C., Dáttilo, W., & Izzo, T. J. (2015). Efficiency of different planted forests in
841 recovering biodiversity and ecological interactions in Brazilian Amazon. *Forest Ecology*
842 *and Management, 339,* 105-111. https://doi.org/10.1016/j.foreco.2014.12.007

843 Fernandes, T. T., Souza-Camapana, D. R., Silva, R. R., & Morini, M. S. C. (2018). Ants that
844 frequently colonize twigs in the leaf litter of different vegetation habitats. *Sociobiology,*
845 *65(2),* 340-344. https://doi.org/10.13102/sociobiology.v65i2.2742

846 Fernandes, W. D., Lange, D., & de Almeida Soares, S. (2010). Communities of ants
847 (Hymenoptera: Formicidae) in fragmented environments. *Sociobiology, 55(1),* 255.

848 Ferreira, C. R, de Souza, R. C., Correia, M. E. F., de Resende, A. S., dos Anjos, L. H. C., &
849 Pereira, M. G. (2017). Edaphic arthropods in different successional stages of Atlantic
850 forest and abandoned pasture areas. *Comunicata Scientiae*, *8(2),* 296-306.
851 https://doi.org/10.14295/cs.v8i2.1750

852 Fialho, J. S., Primo, A. A., de Aguiar, M. I., Magalhães, R. B., dos Santos Maia, L., Correia, M.
853 E. F., ... & de Oliveira, T. S. (2021). Pedofauna diversity in traditional and agroforestry
854 systems of the Brazilian semi-arid region. *Journal of Arid Environments, 184,* 104315.
855 https://doi.org/10.1016/j.jaridenv.2020.104315

856 Fontenele, L. K., & Schmidt, F. A. (2021). Forest-pasture shifting alters the assemblages of
857 seed-removing ants in southwestern Brazilian Amazon. *Journal of Insect Conservation,*
858 *25,* 213-220. https://doi.org/10.1007/s10841-021-00295-x

859 Frainer, A., & Duarte, M. M. (2009). Soil invertebrates in southern Brazilian Araucaria forest-
860 grassland mosaic: differences between disturbed and undisturbed areas. Iheringia. *Série*
861 *Zoologia, 99,* 307-312. https://doi.org/10.1590/S0073-47212009000300013

862 Franco, A. L., Bartz, M. L., Cherubin, M. R., Baretta, D., Cerri, C. E., Feigl, B. J., ... & Cerri,
863 C. C. (2016). Loss of soil (macro) fauna due to the expansion of Brazilian sugarcane
864 acreage. *Science of the Total Environment, 563,* 160-168.
865 https://doi.org/10.1016/j.scitotenv.2016.04.116

866 Frizzo, T. L., & Vasconcelos, H. L. (2013). The potential role of scattered trees for ant
867 conservation in an agriculturally dominated neotropical landscape. *Biotropica*, *45(5),*
868 644-651. https://doi.org/10.1111/btp.12045

869 Fröhlich, F. R. S., Strohschoen, A. A. G., Rempel, C., & Ferla, N. J. (2011). Diversidade de
870 formigas (Formicidae) em áreas de Eucalipto e vegetação nativa no município de Capitão,
871 Rio Grande do Sul. *Revista Caderno Pedagógico, 8(2).*

872 Gomes, D. S., Almeida, F. S., Vargas, A. B., & Queiroz, J. M. (2013). Response of the ant
873 assemblage to a gradient of environmental change in the soil-litter interface. Iheringia.
874 *Série Zoologia, 103,* 104-109. https://doi.org/10.1590/S0073-47212013000200004

875 Gomes, J. B. V., Barreto, A. C., Michereff Filho, M., Vidal, W. C. L., Costa, J. L. D. S., Oliveira-
876 Filho, A. T. D., & Curi, N. (2010). Relationship among soil attributes and ant activity in
877 restinga soils. *Revista Brasileira de Ciencia do Solo, 34,* 67-78.
878 https://doi.org/10.1590/S0100-06832010000100007

879 Gusmão, L. G., & Loeck, A. (1999). Distribuição geográfica de formigas cortadeiras do gênero
880 Acromyrmex (Hymenoptera: Formicidae) na Zona Sul do estado do Rio Grande do Sul,
881 Brasil. *Current Agricultural Science and Technology, 5(1).*

882 Haddad, G. Q., Cividanes, F. J., & Martins, I. C. F. (2011). Species diversity of myrmecofauna
883 and araneofauna associated with agroecosystem and forest fragments and their interaction
884 with Carabidae and Staphylinidae (Coleoptera). *Florida Entomologist*, 500-509.

885 Jordani, M. X., Hasui, E., & da Silva, V. X. (2015). Natural enemies depend on remnant habitat
886 size in agricultural landscapes. *Journal of Forestry Research, 26,* 469-477.
887 https://doi.org/10.1007/s11676-015-0043-y

888 Kalif, K. A., Azevedo-Ramos, C., Moutinho, P., & Malcher, S. A. (2001). The effect of logging
889 on the ground-foraging ant community in eastern Amazonia. *Studies on Neotropical*
890 *Fauna and Environment, 36(3),* 215-219. https://doi.org/10.1076/snfe.36.3.215.2119

891 Kersch-Becker, M. F., Buss, S. R., & Fonseca, C. R. (2013). Conservation of an ant–plant
892 mutualism in native forests and ecologically-managed tree monocultures. *Biotropica,*
893 *45(4),* 520-527. https://doi.org/10.1111/btp.12023

894 Krüger, L. R., Loeck, A. E., & Grützmacher, D. D. (2010). Influence of Eucalyptus plantations
895 on the leaf cutter ants in the Campanha and southern regions of the state of Rio Grande
896 do Sul, Brazil. *Revista Brasileira de Agrociência, 16(1/4),* 51-55.

Lapola, D. M., & Fowler, H. G. (2008). Questioning the implementation of habitat corridors: a case study in interior São Paulo using ants as bioindicators. *Brazilian Journal of Biology, 68,* 11-20.

Lutinski, J. A., Guarda, C., Lutinski, C. J., Busato, M. A., & Garcia, F. R. M. (2018). Fauna of ants in permanent preservation areas of hydroelectric power plants. *Ciência Florestal, 28(4),* 1741-1754.

Lutinski, J. A., Lutinski, C. J., Guarda, C., Busato, M. A., & Garcia, F. R. (2017). Richness and structure of ant assemblies (Hymenoptera: Formicidae) in Atlantic forest in southern Brazil. *Anais da Academia Brasileira de Ciências, 89,* 2719-2729.

Lutinski, J. A., Lutinski, C. J., Iop, S., & Mello Garcia, F. R. (2013). Evaluation of an ant sampling protocol (Hymenoptera: Formicidae) in three modified environments located inside an austral Atlantic Forest area of Brazil. *Ecología austral*, *23(1),* 37-43.

Majer, J. D. (1996). Ant recolonization of rehabilitated bauxite mines at Trombetas, Pará, Brazil. *Journal of Tropical Ecology*, *12(2),* 257-273. https://doi.org/10.1017/S0266467400009445

Majer, J. D., & Delabie, J. H. C. (1999). Impact of tree isolation on arboreal and ground ant communities in cleared pasture in the Atlantic rain forest region of Bahia, Brazil. *Insectes sociaux, 46,* 281-290. https://doi.org/10.1007/s000400050147

Majer, J. D., Delabie, J. H. C., & McKenzie, N. L. (1997). Ant litter fauna of forest, forest edges and adjacent grassland in the Atlantic rain forest region of Bahia, Brazil. *Insectes Sociaux, 44,* 255-266. https://doi.org/10.1007/s000400050046

Marchão, R. L., Lavelle, P., Celini, L., Balbino, L. C., Vilela, L., & Becquer, T. (2009). Soil macrofauna under integrated crop-livestock systems in a Brazilian Cerrado Ferralsol.

Pesquisa Agropecuária Brasileira, 44, 1011-1020. https://doi.org/10.1590/S0100-204X2009000800033

Marinho, C. G., Zanetti, R., Delabie, J. H., Schlindwein, M. N., & Ramos, L. D. S. (2002). Ant (hymenoptera: formicidae) diversity in eucalyptus (myrtaceae) plantations and cerrado litter in Minas Gerais, Brazil. *Neotropical Entomology, 31,* 187-195. https://doi.org/10.1590/S1519-566X2002000200004

Marsh, C. J., Feitosa, R. M., Louzada, J., & Ewers, R. M. (2018). Is β-diversity of Amazonian ant and dung beetles communities elevated at rainforest edges?. *Journal of Biogeography*, *45(8),* 1966-1979. https://doi.org/10.1111/jbi.13357

Martello, F., De Bello, F., Morini, M. S. D. C., Silva, R. R., Souza-Campana, D. R. D., Ribeiro, M. C., & Carmona, C. P. (2018). Homogenization and impoverishment of taxonomic and functional diversity of ants in Eucalyptus plantations. *Scientific Reports, 8(1),* 3266. https://doi.org/10.1038/s41598-018-20823-1

Martins, M. F. D. O., Thomazini, M. J., Baretta, D., Brown, G. G., Rosa, M. G. D., Zagatto, M. R. G., ... & Feitosa, R. M. (2019). Accessing the subterranean ant fauna (Hymenoptera: Formicidae) in native and modified subtropical landscapes in the Neotropics. *Biota Neotropica, 20*. https://doi.org/10.1590/1676-0611-BN-2019-0782

Mathieu, J., Rossi, J. P., Mora, P., Lavelle, P., Martins, P. D. S., Rouland, C., & Grimaldi, M. (2005). Recovery of soil macrofauna communities after forest clearance in Eastern Amazonia, Brazil. *Conservation Biology, 19(5),* 1598-1605. https://doi.org/10.1111/j.1523-1739.2005.00200.x

Melo, T. S., Koch, E. B. A., Andrade, A. R. S., Travassos, M. L. O., Peres, M. C. L., & Delabie, J. H. C. (2021). Ants (Hymenoptera: Formicidae) in different green areas in the

943 metropolitan region of Salvador, Bahia state, Brazil. *Brazilian Journal of Biology, 82.*
944 *https://doi.org/10.1590/1519-6984.236269*

945 Menezes, A. S. O., & Schmidt, F. A. (2020). Mechanisms of species coexistence and functional
946 diversity of ant assemblages in forest and pasture habitats in southwestern Brazilian
947 Amazon. *Sociobiology, 67(1),* 33-40. https://doi.org/10.13102/sociobiology.v67i1.4552

948 Mentone, T. D. O., Diniz, E. A., Munhae, C. D. B., Bueno, O. C., & Morini, M. S. D. C. (2011).
949 Composition of ant fauna (Hymenoptera: Formicidae) at litter in areas of semi-deciduous
950 forest and Eucalyptus spp., in Southeastern Brazil. *Biota Neotropica, 11,* 237-246.
951 https://doi.org/10.1590/S1676-06032011000200024

952 Miranda, P. N., Baccaro, F. B., Morato, E. F., Oliveira, M. A., & Delabie, J. H. C. (2017).
953 Limited effects of low-intensity forest management on ant assemblages in southwestern
954 Amazonian forests. *Biodiversity and Conservation, 26,* 2435-2451.

955 Miranda, P. N., Morato, E. F., Oliveira, M. A., & Delabie, J. H. C. (2013). Richness and
956 composition of ants as indicators of the reduced impact logging in tropical forest in the
957 state of Acre. *Revista Árvore, 37,* 163-173. https://doi.org/10.1590/S0100-
958 67622013000100017

959 Morais, J. W., Oliveira, V. D. S., Sales Dambros, C. D., Tapia-Coral, S. C., & Acioli, A. N. S.
960 (2010). Soil mesofauna in differents systems of land use soil in upper River Solimões,
961 AM, Brazil. *Neotropical Entomology, 39,* 145-152.

962 Morini, M. S. (2014). Diversity of Epigeal Ants (Hymenoptera: Formicidae) in Urban Areas of
963 Alto Tietê. *Sociobiology, 59(3),* 703–717.
964 https://doi.org/10.13102/sociobiology.v59i3.543

965 Munique, L. B., & Calixto, E. S. (2018). Spatial and temporal variation of plant fragment
966 removal by two species of Atta leaf-cutting ants. *Journal of insect behavior, 31,* 255-263.
967 https://doi.org/10.1007/s10905-018-9673-1

968 Muñoz Gutiérrez, J. A., Xavier Rousseau, G., Andrade-Silva, J., & Charles Delabie, J. H.
969 (2017). Ants' higher taxa as surrogates of species richness in a chronosequence of fallows,
970 old-grown forests and agroforestry systems in the Eastern Amazon, Brazil. *Revista de*
971 *Biología Tropical, 65(1),* 279-291. http://dx.doi.org/10.15517/rbt.v65i1.23526.

972 Muscardi, D. C., Almeida, S. S., Schoereder, J. H., Marques, T., Sarcinelli, T. S., & Correa, A.
973 S. (2008). Response of litter ants (Hymenoptera: Formicidae) to habitat heterogeneity and
974 local resource availability in native and exotic forests. *Sociobiology, 52(3),* 655.

975 Neves, F. S., Braga, R. F., Araújo, L. S., Campos, R. I., & Fagundes, M. (2012). Differential
976 effects of land use on ant and herbivore insect communities associated with Caryocar
977 brasiliense (Caryocaraceae). *Revista de biologia tropical, 60(3),* 1065-1073.

978 Nunes, L. A. P. L., Araújo Filho, J. A., & Meneses, R. I. Q. (2008). Recolonização da fauna
979 edáfica em áreas de Caatinga submetidas a queimadas. *Revista Caatinga, 21(3).*

980 Oliveira, A. B. S., & Schmidt, F. A. (2019). Ant assemblages of Brazil nut trees Bertholletia
981 excelsa in forest and pasture habitats in the Southwestern Brazilian Amazon. *Biodiversity*
982 *and Conservation, 28(2),* 329-344. https://doi.org/10.1007/s10531-018-1657-0

983 Oliveira, M. A. D., Della Lúcia, T., Araújo, M. D. S., & Cruz, A. P. D. (1995). Ant fauna of
984 Eucalipt and native forest in the State of Amapa, Brazil. *Acta Amazonica*, 25, 117-126.
985 https://doi.org/10.1590/1809-43921995252126

Oliveira, M. A., Della Lucia, T. M. C., Marinho, C. G. S., Delabie, J. H. C., & Morato, F. F. (2009). Ant (Hymenoptera: Formicidae) diversity in an area of the Amazon forest in Acre, Brazil. *Sociobiology*, *54(1),* 243-267.

Oliveira, M. A., Della Lucia, T. M. C., Morato, E. F., Amaro, M. A., & Marinho, C. G. S. (2011). Vegetation structure and richness: effects on ant fauna of the Amazon—Acre, Brazil (Hymenoptera: Formicidae). *Sociobiology, 57(3),* 471.

Pacheco, R., & Vasconcelos, H. L. (2007). Invertebrate conservation in urban areas: ants in the Brazilian Cerrado. *Landscape and Urban Planning, 81(3),* 193-199. https://doi.org/10.1016/j.landurbplan.2006.11.004

Pacheco, R., & Vasconcelos, H. L. (2012). Subterranean pitfall traps: is it worth including them in your ant sampling protocol?. *Psyche, 2012.* https://doi.org/10.1155/2012/870794

Pacheco, R., Camacho, G. P., Frizzo, T. L., & Vasconcelos, H. L. (2017). Effects of land-use changes on ecosystem services: decrease in ant predation in human-dominated landscapes in central Brazil. *Entomologia experimentalis et applicata, 162(3),* 302-308. https://doi.org/10.1111/eea.12542

Pacheco, R., Silva, R. R., Morini, M. S. D. C., & Brandão, C. R. (2009). A comparison of the leaf-litter ant fauna in a secondary atlantic forest with an adjacent pine plantation in southeastern Brazil. *Neotropical Entomology, 38,* 55-65. https://doi.org/10.1590/S1519-566X2009000100005

Pacheco, R., Vasconcelos, H. L., Groc, S., Camacho, G. P., & Frizzo, T. L. (2013). The importance of remnants of natural vegetation for maintaining ant diversity in Brazilian agricultural landscapes. *Biodiversity and conservation, 22,* 983-997. https://doi.org/10.1007/s10531-013-0463-y

1009 Peixoto, T. S., Praxedes, C. D. L., Baccaro, F. B., Barbosa, R. I., & Mourão Júnior, M. (2010).
1010 Composition and richness of ants (Hymenoptera: Formicidae) in savanna and associated
1011 environments of Roraima State (Northern of Brazil). *Agro@mbiente On-line, 4(1),* 1-10.

1012 Pereira, J. R., & Almeida, F. S. (2023). Influence of environmental heterogeneity on
1013 mirmecofauna in different land uses in the municipality of Bom Despacho, Minas Gerais
1014 state. *Ciência Florestal, 33,* e64534. https://doi.org/10.5902/1980509864534

1015 Pereira, M. P. S., Queiroz, J. M., Souza, G. O., & Mayhé-Nunes, A. J. (2007) Effects of litter
1016 heterogeneity on twig-nesting ants in native forest and eucalyptus plantations.
1017 *Neotropical Biology and Conservation, 2(3),*161-164.
1018 https://doi.org/10.1177/1940082917710617

1019 Pompermaier, V. T., Kisaka, T. B., Ribeiro, J. F., & Nardoto, G. B. (2020). Impact of exotic
1020 pastures on epigeic arthropod diversity and contribution of native and exotic plant sources
1021 to their diet in the central Brazilian savanna. *Pedobiologia, 78,* 150607.
1022 https://doi.org/10.1016/j.pedobi.2019.150607

1023 Przybyszewski, K. R., Vicente, R. E., Ferreira, J. V. A., Pereira, M. J. B., Izzo, T. J., & Storck-
1024 Tonon, D. (2022). Legal reserves ensure alpha and beta ant diversity in highly modified
1025 agricultural landscapes. *Perspectives in Ecology and Conservation, 20(4),* 330-337.
1026 https://doi.org/10.1016/j.pecon.2022.08.001

1027 Queiroz, A. C., Rabello, A. M., Braga, D. L., Santiago, G. S., Zurlo, L. F., Philpott, S. M., &
1028 Ribas, C. R. (2020). Cerrado vegetation types determine how land use impacts ant
1029 biodiversity. *Biodiversity and Conservation, 29,* 2017-2034.
1030 https://doi.org/10.1007/s10531-017-1379-8

1031 Rabello, A. M., Parr, C. L., Queiroz, A. C., Braga, D. L., Santiago, G. S., & Ribas, C. R. (2018).
1032 Habitat attribute similarities reduce impacts of land-use conversion on seed removal.
1033 *Biotropica, 50(1),* 39-49. https://doi.org/10.1111/btp.12506

1034 Rabello, A. M., Parr, C. L., Queiroz, A. C., Braga, D. L., Santiago, G. S., & Ribas, C. R. (2021).
1035 Taxonomic and functional approaches reveal different responses of ant assemblages to
1036 land-use changes. *Basic and Applied Ecology, 54,* 39-49.
1037 https://doi.org/10.1016/j.baae.2021.04.001

1038 Ramos, A. S. de J. C., de Lemos, R. N. S., do Vale, A. M. S., Batista, M. C., Moreira, A. A.,
1039 Harada, A. Y., & Mesquita, M. L. R. (2015). Ant diversity in agro ecosystems and
1040 secondary forest. *African Journal of Agricultural Research, 10(49),* 4449-4454.
1041 https://doi.org/10.5897/AJAR2015.9521

1042 Resende, J. J., de M Santos, G. M., do Nascimento, I. C., Delabie, J. H., & da Silva, E. M.
1043 (2011). Communities of Ants (Hymenoptera—Formicidae) in Different Atlantic Rain
1044 Forest Phytophysionomies. *Sociobiology*, *58(3),* 779.

1045 Resende, J. J., Peixoto, P. E. C., Silva, E. N., Delabie, J. H. C., & Santos, G. M. (2013). Arboreal
1046 ant assemblages respond differently to food source and vegetation physiognomies: A
1047 study in the Brazilian Atlantic rain forest. *Sociobiology, 60(2),* 174-182.
1048 https://doi.org/10.13102/sociobiology.v60i2.174-182

1049 Rizzotto, A. M., Roani, A. H., Guarda, C., Giovenardi, R., & Lutinski, J. A. (2019). Ant fauna
1050 in permanent preservation areas and in forest plantations in the northwestern region of
1051 Rio Grande do Sul state. *Ciência Florestal, 29,* 1227-1240.
1052 https://doi.org/10.5902/1980509836279

1053 Rocha, W. D. O., Dorval, A., Peres Filho, O., Vaez, C. D. A., & Ribeiro, E. S. (2015). Ants
1054 (Hymenoptera: Formicidae) as Bioindicators of Environmental Degradation in Poxoréu,

Mato Grosso, Brazil. *Floresta e Ambiente, 22,* 88-98. https://doi.org/10.1590/2179-8087.0049

Rocha-Ortega, M., Bartimachi, A., Neves, J., Bruna, E. M., & Vasconcelos, H. L. (2017). Seed removal patterns of pioneer trees in an agricultural landscape. *Plant Ecology*, *218,* 737-748. https://doi.org/10.1007/s11258-017-0725-y

Ronchi, D. L., Schorn, L. A., Santos, K. F. D., & Vitorino, M. D. (2022). Soil macrofauna in areas with different successional vegetation stages after Eucalyptus grandis harvest in Brazil. *Semina ciênc. agrar*, 1111-1126. https://doi.org/10.5433/1679-0359.2022v43n3p1111

Rosado, J. L. O., de Gonçalves, M. G., Dröse, W., e Silva, E. J. E., Krüger, R. F., & Loeck, A. E. (2013). Effect of climatic variables and vine crops on the epigeic ant fauna (Hymenoptera: Formicidae) in the Campanha region, state of Rio Grande do Sul, Brazil. *Journal of insect conservation, 17,* 1113-1123. https://doi.org/10.1007/s10841-013-9592-6

Rosado, J., Gonçalves, M., Feitosa, R., Dröse, W., Krüger, R., e Silva, E. E., & Loeck, A. (2012). Epigeic ants (Hymenoptera: Formicidae) in vineyards and grassland areas in the Campanha region, state of Rio Grande do Sul, Brazil. *Check List*, *8(6),* 1184-1189. https://doi.org/10.15560/8.6.1184

Rousseau, G. X., Silva, P. R. D. S., & CARVALHO, C. J. R. D. (2010). Earthworms, ants and other arthropods as soil health indicators in traditional and no-fire agro-ecosystems from Eastern Brazilian Amazonia. *Acta zoológica mexicana, 26(SPE2),* 117-134.

Saad, L. P., Souza-Campana, D. R., Bueno, O. C., & Morini, M. S. C. (2017). Vinasse and its influence on ant (Hymenoptera: Formicidae) communities in sugarcane crops. *Journal of Insect Science, 17(1),* 11. https://doi.org/10.1093/jisesa/iew103

1079 Santos, J. C., Anjos, D. V., de Almeida, W. R., Aguiar, J. J. M., & Delabie, J. H. C. (2021).
1080 Ground-dwelling ant diversity in Amazonian secondary forests and neighboring pastures.
1081 *Tropical Ecology, 62,* 279-287. https://doi.org/10.1007/s42965-021-00146-5

1082 Santos, L. A., Bischoff, A., & Fernandes, O. A. (2018). The effect of forest fragments on
1083 abundance, diversity and species composition of predatory ants in sugarcane fields. *Basic*
1084 *and Applied Ecology, 33,* 58-65. https://doi.org/10.1016/j.baae.2018.08.009

1085 Santos, M. N., Delabie, J. H., & Queiroz, J. M. (2019). Biodiversity conservation in urban
1086 parks: a study of ground-dwelling ants (Hymenoptera: Formicidae) in Rio de Janeiro City.
1087 *Urban Ecosystems, 22,* 927-942. https://doi.org/10.1007/s11252-019-00872-8

1088 Santos, M. P., Carrano-Moreira, A. F. C. M., & Torres, J. B. (2012). Diversidade de formigas
1089 epigeicas (Hymenoptera: Formicidae) em floresta ombrófila densa e em cultivo de cana-
1090 deaçúcar, no município de Igarassu, PE. *Revista Brasileira de Ciências Agrárias, 7(4),*
1091 648-656. https://doi.org/10.5039/agraria.v7i4a1927

1092 Santos-Silva, L., Vicente, R. E., & Feitosa, R. M. (2016). Ant species (Hymenoptera,
1093 Formicidae) of forest fragments and urban areas in a Meridional Amazonian landscape.
1094 *Check List, 12(3),* 1885-1885. https://doi.org/10.15560/12.3.1885

1095 Schmidt, F. A., & Diehl, E. (2008). What is the effect of soil use on ant communities?.
1096 *Neotropical Entomology, 37*, 381-388. https://doi.org/10.1590/S1519-
1097 566X2008000400005

1098 Schmidt, F. A., Ribas, C. R., & Schoereder, J. H. (2013). How predictable is the response of ant
1099 assemblages to natural forest recovery? Implications for their use as bioindicators.
1100 *Ecological Indicators, 24,* 158-166. https://doi.org/10.1016/j.ecolind.2012.05.031

1101 Schoereder, J. H. (2012). Why do ant species occur in the matrix and not in the forests? Invasion
1102 from other habitats or expansion from forest gaps (Hymenoptera: Formicidae).
1103 *Sociobiology, 59(4),* 1137-1149. https://doi.org/10.13102/sociobiology.v59i4.513

1104 Silva, N. S., Saad, L. P., Souza-Campana, D. R., Bueno, O. C., & Morini, M. S. C. (2017).
1105 Comparison between ground ant (Hymenoptera: Formicidae) communities foraging in
1106 the straw mulch of sugarcane crops and in the leaf litter of neighboring forests. *Journal*
1107 *of economic entomology, 110(1),* 111-117. https://doi.org/10.1093/jee/tow295

1108 Silva, R. F. D., Tomazi, M., Pezarico, C. R., Aquino, A. M. D., & Mercante, F. M. (2007).
1109 Edaphic invertebrate macrofauna in cassava cultivation under vegetable cover crops.
1110 *Pesquisa Agropecuária Brasileira, 42,* 865-871. https://doi.org/10.1590/S0100-
1111 204X2007000600014

1112 Soares, S. D. A., Antonialli-Junior, W. F., & Lima-Junior, S. E. (2010). Diversity of epigeic ants
1113 (Hymenoptera, Formicidae) in two environments in Central-Western of Brazil. *Revista*
1114 *Brasileira de Entomologia, 54,* 76-81. https://doi.org/10.1590/S0085-
1115 56262010000100009

1116 Soares, S. D. M., Marinho, C. G. S., & Della Lúcia, T. M. C. (1998). Species richness of soil
1117 ant fauna in an eucalypt plantation and a second growth forest. *Revista Brasileira de*
1118 *Zoologia, 15,* 889-898. https://doi.org/10.1590/S0101-81751998000400006

1119 Solar, R. R. C., Barlow, J., Andersen, A. N., Schoereder, J. H., Berenguer, E., Ferreira, J. N., &
1120 Gardner, T. A. (2016b). Biodiversity consequences of land-use change and forest
1121 disturbance in the Amazon: A multi-scale assessment using ant communities. *Biological*
1122 *Conservation, 197,* 98-107. https://doi.org/10.1016/j.biocon.2016.03.005

1123 Solar, R. R. C., Chaul, J. C. M., Maués, M., & Schoereder, J. H. (2016a). A quantitative baseline
1124 of ants and orchid bees in human-modified Amazonian landscapes in Paragominas, Pará,
1125 Brazil. *Sociobiology, 63,* 925-940. https://doi.org/10.13102/sociobiology.v63i3.1052

1126 Solar, R. R. D. C., Barlow, J., Ferreira, J., Berenguer, E., Lees, A. C., Thomson, J. R., ... &
1127 Gardner, T. A. (2015). How pervasive is biotic homogenization in human-modified
1128 tropical forest landscapes?. *Ecology Letters, 18(10),* 1108-1118.
1129 https://doi.org/10.1111/ele.12494

1130 Souza, J. D. S., Fleck, M. D., Delabie, J. H. C., & Boscardin, J. (2022). Ant fauna in two
1131 phytophysiognomies of the Cerrado Biome and eucalyptus plantation in Minas Gerais,
1132 Brazil. *Ciência Florestal, 32,* 1894-1909. https://doi.org/10.5902/1980509848351

1133 Souza, T., da Silva, L. J. R., dos Santos Nascimento, G., Assumpção, W. T., & Welter, L. J.
1134 (2023). Soil biota community structure and litter traits of grape vine plantation and natural
1135 ecosystem from Southern Brazil. *European Journal of Soil Biology, 114,* 103451.
1136 https://doi.org/10.1016/j.ejsobi.2022.103451

1137 Suguituru, S. S., Silva, R. R., Souza, D. R. D., Munhae, C. D. B., & Morini, M. S. D. C. (2011).
1138 Ant community richness and composition across a gradient from Eucalyptus plantations
1139 to secondary Atlantic Forest. *Biota Neotropica, 11,* 369-376.
1140 https://doi.org/10.1590/S1676-06032011000100034

1141 Tavares, A. A., Bispo, P. C., & Zanzini, A. C. (2008). Effect of collect time on communities of
1142 epigaeic ants (Hymenoptera: Formicidae) in areas of Eucalyptus cloeziana and cerrado.
1143 *Neotropical Entomology, 37,* 126-130. https://doi.org/10.1590/S1519-
1144 566X2008000200003

1145 Vanolli, B. S., Canisares, L. P., Franco, A. L., Delabie, J. H., Cerri, C. E., & Cherubin, M. R.
1146 (2021). Epigeic fauna (with emphasis on ant community) response to land-use change for

sugarcane expansion in Brazil. *Acta Oecologica, 110,* 103702. https://doi.org/10.1016/j.actao.2021.103702

Vasconcelos, H. L., Vilhena, J. M. S., & Caliri, G. J. A. (2000). Responses of ants to selective logging of a central Amazonian forest. *Journal of Applied Ecology, 37(3),* 508-514. https://doi.org/10.1046/j.1365-2664.2000.00512.x

Viana-Silva, F. E. C., & Jacobi, C. M. (2012). Myrmecofauna of ironstone outcrops: composition and diversity. *Neotropical Entomology, 41,* 263-271. https://doi.org/10.1007/s13744-012-0045-9

Wilker, I., Lasmar, C. J., Schmidt, F. A., da Costa, M. M. S., Almeida, D. D. F., Dutra, D. B. D. S., ... & Ribas, C. R. (2023). Land-use change in the Amazon decreases ant diversity but increases ant-mediated predation. *Insect Conservation and Diversity , 16(3), 379*–392. https://doi.org/10.1111/icad.12632

Figures of qualitative review

Fig. A.1

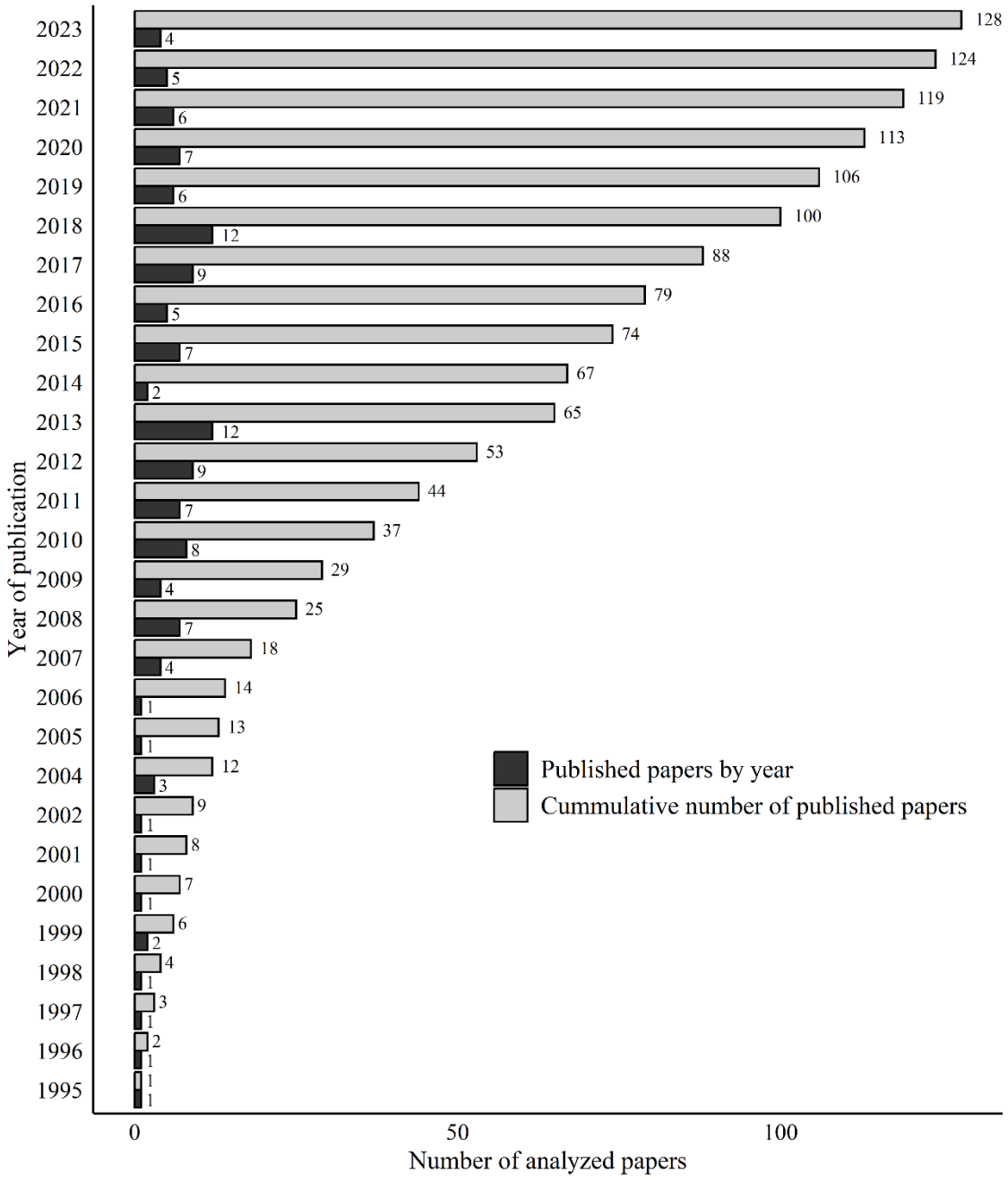


Fig. A.1. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.2

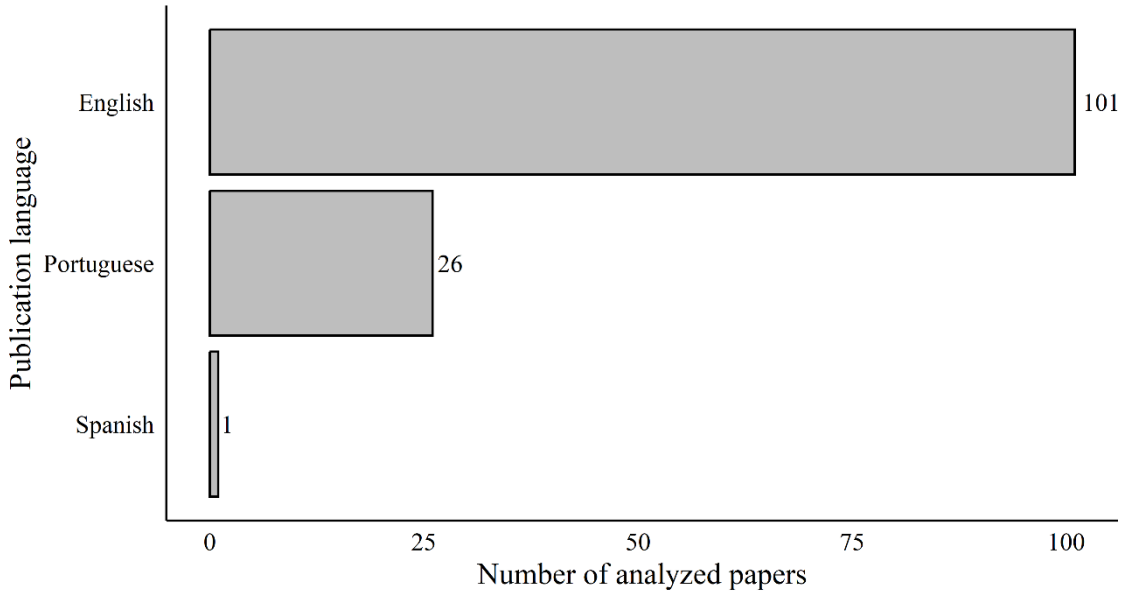


Fig. A.2. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.3

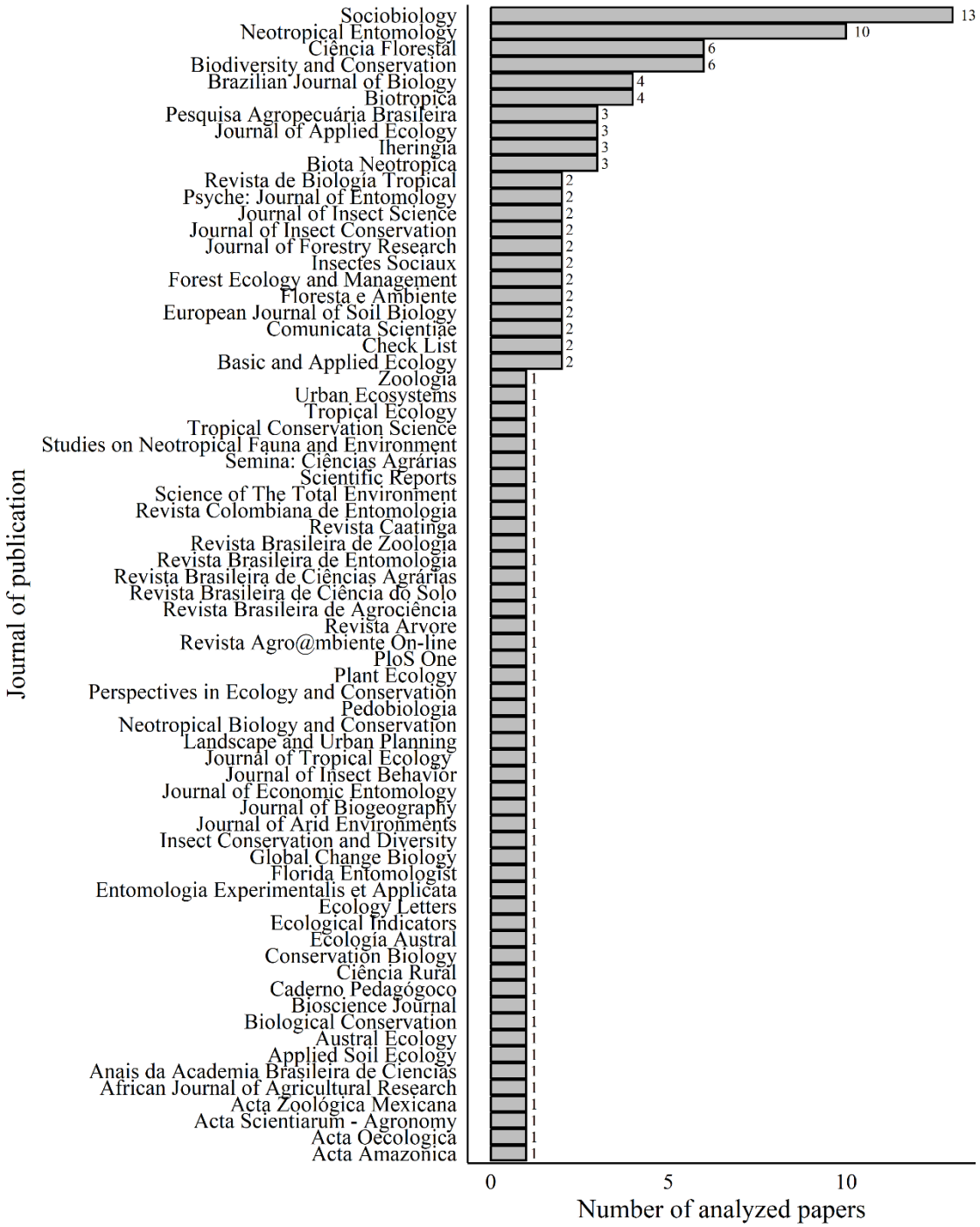


Fig. A.3. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.4

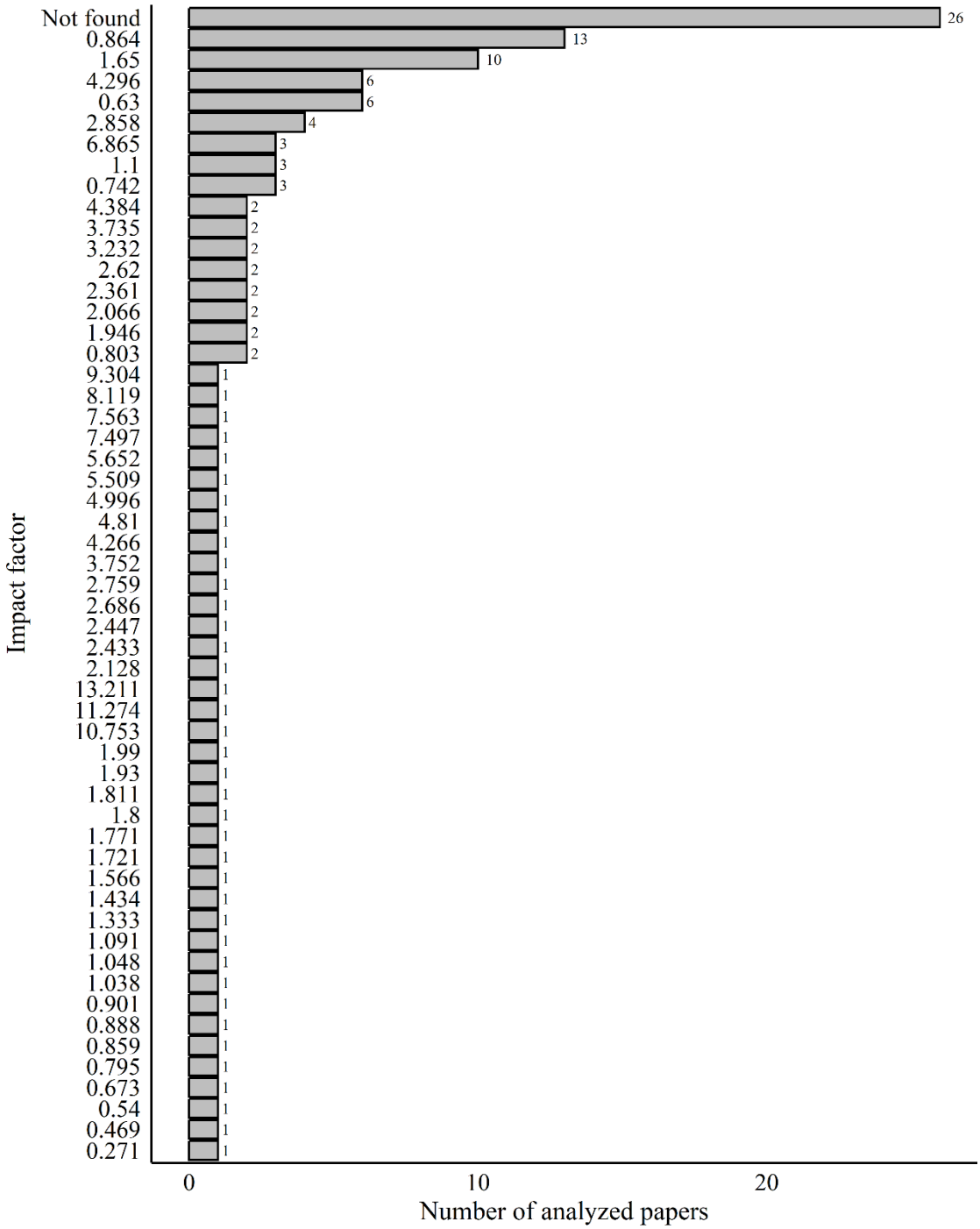


Fig. A.4. Number of analyzed studies related to ants and land use changes in Brazil. “Not found” means that the impact factor is not found for the journal.

Fig. A.5

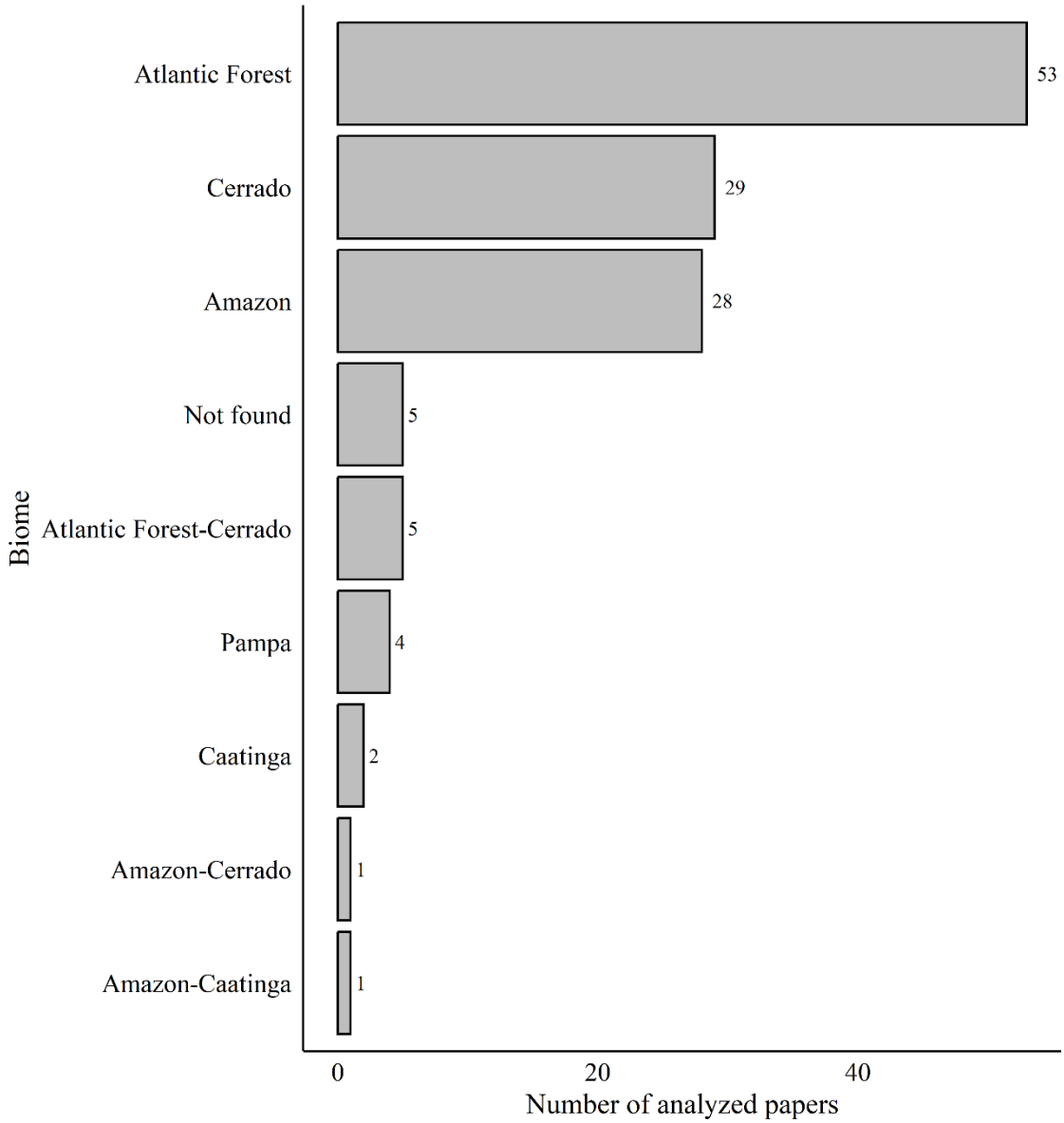


Fig. A.5. Number of analyzed studies related to ants and land use changes in Brazil. “Atlantic Forest-Cerrado”, “Amazon-Cerrado”, and “Amazon-Caatinga” means collection in two biomes. “Not found” means that the biome is not found in the article.

Fig. A.6

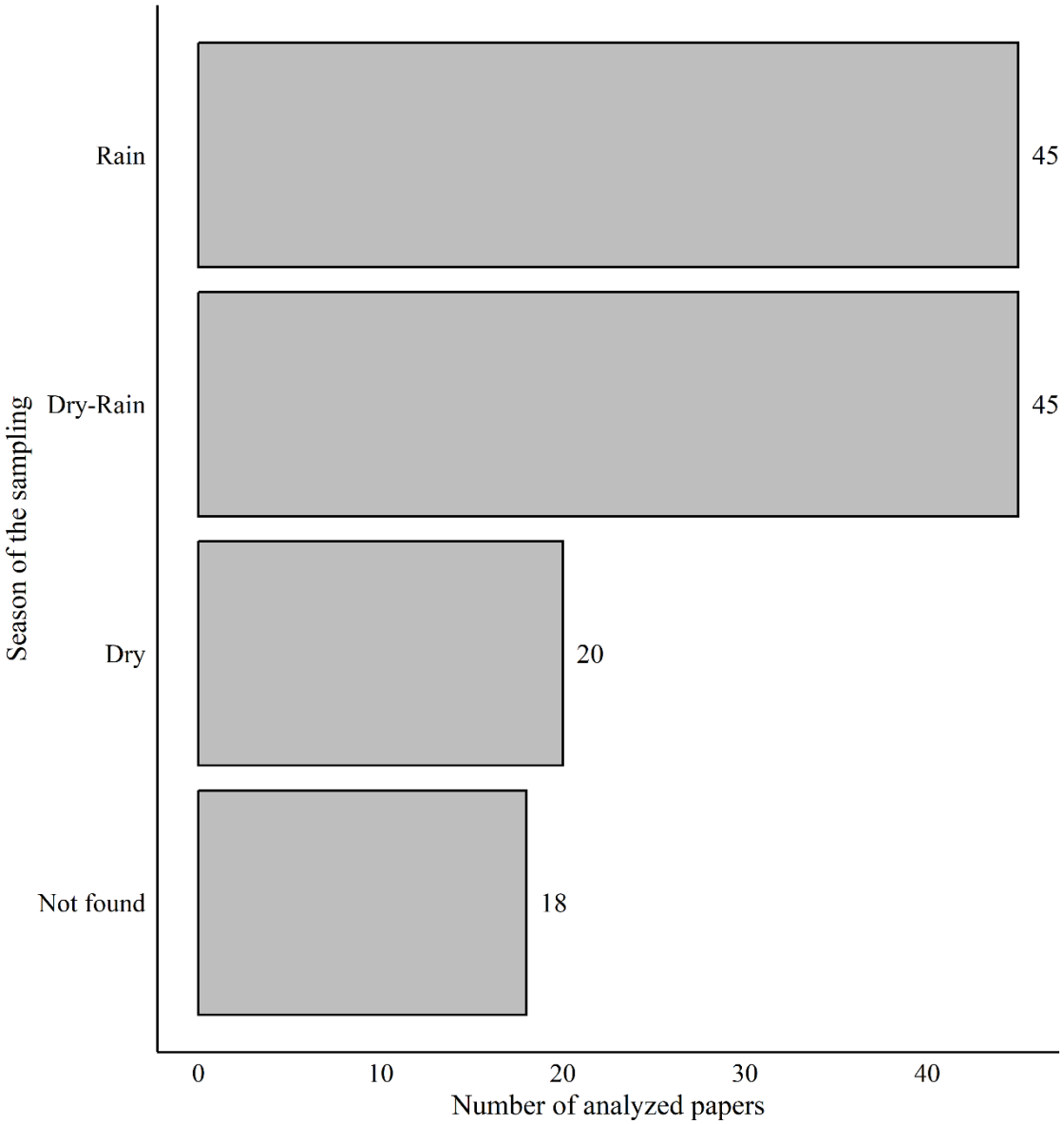


Fig. A.6. Number of analyzed studies related to ants and land use changes in Brazil. “Dry-Rain” means collection in two periods (rain and dry). “Not found” means that the climate seasonality is not found in the article.

Fig. A.7

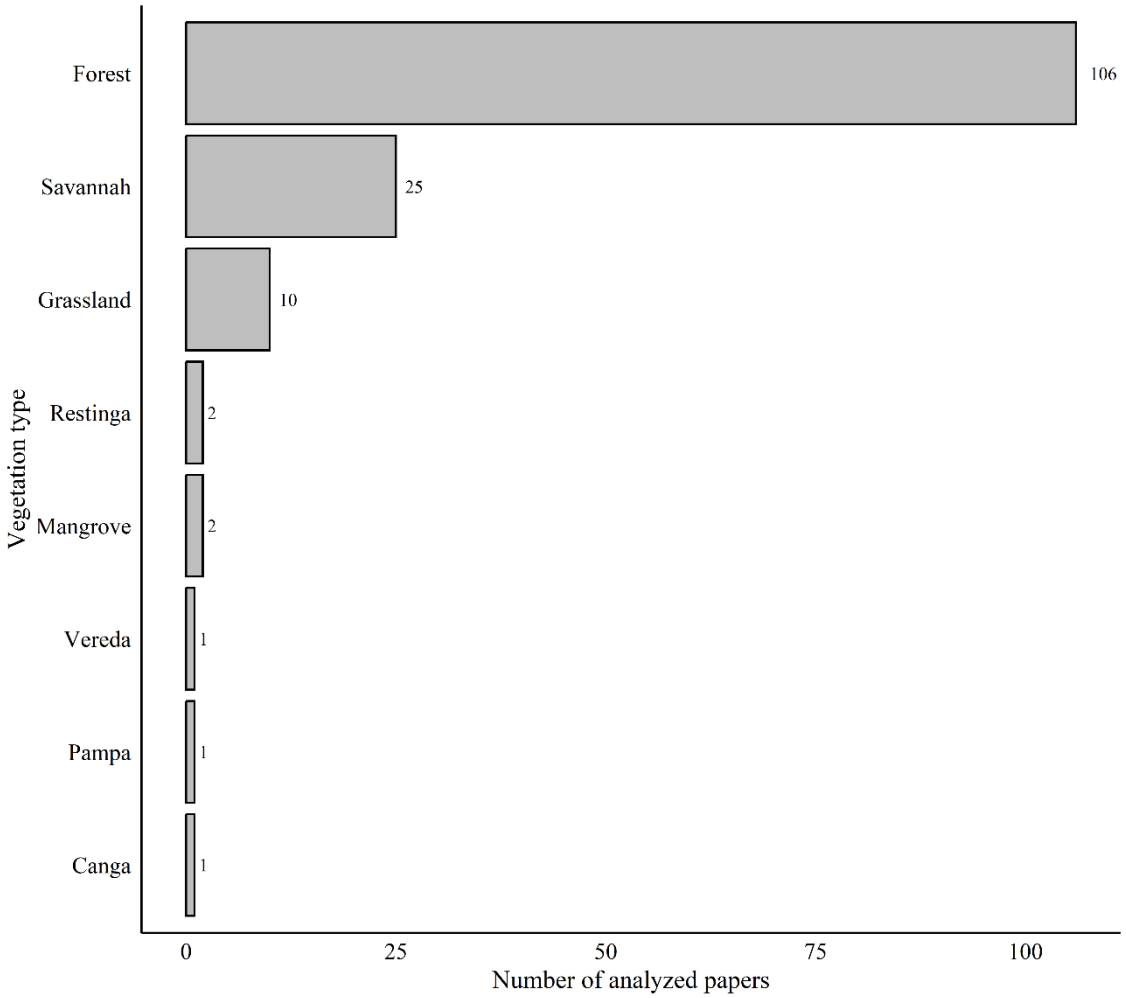


Fig. A.7. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.8

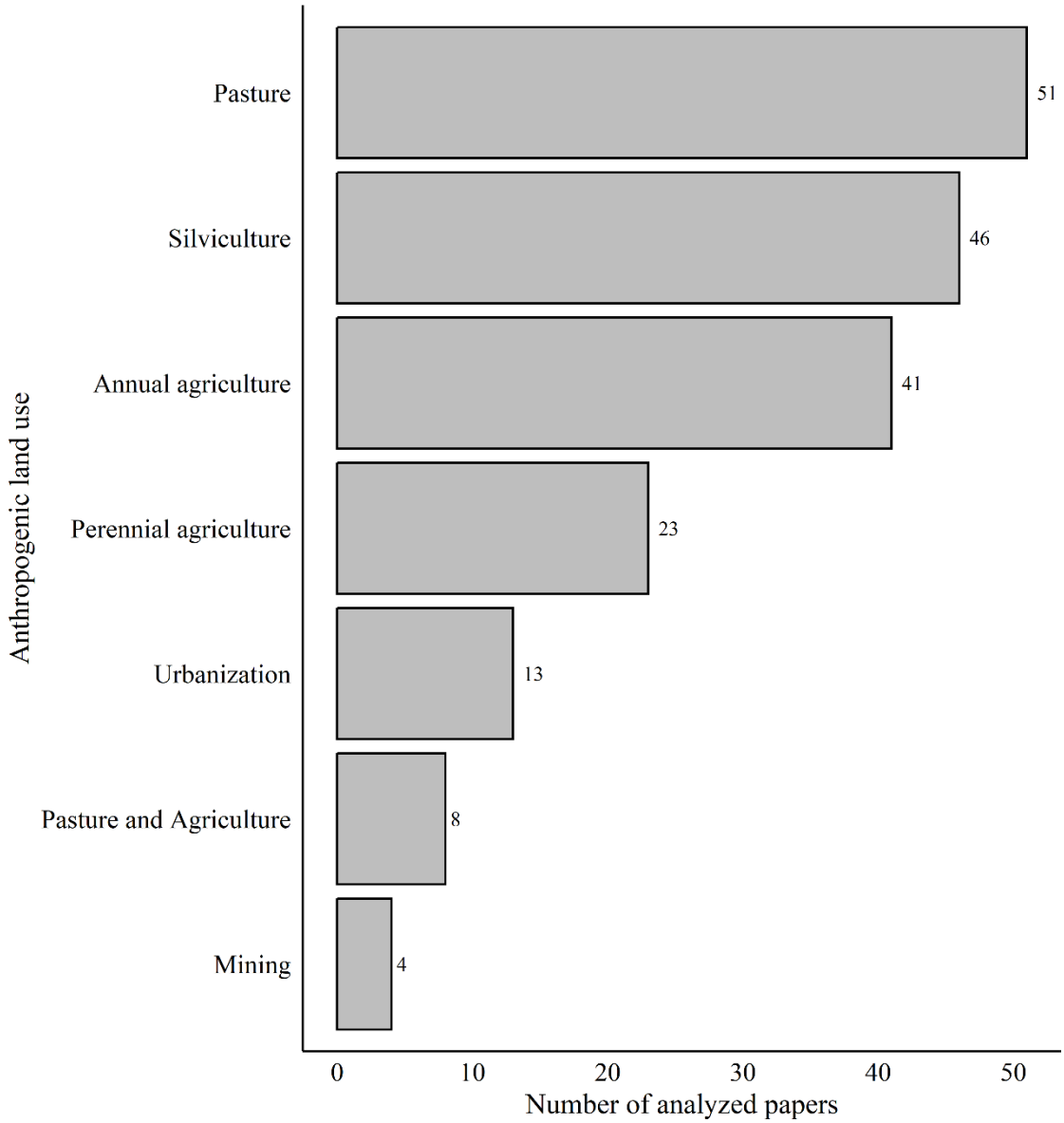


Fig. A.8. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.9

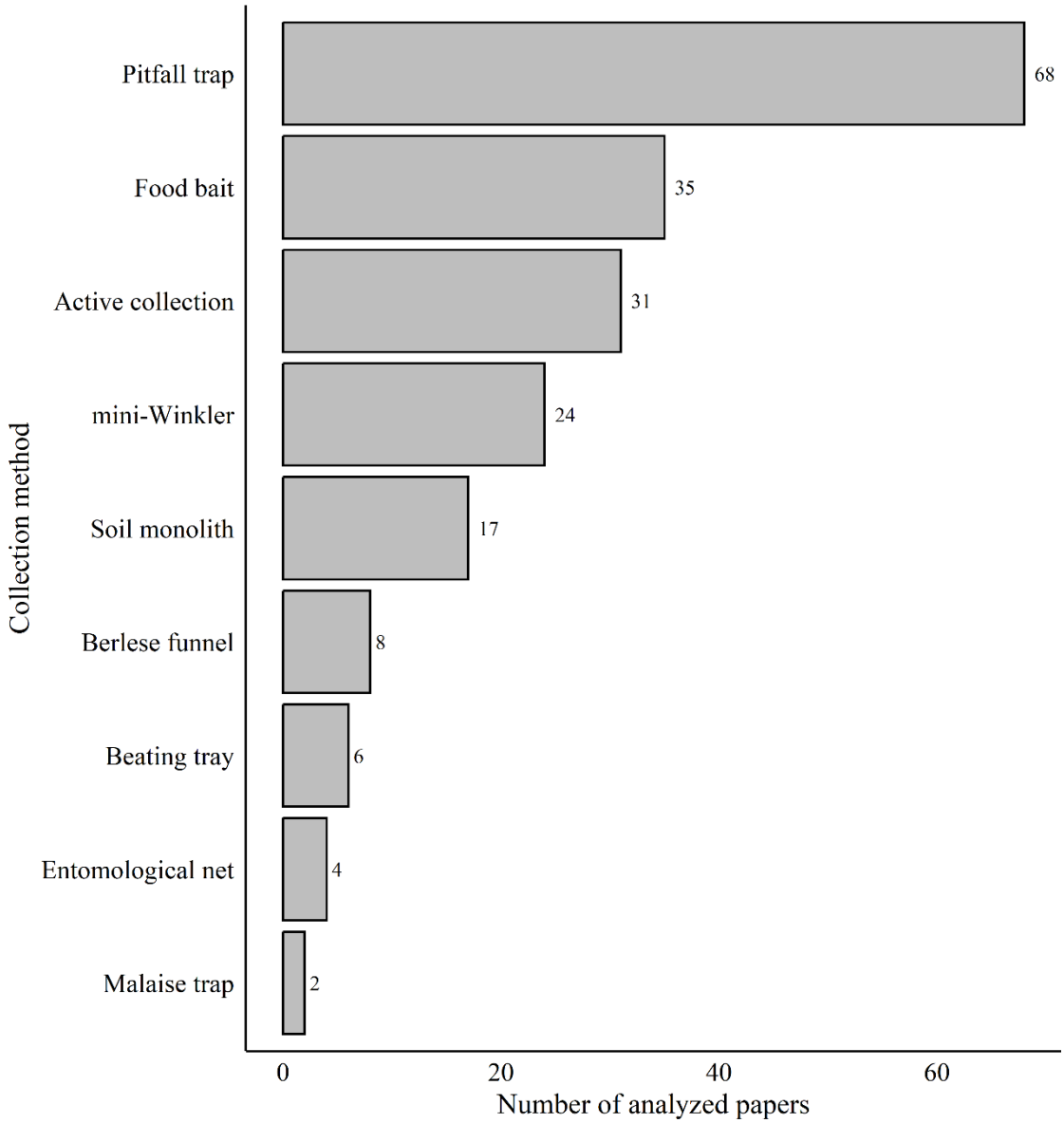


Fig. A.9. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.10

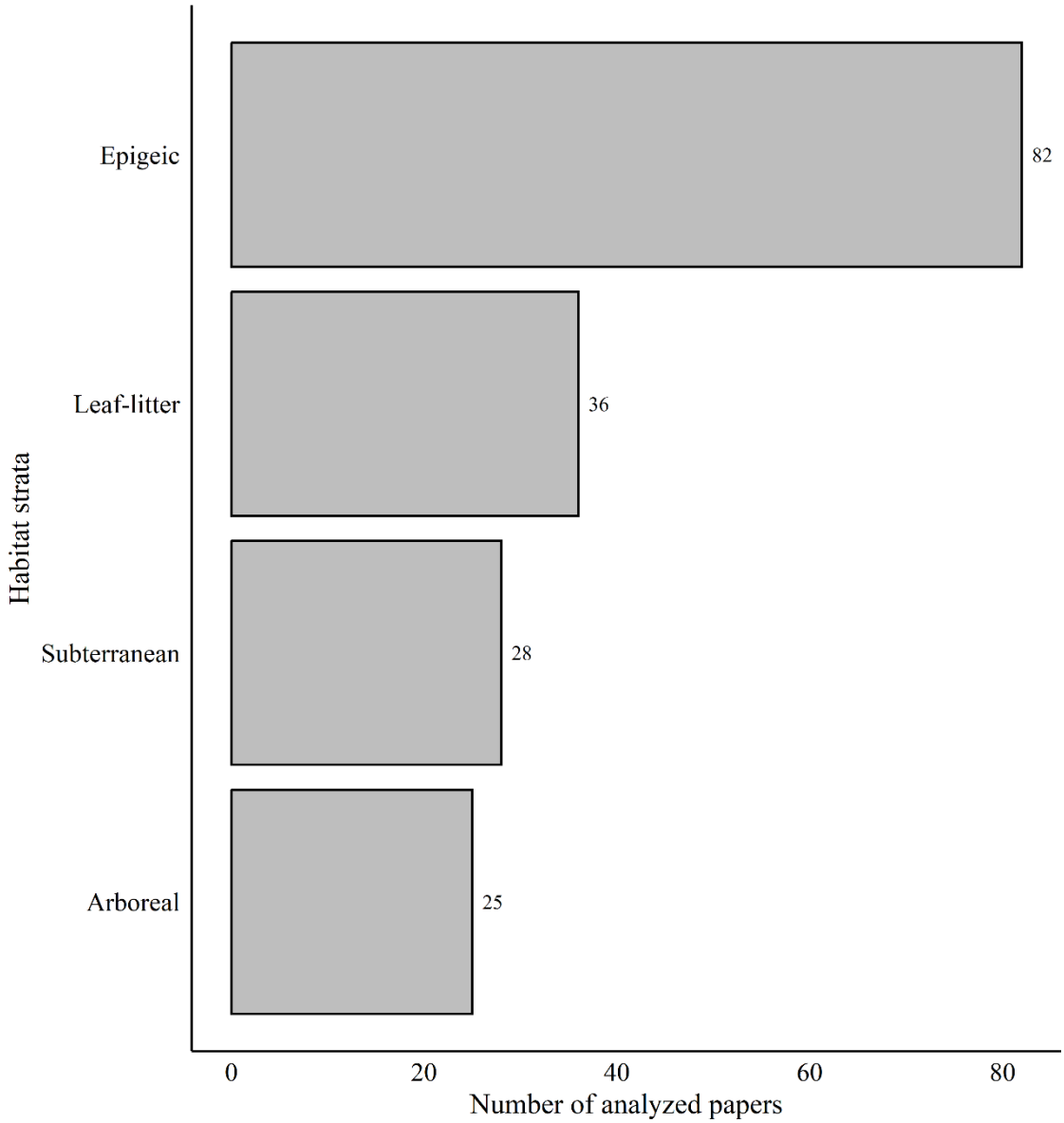


Fig. A.10. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.11

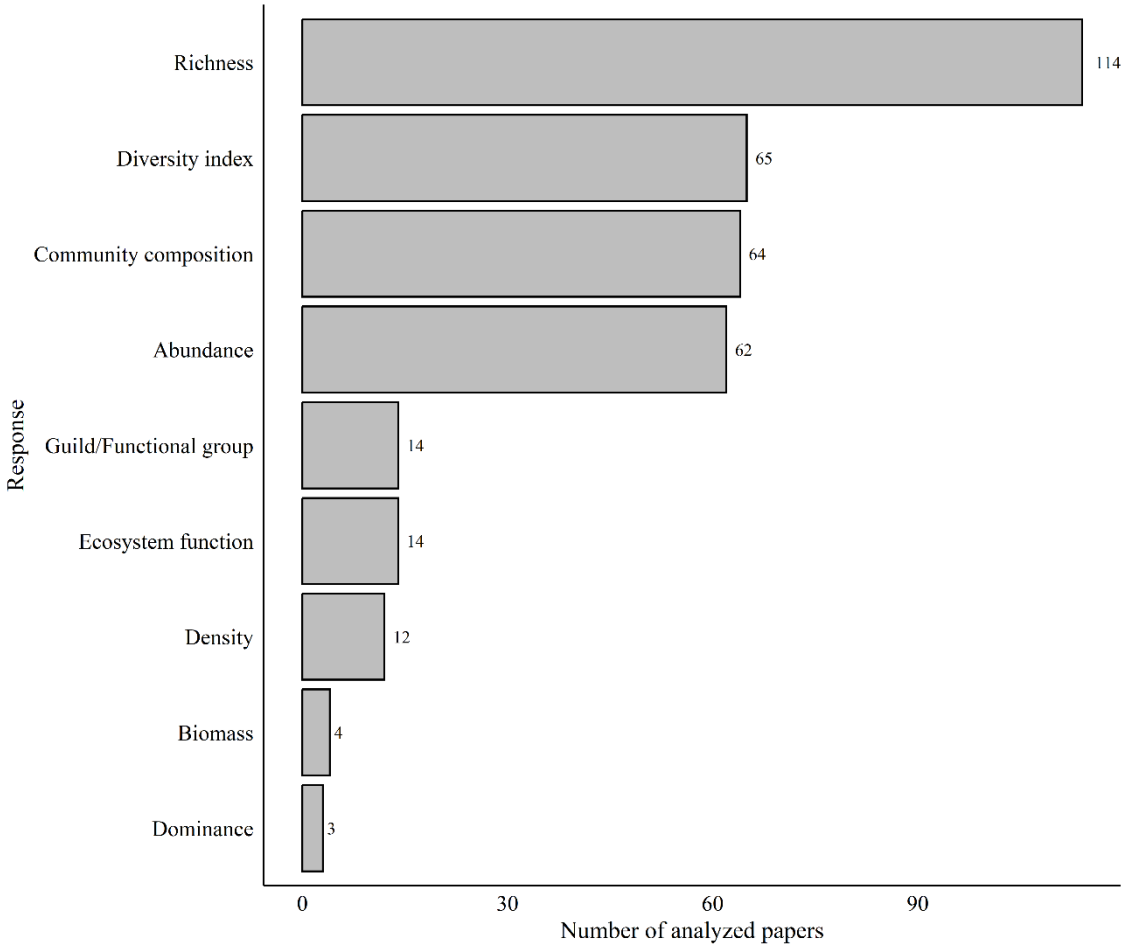


Fig. A.11. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.12

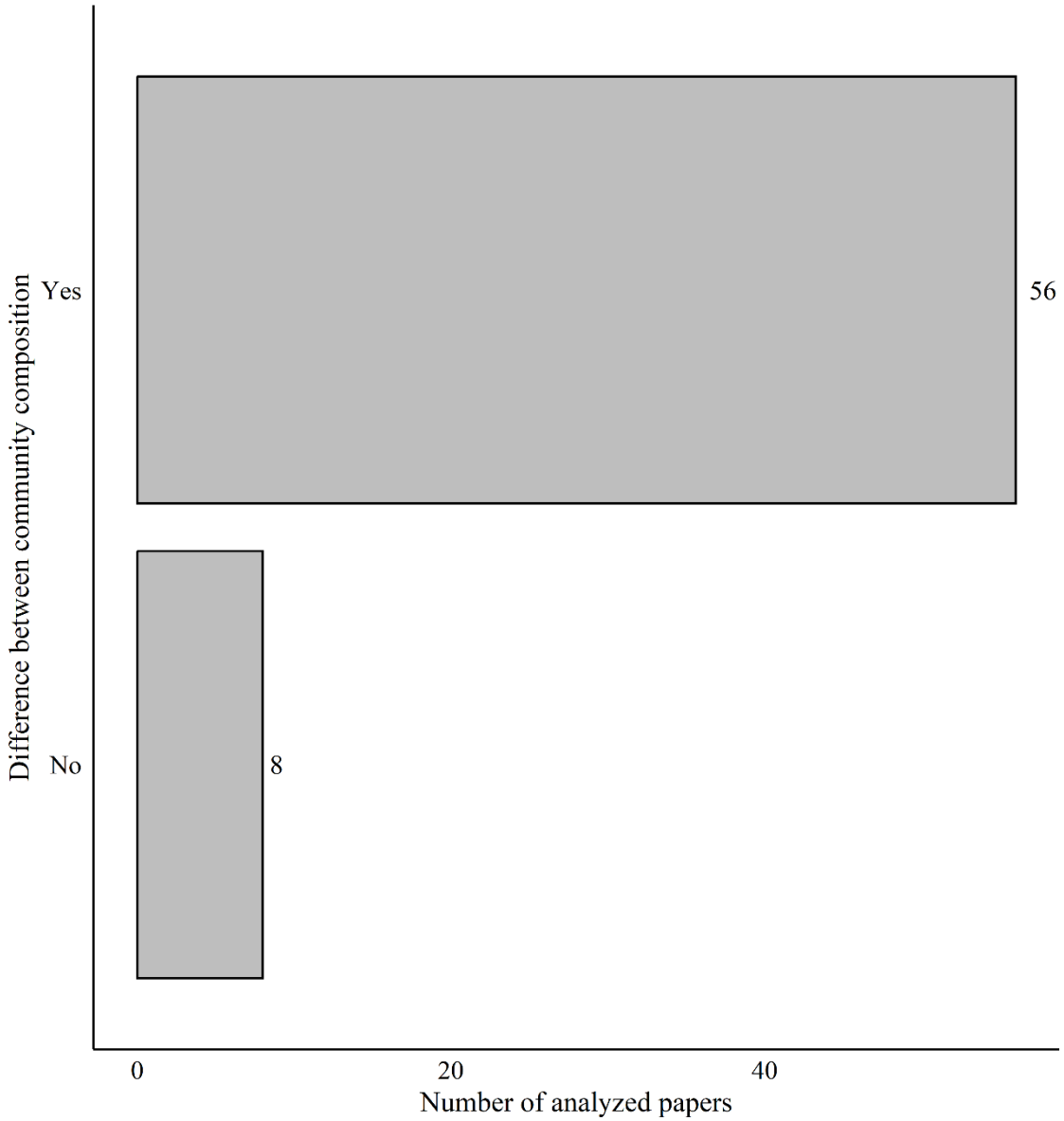


Fig. A.12. Number of analyzed studies related to ants and land use changes in Brazil. The bars indicate the difference of community composition between natural habitat and anthropogenic land use.

Fig. A.13

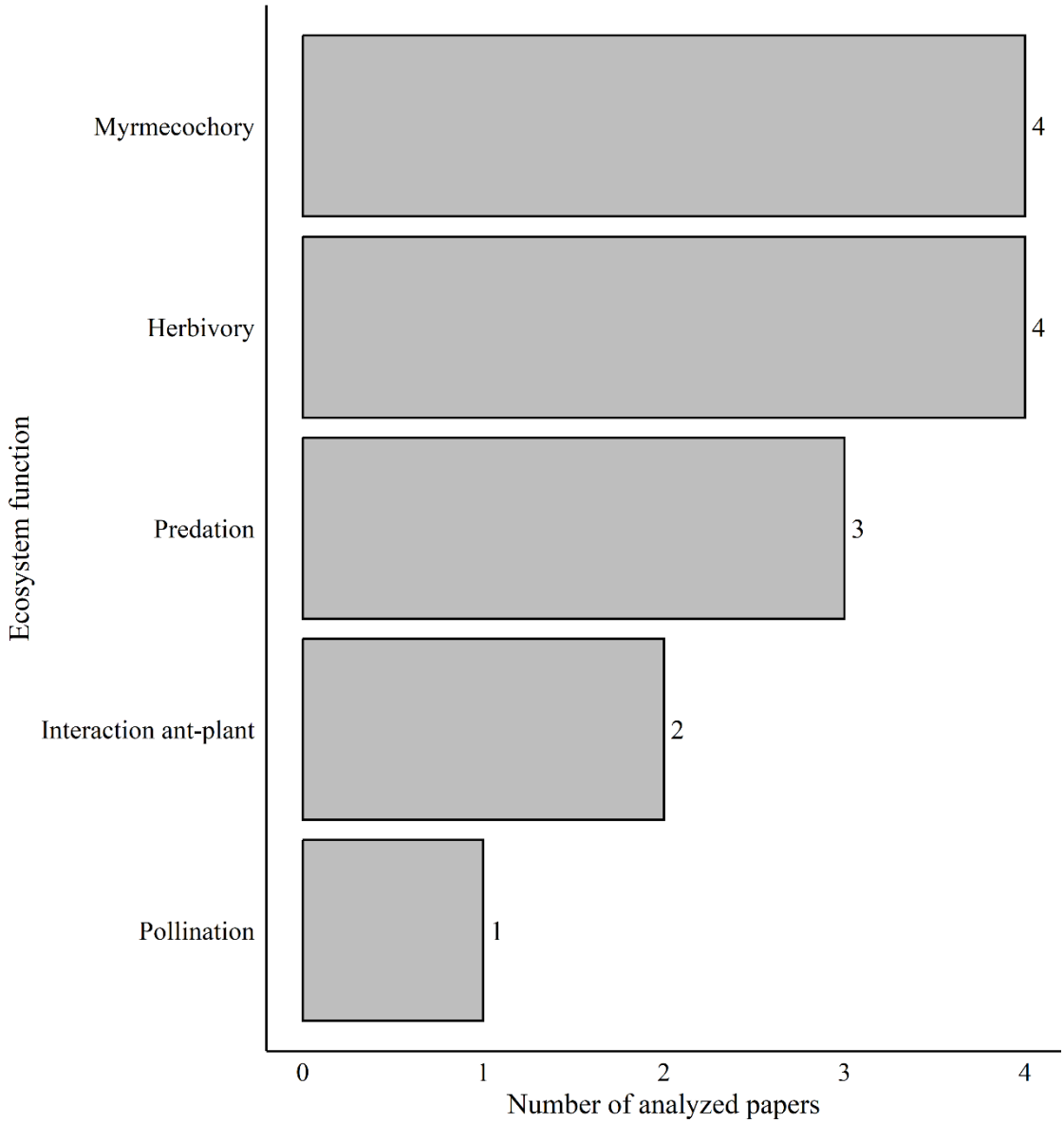


Fig. A.13. Number of analyzed studies related to ants and land use changes in Brazil.

Fig. A.14

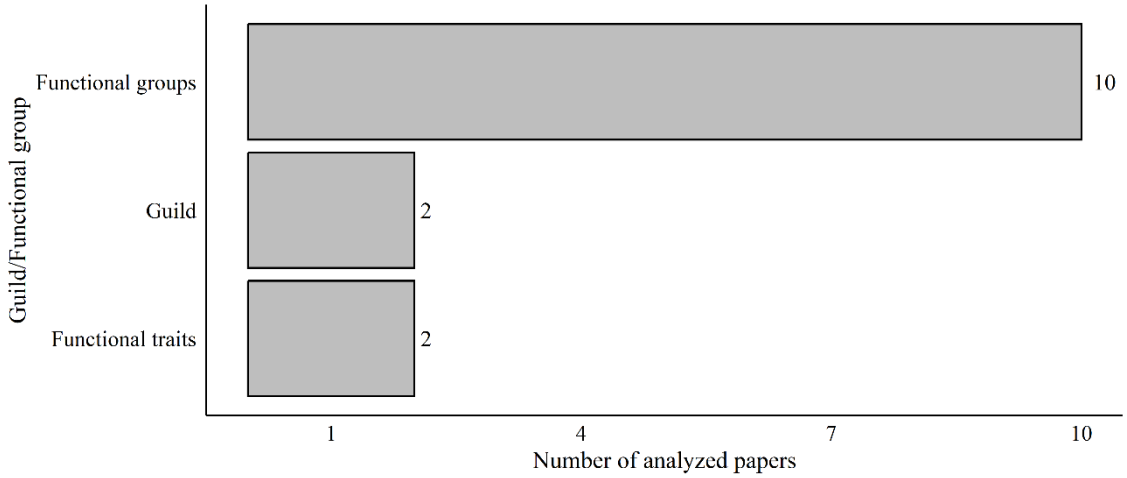


Fig. A.14. Number of analyzed studies related to ants and land use changes in Brazil.

Funnel plots

Fig. A.15

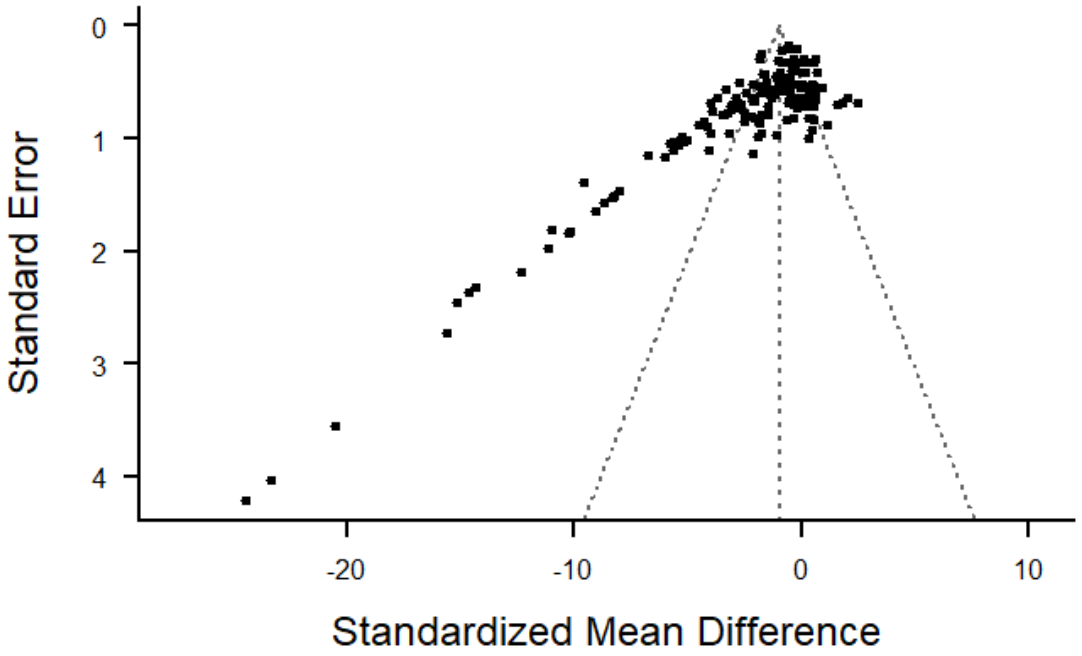


Fig. A.15. Funnel plot for richness of the meta-analysis of published studies on the conversion of natural land use to anthropogenic land use in ant richness. The x-axis indicates de Observed outcome (standardized mean difference), and the y-axis indicates standard error. The white triangle represents the region where 95% of the data points would lie in the absence of a publication bias.

Fig. A.16

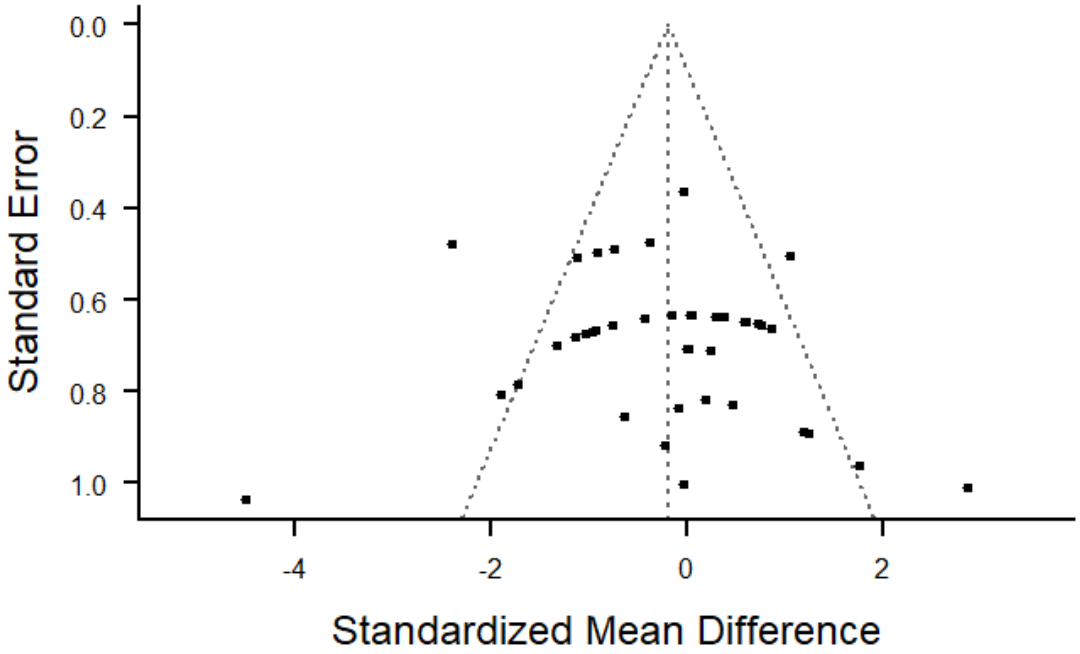


Fig. A.16. Funnel plot for abundance of the meta-analysis of published studies on the conversion of natural land use to anthropogenic land use in ant abundance. The x-axis indicates de Observed outcome (standardized mean difference), and the y-axis indicates standard error. The white triangle represents the region where 95% of the data points would lie in the absence of a publication bias.

Fig. A.17

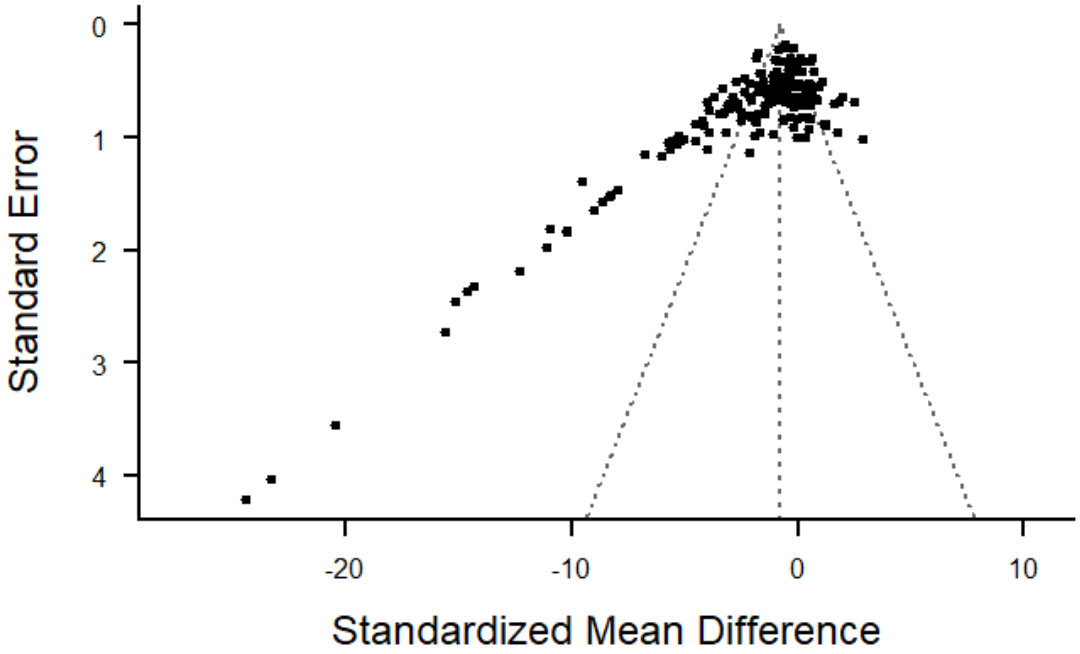


Fig. A.17. Overall funnel plot of the meta-analysis of published studies on the land use changes on ants in Brazil indicating publication bias. The x-axis indicates the Observed outcome (standardized mean difference), and the y-axis indicates standard error. The white triangle represents the region where 95% of the data points would lie in the absence of a publication bias. The funnel indicates that studies with smaller sample sizes (larger standardized error) tend to be published if the result found is negative.

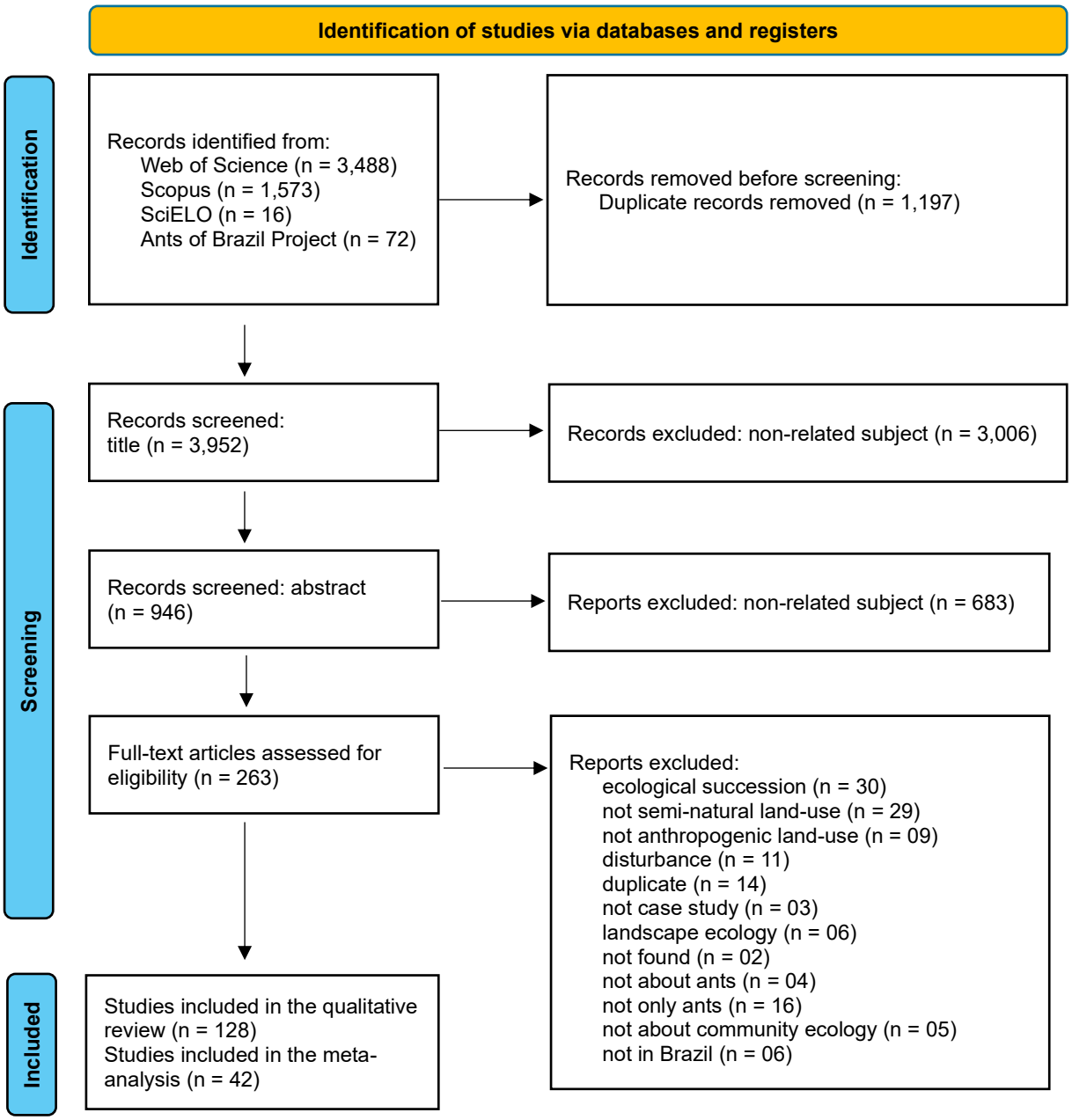
Table A.1. Effect size (E++; Hedges' g, J-corrected form) and confidence intervals (ci.lb: lower bound of the confidence intervals; ci.ub: upper bound of the confidence intervals) for meta-analysis on effects of land use changes with vegetation type moderator. "pval" indicate p value and "p<0.050" indicate significance code "***" to p value < 0.001, "**" to p value = 0.001 and "*" to p value < 0.050. "ns" indicate statistically non-significant.

Biome	E++	ci.lb	ci.ub	pval	p<0.05
Richness					
Amazon	-1.0549	-1.7286	-0.3812	0.0021	**
Atlantic Forest	-0.6516	-1.1643	-0.1390	0.0127	*
Atlantic Forest-Cerrado	-0.1702	-1.4510	1.1106	0.7945	ns
Cerrado	-1.4942	-2.0783	-0.9101	<.0001	***
Pampa	-0.7382	-2.1260	0.6496	0.2971	ns
Abundance					
Amazon	-0.9350	-3.2131	1.3432	0.4212	ns
Atlantic Forest	0.4941	-0.4737	1.4619	0.3170	ns
Atlantic Forest-Cerrado	-0.5038	-2.7366	1.7289	0.6583	ns
Cerrado	-0.8305	-1.9464	0.2854	0.1446	ns

Table A.2. Effect size (E++; Hedges' g, J-corrected form) and confidence intervals (ci.lb: lower bound of the confidence intervals; ci.ub: upper bound of the confidence intervals) for meta-analysis on effects of land use changes with natural ecosystem moderator. "pval" indicate p value and "p<0.050" indicate significance code "***" to p value < 0.001, "**" to p value = 0.001 and "*" to p value < 0.050. "ns" indicate statistically non-significant.

Land-use change type	E++	ci.lb	ci.ub	pval	p<0.05
Richness					
Forest to Annual agriculture	-1.0470	-1.5399	-0.5540	<.0001	***
Forest to Pasture	-0.7776	-1.2409	-0.3143	0.0010	**
Forest to Perennial agriculture	-0.6824	-1.3793	0.0146	0.0550	ns
Forest to Silviculture	-0.6847	-1.1522	-0.2172	0.0041	**
Forest to Urbanization	-2.3533	-3.9813	-0.7253	0.0046	**
Savannah to Annual agriculture	-0.9282	-1.7453	-0.1111	0.0260	*
Savannah to Pasture	-1.4501	-2.0835	-0.8167	<.0001	***
Savannah to Silviculture	-1.8633	-2.5047	-1.2220	<.0001	***
Savannah to Urbanization	-2.7566	-3.8982	-1.6150	<.0001	***
Grassland to Pasture	0.5893	-0.0439	1.2226	0.0681	ns
Grassland to Perennial agriculture	-0.8206	-2.5454	0.9042	0.3511	ns
Grassland to Silviculture	0.5165	-0.1575	1.1904	0.1331	ns
Abundance					
Forest to Annual agriculture	-0.5558	-1.4137	0.3022	0.2042	ns
Forest to Pasture	0.0367	-0.7962	0.8695	0.9312	ns
Forest to Silviculture	0.1016	-0.6232	0.8264	0.7835	ns
Savannah to Annual agriculture	-1.2261	-2.3209	-0.1312	0.0282	*
Savannah to Pasture	0.3573	-0.5819	1.2966	0.4559	ns
Savannah to Silviculture	-0.7927	-1.6420	0.0567	0.0674	ns

Appendix B



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

TERCEIRA PARTE

CONSIDERAÇÕES FINAIS

Nesta tese, encontrei importantes resultados para a ecologia de comunidades e ecossistemas, abordando os impactos dos usos do solo em ambientes tropicais. Avancei na compreensão da ecologia trófica e funcional ao identificar que as formigas modificam suas preferências por recursos alimentares dependendo do bioma e do tipo de uso do solo. Por exemplo, observamos maior forrageamento por aminoácidos na Mata Atlântica em comparação ao Cerrado, sugerindo que formigas da Mata Atlântica são mais limitadas por aminoácidos. Também encontrei uma relação positiva entre o consumo de recursos energéticos e a predação de insetos, sugerindo que formigas predadoras apresentam limitações energéticas. Adicionalmente, verifiquei que os usos do solo afetam direta e indiretamente a função de predação de insetos, sendo esse efeito mediado pela riqueza geral de espécies e pela riqueza de formigas predadoras.

Adicionalmente, fiz uma revisão sistemática com meta-análise e constatei que, no Brasil, usos do solo mais contrastantes (por exemplo, a conversão de florestas para pastagens) reduzem drasticamente a riqueza de formigas e alteram a composição das espécies. Esse tipo de impacto é especialmente evidente nos biomas Amazônia, Cerrado e Mata Atlântica, sendo os dois últimos considerados *hotspots* globais de biodiversidade. No entanto, identifiquei lacunas no conhecimento sobre os efeitos dos usos do solo no Brasil, como a escassez de estudos sobre interações tróficas e funções ecossistêmicas, além do baixo número de estudos em biomas como Caatinga, Pantanal e Pampa.

De maneira geral, identifiquei que as alterações no uso do solo causam impactos negativos significativos nas comunidades terrestres, especialmente em conversões entre habitats com estruturas contrastantes. Diante disso, considero fundamental que as avaliações desses impactos levem em conta o contexto espacial das comunidades, abrangendo tipos de habitat, vegetação e biomas. Além disso, os efeitos do uso do solo podem se manifestar de forma direta e indireta, influenciando a atividades de forrageio e funções ecossistêmicas, onde o mecanismo principal pode ser a perda de riqueza de espécies e alteração na composição de espécies. Assim, como estratégia prática de conservação, evitar conversões extremas no uso do solo pode minimizar impactos negativos sobre a biodiversidade, tanto na conservação de espécies quanto no funcionamento dos ecossistemas. Isso não apenas contribui para a preservação da riqueza e composição das espécies, mas também ajuda a mitigar efeitos adversos sobre funções e serviços ecossistêmicos em habitats antropizados, promovendo a conservação da biodiversidade em ambientes naturais.

Por fim, as mídias de divulgação científica da tese buscam aproximar o conhecimento acadêmico do público em geral, despertando a curiosidade de pessoas fora da universidade sobre a ecologia. A notícia veiculada no Portal da Ciência da UFLA apresentou, de forma acessível, como os usos do solo no Brasil impactam a fauna de formigas, destacando a relevância da manutenção de áreas antropizadas próximas ao habitat nativo original. A notícia foi publicada em 09 janeiro de 2025, e até então, possui 673 acessos. Além disso, como popularização da ciência, desenvolvi um jogo de cartas com livro de regras ilustrado sobre interações tróficas e efeitos de impactos antrópicos no Cerrado, voltados principalmente para crianças a partir de oito anos e professores do ensino básico. Esses materiais têm o objetivo de auxiliar no ensino de cadeias alimentares de maneira lúdica e dinâmica.

APÊNDICE A – Mídias de divulgação

Pesquisa da UFLA analisa como as mudanças nos usos do solo afetam a diversidade de formigas no Brasil

Notícia escrita por Mayara Mesquita Silva

A primeira mídia de divulgação desta tese é uma notícia publicada no Portal da Ciência da UFLA, voltada principalmente para o público adulto. Nela, apresentamos de forma acessível a revisão sistemática com meta-análise publicada na revista *Biological Conservation*. Explicamos de maneira clara como o estudo foi conduzido e destacamos seus principais resultados.

Link da notícia: *https://ciencia.ufla.br/reportagens/meio-ambiente/1046-pesquisa-da-ufla-analisa-como-as-mudancas-nos-usos-do-solo-afetam-a-diversidade-de-formigas-no-brasil*

Figura 1 – Postagem da notícia no Instagram

Legenda: Primeira imagem da postagem do perfil @cienciaufla no Instagram sobre a notícia da revisão sistemática do Formigas do Brasil.

Fonte: Universidade Federal de Lavras (2024).

Guardiões do Cerrado: Entre Predadores e Presas

Icaro Wilker, Dara V. Alves, Guilherme P. Alves, Chaim J. Lasmar, Antônio C. M. Queiroz, Marília M. S. Costa, Carla R. Ribas

A segunda mídia de divulgação desta tese é um jogo de cartas de duelo ambientado no bioma Cerrado. O jogo explora relações tróficas, onde herbívoros atacam plantas, predadores atacam herbívoros e assim por diante, tornando o aprendizado sobre ecologia dinâmico e acessível ao público fora da academia. Além das relações tróficas, incluímos cartas de mutualismo, competição e decomposição, ampliando a compreensão das interações ecológicas. Cartas de habitat natural fortalecem as espécies, enquanto impactos antrópicos as enfraquecem, abordando a conservação da biodiversidade. O jogo e o livro de regras serão disponibilizados gratuitamente *online*, com foco especial em professores e alunos do 4º ano do ensino fundamental, alinhando-se a três das cinco habilidades da BNCC[1].

Figura 1 – Exemplo de carta

Legenda: Exemplo de uma carta de Planta do jogo de baralho sobre interações tróficas.

Fonte: Wilker (2025)

(EF04CI04): Analisar e construir cadeias alimentares simples, reconhecendo a posição ocupada pelos seres vivos nessas cadeias e o papel do Sol como fonte primária de energia na produção de alimentos;

(EF04CI05): Descrever e destacar semelhanças e diferenças entre o ciclo da matéria e o fluxo de energia entre os componentes vivos e não vivos de um ecossistema;

(EF04CI06): Relacionar a participação de fungos e bactérias no processo de decomposição, reconhecendo a importância ambiental desse processo.

[1]BRASIL. Ministério da Educação. **Base Nacional Comum Curricular**. Brasília, DF: MEC, 2018.