

UNIVERSIDADE FEDERAL DE VIÇOSA

**Efeitos do rompimento da barragem de Fundão na comunidade de Orthoptera
da mata ciliar da bacia do Rio Doce**

Nádia Kroth
Doctor Scientiae

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Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Ecologia, para obtenção do título de *Doctor Scientiae*.

Orientador: Ricardo R. de Castro Solar

Coorientadores: Thiago Gechel Kloss
Carlos Frankl Sperber

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“Se admirava de como um grilo sozinho, um só pequeno grilo, podia desmontar os
silêncios de uma noite!”
(Aprendimentos - Manoel de Barros)

RESUMO

KROTH, Nádia, D.Sc., Universidade Federal de Viçosa, julho de 2025. **Efeitos do rompimento da barragem de Fundão na comunidade de Orthoptera da mata ciliar da bacia do Rio Doce.** Orientador: Ricardo Ribeiro de Castro Solar. Coorientadores: Thiago Gechel Kloss e Carlos Frankl Sperber.

Perturbações causadas por atividades antrópicas podem impactar ecossistemas e organismos em graus variados, desde mudanças populacionais e variações morfológicas até alterações em comunidades e funções ecossistêmicas. Dentre as maiores perturbações relacionadas a atividades antrópicas na história do Brasil, destaca-se o rompimento da barragem de Fundão, em Mariana-MG, que causou impactos significativos na biodiversidade da bacia do Rio Doce. Entre os organismos indicados para entender os efeitos destes impactos estão os ortópteros. Esses organismos são sensíveis a alterações ambientais, e exercem funções ecológicas importantes como herbívoros, onívoros, predadores ou detritívoros, atuam na dispersão de sementes e servem de alimento para diversos animais. No entanto, pouco ainda se sabe sobre os efeitos desse distúrbio sobre estes organismos. Diante desta lacuna, nosso objetivo geral foi avaliar como os impactos do rompimento da barragem de Fundão influenciaram a comunidade de Orthoptera da mata ciliar da bacia do Rio Doce. A partir deste objetivo, esta tese foi estruturada em dois capítulos. O primeiro capítulo buscou avaliar se há efeitos de longo prazo da perturbação e indícios de persistência temporal desses efeitos na comunidade de ortópteros na bacia do Rio Doce. Já o segundo capítulo buscou avaliar se as mudanças ambientais causadas pelo distúrbio podem alterar a morfologia de espécies de grilos de serrapilheira na área da bacia mais severamente impactada, o rio Gualaxo do Norte. Para isso, no primeiro capítulo amostramos com armadilhas de queda a comunidade de ortópteros em cinco regiões da bacia do Rio Doce, em áreas de referência e impactadas, nos períodos de seis e quase oito anos após o distúrbio. No segundo capítulo, amostramos em áreas afetadas e não afetadas pelos rejeitos às margens do rio Gualaxo do Norte e selecionamos para o estudo as espécies que apresentavam i) organismos adultos, ii) presença da espécie em ambas as áreas, iii) mínimo de sete indivíduos de cada espécie em cada área e iv) apêndices locomotores intactos. Com estes critérios selecionamos duas espécies *Amanayara bernardesi* Pereira, Sperber & Lhano, 2010 e *Ubiquepuella telytokous* Fernandes, 2015 e medimos seis características morfológicas em todos os indivíduos dessas espécies. Observamos no primeiro capítulo, que as perturbações ainda afetam a comunidade de ortópteros, indicando impactos de longo prazo e

persistência temporal. Houve um aumento da abundância de indivíduos nas áreas impactadas, alteração da composição de espécies e efeito negativo com o aumento da distância do impacto na abundância e na riqueza de espécies, ainda que sem alteração na riqueza de espécies entre as áreas. Além disso, observamos um aumento no número de espécies indicadoras associadas às áreas impactadas após quase oito anos, bem como espécies que se mantiveram como indicadoras ao longo do tempo, além da presença de diferentes espécies indicadoras em cada região. Já no segundo capítulo, as alterações ambientais causadas pelo rompimento podem estar atuando como um filtro ambiental para a espécie *A. bernardesi*, pois observamos uma menor variação do tamanho das estruturas corporais desta espécie nas áreas afetadas. Nossos resultados indicam que as alterações ambientais causadas pelo distúrbio continuam influenciando a comunidade de ortópteros a longo prazo e enfatizam a sensibilidade destes organismos às mudanças ambientais. Além disso, demonstra a importância do uso de diferentes abordagens, como a ecologia de comunidades e ecologia funcional, além de características específicas dos organismos e contextos ambientais locais e regionais para entender os efeitos de distúrbios ambientais na biodiversidade terrestre.

Palavras-chave: desastre ambiental; impactos de mineração; ecologia de comunidades; filtro ambiental; ecologia funcional; ecologia de invertebrados

ABSTRACT

KROTH, Nádia, D.Sc., Universidade Federal de Viçosa, July, 2025. **Effects of the Fundão dam collapse on the Orthoptera community in the riparian forest of the Rio Doce watershed.** Adviser: Ricardo Ribeiro de Castro Solar. Co-advisers: Thiago Gechel Kloss and Carlos Frankl Sperber.

Disturbances caused by human activities can impact ecosystems and organisms to varying degrees, from population shifts and morphological variations to alterations in communities and ecosystem functions. Among the largest disturbances related to human activities in Brazilian history is the collapse of the Fundão dam in Mariana, Minas Gerais, which caused significant impacts on the biodiversity of the Rio Doce basin. Among the organisms indicated for understanding the effects of these impacts are Orthoptera. These organisms are sensitive to environmental changes and perform important ecological functions as herbivores, omnivores, predators, or detritivores, dispersing seeds, and serving as food for various animals. However, little is known about the effects of this disturbance on these organisms. Given this gap, our overall objective was to evaluate how the impacts of the Fundão dam collapse influenced the Orthoptera community of the riparian forest of the Rio Doce basin. Based on this objective, this thesis was structured in two chapters. The first chapter sought to assess whether there are long-term effects of the disturbance and evidence of temporal persistence of these effects on the orthopteran community in the Rio Doce basin. The second chapter sought to assess whether the environmental changes caused by the disturbance can alter the morphology of leaf litter cricket species in the most severely impacted area of the basin, the Gualaxo do Norte River. To this end, in the first chapter, we sampled the orthopteran community using pitfall traps in five regions of the Rio Doce basin, in reference and impacted areas, six and almost eight years after the disturbance. In the second chapter, we sampled areas affected and unaffected by the tailings on the banks of the Gualaxo do Norte River and selected for study those species that presented i) adult organisms, ii) presence of the species in both areas, iii) a minimum of seven individuals of each species in each area, and iv) intact locomotor appendages. Using these criteria, we selected two species: *Amanayara bernardesi* Pereira, Sperber & Lhano, 2010 and *Ubiquepuella telytokous* Fernandes, 2015. We measured six morphological characteristics in all individuals of these species. In the first chapter, we observed that the disturbances continue to affect the orthopteran community, indicating long-term and persistent impacts. There was an increase in the abundance of individuals in the impacted areas, a change

in species composition, and a negative effect on abundance and species richness with increasing distance from the impact, although there was no change in species richness between areas. Furthermore, we observed an increase in the number of indicator species associated with the impacted areas after almost eight years, as well as species that remained as indicators over time, in addition to the presence of different indicator species in each region. In the second chapter, the environmental changes caused by the breach may be acting as an environmental filter for *A. bernardesi*, as we observed less variation in the size of this species' body structures in the affected areas. Our results indicate that the environmental changes caused by the disturbance continue to influence the orthopteran community in the long term and emphasize the sensitivity of these organisms to environmental changes. Furthermore, it demonstrates the importance of using different approaches, such as community ecology and functional ecology, as well as specific organismal characteristics and local and regional environmental contexts, to understand the effects of environmental disturbances on terrestrial biodiversity.

Keywords: environmental disaster; mining impacts; community ecology; environmental filtering; functional ecology; invertebrate ecology

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INTRODUÇÃO GERAL

Impactos ambientais causados por atividades humanas podem influenciar a biodiversidade, funções ecossistêmicas e a perda de espécies em comunidades biológicas (Vaz *et al.*, 2023). Os impactos ambientais podem se manifestar em diferentes intensidades, conforme o grau de perturbação do habitat, tal como previsto na teoria de metacomunidades (Leibold *et al.*, 2004). De acordo com essa abordagem, a estruturação das comunidades biológicas resulta de processos locais, como a filtragem ambiental, e regionais, como a dispersão de organismos (Leibold *et al.*, 2004). Assim, perturbações podem levar à extinção local de espécies e, conseqüentemente, à diminuição da diversidade em escala regional (Hillebrand; Blenckner, 2002; Leibold *et al.*, 2004). Além disso, alterações ambientais podem influenciar sobretudo aqueles táxons incapazes de sobreviver em ambientes desfavoráveis (Brückmann; Krauss; Steffan-Dewenter, 2010; Thompson; Rayfield; Gonzalez, 2017). Por fim, atuando como filtros ambientais, as perturbações podem influenciar indivíduos cujas características fenotípicas ou comportamentais assegurem sua persistência nesses sistemas alterados (Ferrando *et al.*, 2016; Jarčuška; Krištín; Kaňuch, 2023; Whitman, 2008).

Efeitos antrópicos sobre as comunidades biológicas são evidentes na bacia hidrográfica do Rio Doce, uma área de elevada importância ecológica e socioeconômica. Com uma extensão de drenagem de 83.300 km², dos quais 86 % localizam-se em Minas Gerais e 14 % no Espírito Santo (ECOPLAN, 2010). A bacia abriga uma biodiversidade notável: 98 % de seu território está inserido no bioma Mata Atlântica, reconhecido como um dos hotspots mundiais de conservação, enquanto os 2 % restantes ocorrem no bioma Cerrado (Mittermeier *et al.*, 2004). A região abriga cerca de 200 unidades de conservação (UC) (Espindola *et al.*, 2016), além de diferentes tipos de solos e de formações florísticas (ECOPLAN, 2010; Ramos, Leticia *et al.*, 2024), distribuídas nas três principais subdivisões da bacia, definidas como alto, médio e baixo Rio Doce (ECOPLAN, 2010; Felipe *et al.*, 2016). Além disso, a região sustenta uma economia diversificada, destacando-se a agropecuária, a agroindústria, a mineração, a indústria, o comércio, os serviços e a geração de energia elétrica (ECOPLAN, 2010; Santolin *et al.*, 2015).

Devido a essa diversificação econômica e expansão do uso antrópico, a bacia do Rio Doce possui um longo histórico de degradação (De Oliveira *et al.*, 2019; Macêdo *et al.*, 2024; Rodrigues *et al.*, 2014; Santolin *et al.*, 2015). Dentre estas atividades econômicas, a mineração é responsável pela maior parte dessa degradação, principalmente por abrigar o maior complexo siderúrgico da América Latina, com a maior área de mineração a céu aberto do mundo (ECOPLAN, 2010; Santolin *et al.*, 2015). Para a expansão das atividades de mineração, grandes áreas florestais foram removidas, além do considerável aumento da contaminação do solo e dos

corpos hídricos por metais pesados derivados da extração de ferro, ouro, bauxita, manganês, pedras preciosas e outros (Aires *et al.*, 2018; Campos *et al.*, 2023; ECOPLAN, 2010; Santolin *et al.*, 2015). Além destes impactos crônicos, atividades de mineração são suscetíveis a grandes desastres, principalmente pela forma de armazenamento dos seus resíduos, que geralmente ocorre em barragens de rejeitos (Azam; Li, 2010). Essas barragens normalmente são projetadas em encostas íngremes e são estruturadas para ter durabilidade (Azam; Li, 2010; Sitharam; Hegde, 2017). No entanto, nas últimas décadas, distúrbios relacionados ao rompimento destas barragens têm chamado a atenção por causarem sérias alterações ambientais e impactos socioeconômicos (Aires *et al.*, 2018; Fernandes *et al.*, 2016; Gomes *et al.*, 2017; Sitharam; Hegde, 2017).

Dentre as alterações ambientais ocasionadas por distúrbios relacionados ao rompimento de barragens de rejeito de mineração estão a perda de áreas florestais (Omachi *et al.*, 2018), diminuição de crescimento e biomassa vegetal (Cruz *et al.*, 2020), alteração de características do solo (Queiroz, Hermano M. *et al.*, 2018), composição da macrofauna (Gomes *et al.*, 2017; Ribeiro *et al.*, 2023) e atividade microbiana do solo (Couto *et al.*, 2021). Além disso, alterações no uso da terra (Neves *et al.*, 2024), na composição florística (Ramos, Letícia *et al.*, 2024) e aspectos funcionais dos organismos (Andrade Soares *et al.*, 2024; Fietto *et al.*, 2024; Ribeiro *et al.*, 2023). Estas alterações influenciam as condições e recursos ambientais importantes para as comunidades de artrópodes (Tews *et al.*, 2004) quanto ao funcionamento do ecossistema (Andersen *et al.*, 2001). Neste contexto, mesmo que atividades de mineração apresentem grande importância econômica no país, trazem consigo os inerentes impactos e a degradação dos ambientes naturais, além de apresentarem alto risco de ocasionar desastres ambientais (Fernandes; Ribeiro, 2017).

Um dos maiores desastres ambientais relacionados à mineração na história do Brasil foi o rompimento da barragem de Fundão, em Mariana-MG, no dia 5 de novembro de 2015 (Fernandes *et al.*, 2016). Com o rompimento, a pluma de rejeitos alcançou centenas de quilômetros ao longo da calha do Rio Doce, além de avançar mais de um quilômetro nas margens em áreas imediatamente afetadas. Ainda, o rejeito percorreu os canais da bacia do Rio Doce por cerca de 663,2 km até o oceano, impactando diretamente a biota aquática, ripária, recursos naturais e processos que sustentavam as populações locais (Fernandes *et al.*, 2016). Com a deposição de rejeito, a vegetação, o solo, a biodiversidade e as funções ecossistêmicas foram impactados (Fernandes; Ribeiro, 2017; Gomes *et al.*, 2017; Omachi *et al.*, 2018; Queiroz *et al.*, 2018). Além disso, a biota ripária, principalmente os artrópodes, organismos sensíveis a alterações ambientais, pode ter sido impactada. Esses organismos são importantes indicadores

ecológicos e tendem a responder rapidamente a alterações nos ecossistemas (Cabette *et al.*, 2017; Ramey; Richardson, 2017; Tews *et al.*, 2004).

Dentre os artrópodes sensíveis às alterações ambientais, se destacam os Orthoptera (gafanhotos, esperanças, grilos e paquinhos). Esses artrópodes fazem parte da meso e macrofauna do solo e estão presentes em praticamente todos os ecossistemas terrestres, principalmente nos trópicos, com cerca de 34 mil espécies descritas (Cigliano *et al.*, 2025). Estes organismos são considerados indicadores de degradação e regeneração florestal (Szinwelski, Neucir *et al.*, 2012), fragmentação de habitat (Ribas *et al.*, 2005), intensidade do uso da terra (Fumy *et al.*, 2020), heterogeneidade e qualidade do habitat (Löffler; Fartmann, 2017), exposição ambiental a compostos de origem antrópica (Wu *et al.*, 2007) e alteram sua composição em ambientes perturbados por mineração (Andersen *et al.*, 2001). A maioria das espécies são herbívoras, algumas são onívoras ou predadoras, enquanto outras se alimentam de matéria orgânica em decomposição (Sperber *et al.*, 2012). Também são importantes dispersores de sementes (Santana; Baccaro; Costa, 2016) e fazem parte da dieta de inúmeras espécies de animais, como aves (Bock; Bock; Grant, 1992) e lagartos (Cappellari; de Lema; Jr, 2007). Assim, participam de funções importantes do ecossistema, como produtividade e decomposição (Deraison *et al.*, 2015). Além disso, costumam ser sensíveis e responder às perturbações ambientais de diferentes formas, como alterações na comunidade (Tews *et al.*, 2004), interações (Valiente-Banuet *et al.*, 2015) e aspectos funcionais (Ferrando *et al.*, 2016).

Considerando esta variedade de funções ecológicas e sua sensibilidade a alterações ambientais, os ortópteros podem refletir o estado de integridade do ambiente no qual estão inseridos (Anso *et al.*, 2022; Fumy *et al.*, 2020; Löffler; Fartmann, 2017). Uma das formas deste grupo de artrópodes responder às mudanças no ambiente é alterando a composição de espécies da comunidade. Um exemplo disso, são as mudanças na composição de ortópteros em ambientes perturbados pela mineração (Andersen *et al.*, 2001), mudanças no uso da terra (Ogan *et al.*, 2022), diminuição da vegetação e aumento da urbanização (Pernat; Buchholz; Schirmel, 2024), estado de regeneração (Alignan; Debras; Dutoit, 2014) e do grau de distúrbio (Basset *et al.*, 2008). Além disso, são conhecidos por alterar e reduzir sua diversidade e sua população de indivíduos dependendo do estado de recuperação do ambiente (Alignan; Debras; Dutoit, 2014, 2018; Anso *et al.*, 2022; Hoffmann; Lowe; Griffiths, 2002; Pernat; Buchholz; Schirmel, 2024), diferentes elevações (Thomas; Segar; Cherrill, 2024), heterogeneidade do habitat (Löffler; Fartmann, 2017; Weiqiang *et al.*, 2023) e condições e recursos disponíveis, além de mudanças no micro e macroclima (König *et al.*, 2024).

Por outro lado, além dos efeitos na comunidade, as alterações ambientais podem influenciar aspectos funcionais, desde características morfológicas até aspectos relacionados à história de vida destes organismos. Alterações na morfologia corporal adulta de ortópteros podem influenciar diretamente suas funções ecossistêmicas (Whitman, 2008). Estudos mostram que indivíduos expostos a distúrbios, como queimadas, tendem a apresentar menor tamanho corporal (Ferrando *et al.*, 2016), além de mudanças na mobilidade, nos hábitos alimentares e no uso do habitat em diferentes estratos da vegetação e proximidade com estradas (Rebrina *et al.*, 2022). De forma semelhante, em áreas com alta intensidade de uso da terra, tendem a persistir espécies menores, mais móveis e menos especializadas (Simons; Weisser; Gossner, 2016). Essas alterações no tamanho corporal, além de refletirem mudanças nas condições do ambiente, também podem ter implicações diretas na ecologia e na dinâmica populacional destes organismos. Por exemplo, a variação do tamanho do corpo pode implicar na variação de taxas metabólicas, aspectos de longevidade, fecundidade e sucesso reprodutivo (Chown; Gaston, 2010; Laiolo; Illera; Obeso, 2013; Wey; Réale; Kelly, 2019; Whitman, 2008). Além disso, o tamanho do corpo pode influenciar mudanças no nicho alimentar e nas funções ecossistêmicas desempenhadas, como produtividade e decomposição (Deraison *et al.*, 2015). Portanto, alterações em aspectos funcionais dos ortópteros podem influenciar, além de aspectos populacionais, interações tróficas e mudanças nos outros níveis de organização biológica do ambiente (DeLong *et al.*, 2015; Woodward *et al.*, 2005).

Diante disso, tanto medidas de diversidade taxonômicas quanto funcionais se complementam para prever alterações no funcionamento (Flynn *et al.*, 2011; Gagic *et al.*, 2015) e no estado de perturbação de ecossistemas (Mouillot *et al.*, 2013). Assim, compreender como os ortópteros em diferentes proporções foram afetados, tanto taxonômica quanto funcionalmente é essencial, pois impactos sobre estes organismos podem gerar efeitos em toda comunidade biológica local e regional e no funcionamento do ecossistema. A partir disso, nosso objetivo geral foi avaliar como os impactos do rompimento da barragem de Fundão influenciaram a comunidade de Orthoptera da mata ciliar da bacia do Rio Doce. Para isso, esta tese foi estruturada em dois capítulos, redigidos e estruturados como manuscritos para submissão a periódicos científicos.

Capítulo I: Do colapso à mudança na comunidade: estrutura da comunidade de ortópteros e espécies indicadoras após o rompimento da barragem de Fundão, Mariana, MG, Brasil.

Neste capítulo investigamos se há efeitos de longo prazo da perturbação e indícios de persistência temporal desses efeitos na comunidade de ortópteros na bacia do Rio Doce. Para isso, testamos duas hipóteses: 1) de que a perturbação influencia negativamente a comunidade de ortópteros em áreas impactadas; portanto, esperamos um número menor de espécies e um número maior de indivíduos nessas áreas, além de uma composição de espécies mais homogênea, dominada por espécies resistentes. Também esperamos encontrar espécies indicadoras associadas a essas áreas, refletindo condições ambientais ou tolerância a perturbações. Além disso, esperamos que essas áreas tenham menos espécies únicas do que as áreas de referência; e 2) de que a comunidade responde à distância dos rejeitos transbordados mais próximos; portanto, esperamos que os efeitos sejam diluídos por toda a bacia, com menor impacto no número de espécies e de indivíduos das comunidades à medida que a distância do contato com os rejeitos transbordados aumenta. Além disso, investigamos o efeito de variáveis ambientais locais, como heterogeneidade, peso e altura da serapilheira, porcentagem de abertura do dossel e de área florestal ao redor das áreas de amostragem, para avaliar se e como fatores ambientais locais contribuem para explicar as variações na comunidade de Orthoptera em resposta à perturbação.

Capítulo II: Efeitos do rompimento da barragem de Fundão (Mariana, MG) atuando como filtro na variação morfológica de duas espécies de grilos da serapilheira

Neste capítulo investigamos como as mudanças ambientais causadas pela deposição de rejeitos de mineração afetaram a morfologia das espécies de grilos na área ribeirinha mais severamente impactada, o rio Gualaxo do Norte. Para isso, testamos a hipótese de que 1) a perturbação filtra os atributos funcionais dos grilos, levando a mudanças na morfologia corporal dos indivíduos que habitam as áreas afetadas; portanto, esperamos um tamanho corporal e características menores nas áreas afetadas em comparação às áreas não afetadas.

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CAPÍTULO I: From collapse to community change: Orthopteran community structure and indicator species after the Fundão dam break, Mariana, MG, Brazil

Abstract

Disasters caused by mining, such as the rupture of the Fundão dam in Mariana in 2015, can generate significant environmental disturbances, influencing the diversity and ecosystem functions of arthropod communities in the region. Among the possible groups of indicator arthropods, Orthoptera stand out, as they are sensitive to environmental changes and are essential to the functioning of ecosystems, as herbivores and detritivores, in addition to serving as food for various animals. However, little is known about the effects of this disturbance on these organisms. Given this gap, our objective was to evaluate whether there are long-term effects of the disturbance and evidence of temporal persistence of these effects in the orthopteran community in the Rio Doce basin. To this, we sampled the orthopteran community in five regions of the Rio Doce basin, in reference and impacted areas, in periods of six and almost eight years after the disturbance. In each region in reference and impacted areas, orthopterans were sampled using pitfall traps arranged along four 120-meter transects per site, positioned perpendicular to the river and extending into the riparian forest, with traps active for 48 hours. Additionally, we measured environmental variables, such as distance from the nearest overflowed tailings, litter heterogeneity and height, percentage of canopy openness, and forest area around sampling areas. We found that the disturbances still have effects on the orthopteran community, indicating long-term impacts and temporal persistence. We observed an increase in the abundance of individuals in the impacted areas, changes in species composition and a negative effect with increasing distance from the impact on abundance and species richness, although without changes in species richness between areas. In addition, we observed an increase in the number of indicator species associated with the impacted areas after almost eight years, as well as species that remained as indicators over time, in addition to the presence of different indicator species in each region. Our results suggest that environmental changes caused by the disturbances continue to influence the orthopteran community in the long term, and the persistence of these effects over time emphasizes the sensitivity of these organisms to environmental changes.

Keywords: Fundão dam failure, environmental disturbance, anthropogenic impact, invertebrate ecology, cricket, grasshopper, tropical forest

Introduction

Anthropogenic disturbances shape biodiversity, ecosystem functioning and community structure across multiple spatial scales, with effects that intensify as disturbance increases, just as metacommunity theory predicts (Leibold *et al.*, 2004). According to this framework, both local processes (e.g., environmental filtering and species interactions) and regional processes (e.g., dispersal) act together to determine community composition (Leibold *et al.*, 2004). When the alteration and habitat loss occur, local extinctions can drain the regional species pool (Hillebrand; Blenckner, 2002; Leibold *et al.*, 2004). In particular, alteration or habitat loss, which is commonplace in environmental disasters, impedes dispersal and disproportionately affects taxa unable to survive in altered environments (Brückmann; Krauss; Steffan-Dewenter, 2010; Thompson; Rayfield; Gonzalez, 2017).

Environmental disasters, such as the rupture of the iron ore tailings dam, have been frequent in the last decades (Azam; Li, 2010; Sitharam; Hegde, 2017). These disasters impact and degrade local and regional ecosystems (Fernandes; Ribeiro, 2017), such as can drive drastic shifts, including reductions in forest cover (Omachi *et al.*, 2018), decreased growth and plant biomass (Cruz *et al.*, 2020), soil characteristics (Queiroz *et al.*, 2018), macrofauna composition (Gomes *et al.*, 2017), and soil microbial activity (Couto *et al.*, 2021). In addition to these effects, such disturbances reduce habitat complexity and heterogeneity, essential factors for arthropod community structure and diversity, and can also compromise overall ecosystem functioning (Tews *et al.*, 2004).

In this study, we are investigating the effects of the collapse of the Fundão dam, in Mariana, Minas Gerais, Brazil, which occurred on November 5, 2015, and is considered one of the most significant environmental disasters related to mining in Brazil (Fernandes *et al.*, 2016). With the rupture, the iron ore tailings reached hundreds of kilometers along the river channel and more than a kilometer into the riverbanks in the immediately affected areas. It impacted the channels of the Rio Doce basin, traveling about 663.2 km to the ocean, a large part of the aquatic biota (Costa *et al.*, 2022), terrestrial arthropods (Ribeiro *et al.*, 2023), soil (Silva *et al.*, 2021), riparian vegetation (Ramos *et al.*, 2024) and irreplaceable natural resources that sustained the local populations (Fernandes *et al.*, 2016). Consequently, tailings deposition altered biodiversity and ecosystem functioning and promoted habitat simplification and homogenization throughout the affected reaches (Fernandes; Ribeiro, 2017; Fernandes *et al.*, 2025; Omachi *et al.*, 2018; Queiroz *et al.*, 2018). However, the intensity of these effects may act differently throughout the basin, since in the immediately affected areas there was a direct

physical impact from the overflow of the tailings, including the removal of riparian vegetation (Fernandes; Ribeiro, 2017; Fernandes *et al.*, 2025; Omachi *et al.*, 2018; Queiroz *et al.*, 2018). In contrast, in more distant regions, the impacts are more likely to be related to contamination, soil alteration and consequently effects on the structure of vegetation (Fernandes *et al.*, 2025; Queiroz *et al.*, 2018; Ramos *et al.*, 2024; Silva *et al.*, 2021). Understanding this spatial variability is crucial to assessing how these differences influence ecological responses, particularly in riparian arthropod communities, are expected to have suffered marked declines given their sensitivity to environmental change (Cabette *et al.*, 2017; Ramey; Richardson, 2017; Ribeiro *et al.*, 2023; Vasconcellos *et al.*, 2013).

Given their sensitivity, riparian arthropods are essential ecological indicators, as they tend to respond rapidly to changes in ecosystems (Cabette *et al.*, 2017; Ramey; Richardson, 2017; Tews *et al.*, 2004). Among the potential groups of indicator arthropods, orthopterans stand out. With around 30 thousand described species (Cigliano *et al.*, 2025), orthopterans have varied feeding habits (Sperber *et al.*, 2012), act in the dispersion of seeds (Santana; Baccaro; Costa, 2016) and serve as food for various animals (Bock; Bock; Grant, 1992; Cappellari; de Lema; Jr, 2007). Due to their sensitivity, they are recognized as indicators of environmental alterations and conditions (Fumy *et al.*, 2020; Löffler; Fartmann, 2017; Ogan *et al.*, 2022; Pernat; Buchholz; Schirmel, 2024; Ribas *et al.*, 2005; Szinwelski *et al.*, 2012; Szinwelski *et al.*, 2015). For example, in environments affected by mining, orthopterans often show reduced populations and altered species composition (Andersen *et al.*, 2001; Hoffmann; Lowe; Griffiths, 2002). During early vegetation recovery stages, they tend to reduce their diversity, change the number of individuals and homogenize species composition (Alignan; Debras; Dutoit, 2014, 2018; Basset *et al.*, 2008; Fartmann *et al.*, 2012), mainly due to changes in habitat conditions and resources (König *et al.*, 2024). Thus, to be indicators and participate in essential ecosystem functions (Deraison *et al.*, 2015), orthopterans can reflect the state and integrity of the environment (Anso *et al.*, 2022; Fumy *et al.*, 2020; Löffler; Fartmann, 2017). Therefore, evaluating their responses is essential to understanding environmental impacts on the functioning and recovery of ecosystems.

Therefore, understanding how the Orthoptera community was affected is essential, since impacts on the Orthoptera fauna can affect the entire local and regional biological community and ecosystem functioning. Thus, after six and almost eight years of the rupture, our objective was to evaluate whether there are long-term effects of the disturbance and evidence of temporal persistence of these effects in the orthopteran community in the Rio Doce basin. We hypothesize that disturbance 1) negatively influences the orthopteran community in

impacted areas; therefore, we expect a smaller number of species and a larger number of individuals in these areas, in addition to a more homogeneous species composition dominated by resistant species. We also expect to find indicator species associated with these areas, reflecting environmental conditions or tolerance to disturbance. Furthermore, we hope these areas will have a lower number of unique species than reference areas; and 2) the community responds to the distance from the nearest overflowed tailings, therefore, we expect the effects to be diluted throughout the basin, with less impact on the number of species and individuals in communities as the distance from contact with the overflowed tailings increases. Additionally, we investigated the effect of local environmental variables, such as litter heterogeneity and height, percentage of canopy openness, and forest area around sampling areas, to assess whether and how local environmental factors contribute to explaining variations in the orthopteran community in response to the disturbance.

Methods

Study Area

Our study area comprises riparian vegetation in five regions along the Rio Doce basin, Minas Gerais, Brazil (Figure 1). The regions include the municipalities of Mariana (Region 1), Rio Casca (Region 2), Ipatinga (Region 3), Conselheiro Pena (Region 4), and Aimorés (Region 5) (Figure 1). These regions were selected for the study due to the availability of riparian forests and support for the experimental design of the analyzed group along the basin. In each region, two vegetation areas were selected, one impacted area and one reference area. The reference areas were defined as those not affected by the passage of mining tailings and located in riparian zones of tributary rivers in each region, representing the conditions before the failure (see Ramos *et al.*, 2024; Toma *et al.*, 2023) (Figure 1). We considered impacted areas where tailings passed through and overflowed partially or entirely on their margins (Figure 1; see Fernandes *et al.*, 2025). The forests selected are predominantly composed of Atlantic Forest vegetation (Ramos *et al.*, 2024).

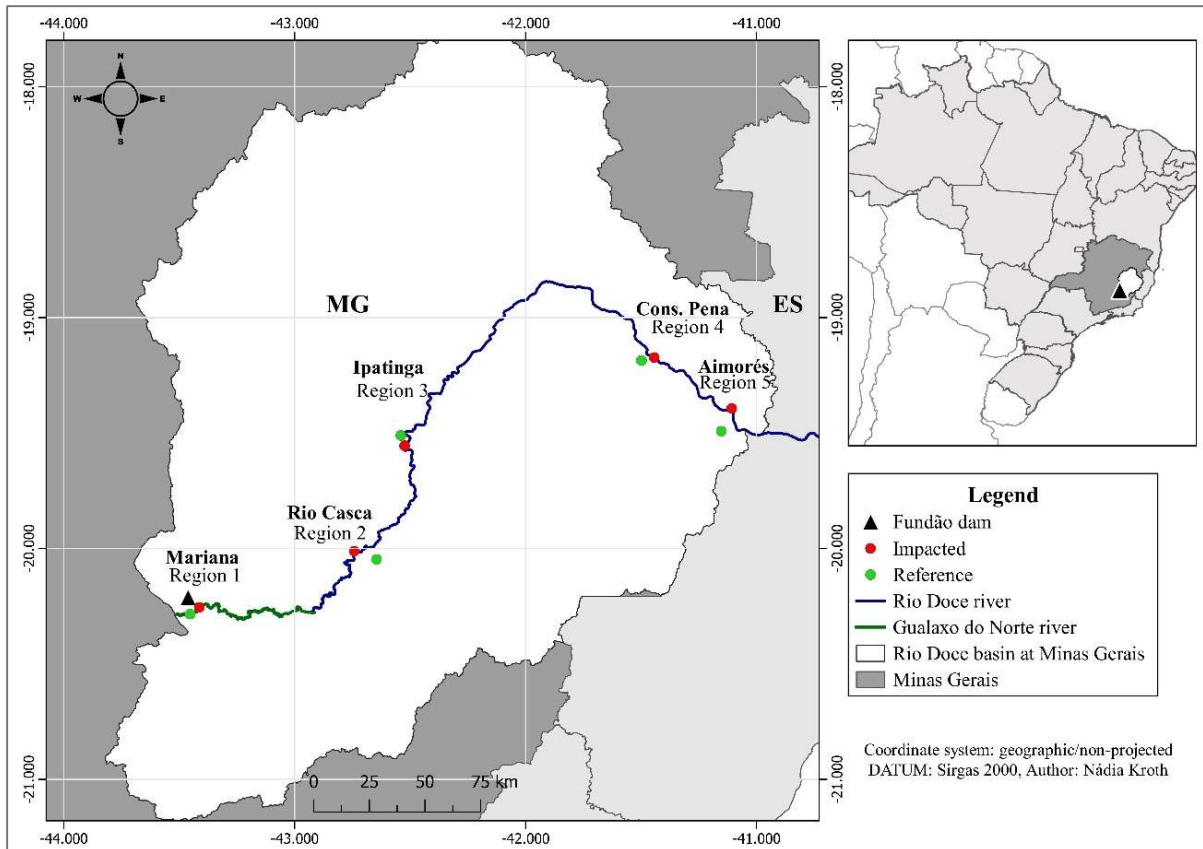


Figure 1. Location of sampling points in reference and impacted areas by the deposition of mining tailings from the Fundão dam collapse in the Rio Doce basin. The red points represent the areas impacted by the deposition of mining tailings, and the green points represent the reference areas in each region sampled.

Experimental Design

To collect the orthopterans, four 120-meter transects were installed perpendicular to the river course, starting 1 m from the edge of the water towards the interior of the riparian forest in each sampling area (impacted/reference) (SI1-A). Each transect was placed 50 meters apart and consisted of five sets of three pitfall traps, each set placed 30 meters apart (SI1-A and SI1-B). The pitfall traps were transparent and had a capacity of two liters (diameter: 1370 mm; height: 165 mm), and were arranged in a triangle, with each trap placed 2 meters apart (SI1-B). Each trap was filled with 500 mL of ethanol fuel, without the addition of attractive baits, using ethanol fuel as the killing and preserving solution, as recommended by Szinwelski *et al.* (2012, 2013), and was kept active for 48 hours. After this period, all individuals were collected, sorted, and stored in vials containing 85% alcohol. This sampling method captures organisms that naturally live in leaf litter, with the most representative group in this environment being the

suborder Ensifera, represented by crickets. Orthopterans were collected during the rainy season and in two sampling expeditions spaced over two years, from December 2021 to March 2022 and from November to December 2023, respectively, six and almost eight years after the disaster. All sampled orthopterans were identified at the lowest possible taxonomic level, and at least one specimen of each species was deposited in the Orthoptera collection of the National Museum of Rio de Janeiro under the care of curator Pedro G.B. Souza-Dias.

Environmental variables

In each sampling area and expedition, we sampled a series of environmental variables (Table 1) that represent the habitat structure and the conditions and resources essential to the orthopteran community (Anso *et al.*, 2022; Farias-Martins *et al.*, 2017; Fumy *et al.*, 2020; Stefanidis *et al.*, 2024).

Table 1. Description of the environmental variables sampled in the study, including the parameters they represent (proxy), the sampling scale, and the methods used for collection and analysis.

Variable sampled	Proxy	Sampling scale	Methods
Litter weight (g)	Conditions and resources	Each set of traps	A sample of all the litter present in the 50×50 cm square structure was collected and dried in an oven at 50°C for 72 hours and then weighed on a precision scale.
Depth of leaf litter (cm)	Conditions and resources	Each set of traps	Use of a millimeter ruler from the top of the litter to the ground, located in the center of the 50×50 cm square framework.
Litter heterogeneity (inv-D)	Conditions and resources	Each set of traps	Dry weight of leaves, branches, trunks, reproductive structures, and miscellaneous (i.e., fragmented organic matter) of the litter collected in the 50x50 cm square. We used the Inverse Simpson index (inv-D) to calculate the diversity of items (Queiroz <i>et al.</i> , 2021).
Canopy openness (%)	Vegetation Conditions	Each set of traps	Hemispherical photos with eye lens fish, positioned 1.5 m above ground, and images processed in imaging software Gap Light Analyzer (GLA).
Distance from nearest tailings (km)	Dilution of the effect of tailings passage	Basin	Estimated by Google Earth in a linear direction to the nearest overflow tailings
Forest area (%)	Habitat quality, conditions, and resources	Region	We acquired the land cover data from the MapBiomas platform. To ensure sample independence, we created 2500 m radius buffers

Variable sampled	Proxy	Sampling scale	Methods
			around each sampling site. These buffers were used to clip the land cover raster and convert it to vector format, allowing us to calculate the area of each land cover class. We assessed the percentage of land use by dividing the area of each class by the total buffer area and multiplying by 100, and used the % of the forest area class for the analysis. We performed all procedures using QGIS version 3.40.6.

Statistical analysis

We performed all analyses in the R environment (R Core Team, 2025). To assess whether there is a difference in species richness (number of species) and abundance (number of individuals) as response variables, we used generalized linear mixed models (GLMMs), incorporating the identity of the regions and transects of sampling expedition as random effects in the models, avoiding possible unwanted effects of pseudo-replication. The identity of the area (impacted vs. reference), year of sampling expedition, litter weight (g), litter depth (cm), and heterogeneity of the litter (inverse Simpson's index), canopy openness (%), distance to the nearest tailings (km), and forest area (%) were used as independent variables. Environmental variables were standardized before being incorporated into the model using the “decostand” function of the *Vegan* package (Oksanen *et al.*, 2025). We used the negative binomial distribution for abundance (number of individuals) and species richness (number of species), using the “nbinom1” function from the *glmmTMB* package (Brooks *et al.*, 2025). To identify the main factors influencing the response variables, we initially fitted a complete model including all explanatory variables. Then, model simplification was conducted by removing variables that did not influence, considering the exclusion categories of each variable based on the highest p-value (> 0.05). At each step of simplification, models were compared using likelihood ratio tests via the `anova()` function in R to assess whether the exclusion of the variable did not influence. To evaluate the significance of the simplified model, it was also compared to the null model using a likelihood ratio test. After this, the significance of the fixed effects of the simplified model was evaluated using the `Anova()` function with type II tests of the *car* package (Fox *et al.*, 2024), and only the reported results are related to the simplified model variables. We utilized functions from the *DHARMA* package (Hartig; Lohse, 2022) to verify the adequacy of the models and residual analysis.

To analyze whether there is a difference in the species composition of the Orthoptera communities between the impacted and reference areas of each region, the analyses were performed separately for each data sampling expedition (2021 and 2023). We used a Non-Metric Multidimensional Scaling (NMDS) analysis based on the Bray-Curtis distance, using transects (true replicates) as the sampling unit to deal with excess zeros, and subsequently verified by a PERMANOVA (considering the Bray-Curtis distance matrix and with 999 permutations). PERMANOVA was performed using the “adonis2” function of the *Vegan* package, with the inclusion of the “strata” argument, utilizing the variable region to control for the effects of the different sampling regions on species composition. We analyzed the species composition data from the expeditions separately to check for evidence of temporal persistence of the effects of the disturbance. By performing analyses separately for each expedition, we also minimized the risk of incorrect grouping of morphotypes, ensuring greater reliability in the results and their interpretation, since species-level identification for the Orthoptera group is not always possible and is often limited to the morphotype or genus level. Furthermore, we used the *VennDiagram* package (Chen, 2022) to visualize shared and exclusive species between the impacted and reference areas in both sampling expeditions. To detect the indicator species of the impacted and reference areas in each region and sampling expedition, we applied the Indicator Value (IndVal) method (Duf rene & Legendre, 1997). We calculated the indicator value of each species using the “IndVal” function of the *labdsv* package (Roberts, 2023). This method combines the fidelity and relative abundance of species occurrences across areas (e.g., impacted and reference), producing an index ranging from 0 to 1, where higher IndVal scores indicate stronger associations with a specific area (Roberts, 2023). The statistical significance of each species’ indicator value was assessed using permutation tests (10000 permutations), and the results are reported only for significant IndVal scores ($p < 0.05$).

Results

We collected a total of 4581 individuals, with 2622 in impacted areas and 1959 in reference areas. Of these, 2606 individuals were collected during the first sampling expedition (2021) and 1975 during the second expedition (2023). The suborder Ensifera was the most representative, with 3982 individuals, while Caelifera accounted for 599 individuals. Specimens were identified across 12 families (SI2): Acrididae, Anostomatidae, Gryllidae, Gryllotalpidae, Mogoplistidae, Oecanthidae, Ommexechidae, Phalangopsidae, Tettigoniidae,

Tridactylidae, and Trigonidiidae, comprising 76 species in the first expedition and 59 in the second (SI2).

In the impacted areas, litter weight ranged from 0 to 660g (mean = 170.84 g, SD = 118.12), and depth of leaf litter ranged from 0 to 12 cm (mean = 2.88 cm, SD = 2.16). Litter heterogeneity (inv-D) ranged from 1.0 to 4.12 (mean = 2.43, SD = 0.70). Canopy openness ranged from 3.29% to 100% (mean = 19.42 %, SD = 18.92), and forest area ranged from 1.67% to 84.47% (mean = 36.30 %, SD = 30.20). Distance from nearest tailings ranged from 0 to 203.98 km (mean = 98.91 km, SD = 83.33). In reference areas, litter weight ranged from 4 to 524g (mean = 147.24 g, SD = 102.73), and depth of leaf litter ranged from 0 to 13 cm (mean = 2.02 cm, SD = 1.75). Litter heterogeneity (inv-D) ranged from 1.0 to 3.97 (mean = 2.41, SD = 0.70). Canopy openness ranged from 3.09% to 98.26% (mean = 22.34 %, SD = 18.81), and forest area varied from 0.58% to 76.37% (mean = 37.56 %, SD = 32.85). Distance from nearest tailings ranged from 3.22 to 194.950 km (mean = 98.52 km, SD = 78.30). For information on range, mean, and standard deviation (SD) of each environmental variable in each region and area, see supplementary material (SI3).

In the first sampling expedition (2021), we recorded 29 species exclusive to impacted areas, 27 species exclusive to reference areas, and 20 species occurring in both (Figure 2). In contrast, during the second expedition (2023), the number of shared species increased (28 species), while 23 were exclusive to impacted areas and only 7 to reference areas (Figure 2). In Region 1, we recorded 30 species in both expeditions, with an increase in shared species and a reduction in those exclusive to reference areas, as well as a decrease in exclusive species to impacted areas in 2023 (Figure 2). In Region 2, species increased from 21 (2021) to 34 (2023) (Figure 2), with a more balanced distribution between exclusive and shared species in 2023 (Figure 2). In Region 3, 18 species were recorded in both years, with an increase in species exclusive to impacted areas and a decrease in those exclusive to reference areas in 2023 (Figure 2). In Region 4, there was a decline in total species richness (from 28 to 11), with a predominance of species exclusive to reference areas in 2021, shifting to a predominance of exclusive species in impacted areas in 2023 (Figure 2). In Region 5, the total number of species remained the same in both years, but a more balanced distribution of exclusive species between the two areas was observed in 2023 (Figure 2).

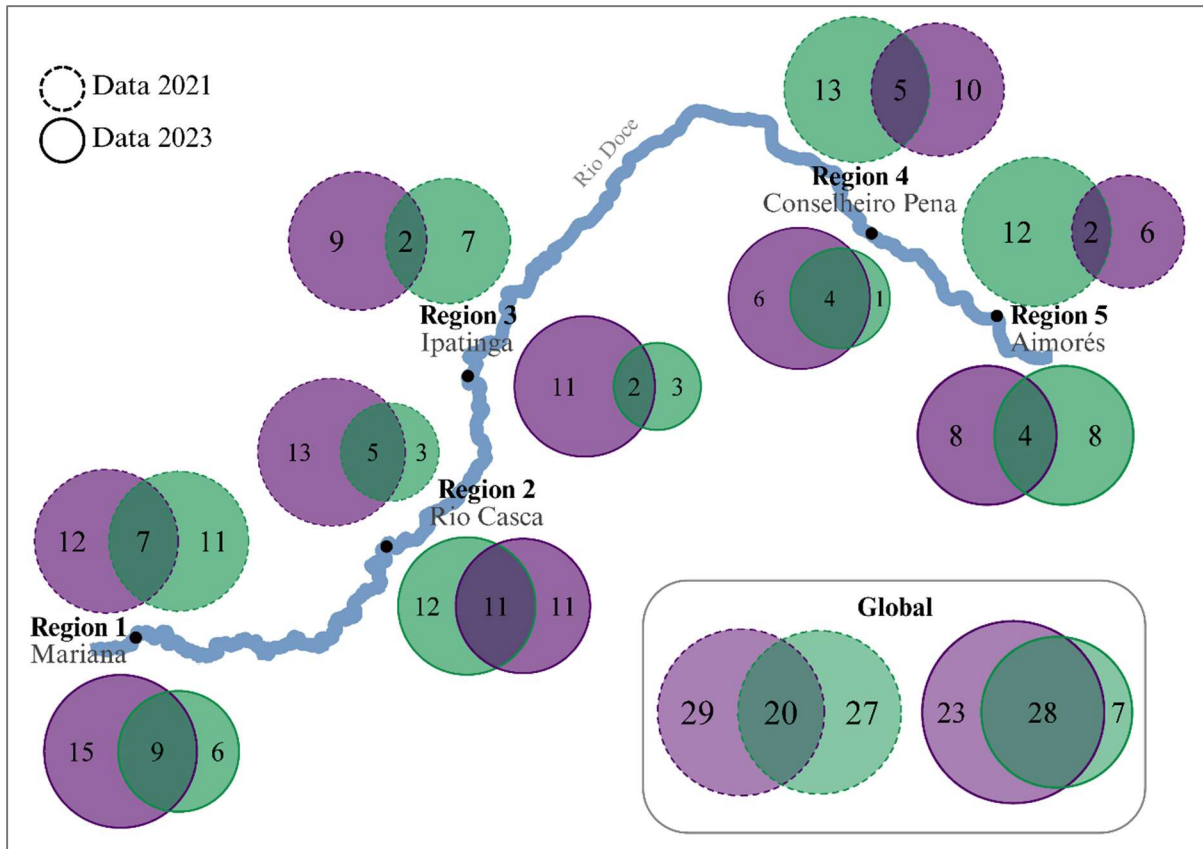


Figure 2. Venn diagram illustrating the number of exclusive and shared species between the impacted and reference areas from five regions of the Rio Doce basin. The colors indicate the type of area (green reference; purple impacted), and the kind of line indicates the year of data collection (solid: 2023, dashed: 2021).

The abundance of orthopterans is influenced by the disturbance of the tailings passage with the increase in the number of individuals in the impacted areas in comparison to the reference areas (Figure 3, $\chi^2 = 12.0847$, $Z = -3.48$, $P < 0.001$). Still, we observe the difference between the expeditions with the decrease in the number of individuals in the last expedition (2023) in the impacted areas in comparison to the first expedition (2021) (Figure 3, $\chi^2 = 8.9409$, $Z = -2.99$, $P = 0.002$). In addition, we observed a decrease between the number of individuals and the increase of the litter weight (SI4, $\chi^2 = 3.9049$, $Z = -1.97$, $P = 0.04$), but we did not observe effects of the depth of leaf litter ($\chi^2 = 0.3080$, $P = 0.57$), litter heterogeneity (inv-D) ($\chi^2 = 0.4041$, $P = 0.52$), canopy openness ($\chi^2 = 0.0119$, $P = 0.91$) and forest area ($\chi^2 = 2.6840$, $P = 0.10$). On the other hand, we did not observe a relationship between disturbance by tailings passage and species richness (Figures 4, $\chi^2 = 2.9914$, $Z = -1.73$, $P = 0.08$) but observed a difference between the expeditions with the increase in the number of species in the last expedition (2023) in the impacted areas in comparison to the first expedition (2021) (Figure 4, $\chi^2 = 10.7887$, $Z = 3.28$,

$P = 0.001$) an increase in the number of species with an increase in the percentage of canopy openness (SI5, $\chi^2 = 19.1613$, $Z = 4.37$, $P < 0.001$), but we did not observe effects of the litter weight ($\chi^2 = 0.3884$, $P = 0.53$), depth of leaf litter ($\chi^2 = 1.1638$, $P = 0.28$), litter heterogeneity (inv-D) ($\chi^2 = 0.0028$, $P = 0.95$) and forest area ($\chi^2 = 0.1927$, $P = 0.66$).

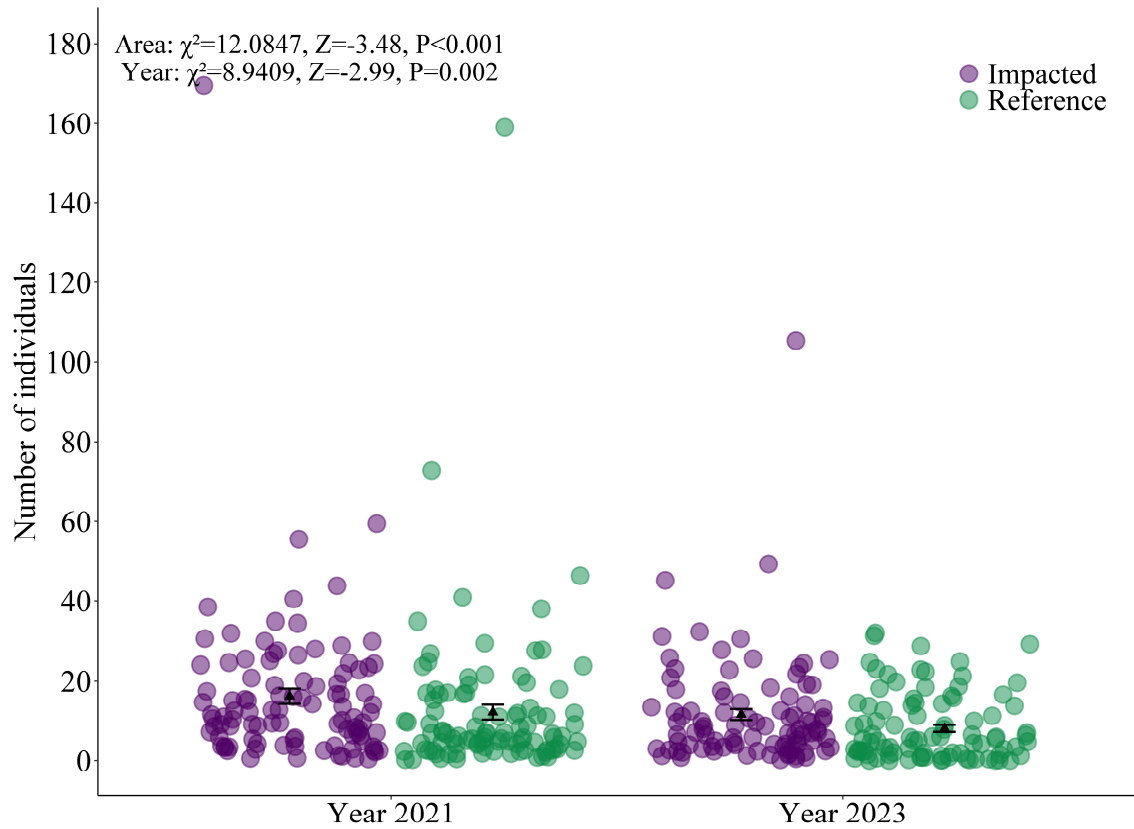


Figure 3. Effect of disturbance on the abundance of orthopterans in the Rio Doce basin. The central line represents the standard error of each group, and the central triangle represents the mean.

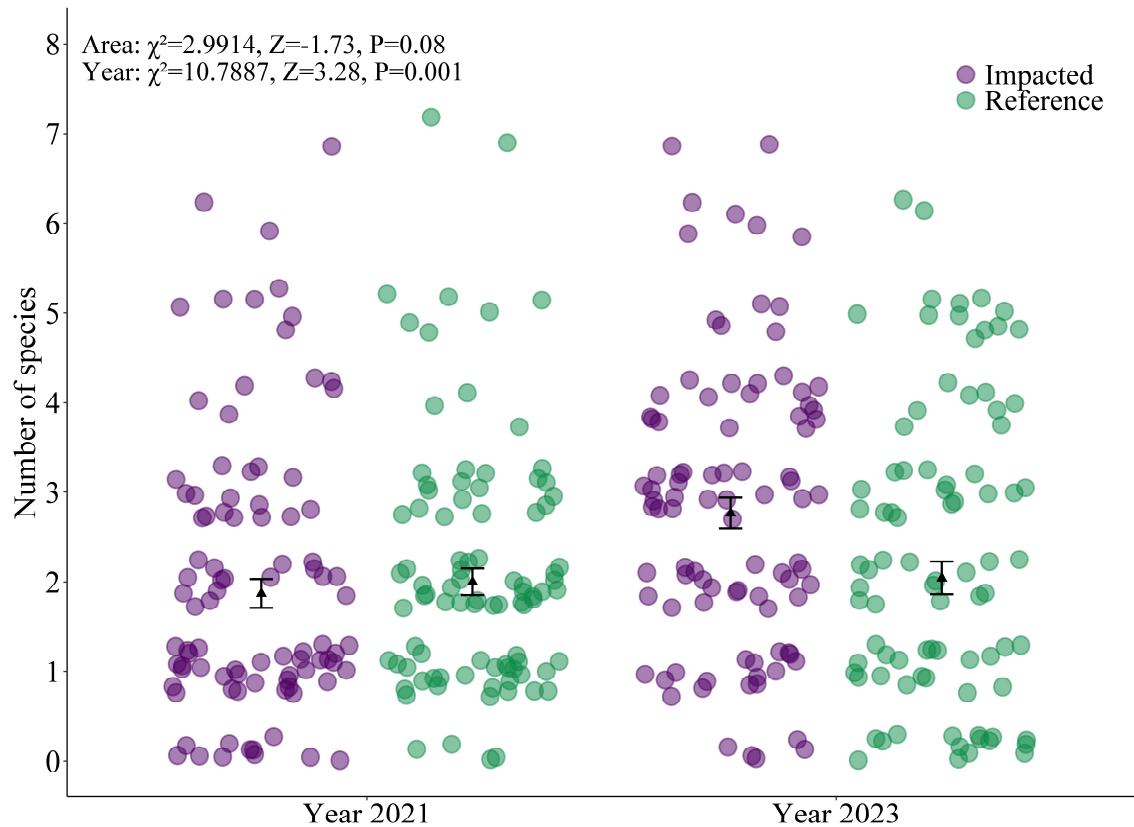


Figure 4. Effect of disturbance on the richness of orthopterans in the Rio Doce basin. The central line represents the standard error of each group, and the central triangle represents the mean.

The distance from the nearest tailings also influenced the community; we observed a decrease in the number of individuals with increasing distance from the nearest tailings (Figure 5, $\chi^2= 17.5201, Z = -4.18, P < 0.01$). The same pattern was observed with a decrease in the number of species with the increase of the distance from the nearest tailings (Figure 6, $\chi^2 = 97.2383, Z = -9.86, P < 0.001$).

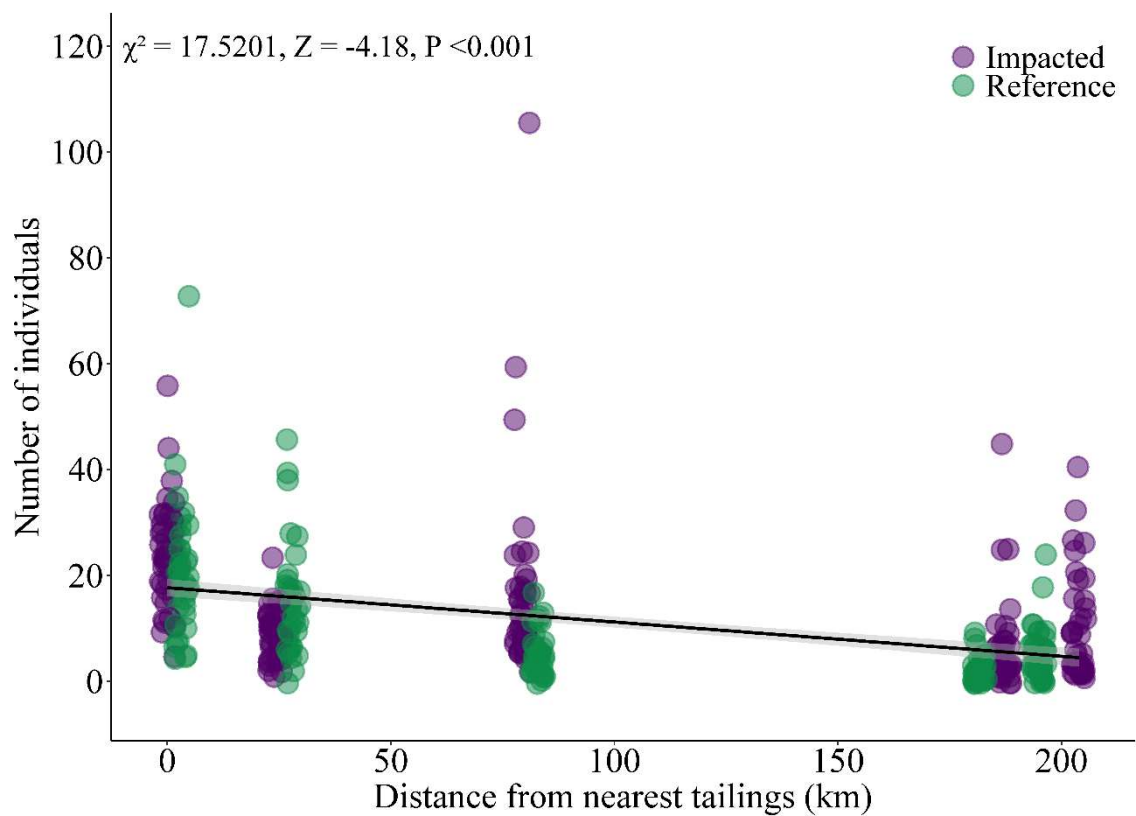


Figure 5. Effect of distance from nearest tailings (km) on the abundance of orthopterans in the impacted and reference areas of the Rio Doce basin. The points represent the raw data, and the line indicates the trend of these values for the two environments (impacted and reference), and the shaded areas represent the confidence intervals (95%).

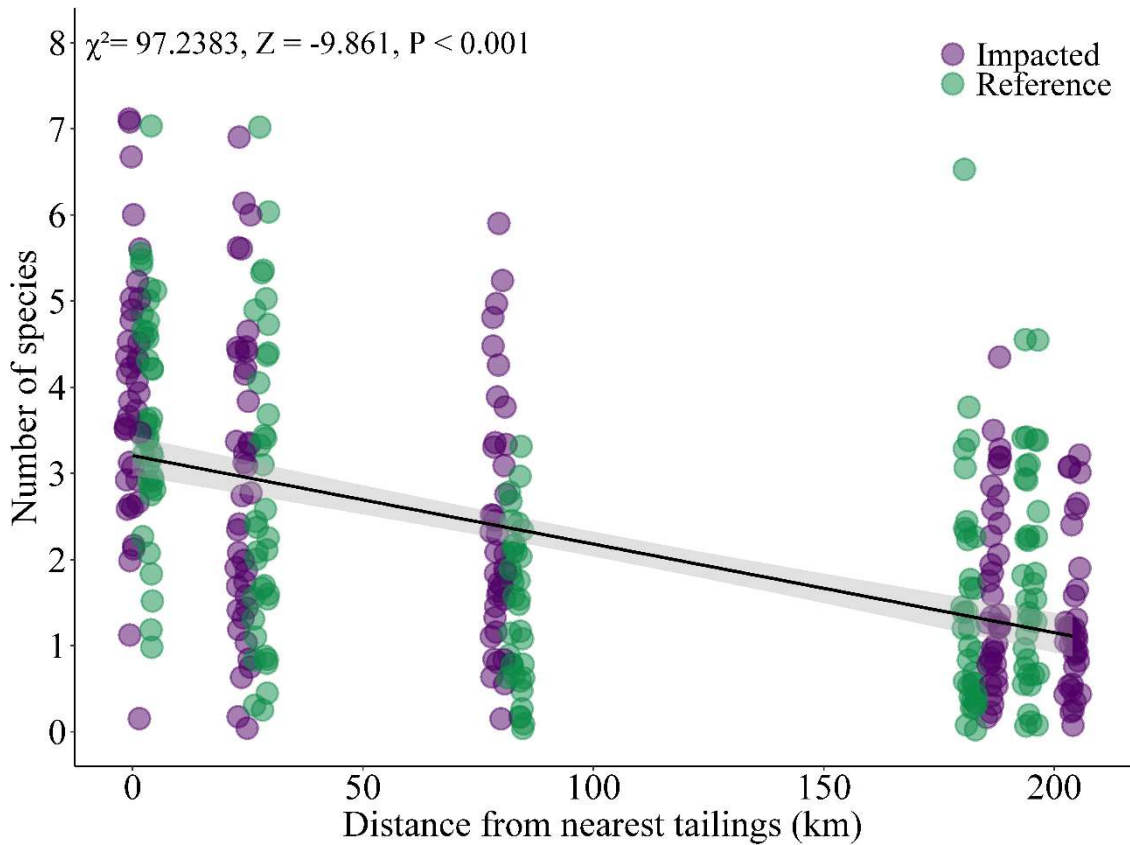


Figure 6. Effect of distance from nearest tailings (km) on the richness of orthopterans in the impacted and reference areas of the Rio Doce basin. The points represent the raw data, and the line indicates the trend of these values for the two environments (impacted and reference), and the shaded areas represent the confidence intervals (95%).

The composition of orthopteran species is influenced by disturbance of the tailings passage, with the difference between the species composition in all regions of the Rio Doce basin. This pattern is maintained over time, both for the species collected in 2021 (Figure 7, Stress = 0.13, $R^2 = 0.043$, $P = 0.002$) and in 2023 (Figure 7, Stress = 0.18, $R^2 = 0.043$, $P = 0.001$). Still, in the first expedition (2021), we identified 16 indicator species present in the sampled areas, with eight indicator species in the impacted areas and eight species in the reference areas (Table 2). In the second expedition (2023), the number of indicator species increased to 18, with a greater number of indicator species in the impacted areas (13 species) (Table 2).

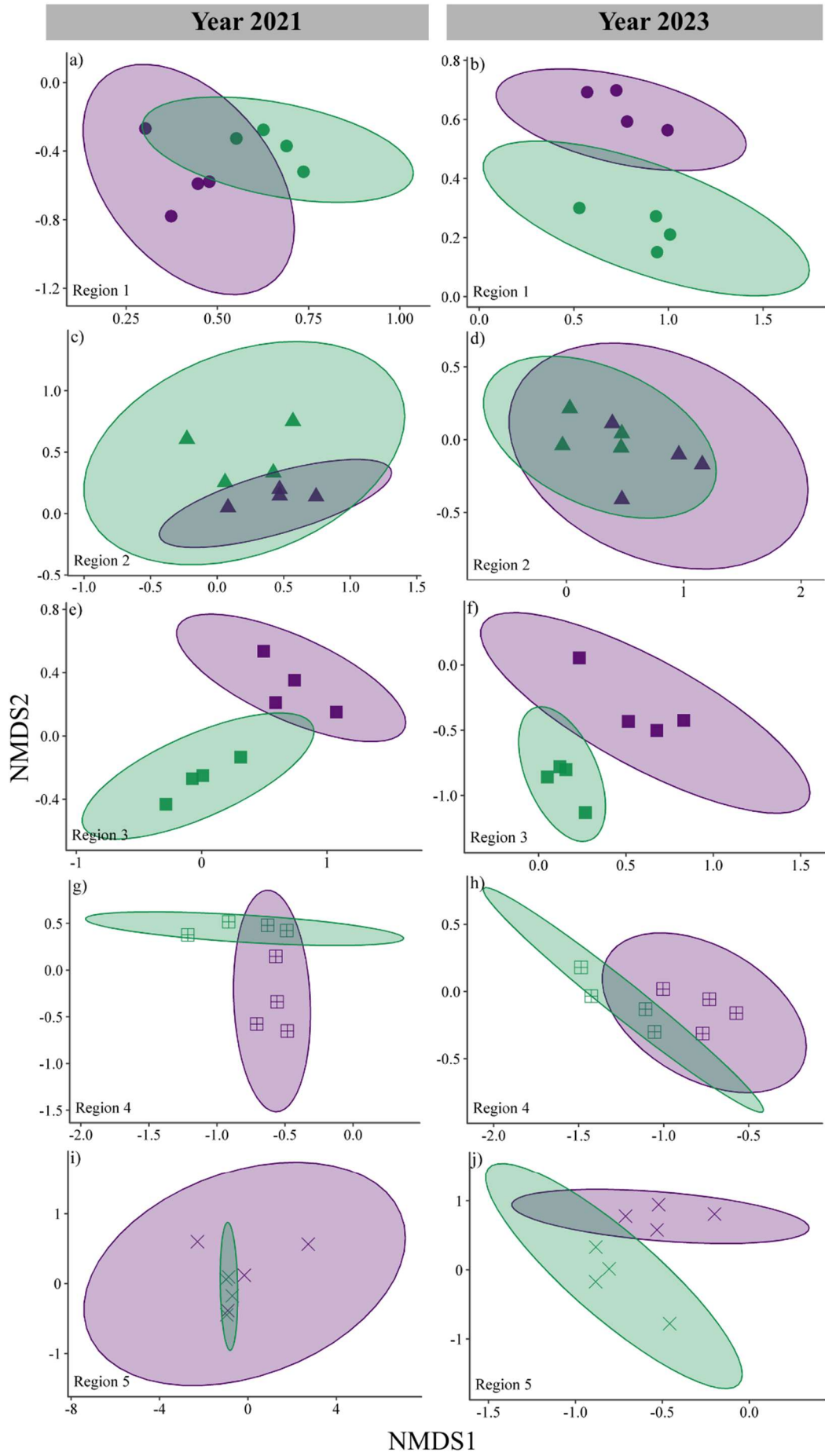


Figure 7. The Non-metric Multidimensional Scaling (NMDS) plot shows the composition of orthopteran species across different areas in 2021 and 2023. Each plot represents a region, with colors indicating the type of area (green reference; purple impacted). The relative positioning of points reflects similarities in species composition, as determined by Bray-Curtis dissimilarity. Ellipses represent 95% confidence intervals.

Table 2. Indicator species recorded in the 2021 and 2023 expeditions in impacted and reference areas in the sampled regions. IndVal represents the indicator species index values for each species, and (P) represents the significance values.

Region	Year 2021				Year 2023			
	Species	IndVal	P	Species	IndVal	P		
1	Impacted	<i>Lutosa sp.</i>	0.55	0.005	Impacted	<i>Apotetamenus sp.</i>	0.41	0.04
1		<i>Neotridactylus sp. 1</i>	0.98	0.0002		<i>Batrachidea sp.</i>	0.60	0.01
1		<i>Metrodora sp. 1</i>	0.44	0.03		<i>Gryllinae sp. 1</i>	0.54	0.02
1		<i>Tetrigidae sp. 3</i>	0.69	0.0005		<i>Izecksohniella sp.</i>	0.68	0.0001
1		<i>Tettigidea sp. 3</i>	0.75	0.004		<i>Neotridactylus sp. 2</i>	0.75	0.004
1		—	—	—		<i>Zucchiella sp.</i>	0.47	0.001
2		<i>Ubiquepuella telytokous</i>	0.32	0.009		<i>Ubiquepuella telytokous</i>	0.28	0.02
2		<i>Zucchiella sp.</i>	0.43	0.01		—	—	—
3		<i>Trigonidiinae sp. 2</i>	0.54	0.01		<i>Brasilodontus sp. 2</i>	0.75	0.0002
3		<i>Brasilodontus sp.</i>	0.92	0.0002		<i>Eidmanacris sp.</i>	0.78	0.0001
4	Reference	<i>Abracris dilecta</i>	0.50	0.01	Reference	<i>Eneoptera surinamensis</i>	0.56	0.004
4		—	—	—		<i>Lerneca sp. 1</i>	0.44	0.03
5		<i>Eneoptera surinamensis</i>	0.49	0.0003		<i>Guabamima sp. 2</i>	1	0.0001
5		<i>Lerneca sp.</i>	0.49	0.01		<i>Melanotes sp.</i>	0.75	0.004
1		<i>Amanayara bernardesi</i>	0.92	0.0001		<i>Amanayara bernardesi</i>	0.65	0.0007
1		<i>Tetrigidae sp. 1</i>	0.75	0.004		<i>Bolivaridora aff. cipolai</i>	0.81	0.0002
1		<i>Tetrigidae sp. 2</i>	0.75	0.004		<i>Trigonidiinae sp. 1</i>	0.55	0.002
2		<i>Guabamima sp.</i>	0.38	0.01		<i>Guabamima sp.</i>	0.43	0.01
2		—	—	—		<i>Guabamima sp. 1</i>	0.75	0.0002

Discussion

We confirm that the passage of tailings from the dam collapse still has effects on the community of Orthoptera in the Rio Doce basin, indicating long-term impacts and temporal persistence. These effects are reflected in the increase in the abundance of individuals in the impacted areas and changes in species composition. Also, we observed a reduction in abundance and richness with the increase in the distance of the impact, although without a change in the species richness between the areas. These results partially support the first

hypothesis and fully support the second, indicating that the environmental changes caused by the disaster maintain their influence on orthopteran communities over time. We also observed an increase in the number of indicator species associated with the impacted areas after almost eight years, as well as species that remained as indicators over time, in addition to the presence of different indicator species in each region. These patterns indicate that the effects on these organisms are long-lasting and suggest that the community is being structured by different ecological processes, driven by both disturbance and local and regional particularities.

The mining tailings from the collapse severely impacted plant communities along the Rio Doce basin (Fernandes *et al.*, 2025; Ramos *et al.*, 2024), in addition to changing the composition of the soil (Aires *et al.*, 2018; Buch *et al.*, 2021) and litter and organic matter characteristics (Batista *et al.*, 2022). These environmental characteristics are directly related to the abundance and diversity of orthopteran communities (Alignan; Debras; Dutoit, 2014; Fumy *et al.*, 2020; Löffler; Fartmann, 2017). This is particularly relevant, environments that have undergone disturbances or are in regeneration are usually more heterogeneous and may have greater availability of micro-habitats and resources (Campanharo *et al.*, 2021; Klimm *et al.*, 2025; Zemlerová *et al.*, 2023). This heterogeneity can facilitate the favoring of particular species (Simons; Weisser; Gossner, 2016; Tews *et al.*, 2004), which are generally more tolerant of environmental changes (Sutton *et al.*, 2023). Among the orthoptera, this pattern is known (Reiss; Hochkirch, 2025), as demonstrated by the increased abundance of crickets in environments with an intermediate stage of ecological succession (Anso *et al.*, 2022), in addition to the greater presence of individuals positively influenced by habitat heterogeneity in areas of natural regeneration (Löffler; Fartmann, 2017). Thus, the changes in the structure of the environment resulting from the disturbance may be promoting changes in the orthoptera community, favoring particular species and contributing to the increase in abundance in the impacted areas.

The effects of environmental changes also influenced the composition of orthoptera species, even though species richness remained unchanged. This pattern, with species richness remaining stable, but with increasing abundance and differences in composition, suggests a possible species replacement in these environments. Furthermore, marked differences were observed in the two years of the expedition, suggesting a possible temporal effect of the disturbance in all regions of the Doce River basin. However, this pattern needs more robust evidence to be effectively confirmed. Multiple studies have also shown similar effects on other groups of invertebrates. For example, ant communities showed changes in composition and ecosystem functions (Fietto *et al.*, 2024). Arthropod communities had changes in species

composition, with a reduction in the abundance of omnivorous and detritivorous functional groups in the impacted areas (Ribeiro *et al.*, 2023). Horntails showed alterations in reproductive aspects (Alves *et al.*, 2023), while earthworm communities, both native and exotic, have altered their composition (Kenedy-Siqueira *et al.*, 2025). Furthermore, changes in functional level were observed in caddisflies, with increased fluctuating asymmetry in impacted areas, variation in tooth position and reduced and irregular forewing (Andrade Soares *et al.*, 2024). This indicates that in addition to habitat alterations, the community may be structured by different ecological processes, such as changes in interspecific interactions (Valiente-Banuet *et al.*, 2015), as well as possible processes of species replacement and reorganization of communities over time.

These changes in the community complement each other when we observe the increase in indicator species in the impacted areas and species that have remained as indicators over time. In the impacted areas, we have indicator species that are grasshoppers (*Neotridactylus sp.* 1 and *sp.* 2, *Metrodora sp.* 1 and *Tettigidea sp.* 3) with small body size (a few millimeters) and characteristic of open environments, little litter cover and sandy soils close to rivers (Rafael *et al.*, 2012). In addition, in these environments we have indicator species of crickets, known to be present in disturbed and fragmented environments, such as *Zuchiella sp.* (Ribas *et al.*, 2005), and *U. telytokous* (Fernandes, Maria; Zacaro; Serrão, 2015). On the other hand, the species *E. surinamensis* and *Lerneca sp.*, traditionally associated with forest areas at the beginning of regeneration (Szinwelski *et al.*, 2012), went from reference area indicators to impacted areas between expeditions. In contrast, the permanence of species belonging to conserved areas, such as *A. bernardesi* (Ribas *et al.*, 2005; Sperber; Soares; Pereira, 2007) and species with a wide distribution in the Atlantic Forest, such as *Guabamima sp.* (De Mello; Jacomini, 1994; Souza-Dias; Desutter-Grandcolas; Pereira, 2015), remained as indicators of reference areas during the period. These findings reinforce the sensitivity that orthopterans have to degradation, forest regeneration, and microhabitat conditions in each region (Guido; Gianelle, 2001; Szinwelski *et al.*, 2012). In addition, they reflect the process of change in the orthopteran community in the impacted environments and the conditions of these environments.

When relating the orthopteran community to the distance from the tailings, we observed an effect reflected mainly in the reduction of the abundance and richness of orthopterans with the increase in distance. This is the opposite of what we expected, since in the nearest areas, the overflow of tailings reached up to 1km into the banks, drastically altering the structure and conditions of the environment (Aires *et al.*, 2018; Fernandes *et al.*, 2025; Fernandes *et al.*, 2016). This contrary effect suggests that local and regional factors may be influencing the orthopteran community as much as the disorder itself. Among these factors are the variation in

elevation, in the types of vegetation (Ramos *et al.*, 2024), level of anthropogenic land use (De Oliveira *et al.*, 2019) and in local cultural aspects, which differ along the basin. For example, the regions closest to the collapse (Regions 1 and 2) have about 31 to 76% (SI3) of forest area surrounding the sampled areas, while more distant regions (4 and 5) show a significant decrease in forest area, between 0.94 and 12 % (SI3). This difference in the forest area can favor the reestablishment of communities in the closest areas (Brückmann; Krauss; Steffan-Dewenter, 2010; Klimm *et al.*, 2025; Thompson; Rayfield; Gonzalez, 2017), which would help explain the greater abundance of orthoptera in these regions compared to more distant ones. In addition, the regions present marked differences in the level of anthropization, soil characteristics and floristic compositions of the Atlantic Forest (Figueiredo *et al.*, 2024; Ramos *et al.*, 2023; Ramos *et al.*, 2024). This indicates that multiple local and regional factors act in conjunction with the direct effects of the disturbance on orthopteran communities in these environments.

In this context, it is essential to consider that the differences between the regions are also part of the changes in land use after the collapse (Neves *et al.*, 2024) and the long history of anthropization and degradation of the basin (De Oliveira *et al.*, 2019; Macêdo *et al.*, 2024; Rodrigues *et al.*, 2014; Santolin *et al.*, 2015). This degradation is mainly due to the Rio Doce basin housing the largest steel complex in Latin America, with the largest open-pit mining area in the world (Santolin *et al.*, 2015). In this way, mining activities caused the removal of large forest areas and the contamination of soil and water bodies by heavy metals (Aires *et al.*, 2018; Campos *et al.*, 2023; Santolin *et al.*, 2015). In addition, the basin has a mosaic severely degraded by intensive land use, especially for agriculture and pastures (Campos *et al.*, 2023). Given this, it is essential to emphasize that, in addition to the direct effects of the collapse disorder and the specific characteristics of each region, these communities were already being subjected to several other environmental and anthropogenic stressors.

In view of this, this study highlights the relevance of ecological community-based approaches to understand the impacts of the Fundão dam collapse on terrestrial biodiversity. Almost eight years after the disaster, our findings offer partial support to the first hypothesis and full support to the second: the distinct composition of species, the increase in abundance at impacted areas, and their attenuation with distance from the source confirm the persistence of the effect of the disturbance associated with specific local factors. Important environmental variables, such as litter weight and canopy openness, also contributed to the explanation of the variation observed in the community, indicating that multiple local and regional factors act in conjunction with the direct effects of the disturbance. Furthermore, the identification of indicator taxa exclusive to the impacted areas highlights both the sensitivity of orthopterans to

environmental changes and their value as bioindicators of habitat integrity status. Thus, these findings reinforce the importance of long-term monitoring to capture the lasting effects of mining disasters and underline the need to incorporate into conservation and restoration strategies not only the direct and indirect impacts of the disturbance, but also regional particularities. Finally, continuous monitoring of these effects, combined with studies with other groups, can deepen the understanding of the processes that shape communities in disturbed environments.

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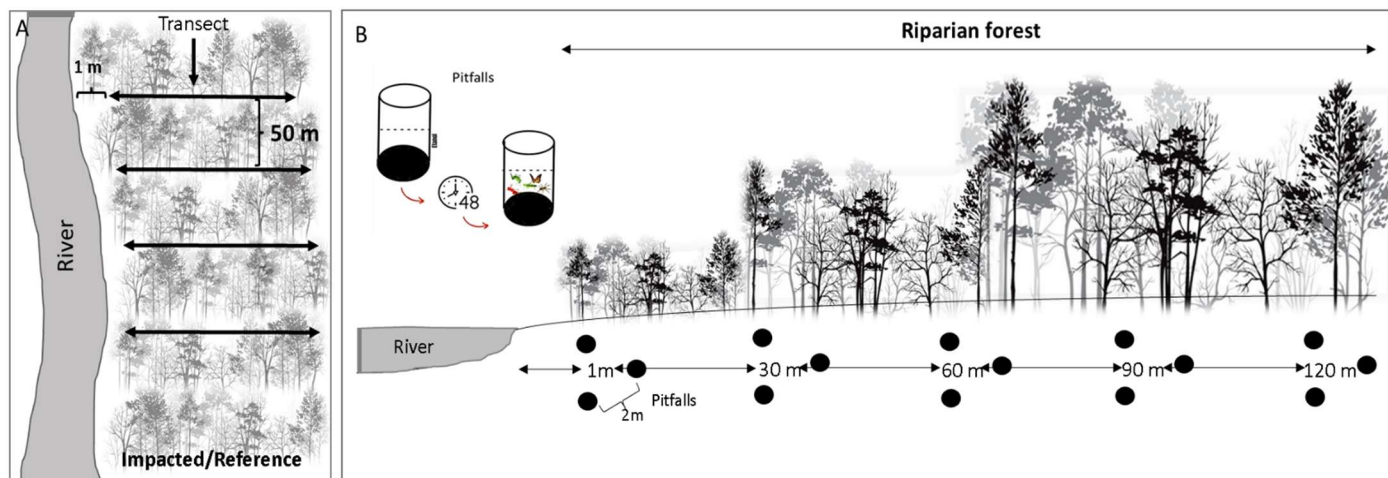
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Supplementary Information



SI1. Experimental design of transects and pitfall trap sets in the sampling areas.

SI2. Table with species and morphotypes identified in each collection expedition and the type of environment. Values represent the number of individuals collected in each area (impacted and reference) and the total number of each species.

Data 2021			
Taxon	Impacted	Reference	Total
Acrididae			
<i>Abracrini sp.</i>	3	0	3
<i>Abracris dilecta</i> Walker, 1870	1	8	9
<i>Abracris flavolineata</i> (De Geer, 1773)	1	4	5
<i>Abracris sp.</i>	1	0	1
<i>Acrididae sp. 1</i>	1	0	1
<i>Acrididae sp. 2</i>	1	0	1
<i>Acrididae sp. 3</i>	1	0	1
<i>Acrididae sp. 4</i>	0	1	1
<i>Acrididae sp. 5</i>	0	1	1
<i>Acrididae sp. 6</i>	0	1	1
<i>Acrididae sp. 7</i>	0	2	2
<i>Acrididae sp. 8</i>	0	1	1
<i>Acrididae sp. 9</i>	1	0	1
<i>Acrididae sp. 10</i>	4	0	4
<i>Dichroplini sp. 1</i>	0	3	3
<i>Fenestra sp.</i>	1	0	1
<i>Melanoplinae sp. 1</i>	1	0	1
<i>Orphula pagana</i> (Stål, 1861)	1	0	1
<i>Orphulella punctata</i> (De Geer, 1773)	0	1	1
<i>Ronderosia bergii</i> (Stål, 1878)	0	28	28
<i>Vilerna sp. 1</i>	0	1	1
Anostostomatidae			
<i>Lutosa sp.</i>	11	4	15
Gryllidae			
<i>Brasilodontus sp.</i>	0	93	93
<i>Diatrypa sp.</i>	0	1	1
<i>Eneoptera surinamensis</i> (De Geer, 1773)	34	80	114

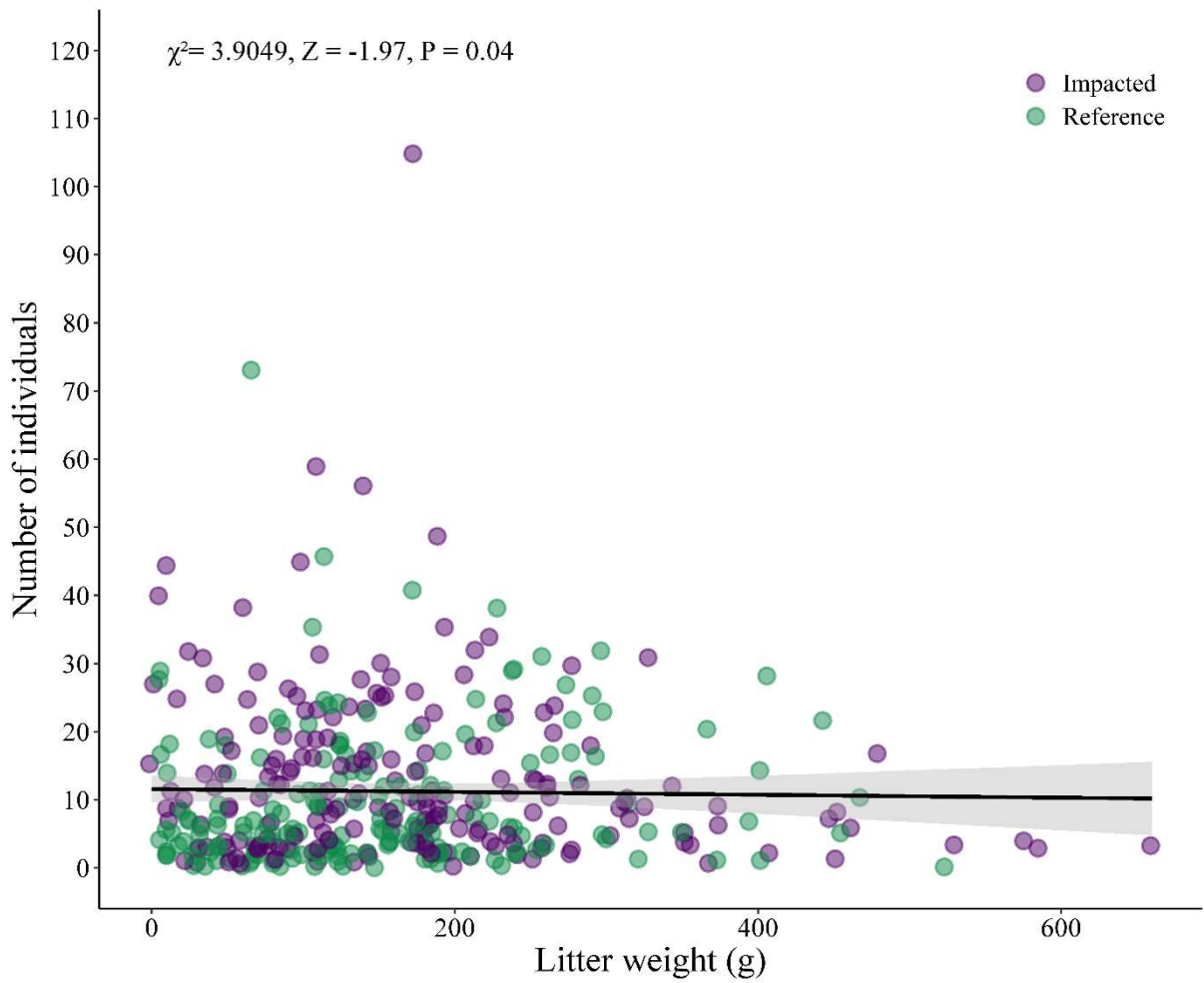
<i>Gryllidae sp.</i>	0	2	2
<i>Gryllus sp.</i>	0	2	2
<i>Miogryllus sp.</i>	2	2	4
<i>Oecanthus sp.</i>	0	1	1
Mogoplistidae			
<i>Mogoplistinae sp. 1</i>	2	0	2
<i>Mogoplistinae sp. 2</i>	0	1	1
<i>Mogoplistinae sp. 3</i>	0	1	1
<i>Mogoplistinae sp. 4</i>	0	1	1
<i>Mogoplistinae sp. 5</i>	0	1	1
<i>Ornebius sp.</i>	1	0	1
Oecanthidae			
<i>Neometrypus sp.</i>	0	1	1
<i>Neometrypus sp. 2</i>	1	0	1
Ommexechidae			
<i>Ommexechidae sp.</i>	1	0	1
Phalangopsidae			
<i>Adelosgryllus rubricephalus</i> Mesa & Zefa, 2004	2	8	10
<i>Adelosgryllus sp.</i>	5	0	5
<i>Eidmanacris cf. fontanettiae</i> Campos, Nihei & de Mello, 2017	2	0	2
<i>Eidmanacris putuhra</i> Campos, 2017	0	1	1
<i>Eidmanacris sp.</i>	3	0	3
<i>Endecous (Endecous) aguassay</i> Mews, 2008	5	0	5
<i>Endecous sp.</i>	4	3	7
<i>Guabamima sp.</i>	18	11	29
<i>Izecksohniella sp.</i>	13	5	18
<i>Lerneca sp.</i>	4	16	20
<i>Luzaninae sp.</i>	1	0	1
<i>Melanotes sp.</i>	1	0	1
<i>Paragryllinae sp. 1</i>	1	0	1
<i>Paragryllinae sp. 2</i>	1	0	1
<i>Ubiquepuella telytokous</i> Fernandes, 2015	93	52	145
Romaleidae			
<i>Xyleus sp.</i>	0	1	1
Tetrigidae			
<i>Crimisus sp. 1</i>	2	0	2
<i>Halmatettix sp.</i>	2	0	2
<i>Halmatettix sp. 1</i>	0	1	1
<i>Metrodora sp. 1</i>	16	0	16
<i>Tetrigidae sp. 1</i>	0	5	5
<i>Tetrigidae sp. 2</i>	0	6	6
<i>Tetrigidae sp. 3</i>	48	22	70
<i>Tettigidea sp. 1</i>	0	1	1
<i>Tettigidea sp. 2</i>	1	0	1
<i>Tettigidea sp. 3</i>	8	0	8
<i>Tettigidea sp. 4</i>	1	1	2
Tettigoniidae			
<i>Agraecini sp.</i>	1	0	1
<i>Meronicidius sp.</i>	0	1	1
<i>Phaneropterinae sp.</i>	1	0	1
Tridactylidae			
<i>Neotridactylus sp.</i>	10	0	10
<i>Neotridactylus sp. 1</i>	214	2	216
Trigonidiidae			
<i>Amanayara bernardesi</i> Pereira, Sperber & Lhano, 2010	2	23	25
<i>Hygronemobius sp.</i>	5	1	6
<i>Nemobiinae sp.</i>	1	0	1
<i>Phylloscyrtus amoenus</i> Burmeister, 1880	0	1	1
<i>Trigonidiinae sp. 1</i>	1	3	4
<i>Trigonidiinae sp. 2</i>	5	2	7

<i>Trigonidiinae sp. 3</i>	0	1	1
<i>Zucchiella sp.</i>	19	4	23
Nymph	920	715	1635
Total	1479	1127	2606
Data 2023			
Taxon	Impacted	Reference	Total
Acrididae			
<i>Abracris flavolineata</i> (De Geer, 1773)	1	2	3
<i>Liebermannacris dorsualis</i> (Giglio-Tos, 1898)	1	0	1
<i>Omalotettix obliquus</i> (Thunberg, 1824)	1	0	1
<i>Orphulellini sp.</i>	1	0	1
<i>Peruvia nigromarginata</i> (Scudder, 1875)	0	2	2
<i>Ronderosia sp.</i>	0	2	2
<i>Vilema aff. rugulosa</i> Stål, 1878	1	1	2
<i>Orphula sp.</i>	2	0	2
<i>Orphulella punctata</i> (De Geer, 1773)	1	7	8
Anostostomatidae			
<i>Apotetamenus sp.</i>	19	1	20
<i>Lutosa sp.</i>	0	1	1
Gryllacrididae			
<i>Gryllacridinae sp.</i>	1	0	1
Gryllidae			
<i>Brasilodontus sp. 1</i>	1	0	1
<i>Brasilodontus sp. 2</i>	24	8	32
<i>Eneoptera surinamensis</i> (De Geer, 1773)	54	34	88
<i>Gryllinae sp. 1</i>	6	1	7
<i>Gryllinae sp. 3</i>	1	0	1
<i>Gryllinae sp. 4</i>	1	0	1
<i>Miogryllus sp. 1</i>	2	4	6
<i>Miogryllus sp. 2</i>	4	0	4
Gryllotalpidae			
<i>Neoscapteriscus sp.</i>	1	0	1
Mogoplistidae			
<i>Mogoplistinae sp. 1</i>	12	17	29
<i>Mogoplistinae sp. 2</i>	4	3	7
<i>Mogoplistinae sp. 3</i>	1	0	1
<i>Mogoplistinae sp. 4</i>	1	0	1
<i>Mogoplistinae sp. 5</i>	0	3	3
<i>Mogoplistinae sp. 6</i>	4	2	6
<i>Mogoplistinae sp. 7</i>	2	1	3
Oecanthidae			
<i>Podoscirtinae sp.</i>	1	0	1
<i>Tafaliscinae sp.</i>	3	2	5
Phalangopsidae			
<i>Adelosgryllus rubricephalus</i> Mesa & Zefa, 2004	3	6	9
<i>Eidmanacris sp.</i>	36	6	42
<i>Eidmanacris sp. 1</i>	17	0	17
<i>Eidmanacris sp. 2</i>	0	1	1
<i>Endecous sp.</i>	0	1	1
<i>Guabamima sp.</i>	6	9	15
<i>Guabamima sp. 1</i>	5	19	24
<i>Guabamima sp. 2</i>	16	0	16
<i>Izecksohniella sp.</i>	40	10	50

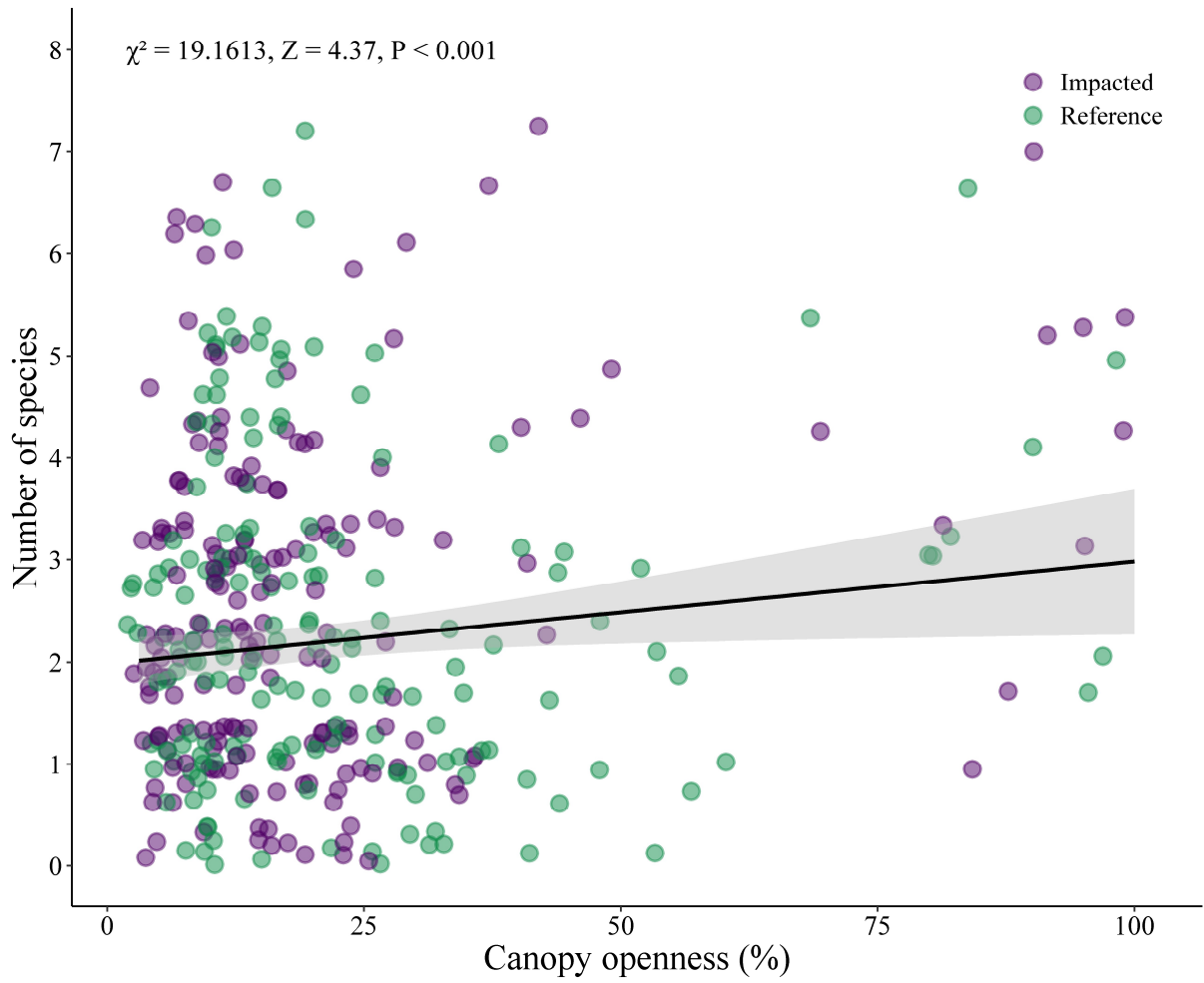
<i>Laranda sp.</i>	1	0	1
<i>Lerneca sp. 1</i>	23	4	27
<i>Melanotes sp.</i>	3	0	3
<i>Mellopsis doucasae</i> Mews & Sperber, 2010	4	0	4
<i>Ubiquepuella telytokous</i> Fernandes, 2015	84	62	146
Tetrigidae			
<i>Allotettix sp.</i>	1	0	1
<i>Batrachidea sp.</i>	9	1	10
<i>Bolivariadora aff. cipolai</i> Cadena-Castañeda & Tavares, 2025	6	26	32
<i>Clypeotettix aff. zonatus</i> (Walker, 1871)	1	1	2
<i>Halmatettix sp.</i>	2	3	5
Tettigoniidae			
<i>Tettigoniidae sp.</i>	0	1	1
Tridactylidae			
<i>Neotridactylus sp. 1</i>	15	2	17
<i>Neotridactylus sp. 2</i>	29	0	29
Trigoniidae			
<i>Amanayara bernardesi</i> Pereira, Sperber & Lhano, 2010	0	49	49
<i>Hygronemobius sp.1</i>	1	0	1
<i>Hygronemobius sp.2</i>	1	0	1
<i>Hygronemobius sp.3</i>	4	1	5
<i>Trigoniinae sp. 1</i>	5	6	11
<i>Trigoniinae sp. 2</i>	11	4	15
<i>Zucchiella sp.</i>	241	219	460
<i>Zucchiella sp. 2</i>	0	3	3
Nymph	429	307	736
Total	1143	832	1975

SI3. Table with environmental variables sampled in the five regions of the Rio Doce basin, describing the means, standard deviations (SD), and range of each variable in the environments.

Variable sampled	Region 1		Region 2		Region 3		Region 4		Region 5	
	Impacted (N=40)	Reference (N=40)	Impacted (N=40)	Reference (N=39)	Impacted (N=40)	Reference (N=40)	Impacted (N=40)	Reference (N=40)	Impacted (N=40)	Reference (N=40)
Litter weight (g)										
Mean (SD)	148.310 (88.222)	171.475 (116.722)	171.974 (66.802)	181.889 (116.797)	216.325 (111.188)	195.075 (101.409)	110.825 (100.970)	71.925 (53.553)	199.000 (173.117)	118.590 (53.434)
Range	0.000 - 373.000	4.000 - 444.000	57.000 - 312.000	8.000 - 524.000	70.000 - 575.000	44.000 - 453.000	10.000 - 452.000	9.000 - 244.000	5.000 - 660.000	25.000 - 241.000
Depth of leaf litter (cm)										
Mean (SD)	1.645 (1.295)	2.618 (1.281)	5.240 (2.185)	3.551 (2.375)	3.292 (2.083)	2.380 (1.093)	1.970 (1.844)	0.853 (1.015)	2.240 (0.899)	0.710 (0.419)
Range	0.000 - 4.200	0.500 - 5.000	1.000 - 9.000	0.500 - 13.000	0.500 - 12.000	0.500 - 5.700	0.000 - 8.000	0.000 - 6.000	1.000 - 5.500	0.100 - 2.000
Litter heterogeneity (inv-D)										
Mean (SD)	2.636 (0.539)	2.265 (0.624)	2.720 (0.564)	2.627 (0.541)	2.852 (0.452)	2.801 (0.607)	1.919 (0.724)	1.955 (0.689)	2.057 (0.651)	2.402 (0.698)
Range	1.543 - 3.736	1.000 - 3.264	1.593 - 3.777	1.017 - 3.579	1.890 - 4.118	1.435 - 3.969	1.000 - 3.660	1.000 - 3.955	1.015 - 3.642	1.139 - 3.906
Canopy openness (%)										
Mean (SD)	32.697 (28.879)	16.046 (13.835)	12.102 (5.430)	17.008 (18.750)	6.969 (2.945)	10.704 (5.179)	25.160 (19.898)	36.357 (20.492)	20.174 (11.374)	31.427 (17.921)
Range	4.710 - 100.000	3.490 - 89.500	4.010 - 23.400	3.370 - 98.260	3.290 - 17.570	3.090 - 22.090	3.790 - 93.830	9.050 - 95.900	4.320 - 60.890	5.270 - 96.810
Distance from nearest tailings (km)										
Mean (SD)	0.000 (0.000)	3.285 (0.052)	24.160 (0.052)	27.954 (0.041)	79.422 (0.060)	83.120 (0.052)	187.048 (0.019)	181.585 (0.021)	203.923 (0.038)	194.895 (0.041)
Range	0.000 - 0.000	3.220 - 3.360	24.090 - 24.230	27.890 - 28.000	79.340 - 79.500	83.050 - 83.190	187.020 - 187.070	181.560 - 181.610	203.880 - 203.980	194.840 - 194.950
Forest area (%)										
Mean (SD)	57.650 (0.527)	76.115 (0.258)	25.556 (1.035)	31.502 (0.314)	83.600 (0.881)	74.670 (0.871)	2.515 (0.856)	0.945 (0.370)	12.165 (1.291)	4.415 (1.251)
Range	57.130 - 58.170	75.860 - 76.370	25.200 - 31.820	31.200 - 31.820	82.730 - 84.470	73.810 - 75.530	1.670 - 3.360	0.580 - 1.310	10.890 - 13.440	3.180 - 5.650



SI4. Effect of litter weight (g) on the abundance of Orthoptera in the impacted and reference areas of the Rio Doce Basin. The line indicates the trend of the values, and the shaded area represents the confidence intervals.



SI5. Effect of canopy openness (%) on the richness of Orthoptera in the impacted and reference areas of the Rio Doce Basin. The line indicates the trend of the values, and the shaded area represents the confidence intervals.

CAPÍTULO II: Effects of the Fundão dam rupture (Mariana, MG) acting as a filter on the morphological variation of two species of litter crickets

Abstract

Disturbances caused by anthropogenic activities impact ecosystems and organisms to varying degrees, from population changes to morphological variations. One of the most significant disturbances in Brazil's history was the collapse of the Fundão dam in Mariana, MG, which significantly impacted the biodiversity of the Rio Doce watershed. Orthopterans, sensitive to environmental changes, are particularly affected by these disturbances, which can act as environmental filters and cause morphological variations in individuals. This study evaluated whether the environmental disturbance caused by the dam collapse altered the morphological traits of leaf litter crickets. To do this, we selected riparian vegetation areas affected and unaffected by the mining tailings released by the dam's collapse. In each area, we sampled orthopterans using pitfall traps and measured environmental variables. Following the criteria for selecting species and organisms for measuring body metrics, we selected the species *Amanayara bernardesi* and *Ubiquepuella telytokous* and measured six morphological characteristics in each individual. We observed that the environmental changes caused by the rupture may be acting as an environmental filter for the species *A. bernardesi*, since we observed a smaller variation in the size of the body structures of this species in the affected areas, but not influencing the morphology of the *U. telytokous*, which partially confirms our hypothesis. Thus, our study demonstrates the importance of using functional ecology approaches, specific organism characteristics, and local environmental contexts to understand the effects of the Fundão dam collapse on terrestrial biodiversity.

Keywords: morphological traits, mining disaster, environmental filters, Fundão dam failure, Rio Doce watershed

Introduction

Human-induced disturbances can lead to different impacts on ecosystems and influence organisms in varying proportions. These impacts range from community structure alterations to species morphological characteristics related to new environmental conditions (Dziock *et al.*, 2011; Ferrando *et al.*, 2016). In this context, altered environments can act as environmental filters, where both environmental conditions and species interactions, whether biotic or abiotic, shape ecological dynamics (HilleRisLambers *et al.*, 2012). Therefore, environmental filters can select species and individuals with traits that allow them to survive, reproduce, and persist in these environments (e.g., Grime *et al.*, 2012).

To understand these environmental influences on organisms, quantitative diversity metrics such as species richness and abundance are commonly used (Tews *et al.*, 2004). However, these metrics have limitations in understanding ecosystem functions and how different species respond to environmental stresses (Cadotte; Carscadden; Mirotchnick, 2011). Therefore, it is essential to include the use of functional ecology approaches, as they enable the analysis of how environmental filters may shape organisms' morphological responses and the ecological functions they perform within ecosystems (Deraison *et al.*, 2015; Ferrando *et al.*, 2016; Picaud; Petit, 2007; Pierce *et al.*, 2017; Whitman, 2008).

In arthropods, morphological variations in response to environmental changes are common and often include adjustments in body size, appendage dimensions, and dispersal capacity (Ferrando *et al.*, 2016; Whitman, 2008). These characteristics are influenced by different environmental factors such as elevation (Jarčuška; Krištín; Kaňuch, 2023), disturbance levels, and urbanization (Waterschoot; Bataille; Van Dyck, 2023), among others. For example, arthropods tend to be smaller in areas with high land use intensity and have greater dispersal capacity (Simons; Weisser; Gossner, 2016). On the other hand, with pasture burning, grasshoppers tend to have smaller femurs and, consequently, lower dispersal capacity (Ferrando *et al.*, 2016). Furthermore, morphological variations reflect important characteristics of the fitness and life history of organisms, such as growth, survival and reproduction, consequently affecting population dynamics (Whitman, 2008).

One of the most significant environmental disasters in Brazil occurred in 2015 with the collapse of the Fundão mining tailings dam in Mariana, Minas Gerais (Fernandes *et al.*, 2016). After the collapse, the mining tailings immediately reached more than a kilometer inside the margins of the Gualaxo do Norte river, located downstream of the dam, impacting much of its margins (Fernandes *et al.*, 2016; Silva *et al.*, 2021). Subsequently, the mining tailings moved

along the Rio Doce watershed, traveling 632 km to the Atlantic Ocean. With the passage of the mining tailings, there were direct impacts on aquatic life (Costa *et al.*, 2022), terrestrial arthropods (Ribeiro *et al.*, 2023), caused microbiological changes in the soil of riparian areas (Couto *et al.*, 2021) and affected the natural resources that sustained local populations (Czajkowski *et al.*, 2023; Fernandes *et al.*, 2016). Additionally, in the immediately affected areas, mining tailings deposition on the margins suppressed vegetation and caused impacts on soil, biodiversity, and ecosystem functions (Fernandes; Ribeiro, 2017; Omachi *et al.*, 2018; Queiroz *et al.*, 2018; Ramos *et al.*, 2024).

Riparian biota, including arthropods, may have also been impacted by this alteration (Ribeiro *et al.*, 2023). One of the main groups of arthropods that make up riparian biota is orthopterans (grasshoppers, katydids, crickets, and mole crickets) (Pronk *et al.*, 2017; Ribeiro *et al.*, 2023). These organisms are sensitive to environmental changes and indicators of environmental degradation, forest regeneration (Szinwelski *et al.*, 2012), fragmentation (Ribas *et al.*, 2005) and habitat heterogeneity (Löffler; Fartmann, 2017). Commonly, these organisms respond through loss of diversity (Tews *et al.*, 2004), changes in ecological interactions (Valiente-Banuet *et al.*, 2015), and alterations in functional traits and species morphology (Dziocik *et al.*, 2011; Ferrando *et al.*, 2016). Additionally, they participate in essential ecosystem functions such as seed dispersers (Santana; Baccaro; Costa, 2016) and are part of the diet of numerous animal species (Bock; Bock; Grant, 1992; Cappellari; de Lema; Jr, 2007).

The adult body morphology of orthopterans reflects the influence of the environment on their ecosystem functions, life history traits, and organism ecology (Whitman, 2008). For example, body size variation implies variation in metabolic rates, longevity aspects, fecundity, and reproductive success (Chown; Gaston, 2010; Laiolo; Illera; Obeso, 2013; Wey; Réale; Kelly, 2019; Whitman, 2008). Additionally, body size can be related to the feeding niche occupied and the ecosystem functions performed, such as productivity and decomposition (Deraison *et al.*, 2015). Therefore, body changes influence trophic interactions and changes at other levels of biological organization (DeLong *et al.*, 2015; Woodward *et al.*, 2005). It also influences factors important for the organisms' survival, such as dispersal capacity and predator escape ability (Picaud; Petit, 2007). Thus, it is essential to evaluate morphological characteristic variations to understand the effects of environmental impacts on species' ecology and life history (Vandewalle *et al.*, 2010; Wong; Guénard; Lewis, 2019).

Thus, considering the importance of understanding and filling up the gaps in our knowledge on the effects of the largest mining disaster caused by the breach of the Samarco's Fundão dam on riparian biota, our objective was to assess how the environmental changes

caused by the mining tailings deposition affected the morphology of cricket species in the area most severely impacted riparian area, the Gualaxo do Norte river. Almost seven years after the collapse, this goal allows us to evaluate whether there are long-term effects of the disturbance on the morphology of species. We hypothesize that the disturbance filtered the crickets' functional attributes, leading to changes in the body morphology of individuals inhabiting the affected areas; therefore, we expect a smaller body size and trait size in affected areas compared to unaffected areas.

Methods

Study Area

Our study area comprised the riparian vegetation along the Gualaxo do Norte River, located in the municipality of Mariana, Minas Gerais (Figure 1). This river is known for its shallow depth for most of the year, and its banks are predominantly composed of riparian Atlantic Forest vegetation. We chose this study area because of its proximity to the Fundão dam and because it is the area immediately affected by the mining tailings from the collapse, which subsequently moved throughout the Doce River basin. Therefore, the study area offers the possibility of comparing affected and unaffected areas along the same river, thus reducing the influence of factors related to spatial variation throughout the Doce River basin. Based on this, we consider affected areas to be those located downstream of the Fundão dam, where the mining tailings passed and overflowed, and unaffected areas to be those located upstream of the dam in the stretch of the river without contact with the mining tailings (Figure 1). Therefore, the sampling area comprises a region covering a 20.1 km stretch following the course of the river.

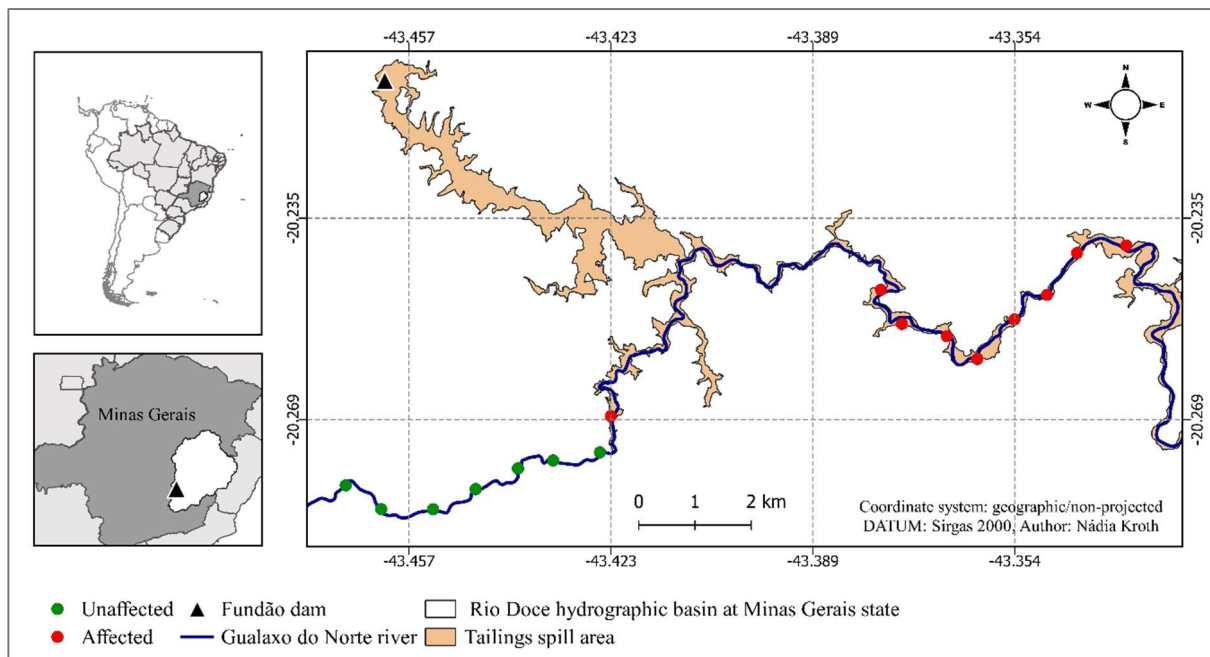


Figure 1. Location of sampling points in affected and unaffected areas in the region immediately affected by the deposition of mining tailings (represented by the projection of the tailings spill area in brown) from the Fundão dam collapse along the banks of the Gualaxo do Norte River. The red points represent the sampling points affected by the deposition of mining tailings located downstream of the Gualaxo do Norte River, and the green points represent the unaffected sampling points situated upstream. Each sampling point is located 1 km apart, and this sampling area covers a 20.1 km stretch following the course of the river.

Experimental Design

To collect orthopterans, we selected seven sampling points unaffected by tailings and nine affected by mining tailings passage along the Gualaxo do Norte river (Figure 1). In each area (affected and unaffected), the sampling points were selected 1 km apart from each other (Figure 1), and at each sampling point, we installed two 10 x 4-meter plots 50 meters apart (S11) for orthopteran collection. We used the criterion of installing the plots in the riparian forest area closest to the river, resulting in plots at different distances from the river, which was considered a covariate in the data analysis. We used this criterion because, particularly in the affected areas, the passage and overflow of the tailings resulted in the suppression of the original vegetation, resulting in different distances between the riparian forest and the riverbed (Figure 1).

In each plot, two sets of three transparent pitfall traps with a capacity of two liters (Diameter: 13,7 mm; Height: 16,5 mm) were arranged in a triangle, with each trap placed 2

meters apart (SI1). Each trap was filled with only 500 ml of fuel alcohol without adding attractive baits, with alcohol as the killing and preserving solution recommended by Szinwelski *et al.* (2012) and kept active for 48 hours. After this period, all individuals were collected, sorted, and stored in vials containing 85% alcohol. Furthermore, important environmental variables and descriptors related to conditions and resources for leaf litter crickets were estimated: 1) distance in meters from each pitfall set to the water (SI1); 2) the percentage of canopy cover measured using a forestry densiometer at the central point of each pitfall set, 3) the litter height, measured in centimeters with a millimeter ruler next to each pitfall, with values transformed into a mean value per pitfall set. The plots at each sampling point were installed during a previous expedition, carried out in the first week of December 2021, and sampling was carried out on a subsequent expedition, from March 23 to 31, 2022, totaling 100 days. This period between the installation of the plots and the sampling aims to avoid the possible effect of environmental disturbance caused by the installation of the pitfall trap and delimitation of the plots on the crickets' community (Sperber; Soares; Pereira, 2007). All sampling crickets (Ensifera) were identified to the species level, and at least one specimen of each species was deposited in the Entomological Collection of the Museu Nacional (MNRJ).

For selecting species and individuals to evaluate the influence of the area on the morphological variation of individuals in the affected and unaffected areas, we established criteria. The selection criteria were as follows: i) adult organisms; ii) presence of the species in both areas; iii) a minimum of seven individuals of each species in each area; and iv) intact locomotor appendages (since, in Orthoptera, it is common to lose the locomotor appendages when they are captured in the pitfall trap). Based on these criteria, the two species selected were *Amanayara bernardesi* Pereira, Sperber & Lhano, 2010 (Trigonidiidae, Nemobiinae) (Figures 2a and 2b) and *Ubiquepuella telytokous* Fernandes, 2015 (Phalangopsidae, Paragryllinae) (Figure 2c).

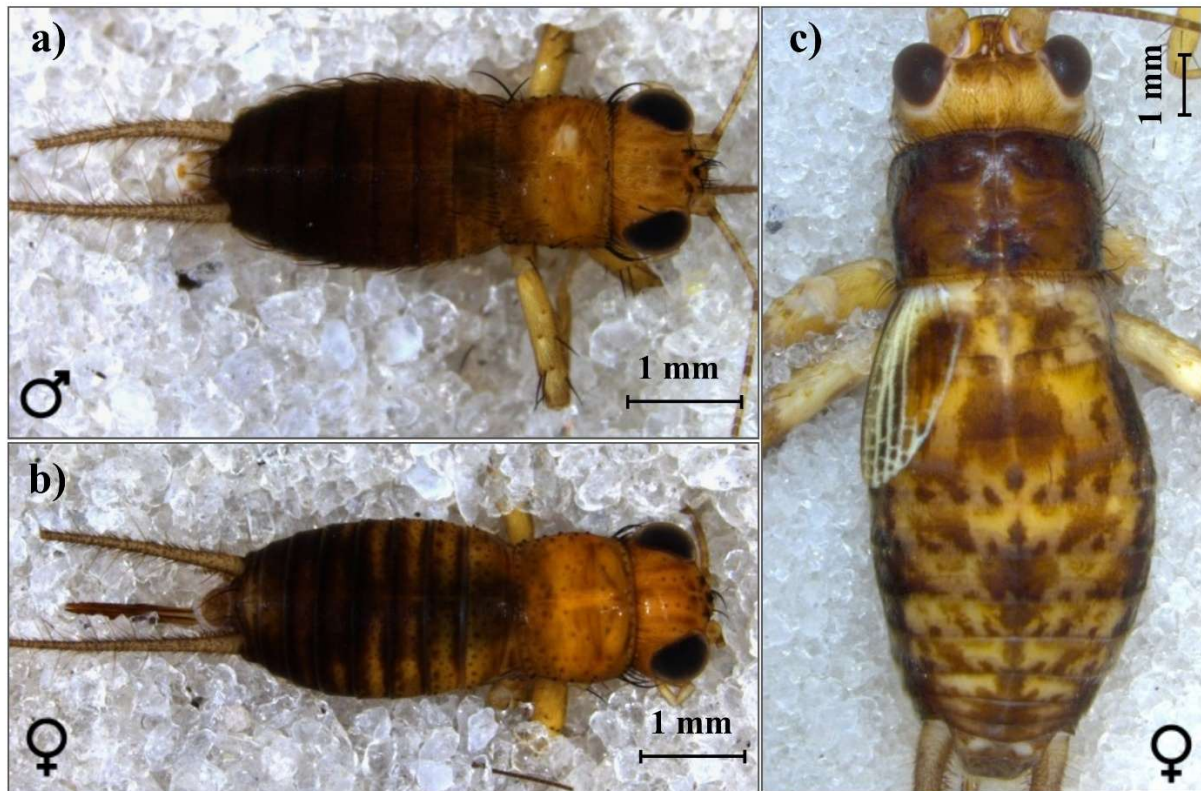


Figure 2. Representation of the species selected for body metrics, on the left represented by the letters a) male and b) female of the species *A. bernardesi*, and on the right represented by the letter c) the female of the species *U. telytokous*.

Nemobiinae crickets are inhabitants of forest litter and constitute an important component of the epigeal fauna. The species *A. bernardesi* belongs to one of the most abundant genera of litter crickets in the Atlantic Forest (Ribas *et al.*, 2005; Sperber; Soares; Pereira, 2007). A distinctive characteristic of the genus and the species is their small size (less than 9 mm), and both males and females are apterous (Figures 2a and 2b) (De Mello; Jacomini, 1994; Pereira; Sperber; Lhano, 2010). For this species, males and females have different body sizes, with males ranging between 6.29–7.62 mm and females ranging between 7.05–7.60 mm, both presenting intraspecific variations naturally (Pereira; Sperber; Lhano, 2010). On the other hand, the species *U. telytokous* is medium-sized, with a body length ranging from 14.54–16.89 mm and micropterous tegmina, not exceeding the third tergite (Figure 2c) (Fernandes; Zacaro, 2015). This species belongs to the Paragryllinae, a group of dendrophilous crickets, i.e., inhabitants of the trunks of living trees. Widespread throughout the Atlantic Forest, the main characteristic of this species is the parthenogenetic condition of the females (Fernandes; Zacaro, 2015), which is why we measured only female metrics for this species.

Morphological traits

To assess the morphological variation of the specimens' bodies, we selected six traits: body length, pronotum length, length of the hind leg femur and tibia, ovipositor length, and mandible length (Table 1, Figure 3). The morphological traits were measured in millimeters using a Zeiss Discovery.V20 stereomicroscope with a 1.0x FWD 60mm magnification lens. The orientation of the images and the measurements recorded for each cricket (Figure 3) were adapted according to Ferrando *et al.* (2016) and Whalen *et al.* (2022).

Table 1. Measured morphological traits and their respective response proxies.

Trait	Response Proxy
Body length	The environment influences the organism's life history characteristics, function, and ecology (Whitman, 2008).
Pronotum length	Body condition (Kelly <i>et al.</i> , 2014)
Mandible length	Dietary niche and ecosystem functions (e.g., productivity and decomposition) (Deraison <i>et al.</i> , 2015).
Hind femur and tibia length	Dispersal capability, predator evasion (Picaud and Petit 2007), and response to environmental disturbances (Ferrando <i>et al.</i> , 2016).
Ovipositor length	Assurance of reproductive success and adaptability (Bradford <i>et al.</i> , 1993; Laiolo <i>et al.</i> , 2013)

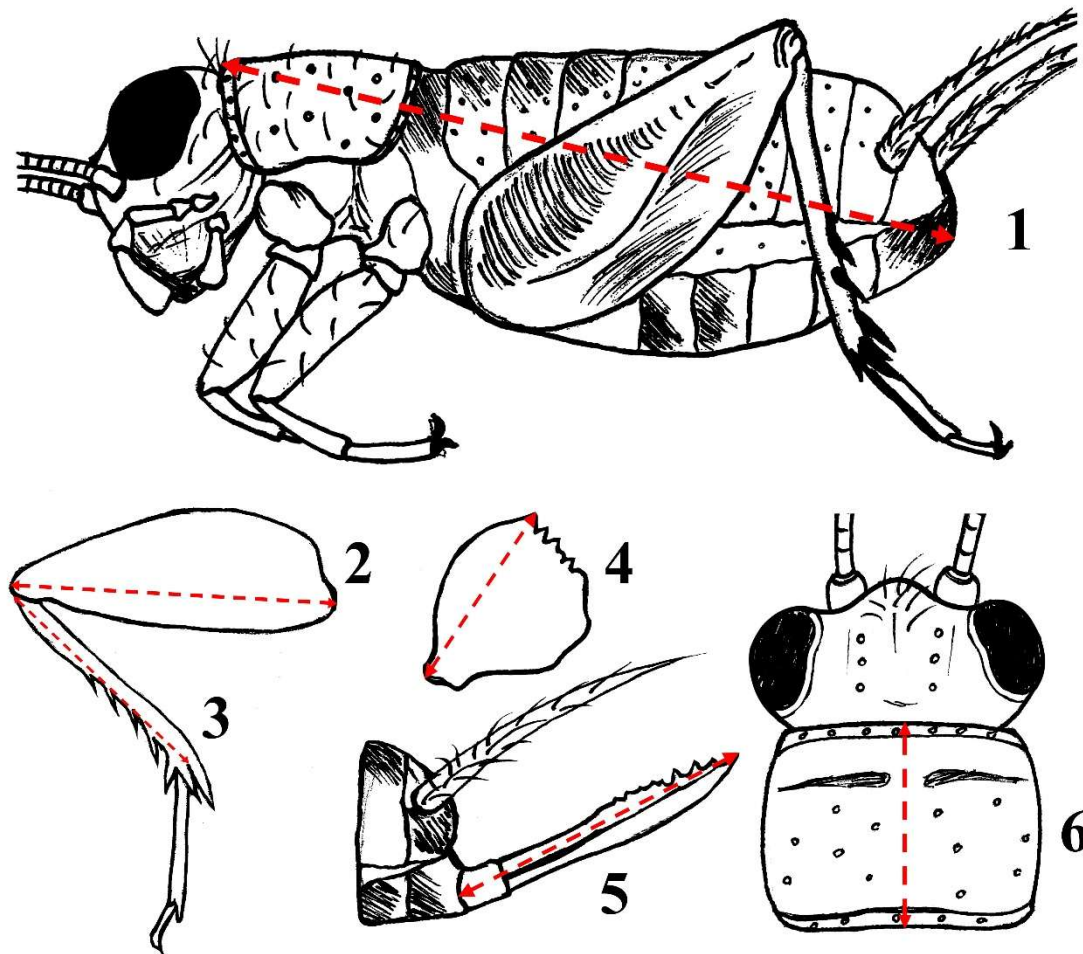


Figure 3. Diagram of the six morphological characteristics recorded for each cricket and the orientation of the images for measurement extraction: lateral view of the body (1), lateral view of the hind leg showing femur (2) and tibia (3); ventral view of the mandible (4), lateral view of the female ovipositor (5), and dorsal view of the pronotum (6). Dashed lines represent how each morphological measurement was extracted from each structure. The drawings are not to scale and describe the morphology of *A. bernardesi*.

Statistical Analysis

To evaluate the impact of disturbance (mining tailings) on the total morphological variation of individuals, we employed Principal Component Analysis (PCA). PCA was used to reduce the dimensionality and redundancy of the data, transforming the recorded characteristics for each individual into a new dataset summarized by principal components that capture most of the variation in the data (Jolliffe; Cadima, 2016). Thus, all characteristics separately recorded for each individual were transformed into a single eigenvalue resulting from Principal Component 1 (PC1), representing the total morphological variation of each individual. Each

individual was considered a sampling unit. In addition, to determine if there was morphological variation among individuals between environments, the eigenvalues generated in PC1 (response variable) were tested using a Generalized Linear Model (GLM). The analysis was performed separately for each gender (male and female). The model considered the type of environment (affected and unaffected) as the explanatory variable. We utilized functions from the "*DHARMA*" package to ensure model adequacy and residual analysis. In cases of non-normality in data and model residuals, data adjustment used the "*log*" function for data transformation. We then used an F-test with a 95% confidence interval to check for differences in variances in the size of each body structure between the affected and unaffected areas.

To evaluate whether environmental variables influence the morphological variation of the evaluated species' individuals, we used the means of morphological characteristics from each pitfall trap set as the sampling unit. We used the mean values of the traits because we had only one metric for each environmental variable per pitfall trap set, thus avoiding the repetition of environmental data. Thus, we employed PCA to transform the mean of the six morphological characteristics into a single value for the response variable. Similarly, we analyzed the influence of environmental variables by separating the analysis for males and females. The eigenvalues generated in PC1 were used as the response variable representing the total morphological variation of each trap set. We then used a Generalized Linear Mixed Model (GLMM), considering the distance to the river, the percentage of canopy cover, and the mean litter height of each trap set as explanatory variables and the sampling points as a random variable. In cases of non-normality in data and model residuals, data adjustment used the "*sqrt*" function for data transformation. We also assessed model adequacy and residual analysis using functions from the "*DHARMA*" package for these data. All analyses were conducted in R (version 4.3.1, 2024).

Results

We collected 1247 individuals, with 761 in the affected area and 486 in the unaffected area, identified across six families: Trigonidiidae (n=874), Phalangopsidae (n=177), Gryllidae (n=32), Anostomatidae (n=9), Mogoplistidae (n=2), and Oecanthidae (n=2). We identified a total of 14 crickets' species in the riparian regions of the Gualaxo do Norte river, with the species selected according to the criteria being *A. bernardesi* (Trigonidiidae) (n=290) and *U. telytokous* (Phalangopsidae) (n=68). Of these, only 137 individuals of *A. bernardesi* were suitable for analysis of body characteristics, including 108 females (unaffected area = 50, affected area = 58) and 29 males (unaffected area = 17, affected area = 12). For the species *U.*

telytokous, only 21 individuals were suitable, seven from the unaffected area and 14 from the affected area. Regarding environmental metrics, in affected areas, canopy cover ranged from 11.76 to 100.00% (mean = 89.38, SD = 16.26), litter height ranged from 0.67 to 5.33 cm (mean = 2.67, SD = 1.21), and distance to the river ranged from 3.24 to 139.70 m (mean = 49.43, SD = 39.15). In unaffected areas, canopy cover ranged from 70.59 to 100.00% (mean = 89.49, SD = 10.04), litter height ranged from 0.00 to 4.00 cm (mean = 1.98, SD = 1.04), and distance to the river ranged from 0.92 to 30.00 m (mean = 11.57, SD = 7.36).

For females of *A. bernardesi*, the first axis of the PCA explained 56.4% of the total morphological variation (SI2), while the second axis explained 14.9%. These two axes account for 71.3% of the total morphological variation (SI2). The percentages of contribution of each structure were: femur (20.7%), tibia (18.9%), pronotum (6.7%), body length (17.4%), mandible (15.5%) and ovipositor (15%). Based on PCA1, total morphological variation of female *A. bernardesi* individuals was not influenced by mining tailings deposition ($F_{1,63} = 1.3515$, $P = 0.22$, $\beta = 0.29 \pm 0.24$ SE). For males of *A. bernardesi*, the first axis of the PCA explained 56.7% of the total morphological variation (SI3), while the second axis explained 18.5%, hence accounting for 75.2%. The percentages of contribution of each structure were as follows: femur (30.1%), tibia (31.4%), pronotum (6.8%), body length (24.9%), and mandible (6.6%). Based on PCA1, the total morphological variation of male *A. bernardesi* individuals was not influenced by mining tailings deposition ($F_{1,27} = 0.53$, $P = 0.46$, $\beta = -0.48 \pm 0.65$ SE) (SI3).

Females of *A. bernardesi* showed greater variation in the size of body structures in unaffected areas, for most structures, such as the size of the femur ($F_{57,49} = 0.107$, $P < 0.001$ CI = 0.062 – 0.183, Figure 4a), tibia ($F_{57,49} = 0.292$, $P < 0.001$, CI = 0.168 – 0.501, Figure 4b), pronotum ($F_{57,49} = 0.110$, $P < 0.001$, CI = 0.063 – 0.189, Figure 4c), body ($F_{57,49} = 0.279$, $P < 0.001$, CI = 0.161 – 0.479, Figure 4d), ovipositor ($F_{57,49} = 0.291$, $P < 0.001$, CI = 0.168 – 0.500, Figure 4f), but not for mandible ($F_{57,49} = 0.876$, $P = 0.62$, CI = 0.505 – 1.504, Figure 4e). For males, variation was higher in unaffected areas for femur ($F_{11,16} = 0.228$, $P = 0.017$, CI = 0.078 – 0.754, Figure 4a), pronotum ($F_{11,16} = 0.055$, $P < 0.001$, CI = 0.019 – 0.182, Figure 4c), body ($F_{11,16} = 0.081$, $P < 0.002$ CI = 0.028 – 0.268, Figure 4d), but not for tibia ($F_{11,16} = 0.579$, $P = 0.361$, CI = 0.197 – 1.912, Figure 4b) nor mandible ($F_{11,16} = 2.478$, $P = 0.097$, CI = 0.845 – 8.188, Figure 4e). Mean values (mm), standard deviation, and range for each trait (femur, tibia, body, pronotum, mandible, and ovipositor) from each type of environment are presented in Table 2 for both species.

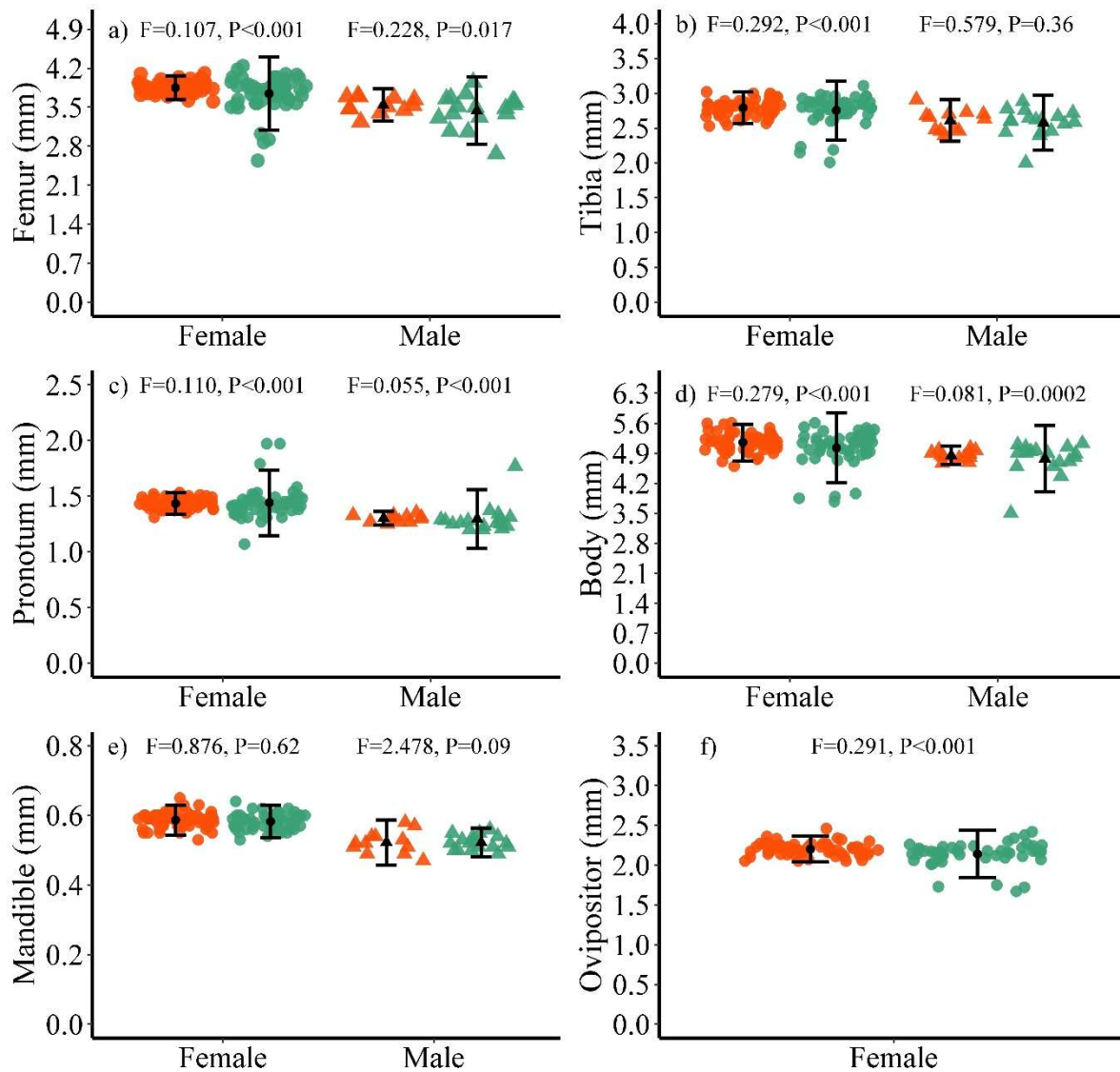


Figure 4. The length of the six traits of females and males of *A. bernardesi* present in areas affected (orange) and unaffected (green) by mining tailings. Females are represented by circles, and males by triangles. The central line represents the standard deviation of each group, and the central point represents the mean. The F and P values presented in each graph correspond to the results of the F-test, which compares the variances of the sizes of each trait between the affected and unaffected areas.

Table 2. Morphological variation of structures in *A. bernardesi* and *U. telytokous*, describing the means, standard deviations (SD), and range of femur, tibia, body, pronotum, mandible, and ovipositor in each group of individuals present in areas affected and unaffected by mining tailings. The values are represented in millimeters.

	<i>Amanayara bernardesi</i>				<i>Ubiquepuella telytokous</i>	
	Male		Female		Female	
	Affected (n=12)	Unaffected (n=17)	Affected (n=58)	Unaffected (n=50)	Affected (n=14)	Unaffected (n=7)
Femur						
Mean (SD)	3.540 (0.144)	3.439 (0.301)	3.851 (0.108)	3.746 (0.329)	8.673 (0.397)	8.659 (0.615)
Range	3.240-3.710	2.660-3.950	3.600-4.110	2.540-4.240	8.070-9.340	7.680-9.400
Tibia						
Mean (SD)	2.609 (0.150)	2.577 (0.197)	2.792 (0.115)	2.756 (0.212)	7.258 (0.434)	7.280 (0.413)
Range	2.400-2.910	2.000-2.880	2.530-3.020	2.010-3.110	6.560-8.240	6.610-7.750
Body						
Mean (SD)	4.851 (0.110)	4.772 (0.385)	5.151 (0.214)	5.027 (0.404)	9.071 (0.735)	9.327 (0.607)
Range	4.670-5.020	3.500-5.130	4.600-5.610	3.770-5.610	7.720-10.090	8.190-9.850
Pronotum						
Mean (SD)	1.302 (0.031)	1.296 (0.131)	1.434 (0.049)	1.441 (0.147)	2.059 (0.165)	2.063 (0.213)
Range	1.250-1.350	1.200-1.770	1.310-1.530	1.070-1.970	1.610-2.280	1.790-2.490
Mandible						
Mean (SD)	0.522 (0.032)	0.522 (0.020)	0.587 (0.022)	0.582 (0.023)	0.967 (0.043)	0.960 (0.046)
Range	0.470-0.580	0.490-0.560	0.530-0.650	0.530-0.640	0.850-1.030	0.900-1.020
Ovipositor						
Mean (SD)	-	-	2.200 (0.081)	2.139 (0.150)	8.844 (0.479)	8.636 (0.661)
Range			2.050-2.460	1.670-2.420	8.090-9.720	7.750-9.510

For the influence of environmental variables on the mean body characteristics of each pitfall set, the females *A. bernardesi*, the first axis of the PCA explained 61.6% of the morphological variation, and the second axis explained 16.3%, hence accounting for 77.9% of the total (SI4). Based on PC1, litter height ($\chi^2 = 0.1847$, $P = 0.66$), canopy cover ($\chi^2 = 0.0114$, $P = 0.91$), and distance from the river ($\chi^2 = 0.4662$, $P = 0.49$) did not influence body morphological variation in females. Finally, for *A. bernardesi* males, first axis of the PCA explained 57.5% of the morphological variation, and the second axis explained 19.4%, therefore accounting for 76.9% of the total (SI5). Based on PC1, litter height ($\chi^2 = 4.3941$, $P = 0.03$) influenced the average body characteristics of males (Figure 5), showing a positive relationship between increasing litter height and morphological variation in unaffected areas, while in affected areas this relationship was weak or non-existent (Figure 5). On the other hand, no relationship was observed for canopy cover ($\chi^2 = 1.3886$, $P = 0.23$), and distance from river ($\chi^2 = 0.6784$, $P = 0.41$).

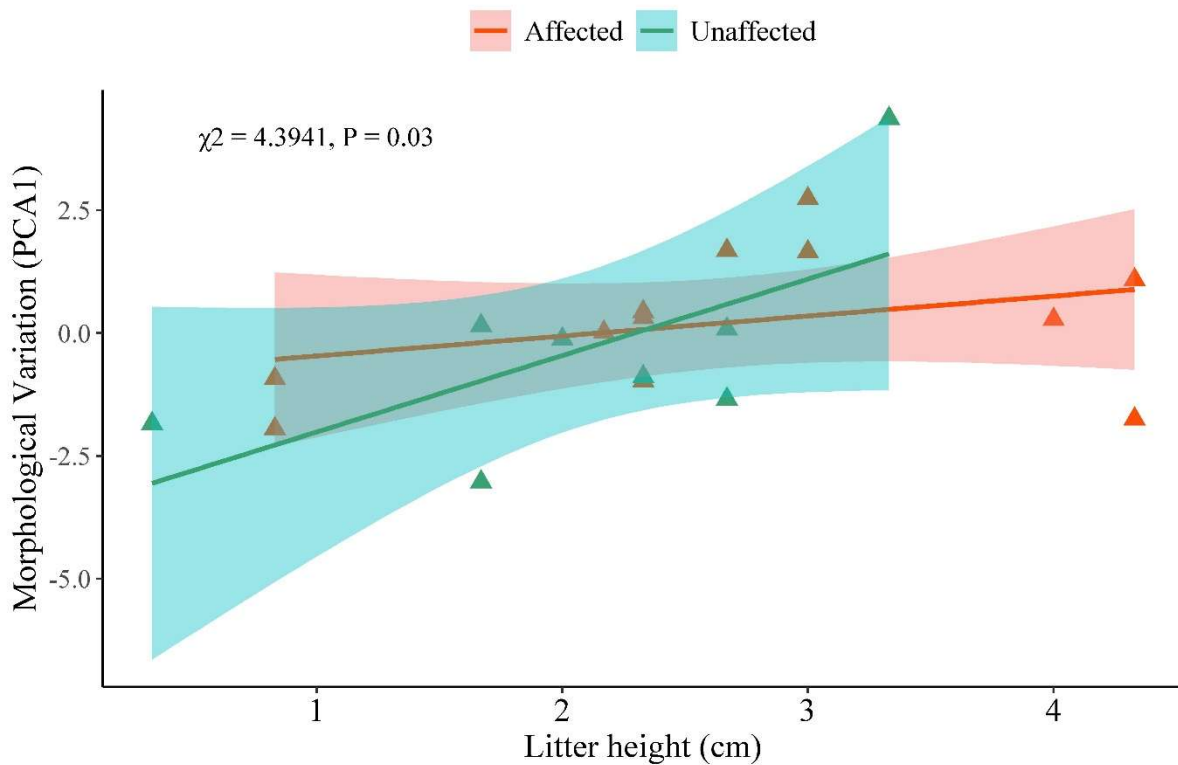


Figure 5. Relationship between the eigenvectors of PC1 of the mean of the morphological traits of males and litter height, according to the environment type. Triangles represent males, and colors indicate the environment (affected/unaffected). The lines indicate the trend of the eigenvectors (PC1) for the two environments, and the shaded areas represent the confidence intervals.

For the species *U. telytokous*, the first axis of the PCA explained 76.3%, while the second axis explained 10% of the variation, thus accounting for 86.3% of the total morphological variation (SI6). The traits that showed correlation and contributed to this result were the femur (19.2%), tibia (19.3%), pronotum (12.5%), body length (18.3%), mandible (14.6%), and ovipositor (15.8%) (SI6). Based on PC1, the mining tailings deposition ($F_{1,19} = 0.0016$, $P = 0.96$, $\beta = -0.041 \pm 1.04$ SE) did not influence the morphological variation in this species. Furthermore, the mining= 0.099s deposition did not influence the variation in the size of the femur ($F_{13,6} = 0.416$, $P = 0.175$, $CI = 0.078 - 1.501$), tibia ($F_{13,6} = 1.103$, $P = 0.961$, $CI = 0.207 - 3.976$), pronotum ($F_{13,6} = 0.598$, $P = 0.411$, $CI = 0.112 - 2.155$), ovipositor ($F_{13,6} = 0.526$, $P = 0.311$, $CI = 0.099 - 1.894$), body ($F_{13,6} = 1.466$, $P = 0.665$, $CI = 0.275 - 5.284$), and mandible ($F_{13,6} = 0.883$, $P = 0.794$, $CI = 0.166 - 3.182$).

For the influence of environmental variables on the average body characteristics of each pitfall set for *U. telytokous*, the first axis of the PCA explained 72.5%, and the second axis

explained 12.9%, thus accounting for 85.4% of the variation (SI7). Based on PC1, the distance from the river ($\chi^2 = 7.7292$, $P = 0.005$) influenced the average body characteristics, but not the canopy cover ($\chi^2 = 0.0064$, $P = 0.93$), and litter height ($\chi^2 = 0.9219$, $P = 0.33$) for *U. telytokous*.

Discussion

We confirmed that, with data collected almost seven years after the disaster, the passage of mining tailings from the collapse of the Samarco dam in the riparian zone is an important environmental filter, selecting morphological traits for the cricket *A. bernardesi*, although our results show a modest effect and should inspire caution in their interpretation. At the same time, the deposition of tailings did not influence the cricket *U. telytokous*. This finding partially supports our hypothesis, suggesting that morphological variation in *A. bernardesi* may be influenced by environmental changes caused by the collapse of the Fundão dam. When examining individual metrics, we observed less variation in the size of morphological traits of individuals from the affected areas. This indicates a distinct difference in morphology between individuals from affected and unaffected areas, even though the average size of the structures is very similar.

In affected areas, the passage of the tailings altered environmental conditions, such as soil characteristics and vegetation structure (Aires *et al.*, 2018; Buch *et al.*, 2021; Cruz *et al.*, 2020; Fernandes *et al.*, 2025; Ramos *et al.*, 2024), which are important traits in the habitats of tropical crickets. Variations in humidity, ambient temperature, and vegetation characteristics (Farias-Martins *et al.*, 2017; Srygley, 2014) are crucial factors for the development of individuals. These factors may influence with female oviposition site selection (Farias-Martins *et al.*, 2017), the duration of embryogenesis, and nymph development (Srygley, 2014), consequently influencing the body morphological variation of adults. For example, the cricket *Velarifictorus micado* Saussure, 1877 tends to have smaller body sizes due to the limited development time in relation to the different temperature conditions of higher latitudes (Zeng; Zhu, 2014). Additionally, females of *A. bernardesi* have an ovipositor with a serrated tip, a specific characteristic of species that lay their eggs in plant material (Chen *et al.*, 2021; Kim, 2013). This trait highlights the species' sensitivity to changes in vegetation characteristics, especially in areas affected by the passage of tailings, where the availability of habitats and suitable conditions for the development of offspring may have been directly influenced.

Amanayara bernardesi is a small, apterous species, characteristic of dense forest environments with a large amount of litter (Pereira; Sperber; Lhano, 2010), making it sensitive

to changes in vegetation structure and environmental conditions, as is known for other species in this genus (Ribas *et al.*, 2005; Sperber; Soares; Pereira, 2007). This is particularly relevant as we observed an effect of leaf litter height on the body size of males in this species. Following the passage of the tailings, the soil characteristics and vegetation structure in the riparian zone were significantly altered (Aires *et al.*, 2018; Buch *et al.*, 2021; Cabette *et al.*, 2017; Cruz *et al.*, 2020; Fernandes *et al.*, 2025). In many areas, these changes were caused by the deposited tailings, which modified the soil composition from its original state. This, in turn, affected the establishment and regeneration of vegetation (Buch *et al.*, 2021; Cruz *et al.*, 2020; Ramos *et al.*, 2024) and altered the characteristics of the leaf litter and soil organic matter (Batista *et al.*, 2022). Moreover, these changes influenced the taxonomic and functional structure of the arthropod community in these regions after the disaster (Ribeiro *et al.*, 2023). These factors are essential and may also influence changes in interactions and competition for resources in these environments, consequently affecting the body morphological variation of organisms (HilleRisLambers *et al.*, 2012). For example, under competitive conditions, the cricket species *Dianemobius nigrofasciatus* Matsumura, 1904 and *Polionemobius taprobanensis* Walker, 1869, both from the Trigonidiidae family, which share the same habitat but have distinct preferences, tend to alter their development by increasing the frequency of long-winged individuals and tibia length (Fujii; Reddy; Kuriwada, 2024). These changes may be related to adaptive abilities associated with escaping and/or moving within the environment. Therefore, the morphological variation in this species may have been influenced by changes in vegetation, soil, and interactions, highlighting the importance of considering both the direct and indirect effects of the disaster on the populations of riparian environments affected by the passage of the tailings.

For the species *U. telytokous*, we did not observe any influence of the disaster and environmental variables on body morphological variation. This result may be related to the parthenogenetic condition of this species (Fernandes; Zacaro, 2015), since parthenogenetic species tend to have low genetic variability and, consequently, less variability in the size of morphological traits (Jaron *et al.*, 2022). Furthermore, this result provides evidence that differences between species, such as size and ability to escape and/or move within the environment, likely explain the lack of effect of environmental changes and their impact on the morphology of this species. In general, the effects of disturbances are more significant in small, wingless insect species, which tend to move less within the environment (e.g., *A. bernardesi*) (Armitage *et al.*, 2013; Van Langevelde *et al.*, 2020). In contrast, *U. telytokous* is a medium-sized species belonging to the subfamily Paragryllinae, which has a striking characteristic of elongated legs and appendages relative to its body size (Fernandes; Zacaro, 2015). These

characteristics would allow for greater movement within the environment; therefore, it is possible that the changes resulting from the disturbance were insufficient to cause spatial limitations and the flow of individuals between areas for this species, and consequently, its morphological variation. Furthermore, the limited number of individuals analyzed may have restricted the detection of more subtle morphological variations. Finally, these results suggest that, despite the significant disturbance caused by the passage of tailings in the affected areas, species-specific characteristics such as genetic variability, body size, and locomotion capacity are essential for understanding ecological processes and the effects of disturbance on these organisms, even almost seven years after the disaster.

The correlation of the results for the two species reveals that the intensity of the effect depends on the specific characteristics of each species or group of organisms. In the areas affected by the Fundão disaster, this is also observed for other species and groups of arthropods through changes in the species present in the community and the functional groups of arthropods. For example, the abundance of omnivorous and detritivorous functional groups is lower in the affected areas (Ribeiro *et al.*, 2023), as well as negative effects reported on the fluctuating asymmetry of caddisflies in these areas compared to unaffected areas (Andrade Soares *et al.*, 2024). Furthermore, this pattern is also observed when some species are more capable than others of persisting in environments with high land use intensity, even if their morphological characteristics change (Simons; Weisser; Gossner, 2016). Another example is the male cricket *Isophya rizeensis* Sevgili, 2003 tends to present different variations in body size influenced by their phenotypic characteristics and environmental and geographic variations (Çağlar *et al.*, 2014). In this regard, it is essential to consider the general characteristics of species, individual variations, and specific environmental contexts to understand species' responses to environmental changes. In addition, a community-based evaluation is needed to understand it at a higher organizational level.

In this specific environmental context, it is important to mention that the Rio Doce watershed, to which the Gualaxo do Norte river belongs, has a long history of environmental degradation that dates long before the Fundão dam collapse (Macêdo *et al.*, 2024). This historical degradation is related to intense gold and iron ore mining, farming and other human activities in the region, which resulted in the high concentration of iron and other metals in the sediments of the Gualaxo do Norte river (Rodrigues *et al.*, 2014; Santolin *et al.*, 2015). Given this, it is important to emphasize that in addition to the direct effects of the deposition of mining tailings coming from the Fundão da collapse, these populations of organisms were already being subjected to several other anthropogenic stressors that might have been acting synergistically.

On the other hand, it is crucial to assess the significant impact of the mud tsunami (as described by Fernandes *et al.*, 2016) on riparian habitats and their associated biodiversity, as well as the harmful effects of toxic components that were likely sealed in the riverbed before the wave swept through (Fernandes *et al.*, 2025).

Therefore, this study showed that it is essential to consider species-specific traits to understand the effects of the Fundão dam collapse on terrestrial biodiversity. Our hypothesis was partially supported, as even almost seven years after the collapse, we found effects on the morphological variation of one of the studied orthopteran species. These findings highlight the importance of long-term monitoring and functional ecology approaches in conjunction with quantitative methods to understand the effects of mining disaster induced changes on this group of arthropods. Furthermore, it highlights the need to consider indirect effects, species specificity and specific environmental contexts to understand the effects of environmental disturbances on organismal body variation. This study also calls attention to deeper toxicological and experimental studies on the effects of tailings on the biodiversity of the Rio Doce watershed.

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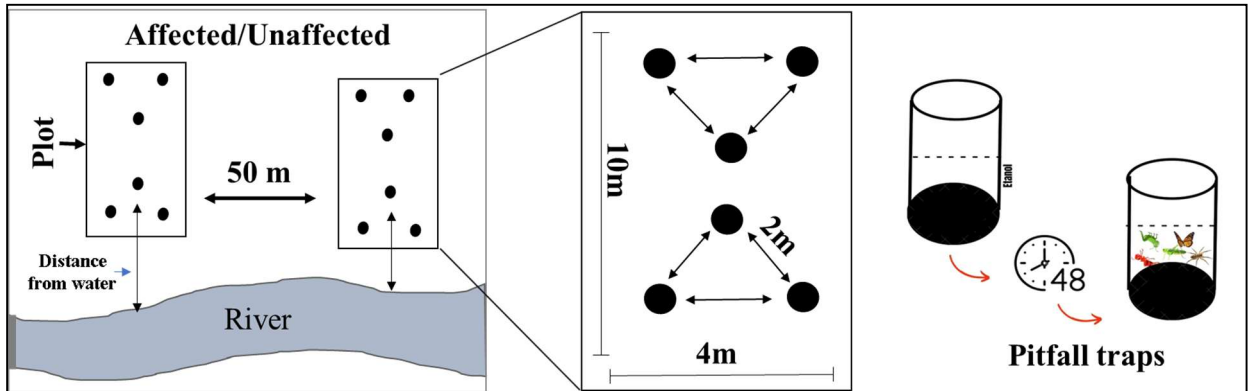
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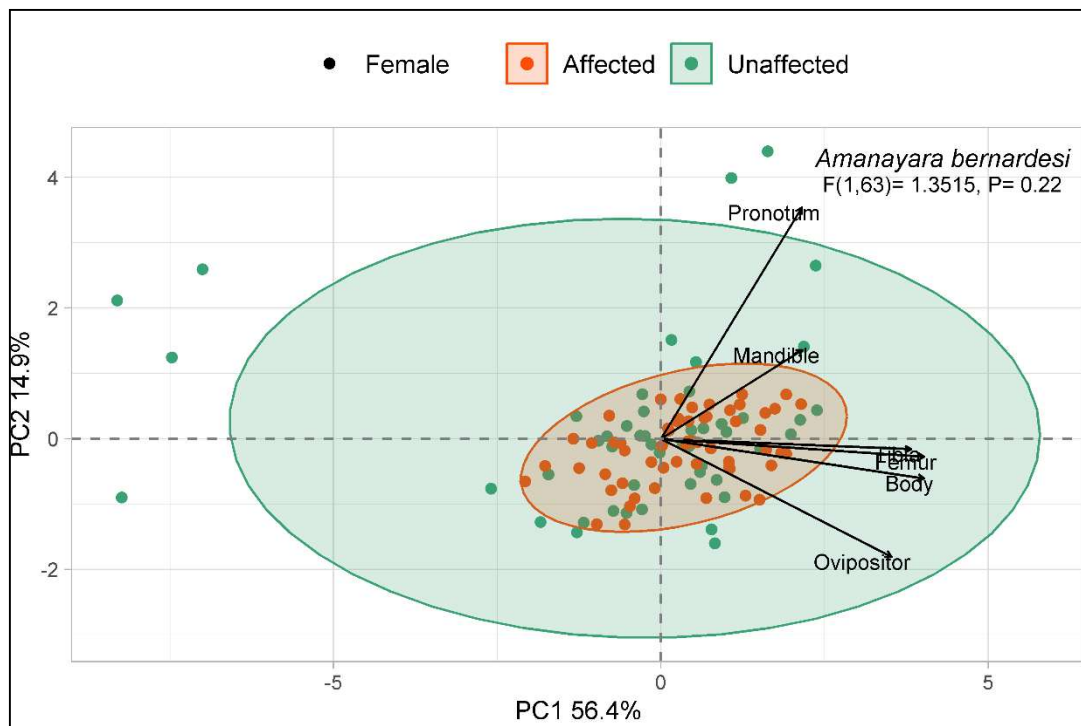
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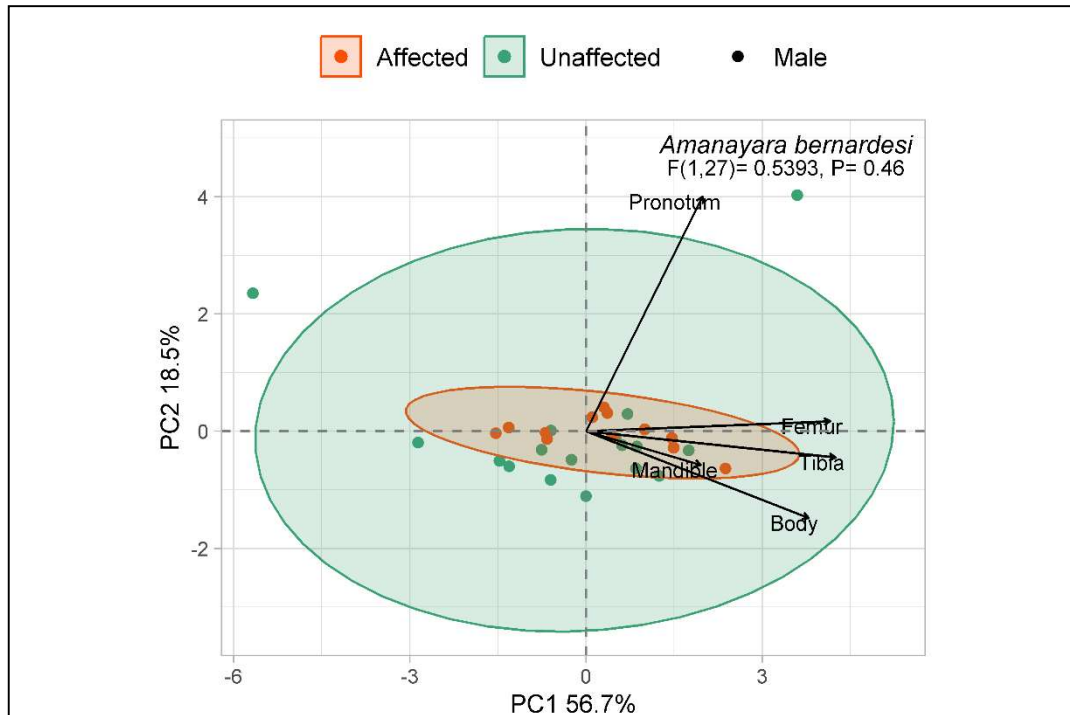
Supplementary Information



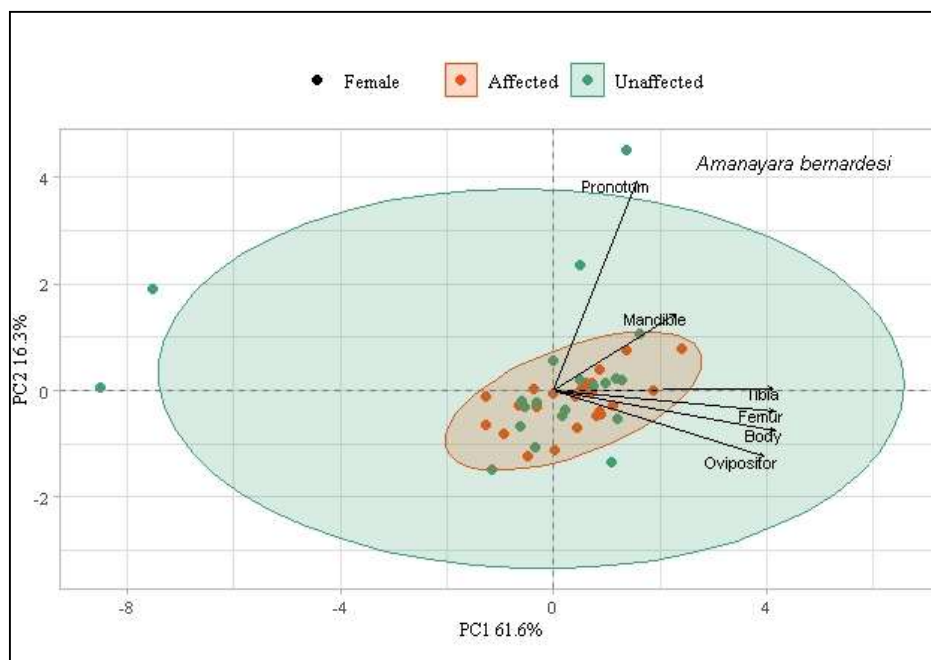
SI1. A diagram representing the sampling design at each sampling point in the affected and unaffected areas.



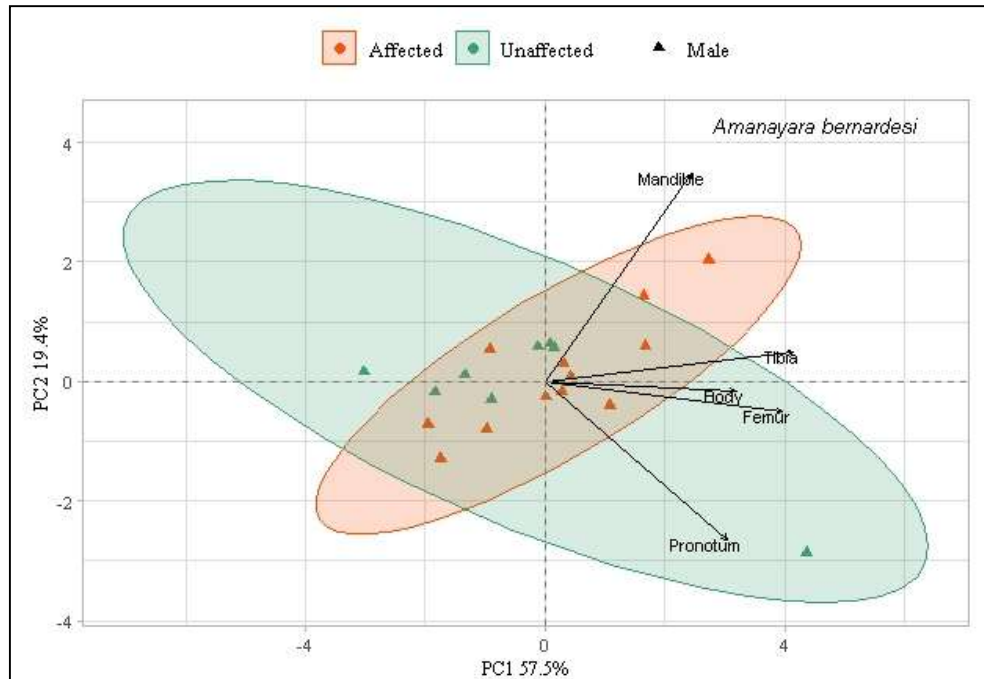
SI2. Principal Component Analysis (PCA) illustrating the relationship between morphological structures, variation in body morphology, and types of environments. Each point on the plot corresponds to a sampled individual, with females represented by circles and colors indicating the types of environments (affected / unaffected).



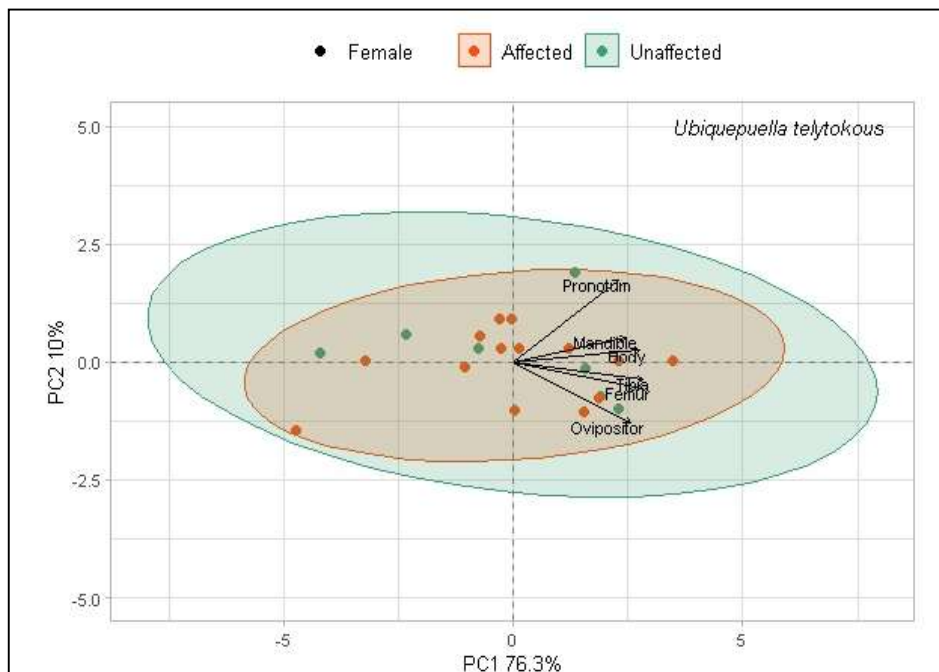
SI3. Principal Component Analysis (PCA) illustrating the relationship between morphological structures, variation in body morphology, and types of environments. Each point on the plot corresponds to a sampled individual, with males represented by triangles and colors indicating the types of environments (affected / unaffected).



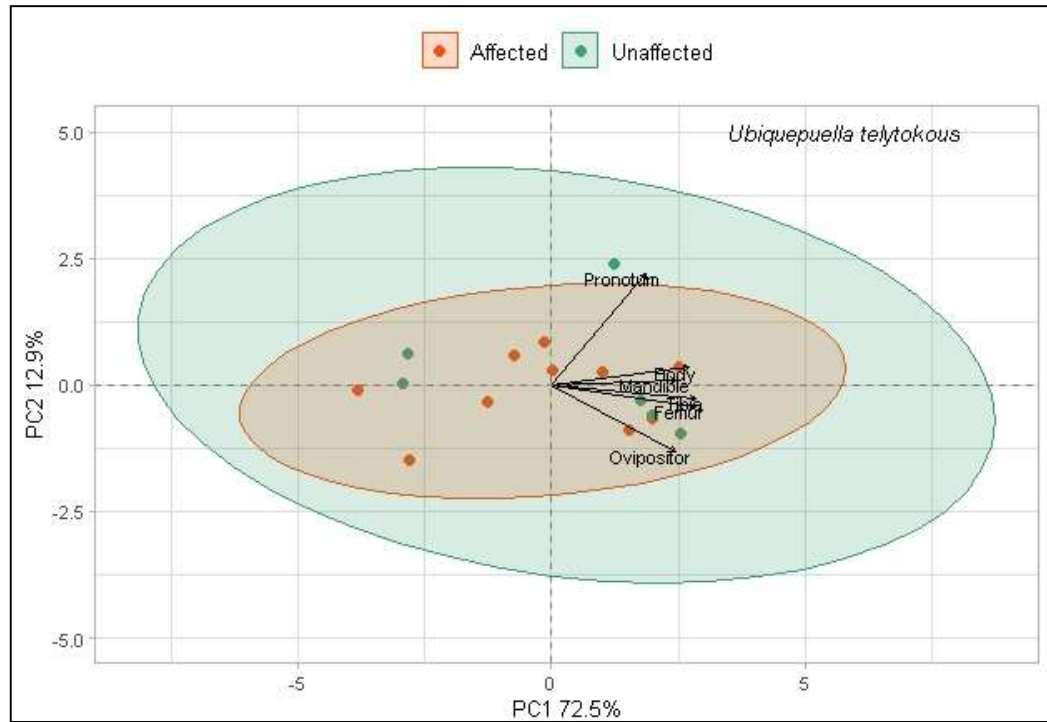
SI4. Principal Component Analysis (PCA) illustrates the relationship between females' mean morphological structures in body morphology variation and types of environments. Each point on the graph corresponds to a pitfall set, with females represented by circles and colors indicating environments (affected/unaffected).



SI5. Principal Component Analysis (PCA) illustrates the relationship between males' mean morphological structures in body morphology variation and types of environments. Each point on the graph corresponds to a pitfall set, with males represented by triangles and colors indicating environments (affected/unaffected).



SI6 Principal Component Analysis (PCA) illustrating the relationship between morphological structures, body morphology variation, and types of environments. Each point on the graph corresponds to a sampled individual, with females represented by circles and the colors representing the types of environments (affected/ unaffected).



SI7. Principal component analysis (PCA) illustrates the relationship between the mean of the morphological structures of the species *Ubiquepuella telytokous* and the variation in body morphology and types of environments. Each point on the graph corresponds to the value of the pitfall set; circles represent females, and the colors represent the types of environments (affected/unaffected).

CONCLUSÃO GERAL

A presente tese investigou os efeitos do rompimento da barragem de Fundão sobre a comunidade de Orthoptera da mata ciliar da bacia do Rio Doce, revelando respostas importantes destes organismos a perturbações em diferentes níveis. No primeiro capítulo, observamos efeitos de longo prazo e indícios de persistência temporal na comunidade de ortópteros, mesmo após seis e quase oito anos do rompimento. Esses efeitos incluem o aumento da abundância de indivíduos nas áreas impactadas, alteração da composição de espécies e um impacto negativo do aumento da distância do impacto na abundância e na riqueza de espécies. Também identificamos a presença de espécies indicadoras associadas às áreas impactadas e espécies que se mantiveram como indicadoras ao longo do tempo. No segundo capítulo, observamos que os efeitos do distúrbio podem atuar como um filtro ambiental na morfologia de uma espécie de grilo de serrapilheira, *A. bernardesi* na área ribeirinha do rio Gualaxo do Norte. Nas áreas afetadas, essa espécie apresentou menor variação no tamanho das estruturas corporais, mesmo não apresentando diferenças no tamanho médio das estruturas. Esses resultados indicam que as alterações ambientais causadas pelo rompimento continuam influenciando os ortópteros a longo prazo e em diferentes proporções, desde aspectos da comunidade até aspectos morfológicos. Esses achados também reforçam o potencial dos ortópteros como bioindicadores valiosos para o monitoramento da recuperação de ecossistemas perturbados e a sensibilidade destes organismos frente às alterações ambientais. Além disso, sugerem que a comunidade e os organismos estão sendo influenciados por diferentes processos ecológicos, impulsionados tanto pelas alterações provenientes do distúrbio quanto por particularidades locais e regionais. Isso destaca a necessidade do uso de diferentes abordagens, que considerem tanto características específicas dos organismos quanto os contextos ambientais locais e regionais para entender os efeitos de distúrbios ambientais na biodiversidade terrestre. Ainda, embora a ausência de dados prévios ao desastre limite comparações diretas com a condição original da comunidade, os achados desta tese contribuem significativamente para a compreensão das respostas destes e de outros organismos aos distúrbios ambientais ocasionados pelo rompimento. Por fim, este estudo reforça a necessidade de monitoramentos de longo prazo e de estratégias de conservação e restauração que considerem não apenas os impactos diretos e indiretos dos distúrbios, mas também as particularidades locais e regionais que moldam a montagem das comunidades.