TreeDimensional Journal, Vol. 15, e025276, 2025
Original Article | DOI: doi.org/10.55746/treed.2025.08.276

Can legal mining activities affect conservation metrics in the eastern Brazilian Amazon?

Félix Jossãn Costa Cordeiro[1], Jovanna de Brito Araújo[1], Ximena Mendes de Oliveira[1,*], Rafaella Carvalho Mayrinck[2], Selma Lopes Goulart[1], Luiz Coelho Lemos Neto[3]

Abstract
Sustainable Use Conservation Units (UCs) are territorial spaces aimed at reconciling the exploitation and conservation of natural resources in Brazil. The objective of this study was to analyze the influence of mining on the protection of UCs with and without legalized mining activity. The study area includes three UCs located in the Carajás region, in the state of Pará: two with legalized mining activity (Carajás National Forest – FLONACA and Tapirapé-Aquiri National Forest – FLONATA), and one where mining occurs illegally (Itacaiúnas National Forest – FLONITA). To assess the protection of the UCs, the following variables were considered: land cover, infraction notices, and fire hotspots. Each variable was quantified, analyzed, and georeferenced. Geographic Information System (GIS) programs, business intelligence tools, and Microsoft Office software were used. The data sources used were mostly of governmental origin. The results showed that FLONITA has the highest percentage of anthropized (human-modified) area and the highest annual rate of natural area loss. Additionally, it was also the second highest in terms of the number of infraction notices and the first in infraction and fire hotspot density per hectare. Conversely, FLONATA had the lowest values for the analyzed variables, followed by FLONACA. It was concluded that FLONITA has the lowest levels of protection compared to FLONATA and FLONACA, which have legalized mining activity.

Keywords
Floresta Nacional de Carajás (FLONACA) — Floresta Nacional do Tapirapé-Aquiri (FLONATA) — Floresta Nacional do Itacaiúnas (FLONITA)

[1] *Universidade Federal Rural da Amazônia*
[2] *University of New Brunswick, Forestry & Environmental Management*
[3] *Universidade Católica Pontifícia*
***Corresponding author**: ximena@ufra.edu.br

1. Introduction

The Amazon Forest provides crucial environmental services with local, and global impacts (Marengo et al, 2018). The forest is also home of indigenous populations, surrounding big urban centers and small villages, and sustains agriculture and mining activities. This combination of activities is important for communities, locally and beyond. The maintenance of the forest is crucial for the maintenance of the environmental services, which is impressive for global rain patterns, climate regulation, and carbon stocks (Acharya et al., 2019; Baciu et al., 2021). To guarantee that the natural resources will be preserved, the Conservation Unit (CU) legislation was created.

CUs were established by the government with the goal of protecting natural resources (Brasil, 2000). They have great relevance on the maintenance of ecosystemic services, including mitigating climate change (Basso et al., 2023; Gatti et al., 2021). CUs are managed by the Nacional Conservation Units system (SNUC) Act 9.985/2000 (Brasil, 2000). There are two kinds of CU. The first is for integral protection, meaning that no human activity involving harvesting natural resources is allowed. The second kind of conservation unit is used for sustainable management, so sustainable activities are allowed to a certain point, as long as it is foreseen in its management plan. For example, management plans at CU may allow timber harvesting over time under defined planning and monitoring, (Ramos et al., 2015; Moraes et al., 2024; Sist et al., 2024), and mining activity (Rodrigues et al., 2020; Lloyd et al., 2023).

Allowing mining activities at CUs may be controversial due to the negative impact it causes, for example air,

Received: 2024/12/16 | **Accepted:** 2025/08/06 | **Online published:** 2025/08/19

noise, and water pollution, land use change by removing natural soil cover, affecting flora and fauna (Sonter et al., 2017). Thus, it is mandatory that all mining activity be presented at a report assessing all impacts and proposing actions to compensate it (Souza Filho et al., 2020). However, studies assessing the impact of mining activities are lacking to fully inform policymakers and guide management decisions. The aim of this study was to assess the conservation status of three CUs, one of the full protection type (Floresta Nacional de Itacaiúnas – FLONITA), and two allowing sustainable management (Floresta Nacional de Carajás – FLONACA and Floresta Nacional de Tapirapé-Aquiri – FLONATA). The attributes used to assess the CUs were land use change, infractions committed against the CU and fire outbreaks.

2. Material and Methods

2.1 Study area

This study took place in three interconnected CUs, area known as Carajás Mosaic, FLONATA, FLONACA and FLONITA, at Eastern Brazilian Amazon, state of Pará. Besides these three CUs, the Carajas Mosaic includes other CUs and an Indigenous Reserves (Figure 1).

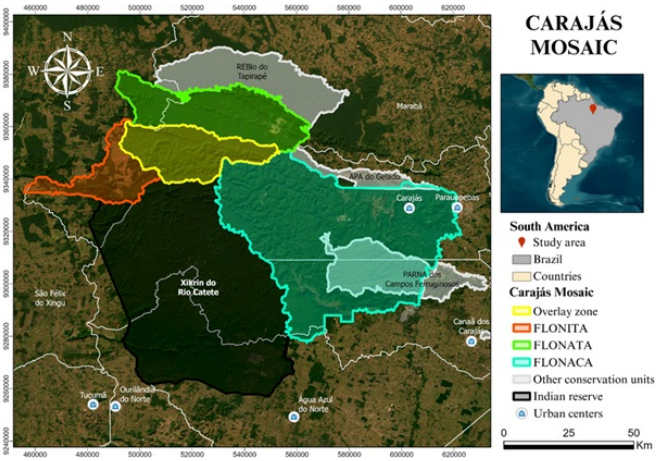

Figure 1. Carajás Mosaic location evidencing FLONATA, FLONACA and FLONITA CUs.

According to Köppen climate classification, the area is in the Af zone (tropical climate without dry season) (Alvares et al., 2014). Average temperature is 21 ºC, rainy season from December to March (ICMBio, 2016). Part of the land is occupied by Ombrophiles Dense Forest, with large trees and closed canopy; part of the land is occupied with a savannah formation established in iron-rich soil, and numerous endemic species. The CUs area is deemed on its creation FLONITA and FLONATA happened to have some overlapping area. This study considered this area (overlay zone) belonging to FLONATA CU. The overlapping area was incorporated in FLONATA area due to management similarities.

The Carajas Mosaic is known for its mineral-rich subsoil (Virgens, 2023), and has been targeted for mining activities by legal and illegal parties since its potential was uncovered in the 1960's. Although the three CU are classified by the National System of Conservation Units in the category of National Forest, the nature of activities allowed in each one depends on what is defined by its creation Act. Mining activity is allowed at FLONATA and FLONACA, not at FLONITA.

2.2 Data source and processing

Variables assessed were land use change, fire outbreaks and infractions reported at each CU. To describe land use change, rasters were retrieved from MapBiomas, stratified into two classes: natural or non-natural areas. Land use was assessed at CU creation then at the present, 2022. Data were analyzed with Qgis 3.26 (Qgis, 2023) and maps were created using ArcGIS Pro 3.0 ESRI (2022). Charts were prepared using Microsoft Power BI (2019). Infractions reported against each CU were filed and provided by ICMBio from 2009 to 2024, stratified into five classes of offenses (Table 1). Fire outbreaks in terms of number of fires and area burned were retrieved from INPE from 2002 to 2024.

The limitation of the methodology includes data being from remote sensing, not from field sampling. Also, relying on secondary data from an independent organization may be a problem in replicating the study in the future if the data is unavailable. Also, the area assessed is too big, and in a next study, each CU could be stratified to assess heterogeneity for more precise results.

3. Results

3.1 Land use

The total area and proportion of non-natural areas was higher at FLONITA (30.2%), than at FLONATA (1.5%) and FLONACA (3.4%) in 2022 (Table 2). It means that the annual conversion rate for FLONITA, FLONATA and FLONACA were 587 ha or 1,08%; 88 ha or 0,05%; and 440 ha or 0,11%, respectively. Figure 2 shows the location of land use changes. It is noticeable that land use conversions are more common towards CUs borders, in terms of frequency, and size of the fragments.

3.2 Infractions against the CU

Infractions committed by third parties against each CU were assessed from 2009 to 2024. Table 3 shows the total number of infractions at each class of offense and CU.

Table 1. Infraction class and description

Infraction	Description
1-Administration	To omit or hide information, to operate in disagreement with the law
2-Particular to CU	To introduce exotic species, to bypass borders, to do research without permit
3-Against fauna	To kill, chase, and hunt animals in the area
4-Against flora	To destroy the forest, to cut individual trees without permit, to start a fire
5-Pollution	To release a pollutant in the environment above the allowed limits, presenting any impact on fauna, flora and human

Source: Brasil (1998b).

Table 2. Non-natural and natural land uses (ha and %) for each CU in 2022

CU	Non-natural		Natural		Total area
	ha	%	ha	%	ha
FLONITA	16,485.8	30.2	38,047.3	69.7	54,533.1
FLONATA	3,068.8	1.5	193,432.5	98.4	196,501.2
FLONACA	13,313.4	3.4	381,547.9	96.6	394,861.3

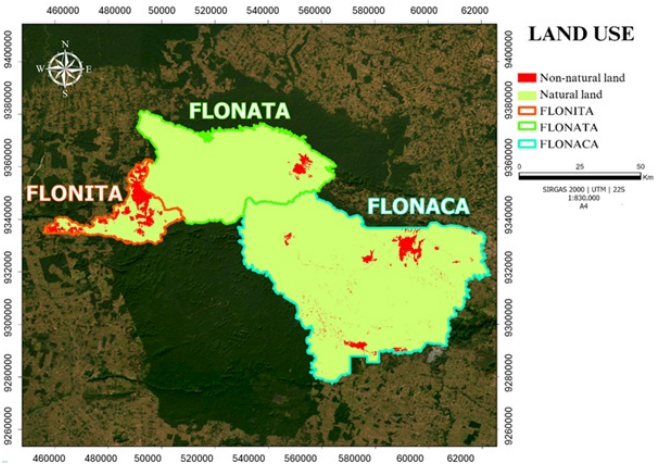

Figure 2. Non-natural and natural land uses int 2022 year for FLONITA, FLONATA and FLONACA.

Despite FLONACA and FLONITA showing similar numbers, these CU have different total areas, so the number of hectares per infraction accounted (Table 3). FLONACA was the CU with the highest absolute number of infractions, followed by FLONITA and FLONATA. FLONITA had the highest density of infractions per hectare, followed by FLONACA and FLONATA. One infraction was reported to every 1,069 ha in FLONITA, 6,369 ha in FLONACA and 24,563 ha in FLONATA. Regarding the location of the infraction, it tended to be committed more towards the CU border, especially at FLONITA (Figure 3), which apparently is where the CU is more easily accessed.

Table 3. Total number of infractions against FLONITA, FLONATA and FLONACA from 2009 and 2024 according to offense class and infraction committed by the number of hectares

CU	Ofense class					Total	Ha/infraction
	1	2	3	4	5		
FLONITA	7	8	1	29	6	51	1,069
FLONATA	0	5	1	0	2	8	24,563
FLONACA	1	43	11	2	5	62	6,369
TOTAL	8	56	13	31	13	121	5,338

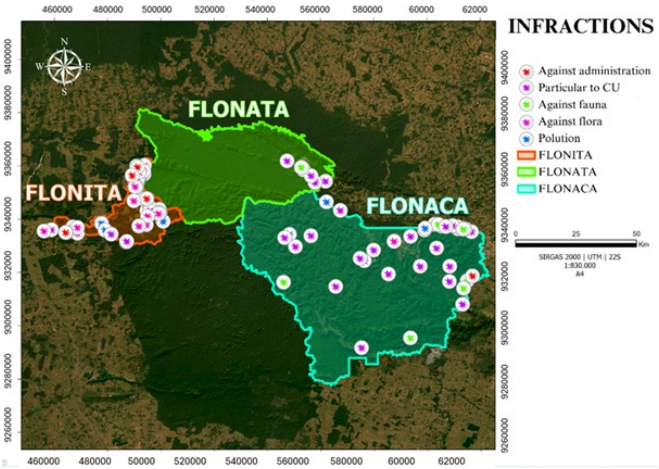

Figure 3. Location where infractions were committed at FLONITA, FLONATA and FLONACA between 2009 and 2024 at each infraction class

3.3 Fire outbreaks

FLONITA was the CU with the highest frequency of fire outbreaks, followed by FLONACA and FLONATA (Figure 4). In terms of area per fire outbreaks, FLONITA had in average one fire outbreak for every 487 ha, which means a much denser fire occurrences than at FLONATA and FLONACA, where one fire outbreak was identified at each 4,793 ha and 5,484 ha, respectively (Table 4).

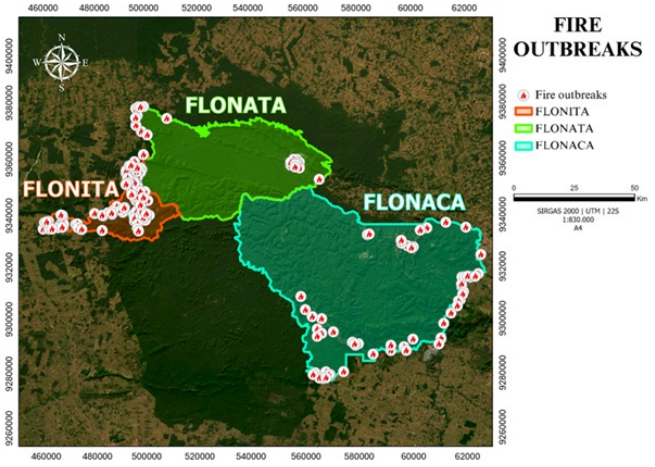

Figure 4. Fire outbreak location at FLONITA, FLONATA and FLONACA from 2002 to 2024.

Table 4. Total fire outbreaks and density (ha/fire outbreaks) for FLONITA, FLONATA and FLONACA from 2002 to 2024.

UC	Fire outbreaks	Ha/Fire outbreaks
FLONITA	112	487
FLONATA	41	4,793
FLONACA	72	5,484

4. Discussion

FLONITA was the CU with most non-natural land and the highest natural-area loss rate. Supposing the deforestation rate is kept constant, we hypothesize the natural area at FLONITA will be extinguished in 63 years, in the year 2,087. Applying the same reasoning to FLONATA and FLONACA, the situation is less alarming, the natural areas would be over in 2,198 and 865 years, respectively, in the years 4,222 and 2,889, which allows more time to accommodate policies and constrains to stop deforestation. Same trends were observed regarding infractions against the CU and fire outbreaks. Andrade (2020) assessed the causes of land use at the Carajas Mosaic over 35 years and found that the main conversion cause was pasture. If the demand for beef indeed rise, as predicted, with the increasing global population, it would be harder to stop, even drop land use changes at the CUs, in general.

FLONITA's vulnerability can be explained first by the fact that especially at this CU, irregular miners and farmers are frequently encountered in the area conducting illegal activities (EcoAmazônia, 2018; Isa, 2024). Illegal mining produced negative impacts in an uncontrolled manner to the environment, threatening the survival of traditional communities at its surroundings, poisoning rivers, flora and fauna (Basta et al., 2023; Ferreira et al., 2022). Second, FLONITA is geographically isolated: the closest urban centers, São Félix do Xingu and Tucumã, are 100 km plus away from FLONITA, and the difficult access due to bad road condition makes more difficult to implement and enforce policies aiming to protect and preserve the area, even though educational activities have been done to raise, awareness in the area (Vieira et al., 2018).

Diverging from illegal, legal mining activities performed under concessions may avoid deforestation at some level. At FLONACA and FLONATA, the presence of mining companies and their service providers is constant. They are conducting legal activities there; therefore, they need to comply with environmental legislation, and their presence is likely discouraging illegal actions in the area. The damage from either legal or illegal activity is hard to be quantified. However, legal business look forward to how to do it, or how to implement less damaging methods. For example, Souza Filho et al. (2020) proposed an index integrating 20 indicators related to land use change, direct impact caused by operations, residues generation, energy, water and soil uses, and environmental compensations. Such indicators along with other studies are important to help on the understanding of the impact of human activity on fauna and flora. For example, Fraga et al (2023) found out that caves have been used by the fauna as a wildlife refugee in degraded lands in the Brazilian Amazon.

Legal mining companies acting in the region also bring positive socioeconomic impacts, such ascreating jobs, circulate local economy, and pay a particular tax related to mining activity since 1988 (Brasil, 1988). This tax is called Financial Compensation for Mining Exploitation (CFEM – In Portuguese - Compensação Financeira pela Exploração Mineral). The value charged depends on the mineral being exploited and the amount produced, 75% paid to the city, 15% for the state, and 10% for federal instance (MME, 2021). It means that most of the money will be locally spent on the needs of the local population. So far, from 2003 to 2024 R$19,8 billion were generated from taxes resulted from mining activity from FLONATA and FLONACA (Agênciagov, 2024). The effect of legal mining business has apparently affected Human Development Index (HDI). The average HDI in Para state is 0.646, and the average HDI in cities under legal mining activities is higher, 0.685. Other examples where mining activity has promoted social development are Floresta Nacional de Saracá-Taquera (Brasil, 1989) and Floresta Nacional do Jamari (Brasil, 1984).

On the other hand, mining activities, even when complying with legislation, may bring a drawbacks to forest integrity because it was shown to increase probability of

deforestation in the nearby due to infrastructure establishment, urban expansion to support a growing workforce, and development of mineral commodity supply chains (Sonter et al. 2017), and to threaten indigenous territories (Villén-Pérez et al. 2022). Mining, either legal or illegal, will suppress a certain forest area, and create activity may induce fragmentation. Indeed, a standing forest provides many crucial ecosystem services, for example global climate regulation, precipitation patterns, biodiversity conservation, soil protection, carbon storage (Marengo et al, 2018) that are of crucial importance, locally and globally. Even though the ecosystem services are crucial, it is difficult to attribute an economical value to it. Brouwer et al. (2022) calculated an approximate value of the Amazon forest considering the environmental services it provides and found a value of 410 USD/ha/year. Considering a period of 20 years, and the dollar value of R$4.00, the value of services provided by FLONITA, FLONACA and FLONATA over time goes above R$20 billion, which could be paid by third parties to a Fund, for example the Amazon Fund, and used to preserve the forest and develop local populations.

We believe that our results are useful for policymakers and managers to better plan mining activities. Activities done under legal requirements were proven to reduce forest degradation in the site and probably at surroundings. We showed that illegal businesses still produces degradation signs, which need to be analyzed, so procedures can be improved. Illegal mining should be combated.

5. Conclusion

FLONITA, the conservation unit where illegal mining have been conducted over years, was the conservation unit with the highest land use change rate, the highest proportion of non-natural areas, the highest rate of infractions reported, and fire outbreak incidences compared to FLONATA and FLONACA, in which only legal mining has been practiced. Legal and illegal businesses have been shown to impact the preservation status of the forest areas. Complying with the environmental law indeed reduces environmental degradation. However, environmental policies can still be improved, given the need to preserve forests ecosystems and the current deforestation pace of the Amazon Forest.

Acknowledgments

No acknowledgments were declared for this work.

Author Statements

✓ No conflicts of interest were declared.

✓ All existing funding sources were acknowledged.

✓ There is no evidence of plagiarism in this article.

References

Acharya, R. P.; Maraseni, T.; Cockfield, G. (2019). Global trend of forest ecosystem services valuation – An analysis of publications. *Ecosystem Services*, 39, 100979.

AgênciaGov. (2024). *Estados e municípios recebem R$ 645 milhões de compensação pela exploração mineral em janeiro: Ministério de Minas e Energia*. Disponível em: https://agenciagov.ebc.com.br/noticias/202403/mais-de-r-645-milhoes-da-cfem-foram-repassados-a-estados-e-municipios-referentes-ao-mes-de-janeiro. 07 de mar. 2024.

Alvares, C. A. Stape, J. L.; Sentelhas, P. C.; Moraes Gonçalves, J. L.; Sparovek, G. (2014). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22 (6), p. 711-728. DOI: https://doi.org/10.1127/0941-2948/2013/050202.

Andrade, M. C. (2020). *Dinâmica de desflorestamento na região de Carajás.* Monografia (Bacharelado em Agronomia), Universidade Federal do Sul e Sudeste do Pará, Marabá-PA.

ArcGIS Pro. (2022). *Versão 3.0. ESRI*. Disponível em: https://www.esri.com/pt-br/arcgis/products/arcgis-pro/overview.

Baciu, G. E.; Dobrotă, C. E.; Apostol, E. N. (2021). Valuing Forest Ecosystem Services. Why Is an Integrative Approach Needed? *Forests*, 12 (6), p. 677. Doi: https://doi.org/10.3390/f12060677.

Basso, L. S., Wilson, C., Chipperfield, M. P., Tejada, G., Cassol, H. L. G., Arai, E., Williams, M., Smallman, T. L., Peters, W., Naus, S., Miller, J. B., & Gloor, M. (2023). Atmospheric CO_2 inversion reveals the Amazon as a minor carbon source caused by fire emissions, with forest uptake offsetting about half of these emissions. Atmospheric Chemistry and Physics, 23(17), 9685-9723.

Basta, P. C. (2023). Gold mining in the Amazon: the origin of the Yanomami health crisis. *Cad Saúde Pública*, 39 (12), e0e00111823.

Brasil. (1984). *Decreto n°90.224, de 25 de setembro de 1984.* Cria a Floresta Nacional do Jamari, no Estado de Rondônia, e dá outras providências. Brasília, DF: Diário Oficial da União.

Brasil. (1988). *Constituição da República Federativa do Brasil de 1988*. Brasília, DF: Presidência da República.

Brasil. (1989). *Decreto n°98.704, de 27 de dezembro de 1989*. Cria a Floresta Nacional de Saracá - Taquera. Brasília, DF: Diário Oficial da União.

Brasil. (1998). *Lei n°9.605, de 12 de fevereiro de 1998*. Dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente, e dá outras providências. Brasília, DF: Diário Oficial da União.

Brasil. (2000). *Lei n°9.985, de 18 de julho de 2000*. Regulamenta o art. 225, § 1°, incisos I, II, III e VII da Constituição Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza e dá outras providências. Brasília, DF: Diário Oficial da União.

Brouwer, R.; Pinto, R.; Dugstad, A.; Navrud, S. (2022). The economic value of the Brazilian Amazon rainforest ecosystem services: A meta-analysis of the Brazilian literature. *PloS One*, *17*(5), e0268425.

EcoAmazônia. (2018). *Ibama e ICMBio apreendem 7 escavadeiras em garimpo ilegal no entorno da Flona do Tapirapé-Aquiri (PA)*. Disponível em: https://www.ecoamazonia.org.br/2018/06/ibama-icmbio-apreendem-7-escavadeiras-garimpo-ilegal-entorno-flona-tapirape-aquiri-pa/

Ferreira, L. C. O.; Costa Neto, A. P.; Fernandes, G. G. C.; Albuquerque, A. R.; Vieira, A. L. M. (2022). Banco de Dados de Produtos não Madeireiros da Floresta Nacional do Tapirapé-Aquiri, Serra de Carajás. *Biodiversidade Brasileira*, 12(1), p. 79-87. Doi: https://doi.org/10.37002/biobrasil.v12i1.1841.

Fraga, R.; Tavares, V.; Simões, M. H.; Prous, X.; Girolano-Neto, C.; Brandi, I. V.; Oliveira, G.; Trevelin, L. C. (2023). Caves as wildlife refuges in degraded landscapes in the Brazilian Amazon. *Scientific Reports*, 13, 6055. Doi: https://doi.org/10.1038/s41598-023-32815-x.

Gatti, L. V.; Basso, L. S.; Miller, J. B.; Gloor, M.; Gatti, D. L.; Cassol, H. L. G.; Tejada, G.; Aragão, L. E. O. C.; Nobre, C.; Peters, W. (2021). Amazonia as a carbon source linked to deforestation and climate change. *Nature*, 595, p. 388–393. Doi: https://doi.org/10.1038/s41586-021-03629-6.

Instituto Chico Mendes de Conservação da Biodiversidade. (2016). *Plano de Manejo da Floresta Nacional de Carajás – Volume II*. Disponível em: https://www.gov.br/icmbio/pt-br/assuntos/biodiversidade/unidade-de-conservacao/unidades-de-biomas/amazonia/lista-de-ucs/flona-de-carajas. Acesso em: 10 out. 2022.

ISA, Instituto Socioambiental. (2018). *Justiça reconhece que garimpo ilegal no Pará causou danos morais coletivos.* Disponível em: https://uc.socioambiental.org/pt-br/noticia/193309. Acesso em: 03 mar. 2024.

Lloyd, T. J.; Oliveira, U.; Soares-Filho, B. S.; Fuller, R. A.; Butt, N.; Ascher, J. S., Barbosa, J. P. P. P.; Batista, J. A. N.; Brescovit, A. D.; Carvalho, C. J. B.; Marco, P.; Ferro, V. G.; Leite, F. S. F.; Löwenberg-Neto, P.; Paglia, A. A. P.; Rezende, D. T.; Santos, A. J.; Silva, D. P.; Vasconcelos, M. F.; Sonter, L. J. (2023). Multiple facets of biodiversity are threatened by mining-induced land-use change in the Brazilian Amazon. *Diversity and Distributions*, 29 (9), p. 1190–1204. Doi: https://doi.org/10.1111/ddi.13753.

Mapbiomas. (2024). *O que é o MapBiomas?* Disponível em: https://brasil.mapbiomas.org/perguntasfrequentes/#:~:text=O%20projeto%20MapBiomas%20%C3%A9%20uma,monitorar%20as%20mudan%C3%A7as%20do%20territ%C3%B3rio. Acesso em: 14 fev. 2024.

Marengo, J. A.; Souza Jr, C. M.; Thonicke, K.; Burton, C.; Halladay, K.; Betts, R. A.; Alves, L. M.; Soares, W. R. (2018). Changes in climate and land use over the Amazon region: current and future variability and trends. *Frontiers in Earth Science*, *6*, 228.

Microsoft. (2019). *Excel*. Versão 16.0. Disponível em: https://www.microsoft.com/pt-br/microsoft-365/excel. Acesso em: 16 fev. 2023.

MME. (2021). *Ministério de Minas e Energia quer liberar mineração dentro de florestas nacionais: Observatório da Mineração*. Disponível em: https://observatoriodamineracao.com.br/ministerio-de-minas-e-energia-defende-liberar-a-mineracao-dentro-de-florestas-nacionais. Acesso em: 07 jan. 2024.

Moraes, R. A.; Oliveira, X. M.; Mayrinck, R. C.; Kohler, S. V.; Goulart, S. L. (2024). Sustainable forest

management for timber and non-timber resources in the Amazon forest under concession. *TreeDimensional Journal*, 13, e2024050.

Power BI Desktop. (2019). Versão 2.112.283.0. Disponível em: https://powerbi.microsoft.com/pt-br/. Acesso em: 16 fev. 2023.

Qgis. (2023). Versão 3.26.1. https://qgis.org/pt_BR/site/. Acesso em: 16 fev. 2023.

Ramos, C. A.; Silva, J. N. M.; Merry, F. (2015). The evolution of Brazilian forest concessions. *Elementa: Science of the Anthropocene*, 3, 000048. Doi: https://doi.org/10.12952/journal.elementa.000048.

Rodrigues, M.; Souza, A. I. A. F.; Goulart, S. L.; Kohler, S. V.; Lima, G. C. P.; Anjos, L. J. S.; Lacerda, J. D. A.; Souza, M. C.; Soares, C. A.; Borges, R. P.; Cruz, W. P.; Ebling, A. A. (2020). Geostatistical modeling and conservation implications for an endemic Ipomoea species in the Eastern Brazilian Amazon. Journal for Nature Conservation, 57, 125893. Doi: https://doi.org/10.1016/j.jnc.2020.125893.

Sist, P.; Piponiot, C.; Kanashiro, M.; Claros, M. P.; Putz, F. A.; Schulze, M.; Verissimo, A.; Vidal, E. (2021). Sustainability of Brazilian forest concessions. Forest Ecology and Management, 496, 119440. Doi: https://doi.org/10.1016/j.foreco.2021.119440.

Sonter, L. J.; Herrera, D.; Barret, D. J.; Galford, G. L.; Moran, C. J.; Soares-Filho, B. S. (2017). Mining drives extensive deforestation in the Brazilian Amazon. *Nat Commun*, 8, 1013. Doi: https://doi.org/10.1038/s41467-017-00557-w.

Souza Filho, P. W. M.; Cavalcante, R. B. L.; Nascimento Jr., W. R.; Nunes, S.; Gastauer, M.; Santos, D. C.; Silva Jr., R. O.; Sahoo, P. K.; Salomão, G.; Silva, M. S.; Ramos, S. J.; Caldeira, C. F.; Dall'Agnol, R.; Siqueira, J. O. (2020). The sustainability index of the physical mining Environment in protected areas, Eastern Amazon. *Environmental and Sustainability Indicators*, 8, 100074.

Vieira, A. L. M.; Mendonça, M. V.; Albuquerque, S. S.; Bezerra, J. R.; Gondin, R. (2018). Práticas agroecológicas no entorno da Floresta Nacional do Tapirapé-Aquiri. *Cadernos de Agroecologia*, 13(1).

Villén-Pérez, S.; Anaya-Valenzuela, L. et al. (2022). Mining threatens isolated indigenous peoples in the Brazilian Amazon. *Global Environmental Change*, *72*, 102398.

Virgens, J. S. (2023). *Caracterização petrográfica e litogeoquímica do Corpo Metaultramáfico da Serra do Jacaré, Domínio Carajás, Brasil*. Rio Claro: Instituto de Geociências e Ciências Exatas.