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CONSERVATION OF GEODIVERSITY IN FERRUGINOUS GEOSYSTEMS

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Abstract

This study examines the evolution of areas surrounding the bat caves in the Ferruginous Geosystem of Carajás from 1985 to 2022, emphasising the significance of geodiversity conservation in this unique context. The land use and cover transformations analysis reveals critical insights into spatio-temporal changes and escalating environmental degradation risks. The findings enhance the literature on geodiversity conservation and speleology, providing a solid foundation for future research. Monitoring mined areas and their ecological impacts is essential for refining management strategies for these sensitive ecosystems. Furthermore, recent attempts to amend cave protection legislation, particularly Decree 10.935, pose significant conservation challenges, necessitating a critical evaluation of environmental policies and fostering dialogue among researchers, policymakers, and the mining industry. This study highlights the urgent need for a balanced approach between resource extraction and environmental conservation to mitigate adverse impacts on biodiversity and ecological processes. Integrated and evidence-based environmental management is crucial for addressing the challenges of mining activities and regulatory changes, ensuring the protection of caves and their ecosystems for a sustainable future.

Keywords: Geodiversity; Bat Caves; Mining Impacts; Landscape Ecology; Environmental Management; Carajás Geosystem; Legislative Changes.

Resumo / Resumen

CONSERVAÇÃO DA GEODIVERSIDADE EM GEOSSISTEMAS FERRUGINOSOS

Este estudo examina a evolução das áreas ao redor de “bat caves” no Geossistema Ferruginoso de Carajás de 1985 a 2022, destacando a importância da conservação da geodiversidade nesse contexto único. A análise das transformações de uso e cobertura do solo revela percepções críticas sobre mudanças espaço-temporais e o aumento dos riscos de degradação ambiental. Os resultados ampliam a literatura existente sobre conservação da geodiversidade e espeleologia, fornecendo uma base sólida para pesquisas futuras. O monitoramento contínuo das áreas mineradas e seus impactos ecológicos é essencial para aprimorar as estratégias de gestão desses ecossistemas sensíveis. Além disso, as recentes tentativas de alteração na legislação de proteção de cavernas, especialmente o Decreto 10.935, representam desafios significativos para a conservação, exigindo uma avaliação crítica das políticas ambientais e promovendo o diálogo entre pesquisadores, formuladores de políticas e a indústria mineradora. Este estudo ressalta a necessidade urgente de uma abordagem equilibrada entre a extração de recursos e a conservação ambiental para mitigar impactos adversos sobre a biodiversidade e os processos ecológicos. A gestão ambiental integrada e baseada em evidências é crucial para enfrentar os desafios das atividades mineradoras e das mudanças regulatórias, garantindo a proteção das cavernas e de seus ecossistemas para um futuro sustentável.

Palavras-chave: Geodiversidade; Cavernas de Morcegos; Impactos da Mineração; Ecologia da Paisagem; Gestão Ambiental.

CONSERVACIÓN DE LA GEODIVERSIDAD EN GEOSISTEMAS FERRUGINOSOS

Este estudio examina la evolución de las áreas alrededor de las “cuevas de murciélagos” en el Geosistema Ferruginoso de Carajás de 1985 a 2022, destacando la importancia de la conservación de la geodiversidad en este contexto único. El análisis del uso de la tierra y las transformaciones de la cobertura terrestre revela conocimientos críticos sobre los cambios espacio-temporales y los mayores riesgos de degradación ambiental. Los resultados amplían la literatura existente sobre conservación de la geodiversidad y espeleología, proporcionando una base sólida para futuras investigaciones. El monitoreo continuo de las áreas minadas y sus impactos ecológicos es esencial para mejorar las estrategias de gestión de estos ecosistemas sensibles. Además, los intentos recientes de cambiar la legislación de protección de cuevas, especialmente el Decreto 10.935, representan desafíos importantes para la conservación, ya que requieren una evaluación crítica de las políticas ambientales y promueven el diálogo entre investigadores, formuladores de políticas y la industria minera. Este estudio destaca la necesidad urgente de un enfoque equilibrado entre la extracción de recursos y la conservación del medio ambiente para mitigar los impactos adversos sobre la biodiversidad y los procesos ecológicos. La gestión ambiental integrada y basada en evidencia es crucial para enfrentar los desafíos de las actividades mineras y los cambios regulatorios, asegurando la protección de las cuevas y sus ecosistemas para un futuro sostenible.

Palabras-clave: Geodiversidad; Cuevas de Murciélagos; Impactos de la Minería; Ecología del Paisaje; Gestión Ambiental.

INTRODUCTION

Ferruginous Geosystems are geographic areas predominantly composed of iron-rich rocks. In Brazil, these geosystems are found in specific regions, such as the Quadrilátero Ferrífero, the eastern edge of the Serra do Espinhaço, and the Vale do Rio Peixe Bravo in Minas Gerais, in Mato Grosso do Sul's Urucum plateau, as well as in the Serra de Carajás in Pará, and the Vale do Rio São Francisco in Bahia (RUCHKYS et al., 2015). Traditionally, the literature has focused on their economic value due to the abundance of iron ore.

However, in recent years, studies from various fields have highlighted the heritage value of these geosystems, covering biological (CARMO, 2010; Ferreira et al., 2018), archaeological (BAETA, 2011), geological (RUCHKYS, 2007; RUCHKYS et al., 2009; RUCHKYS et al., 2012), speleological (CAVALCANTI et al., 2012; PEREIRA, 2012; CALUX, 2013; GOMES et al, 2019), palaeontological (CARMO et al., 2011), and hydrogeological (MOURÃO, 2007) aspects. These geosystems' remarkable geodiversity and evolutionary complexity, including some of the planet's oldest exposed surfaces, are widely recognised for fostering biodiversity preservation (TRENDALL; MORRIS, 1983; MONTEIRO et al., 2014; SALGADO, 2015).

Among the various values associated with ferruginous geosystems, speleological potential is notable, particularly in caves, which are crucial in preserving biological diversity and providing ecosystem services (URBAN et al., 2022; MENIN; BACCI, 2023). Caves, as elements of geodiversity, support services such as soil, water, and mineral resources while offering cultural, scientific, educational, and tourism values (MENIN; BACCI, 2023).

In Brazil, Decree No. 99,556 of 1990, later amended by Decree No. 6,640 of 2008, provides the legal definition of "cave," recognising these features as natural underground spaces, with or without identifiable openings, including their mineral environment, water, fauna, flora, and the rock formations in which they are located. This legal framework underscores the importance of preserving these environments, including them in the broader concept of speleological heritage, encompassing both the cave and the surrounding area (BRAZIL, 2004).

Given the anthropogenic impacts and underrepresentation of caves in global conservation plans, preserving these areas is critical in Brazil and worldwide (ITO et al., 2022). Due to their physical and morphological characteristics and available trophic resources, cave environments harbour highly specialised species, notably bats (FUREY; RACEY, 2015; MEDELLIN et al., 2017). Recent studies emphasise bats as bioengineers whose activities cause geomorphological changes in caves, reinforcing the urgent need to conserve these subterranean environments (PILÓ et al., 2023). In addition to physical transformations, cave-dwelling bats play crucial ecological roles that directly benefit humans. Frugivorous and nectarivorous bats contribute to the pollination and seed dispersal of economically significant plants such as bananas, mangoes, and hardwoods.

In contrast, insectivorous bats control insect populations by consuming thousands each night (PENNISI et al., 2004). With approximately 1,450 species globally, three-quarters of which are insectivorous, their pest suppression service has an economic value ranging from $0.01 to $767.75 per hectare per year, highlighting their importance to agriculture and biodiversity conservation (FREIRE, 2023). Natural underground cavities and their heritage must be preserved as significant geoconservation sites for future generations (WOO; KIM, 2018), particularly to protect roosting sites crucial for the conservation of various bat species (VOIGT et al., 2016).

This paper aims to analyse the evolution of landscape composition around caves that house thousands of bats (bat caves) (PIMENTEL; BERNARD, 2024) within the Ferruginous Geosystem of Carajás, Pará, Brazil, between 1985 and 2021. Landscape composition analysis is essential to understand geosystem structure and function, assess environmental impacts, and guide land-use planning, promoting geodiversity and biodiversity conservation (GOMES et al., 2019).

STUDY AREA AND METHODOLOGICAL PROCEDURES

The study area encompasses the Ferruginous Geosystem of Carajás, located southeast of Pará, in Brazil's Amazon region. It includes the Carajás National Forest (FLONA) and the Ferruginous Fields National Park (PARNA), both managed by ICMBio (Chico Mendes Institute for Biodiversity Conservation) (Figure 1). Current legislation aims to balance environmental conservation with the sustainable use of natural resources in the FLONA, while the PARNA is designated for full protection.

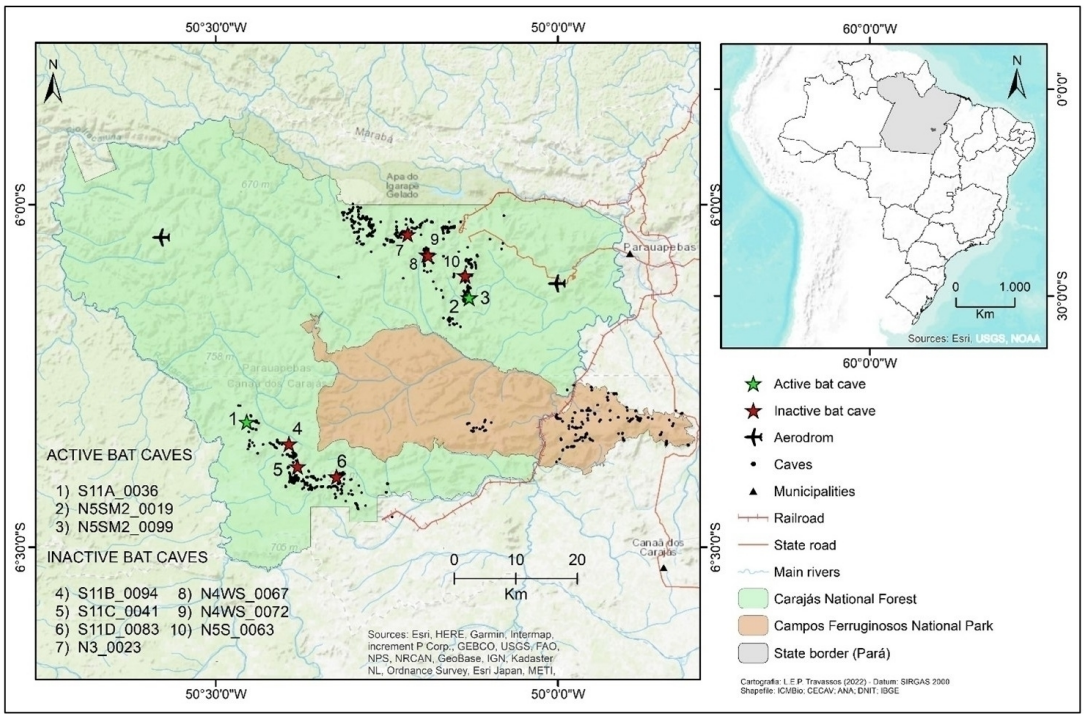

Figure 1 - Location map of the study area. Source: Prepared by the authors.

Geologically, this geosystem is situated in the southeastern portion of the Amazon Craton, with the Neoarchean metavolcanosedimentary sequence of the Grão Pará Group being prominent. This sequence contains banded iron formations, particularly jaspilites from the Carajás Formation, interbedded with mafic rocks of the Parauapebas Formation (MACAMBIRA, 2003). Jaspilite, a variety of chert with hematite inclusions, gives the rock its characteristic red colour and hosts high-grade iron ore bodies exceeding 65%, composed of magnetite/martite and hematite (LOBATO et al., 2005; ROSIÈRE, 2015). Anthropogenic pressure in the region is primarily linked to mining the banded iron formations of the Carajás Formation (DUTRA, 2013).

Concerning speleological heritage, the two conservation units host over 1,600 documented caves (CECAV, 2024). Among these, ten have been classified as bat caves (PILÓ et al., 2023), with three still active (N5SM2_0019, N5SM2_0099, and S11A_0036), providing shelter for thousands of bats. In addition to their role in insect population control, pollinators, and seed dispersers, the bats in these caves perform a unique ecological function as bioengineers.

Recent studies have identified that, over more than 23,000 years, the continuous presence of bats and the large guano deposits accumulated have promoted alterations in the geomorphology of the iron ore caves (PILÓ et al., 2023). These biological and chemical processes have resulted in geomorphological features similar to those observed in limestone caves, such as the dissolution of iron ore rock and the formation of speleothems (Figures 2a and 2b). Changes have also been observed in the external vegetation near the caves, possibly influenced by the highly acidic water runoff during the rainy seasons, as seen in cave S11A_0036 (Figures 2c and 2d).

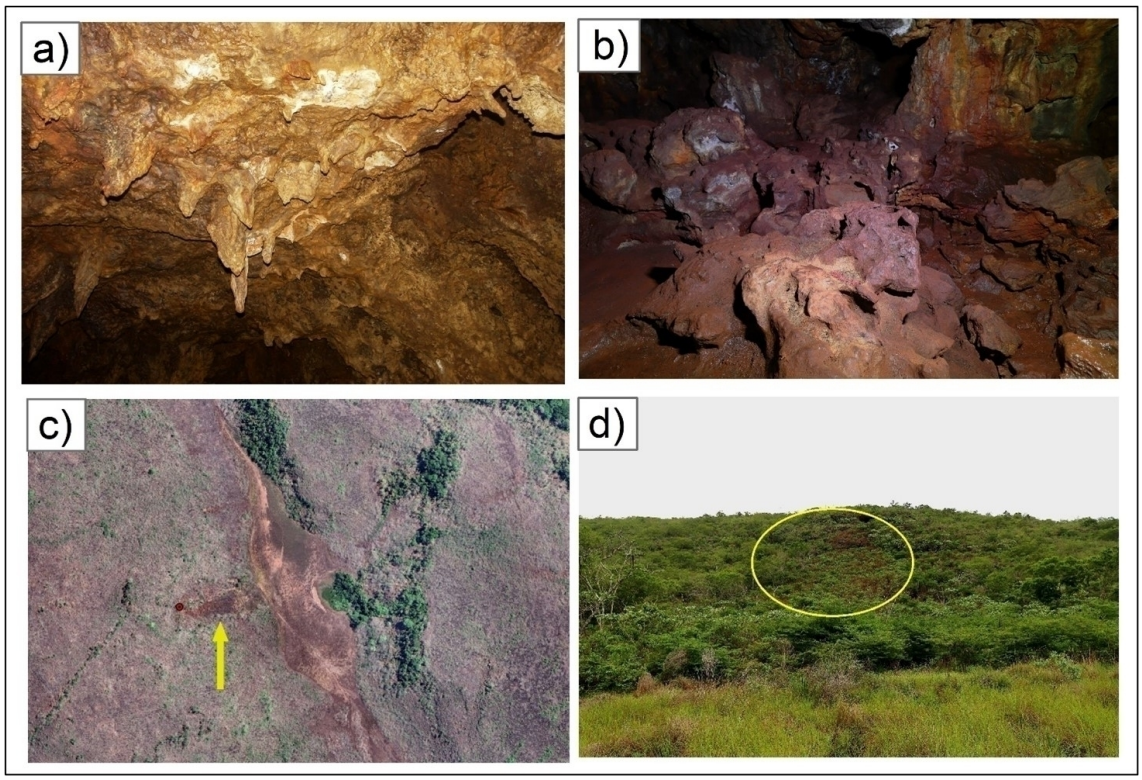

Figure 2 - Long-term effects of bat presence in caves of the Ferruginous Geosystem of Carajás.a) Stalactites in cave S11D_0083, b) Dissolution of iron ore rock in cave N4WS_0067, c) Satellite image showing changes in vegetation composition at the entrance of cave S11A_0036, and d) Vegetation aspects around the entrance of cave S11A_0036. Satellite image: Google Earth. Photos: Authors.

The landscape composition analysis was carried out to quantify the areas occupied by different landscape units, capturing the "information content" of the scene as described by Lang and Blanschke (2009). The landscape surrounding the cavities was mapped using land use and land cover data provided by the MapBiomas Project (2023), covering the years 1985 and 2021, corresponding to the oldest and most recent data available for the study area. These maps, with a spatial resolution of 30 metres, were selected from Collection 8.

The land use and land cover classes analysed include forest formation, grassland formation, pasture, urban areas, mining, rivers, and lakes. The prioritisation of these classes was based on their ecological importance for bats, particularly foraging. The analysis focused on areas surrounding the cavities housing large bat colonies (PILÓ et al., 2023), aiming to assess the potential loss of foraging areas due to vegetation removal.

To improve the accuracy of the analysis, the landscape was segmented by creating buffers around the cavities still used by bats, resulting in two distinct sectors (north and south). Given the lack of specific studies determining the home range of bats in the region, buffers of 3.5 km, 10 km, and 15 km around the bat caves were defined based on conservative estimates and existing literature. Spatial segmentation was performed using advanced Geographic Information Systems (GIS) tools, enabling data on landscape structure for these areas in different temporal and spatial scenarios to be extracted.

Additionally, the analysis of changes in landscape composition between 1985 and 2021 was conducted using a temporal comparison approach, identifying alterations in land use and land cover classes near the cavities. These changes were quantified and analysed to determine the potential impact on local ecology, particularly regarding the ecological functions of bats as bioengineers and the integrity of the caves.

The land use and land cover maps were processed using ArcGIS software, where the land use classes were reclassified and aggregated according to the established categories. The spatial analysis

involved using specific metrics to assess the composition and configuration of landscape units, considering fragmentation and ecological connectivity. Metrics such as the Shannon Diversity Index and the Fragmentation Index were calculated to provide a detailed view of structural changes in the landscape over time.

The results were validated by comparing them with field studies and high-resolution remote sensing data, ensuring the accuracy of the conclusions. Finally, the implications of these changes were discussed in terms of conservation and sustainable management of protected areas, with recommendations for mitigating the identified negative impacts.

RESULTS AND DISCUSSION

The comparison between the land use and cover maps from 1985 and 2021 (Figure 3) reveals a significant intensification of human activities, with mining taking on a prominent role. This evolution in land use highlights the increasing pressure on regional biodiversity in recent years. Small signs of alteration were identified in the Indigenous Land adjacent to the study area, located on the western border of the Carajás National Forest. Two areas were classified as 'urban' (villages), and a small clearing was observed along the riverbank, suggesting a potential loss of vegetation cover.

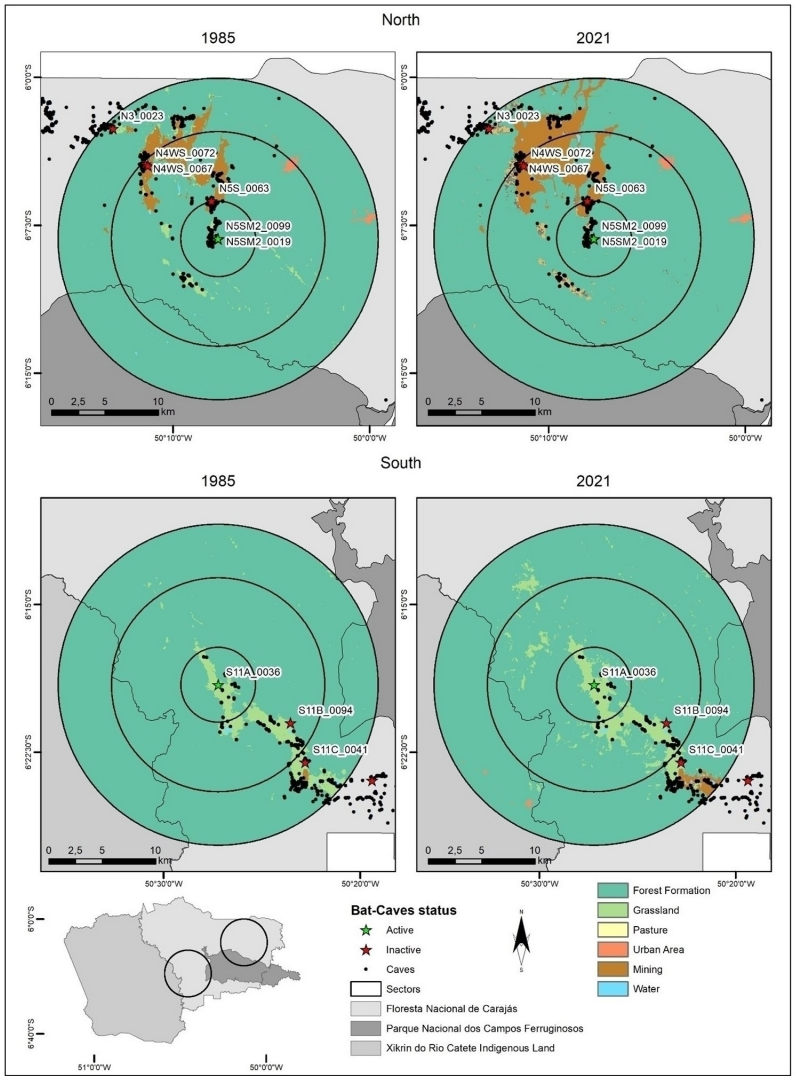

Figure 3 (a and b): Land use and cover maps from 1985 and 2021.

Figure 4 illustrates the transition in landscape composition between 1985 and 2021, focusing specifically on the area surrounding the bat caves. The data show that, during the study period, mining emerged as the primary threat to the caves and adjacent ecosystems.

In the southern sector, within 3.5 km and 10 km radii of the active caves, no mining activities were detected, which is a positive indicator for conserving these sensitive areas. However, within a 15 km radius, an 86.4% increase in mining activity was observed since 1985.

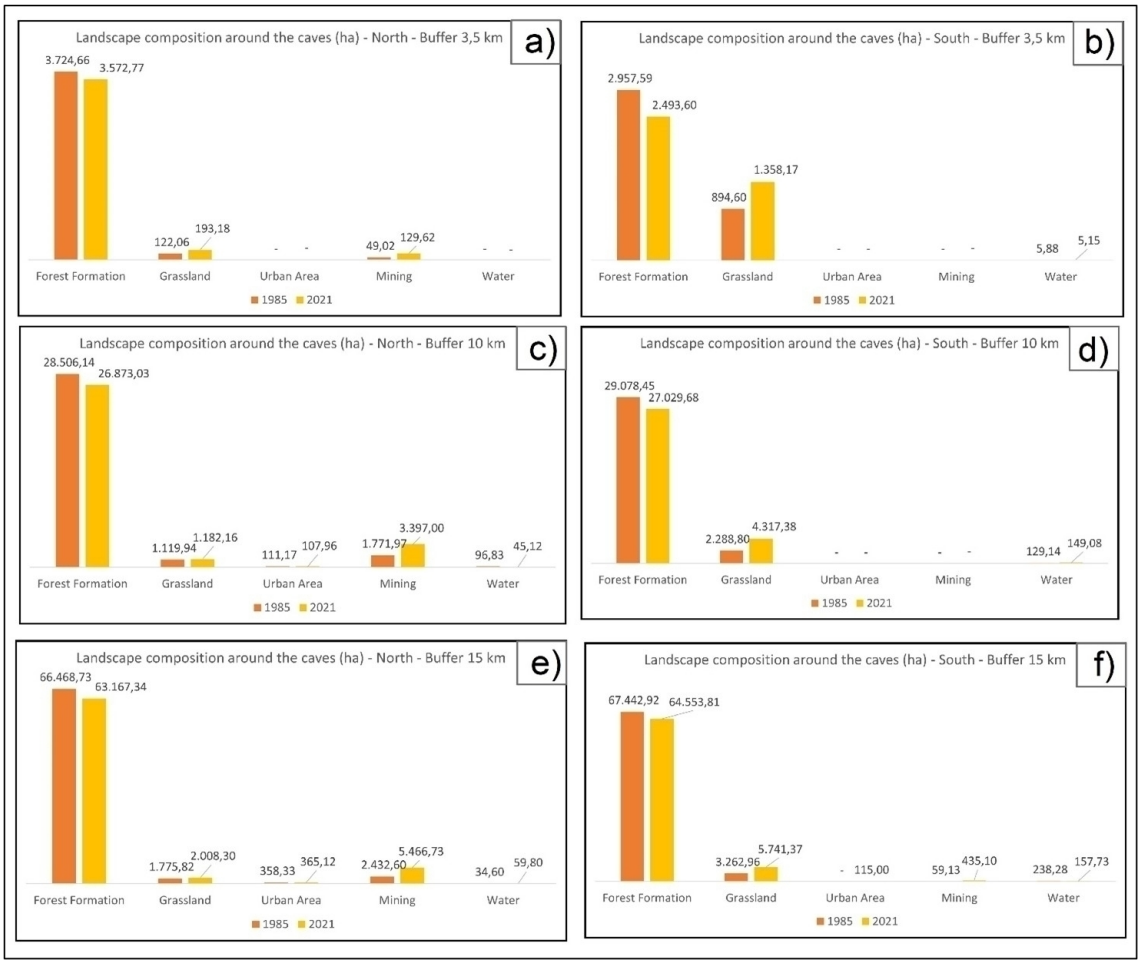

Figure 4 - Landscape composition transition graphs from 1985 to 2021.

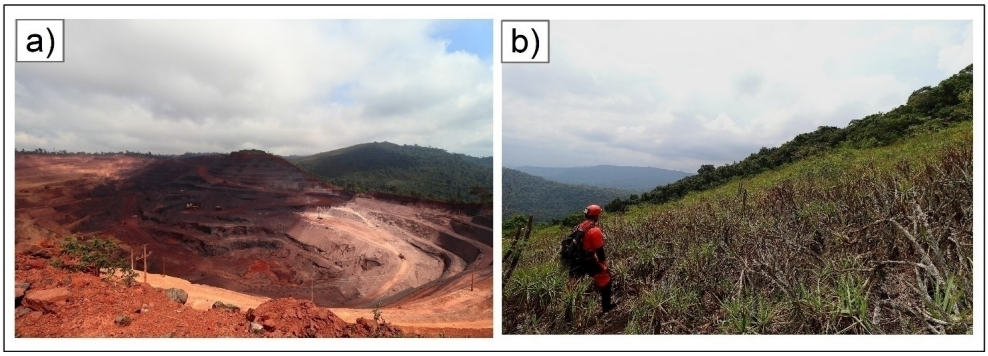

Figure 5 - a) Mining pit (N5) located approximately 2.2 km from the caves and b) Vegetation about 60 metres from the N5SM2_0019 and N5SM2_0099 caves.

In the northern sector (Figure 5), mining was already established by 1985, encompassing the N5SM2_0019 and N5SM2_0099 caves. Over the study period, there was a 62.2% increase in mined area within the 3.5 km radius, 47.8% within the 10 km radius, and 55.5% within the 15 km radius.The results show that while areas close to the active caves remain preserved, the expansion of mining in more distant regions is alarming. The intensification of mining over recent decades has compromised subterranean habitats and affects ecological connectivity and corridors that support bat populations. Even activities in relatively distant areas can significantly impact bat conservation and the integrity of local ecosystems.

Even in areas that have not yet experienced direct impacts, the continued expansion of mining could threaten biodiversity and ecosystem functionality. Caves, especially bat caves, play critical roles in seed dispersal and pest control, underscoring the need for stricter conservation strategies.

Moreover, the analysis of mining polygons registered with the National Mining Agency (Figure 6) provides a critical view of the future of mining in the region. All bat caves, both active and inactive, are located in areas already granted for mining, highlighting the importance of closely monitoring these activities. The attempt to ease legislation allowing impacts on caves of high relevance, suspended by the Supreme Federal Court in 2024, underscores the need to balance economic development and environmental preservation.

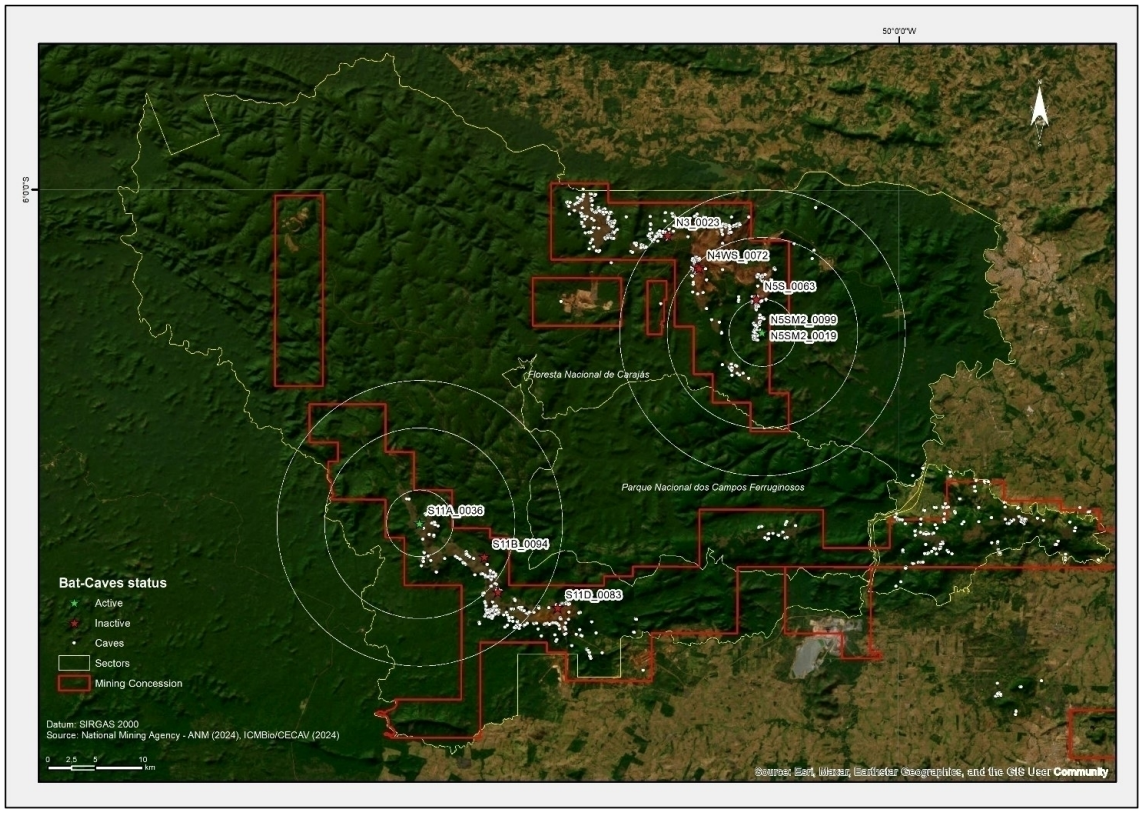

Figure 6 - Mining polygons from the National Mining Agency and the location of caves within the mentioned Conservation Units.

Mining expansion represents a clear risk, and recent legislative and judicial decisions demonstrate the need for robust and effective policies to mitigate these impacts.

CONCLUSION

This study analysed the evolution of the areas surrounding the bat caves in the Ferruginous Geosystem of Carajás between 1985 and 2022, highlighting the importance of conserving geodiversity

in this unique context. Over the decades, land use and cover transformations have provided valuable insights into spatio-temporal changes and the increasing risks of environmental degradation.

The results of this study not only contribute to the existing body of knowledge in the literature on geodiversity conservation and speleology and provide a solid foundation for future research. Investigations focused on continuously monitoring mined areas and their ecological impacts could help refine management and conservation strategies for these sensitive areas.

Moreover, attempts to amend legislation protecting caves, such as the Decree 10.935 of 12 January 2022, which would allow irreversible impacts on caves of high relevance, pose an additional challenge in conserving these unique habitats. Any proposed regulatory change necessitates a critical review of environmental policies and highlights the need for a deeper dialogue between researchers, policymakers, and the mining industry to ensure that economic development does not occur at the expense of the irreversible destruction of natural heritage.

Reflecting on the sustainability of mining practices in the region, it is clear that a more robust balance between resource extraction and environmental conservation is required. The degradation of foraging areas and disturbances in the bat caves can profoundly affect local biodiversity and the fundamental ecological processes that sustain these ecosystems. The preservation of geodiversity, in synergy with biodiversity conservation, should be imperative to ensure the longevity of these ecosystems and the continuity of the ecosystem services they provide.

Finally, this study reinforces the importance of integrated and evidence-based environmental management, which can effectively address the challenges of mining activities and regulatory changes. Continuing research and monitoring efforts, coupled with well-founded public policies, is crucial for protecting the caves and adjacent ecosystems, ensuring a sustainable future for the region.

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REFERENCES

BAETA, A. M. M. Os Grafismos Rupestres e suas Unidades Estilísticas no Carste de Lagoa Santa e Serra do Cipó – MG. 2011. Tese (Doutorado) – Universidade de São Paulo, São Paulo, 2011.

BRASIL. Conselho Nacional do Meio Ambiente. Resolução nº 347, de 10 de setembro de 2004. Estabelece critérios para a proteção de cavidades naturais subterrâneas existentes no território nacional. Diário Oficial da União: seção 1, Brasília, DF, 17 set. 2004.

CALUX, A. S. Gênese e desenvolvimento de cavidades naturais subterrâneas em Formação Ferrífera no Quadrilátero Ferrífero, Minas Gerais. 2013. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2013.

CARMO, F. F. Importância Ambiental e Estado de Conservação dos Ecossistemas de Cangas no Quadrilátero Ferrífero e Proposta de Áreas-Alvo para a Investigação e Proteção da Biodiversidade em Minas Gerais. 2010. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2010.

CARMO, F. F.; SALGADO, A. A. S.; JACOBI, C. M. Novo sítio espeleológico em sistemas ferruginosos, no vale do rio Peixe Bravo, norte de Minas Gerais, Brasil. Espeleo-Tema, Campinas, v. 1, n. 22, p. 25-39, 2011.

CAVALCANTI, L. F.; LIMA, M. F.; MEDEIROS, R. C. S.; MEGUERDITCHIAN, S. Plano de ação nacional para a conservação do patrimônio espeleológico nas áreas cársticas da Bacia do Rio São

Francisco. Brasília: Instituto Chico Mendes de Conservação da Biodiversidade, Instituto Chico Mendes, 2012. Disponível em: https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/pan/pan-cavernas-do-sao-francisco/1-ciclo/pan-cavernas-livro.pdf. Acesso em: 18 set. 2024.

CECAV. Cadastro Nacional de Informações Espeleológicas – CANIE. 2024. Disponível em: https://www.gov.br/icmbio/pt-br/assuntos/centros-de-pesquisa/cavernas/cadastro-nacional-de-informacoes-espeleologicas/canie. Acesso em: 15 jan. 2024.

DUTRA, G. Síntese dos processos de gênese de cavidades em litologias de ferro. In: RASTEIRO, M. A.; MORATO, L. (Orgs.). Congresso Brasileiro de Espeleologia. Campinas: SBE, 2013. p. 415-426.

FERREIRA, R. L.; DE OLIVEIRA, M. P. A.; SILVA, M. S. Subterranean Biodiversity in Ferruginous Landscapes. In: MOLDOVAN, O.; KOVÁČ, Ľ.; HALSE, S. (Eds). Cave Ecology. Ecological Studies, vol. 235. Cham: Springer, 2018. Disponível em: https://doi.org/10.1007/978-3-319-98852-8_21.

FREIRE, J. Valoração de serviços de supressão de insetos por morcegos: uma revisão. 2023. Trabalho de Conclusão de Curso (Ciências Biológicas - Bacharelado) - Universidade Federal de Pernambuco, Recife, 2023.

FUREY, N. M.; RACEY, P. A. Conservation ecology of cave bats. In: VOIGT, C. C.; KINGSTON, T. (Eds.). Bats in the Anthropocene: Conservation of Bats in a Changing World. Cham: Springer, 2015. p. 463-500. Disponível em: https://doi.org/10.1007/978-3-319-25220-9.

GOMES, M.; RUCHKYS, Ú.; FERREIRA, R. L.; GOULART, F. F. Landscape fragmentation around ferruginous caves of the Iron Quadrangle, Minas Gerais, Brazil. Cuadernos de Geografía: Revista Colombiana de Geografía, v.28, 2019. Disponível em: https://doi.org/10.15446/rcdg.v28n1.67506.

ITO, F.; LILLEY, T.; TWORT, V. G.; BERNARD, E. High genetic connectivity among large populations of Pteronotus gymnonotus in bat caves in Brazil and its implications for conservation. Frontiers in Ecology and Evolution, v. 10, 2022. Disponível em: https://doi.org/10.3389/fevo.2022.934633.

LANG, S.; BLASCHKE, T. Análise da Paisagem com SIG. São Paulo: Oficina de Textos, 2009.

LOBATO, L. M.; et al. A mineralização hidrotermal de ferro da Província Mineral de Carajás – Controle estrutural e contexto na evolução metalogenética da província. In: MARINI, O. J.; QUEIROZ, E. T.; RAMOS, B. W. (Eds.). Caracterização de depósitos minerais em distritos mineiros da Amazônia. Brasília: DNPM/CT-Mineral/FINEP/ADIMB, 2005. p. 25-92.

MACAMBIRA, J. B. O ambiente Deposicional da Formação Carajás e uma Proposta de Modelo Evolutivo para a Bacia Grão Pará. 2003. Tese (Doutorado) – Universidade Estadual de Campinas, Campinas, 2003.

MAPBIOMAS. Coleção de Séries de Mapas de Uso e Cobertura da Terra do Brasil [dataset]. 2023. Disponível em: http://mapbiomas.org/.

MEDELLIN, R. A.; WIEDERHOLT, R.; LOPEZ-HOFFMAN, L. Conservation relevance of bat caves for biodiversity and ecosystem services. Biological Conservation, v. 211, 2017. Disponível em: https://doi.org/10.1016/j.biocon.2017.01.012.

MENIN, D. de S.; BACCI, D. de L. C. Serviços Espeleossistêmicos: como caracterizar as cavernas sobre o ponto de vista da Economia Ecológica e dos Serviços Geossistêmicos? Revista do Instituto de Geociências – USP, v.23, 2023. Disponível em: https://doi.org/10.11606/issn.2316-9095.v23-205328.

MONTEIRO, H. S.; VASCONCELOS, P. M.; FARLEY, K. A.; SPIER, C. A.; MELLO, C. L. (U–Th)/He geochronology of goethite and the origin and evolution of cangas. Geochimica et Cosmochimica Acta, v.131, 2014. Disponível em:

https://doi.org/10.1016/j.gca.2014.01.036.

MOURÃO, M. A. A. M. Caracterização Hidrogeológica do Aquífero Cauê, Quadrilátero Ferrífero, MG. 2007. Tese (Doutorado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2007.

PENNISI, L. A.; HOLLAND, S. M.; STEIN, T. V. Achieving Bat Conservation Through Tourism. Journal of Ecotourism, v. 3, 2004. Disponível em:

https://doi.org/10.1080/14664200508668432.

PEREIRA, M. C. Aspectos Genéticos e Morfológicos das Cavidades Naturais da Serra da Piedade, Quadrilátero Ferrífero, Minas Gerais. 2012. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2012.

PILO, L. B.; CALUX, A.; SCHERER, R.; BERNARD, E. Bats as ecosystem engineers in iron ore caves in the Caraja´s National Forest, Brazilian Amazonia. PLoS ONE, v. 18, 2023. Disponível em: https://doi.org/10.1371/journal.pone.0267870.

ROSIÈRE, C. A. Formações Ferríferas e Minérios de Alto Teor Associados. In: RUCHKYS, U. A.; RASTEIRO, M.; TRAVASSOS, L. P.; FARIA, L. (Orgs.). Patrimônio Espeleológico em rochas ferruginosas: propostas para sua conservação no Quadrilátero Ferrífero, Minas Gerais. Campinas: SBE, 2015.

RUCHKYS, U. Patrimônio Geológico e Geoconservação no Quadrilátero Ferrífero, Minas Gerais: Potencial para a Criação de um Geopark da UNESCO. 2007. Tese (Doutorado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2007.

RUCHKYS, U. A.; MACHADO, M. M. M.; CASTRO, P. T. A.; RENGER, F. E.; TREVISOL, A.; BEATO, D. A. C. Geoparque Quadrilátero Ferrífero (MG)- Proposta. In: SCHOBBENHAUS, C.; SILVA, C. R. (Orgs.). Geoparques do Brasil: Propostas. Rio de Janeiro: CPRM, 2012. p. 183-220.

RUCHKYS, U. A.; RENGER, F. E.; NOCE, C. M.; MACHADO, M. M. M. Serra da Piedade, Quadrilátero Ferrífero, MG - da lenda do Sabarabuçu ao patrimônio histórico, geológico, paisagístico e religioso. In: WINGE, M.; SCHOBBENHAUS, C.; BERBERT-BORN, M.; QUEIROZ, E. T.; CAMPOS, D. A.; SOUZA, C. R. G.; FERNANDES, A. C. S. (Orgs.). Sítios Geológicos e Paleontológicos do Brasil. Brasília: CPRM, 2009.

RUCHKYS, U. A.; TRAVASSOS, L. E. P.; RASTEIRO, M. A.; FARIA, L. E. Patrimônio Espeleológico em Rochas Ferruginosas: Propostas para sua Conservação no Quadrilátero Ferrífero, Minas Gerais. Campinas: Sociedade Brasileira de Espeleologia, 2015.

SALGADO, A. A. R. Apresentação. In: CARMO, F. F.; KAMINO, L. H. Y. (Orgs.). Geossistemas Ferruginosos do Brasil: áreas prioritárias para conservação da diversidade geológica e biológica, patrimônio cultural e serviços ambientais. Belo Horizonte: 31 Editora, 2015. p. 9-11.

TRENDALL, A. F.; MORRIS, R. C. (Eds.). Iron-Formation Facts and Problems. Amsterdam: Elsevier, 1983. (Developments in Precambrian Geology, v. 6). Disponível em: https://doi.org/10.1016/s0166-2635(08)x7002-1.

URBAN, J.; RADWANEK-BĄK, B.; MARGIELEWSKI, W. Geoheritage Concept in a Context of Abiotic Ecosystem Services (Geosystem Services) – How to Argue the Geoconservation Better? Geoheritage, v. 54, 2022. Disponível em: https://doi.org/10.1007/s12371-022-00688-7.

VOIGT, C. C.; PHELPS, K. L.; AGUIRRE, L. F.; CORRIE SCHOEMAN, M.; VANITHARANI, J.; ZUBAID, A. Bats and Buildings: The Conservation of Synanthropic Bats. In: VOIGT, C. C.; KINGSTON, T. (Eds.). Bats in the Anthropocene: Conservation of Bats in a Changing World. Cham: Springer, 2016. Disponível em: https://doi.org/10.1007/978-3-319-25220-9_14.

WOO, K. S.; KIM, L. Geoheritage Evaluation of Caves in Korea: A Case Study of Limestone Caves. In: REYNARD, E.; BRILHA, J. (Orgs.). Geoheritage: Assessment, Protection, and Management. Amsterdam: Elsevier, 2018. p. 373-386.

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