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NATIONAL FORESTS IN THE BRAZILIAN AMAZON: DEFORESTATION AND LAND USE PRESSURES (2018-2021)

FLORESTAS NACIONAIS NA AMAZÔNIA BRASILEIRA: DESMATAMENTO E PRESSÕES DE USO DA TERRA (2018-2021)

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Abstract

The National Forests (FLONAs) of the Brazilian Amazon are crucial protected areas; however, they have faced anthropogenic pressures, primarily from agriculture and mining. This study aims to assess deforestation and contextualize the main anthropogenic pressure vectors present in each FLONA. The research utilized deforestation data from the National Institute for Space Research (INPE) and land use and land cover information from MAPBIOMAS for the period from 2018 to 2021, which were highlighted in thematic maps. The research results identified that: a) FLONAS in southwest Pará, such as Jamanxim, Altamira, and Itaituba II, concentrated most of the deforestation occurring between 2018 and 2021; b) Most FLONAS recorded an increase in deforestation between 2018 and 2021; c) Pastures were identified as the primary drivers of deforestation in FLONAS; d) Southwest Pará and Northern Rondônia concentrated the majority of the most deforested FLONAS by 2021; e) FLONAS facing the most pressure from land use are near highways and agricultural fronts; f) A large portion of FLONAS lost less than 2% of their forest areas; g) There is a significant contrast in forest loss among FLONAS.
Keywords:
Logging, Cattle ranching, Environmental monitoring, Amazon Rainforest.

Resumo

As Florestas Nacionais (FLONAs) da Amazônia brasileira são importantes unidades de conservação, no entanto, têm sofrido pressões antrópicas, principalmente da agropecuária e da mineração. Este trabalho visa avaliar o desmatamento e contextualizar os principais vetores de pressão antrópica presentes em cada FLONA do bioma. A pesquisa utilizou dados de desmatamento do Instituto Nacional de Pesquisas Espaciais (INPE) e informações de uso e cobertura da terra do MAPBIOMAS,

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para o período de 2018 a 2021, que foram destacados em mapas temáticos. Os resultados da pesquisa identificaram que: a) as FLONAS do sudoeste do Pará, como Jamanxim, Altamira e Itaituba II concentraram a maioria do desmatamento ocorrido entre 2018 e 2021; b) A maioria das FLONAS registrou aumento de desmatamento entre 2018 e 2021; c) as pastagens foram identificadas como as principais responsáveis pelo desmatamento das FLONAS; d) o sudoeste do Pará e o norte de Rondônia concentraram a maioria das FLONAS mais desmatadas até o ano 2021; d) as FLONAS mais pressionadas por usos da terra estão próximas de rodovias e das frentes agropecuárias; e) Grande parte das FLONAS perdeu menos de 2% das florestas de seus territórios; f) prevalece grande contraste da perda de florestas entre as FLONAS.
Palavras-chave:
Exploração madeireira, Criação de gado, Monitoramento ambiental, Floresta Amazônica.

I. INTRODUCTION

Protected areas (PAs) are crucial in the Amazon for preserving biodiversity and maintaining essential ecosystem services, while acting as a barrier against deforestation (RYLANDS; BRANDON, 2005; NEPSTAD et al., 2006; PELLIN et al., 2022; SOARES-FILHO et al., 2023). They play a key role in carbon storage, helping mitigate climate change effects (RICKETTS et al., 2010; SOARES-FILHO et al., 2010). Additionally, PAs support indigenous populations and traditional communities by promoting sustainable management and preserving traditional lifestyles (SOUZA et al., 2013; CALLE et al., 2014; SOUSA et al., 2018). Effective establishment and management of these units are essential for the long-term survival of the Amazon, protecting biodiversity, environmental balance, and human well-being.

Among the 12 categories of PAs established in Brazil by the National System of Protected Areas (SNUC), a legal framework created to regulate the creation and management of protected areas in the country (BRASIL, 2000), National Forests (FLONAs) are categorized as sustainable use units and aim to reconcile environmental preservation with economic activities in a sustainable manner. Initially created by the Forest Code of 1965 with the primary purpose of protecting mineral reserves, this category gained broader objectives in the 2000s with the National Forest Program (VERÍSSIMO; BARRETO, 2004). Currently, these areas have the fundamental goal of managing natural resources, allowing controlled extraction of forest products, such as timber and fruits, to ensure biodiversity conservation, protect fragile ecosystems, and simultaneously provide socioeconomic benefits to local communities (BRASIL, 2000). Thus, FLONAs represent a balanced approach to the rational use of natural resources, aligned with the preservation of the invaluable ecological values present in the Brazilian Amazon.

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The 34 FLONAs in the Brazilian Amazon cover 182,013.5 km² (ICMBIO, 2023) and are crucial for biodiversity conservation, sustainable forest resource management, and in the regional socioeconomy (IBAMA; WWF-Brazil, 2007). For instance, Tapajós National Forest is recognized for its diversity of aquatic and terrestrial plants and animals across various groups (BROCARDO; GIACOMIN, 2021). In FLONAs with traditional populations, they provide a source of income and subsistence through the management of extractive forest resources (e.g., MCGRATH et al., 2004; SILVA et al., 2010; FÉLIX-SILVA et al., 2018). Furthermore, many FLONAs are strategically located in agricultural frontier areas within the biome, serving as a barrier against illegal deforestation and acting as buffer zones for strict protection units (VERÍSSIMO; BARRETO, 2004).

However, FLONAs face challenges from pressures such as advancing agricultural frontiers, illegal logging, mining, and unlawful occupation (e.g., NUNES et al., 2012; COSTA et al., 2015; DUARTE et al., 2019), as well as difficulties in facilitating concessions for legal timber extraction by private enterprises (VERÍSSIMO; BARRETO, 2004; RODRIGUES et al., 2020). The establishment of sustainable use PAs in regions with high human pressure exacerbates these challenges (SALOMÃO et al., 2011; COSTA et al., 2015; DUARTE et al., 2019). According to a 2007 report on federal PAs' management effectiveness by IBAMA and WWF-Brazil (IBAMA; WWF-Brazil, 2007), FLONAs at that time showed moderate vulnerability (48%) and compromised protection due to factors like easy access, high demand for natural resources, and monitoring difficulties, with a management effectiveness rating of 40%. The report also identifies invasive exotic species, timber extraction, and external influences as the most critical, frequent, and growing threats within FLONAs.

Monitoring the conservation status of PAs is crucial for effective management. While there is data available on deforestation and degradation within PAs (e.g., TerraBrasilis platform [INPE, 2024c]), there is a need for integrated analysis with land use and land cover data to inform territorial management (MAEDA et al., 2023). Understanding current threats and impacts is essential for planning actions within and around PAs.

In this context, focusing on the FLONAs within the Amazon biome, this study assesses the internal impacts and external threats to these PAs, updating their status regarding land use and cover. The analysis covers 2018 to 2021, highlighting temporal changes in deforestation and land use. It addresses the following questions: (1) Which FLONAs have experienced the most forest cover loss due to deforestation? (2) Where are these FLONAs located? (3) What external and internal land use pressures affect the FLONAs? This study is crucial for understanding the spatial patterns and causes of forest loss in these units collectively, identifying the FLONAs most sensitive to anthropogenic pressures in the Amazon region, as previous studies have focused on individual FLONAs (e.g., COHENCA, 2007; NUNES et al., 2012; COSTA et al., 2015; NORONHA et al., 2019).

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II. Materials and methods

Study area

The Brazilian Amazon biome contains 34 FLONAs (Figure 1) covering about 182,013.5 km² (ICMBIO, 2023). Most FLONAs are in Pará (14) and Amazonas (11), with others in Rondônia (3), Acre (3), Roraima (2), Amapá (1), and one spanning Pará and Amazonas. There are no FLONAs in Mato Grosso, Tocantins, and Maranhão. Most were established in the 1980s and 2000s, primarily located in dense ombrophilous forests within an equatorial climate, covering humid zones (IBGE, 2002). They are in Phanerozoic sedimentary basins or Neoproterozoic cratons, with Latosol or Argisol soils (IBGE, 2024). These FLONAs are mainly in the Amazon River Basin (IBGE, 2024), the world's largest river basin, known for its numerous rivers and high water volume.

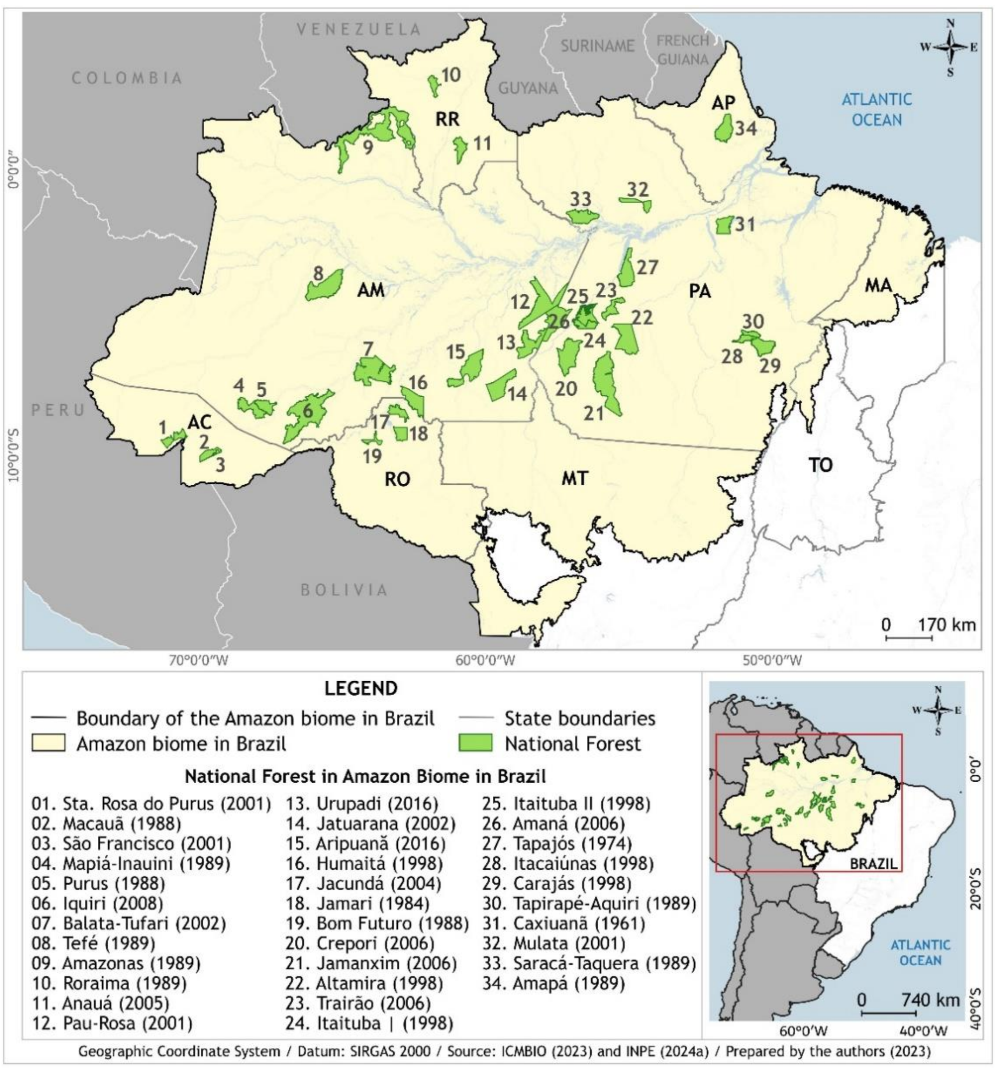

Figure 1 - Location, identification, and year of establishment of the National Forests in the Amazon biome, Brazil (2023). (Source: Authors' elaboration based on ICMBIO, 2023 and INPE, 2024a).

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Data Acquisition and Processing

Vector files of federal protected areas were initially obtained from the Chico Mendes Institute for Biodiversity Conservation (ICMBIO) website (ICMBIO, 2023). Using QGIS, only FLONAs were filtered. The polygons outlining the FLONAs were created by various institutes, such as the now-defunct Brazilian Institute for Forest Development (IBDF) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), with scales ranging from 1:100,000 to 1:250,000 (INDE, 2023).

Deforestation data for 2018, 2019, 2020, and 2021 were obtained for the 34 FLONAs in the Amazon. This period was chosen because these FLONAs were created at different times, covering the post-creation of all units. The data were sourced from the Monitoring Program of the Brazilian Amazon Forest by Satellite (PRODES) on the "PRODES – Deforestation in Protected Areas" platform (INPE, 2024b). Produced by the National Institute for Space Research (INPE), these data monitor annual deforestation by clear-cutting and forest degradation (INPE, 2024a). The minimum mapped area is 6.25 hectares for the Amazon (INPE, 2024a). INPE uses Landsat images (30 x 30 meters resolution) and Sentinel satellite images (10 x 10 meters resolution) for areas with high cloud cover (INPE, 2024a).

Deforestation data were organized in Excel spreadsheets to calculate the annual total deforestation in the Amazon FLONAs. The variations in deforestation between 2018 and 2021 (in absolute and relative terms) were calculated for each FLONA using the following equations:

$$DESv\ (\%) = \frac{(DES_{2021} - DES_{2018}) * 100}{DES_{2018}} \quad (1)$$

Where:

DESv (%) 2021/2018 – relative variation in deforestation between 2021 and 2018.

DES 2021 – deforested area in 2021.

DES 2018 – deforested area in 2018.

$$DESv_{2021-2018} = DES_{2021} - DES_{2018} \quad (2)$$

Where:

DESv 2021/2018 – absolute variation in deforestation between 2021 and 2018.

DES 2021 – deforested area in 2021.

DES 2018 – deforested area in 2018.

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The values calculated from these formulas were added to the attribute table of the Amazon FLONAs' vector file using the free software QGIS 3.28.7 (QGIS DEVELOPMENT TEAM, 2023). This included data up to 2021 for deforested area percentage and total area of each FLONA in km². Centroids were generated for each unit to spatially represent deforestation values through thematic maps. Two cartographic methods proposed by Martinelli (2011) were employed: proportional symbols to show absolute changes in deforestation from 2018 to 2021 and FLONA area in km², and choropleth to display positive or negative percentage variations in deforestation and cumulative deforestation percentage within each FLONA by 2021.

Land use inside and around the FLONAs was analyzed using data from the MapBiomas Project (Annual Land Use and Land Cover Mapping Project in Brazil), collection 8 (MAPBIOMAS, 2023). MapBiomas employs advanced remote sensing and machine learning techniques to map changes in land cover across Brazil. High-resolution satellite images are processed and classified using algorithms trained by experts to detect patterns in categories like forests, agriculture, and urban areas. This automated approach allows for monitoring significant changes such as deforestation and urban expansion over time. The results are validated and compiled into detailed land use maps, which are publicly available and support environmental monitoring and conservation decisions (MAPBIOMAS, 2023).

To generate land use and land cover maps for the Amazon biome including FLONAs, the "Mapbiomas Collection 8.0" plugin within QGIS was used. The tool "Inverted Polygons" was applied to the Amazon biome vector file with georeferenced MapBiomas data to highlight information specific to the Amazon biome.

To assess the area occupied by pasture, agriculture, and mining in the Amazon biome and selected FLONAs, data were extracted from the MapBiomas project's interactive platform under "Maps and Data" and "Statistics" (MAPBIOMAS, 2023). The association between each FLONA and land uses was analyzed using Principal Component Analysis (PCA) implemented with the vegan package (OKSANEN et al., 2022) in R software (R CORE TEAM, 2023). This analysis reduces data complexity, identifies variation patterns, and clarifies the main relationships between variables, aiding interpretation and understanding of the factors influencing land use distribution within FLONAs (BORCARD et al., 2018).

III. RESULTS AND DISCUSSION

Deforestation in FLONAs within the Amazon biome was 126.3 km² in 2018 and increased to 302.5 km² by 2021, marking a 139.5% rise or 176.2 km² over the quadrennial period (Figure 2a). Studies indicate FLONAs are among the most impacted PAs by deforestation in the Amazon (e.g., DUARTE et al., 2019; PELLIN et al.,

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2022). This trend mirrors increased deforestation across protected areas and Indigenous Lands (TIs) in the Amazon, averaging 0.08 million hectares per year (0.04% annually) (QIN et al., 2023). Illegal practices such as deforestation, mining, and logging affect both strict protection and sustainable use units, as well as TIs, within the biome (ARAÚJO et al., 2017; TESFAW et al., 2018; RORATO et al., 2021; QIN et al., 2023). Illegal pressures have led to political efforts aimed at reducing the extent of protected areas, including FLONAs, within the biome (MARQUES; PERES, 2015; MARCUARTÚ et al., 2017).

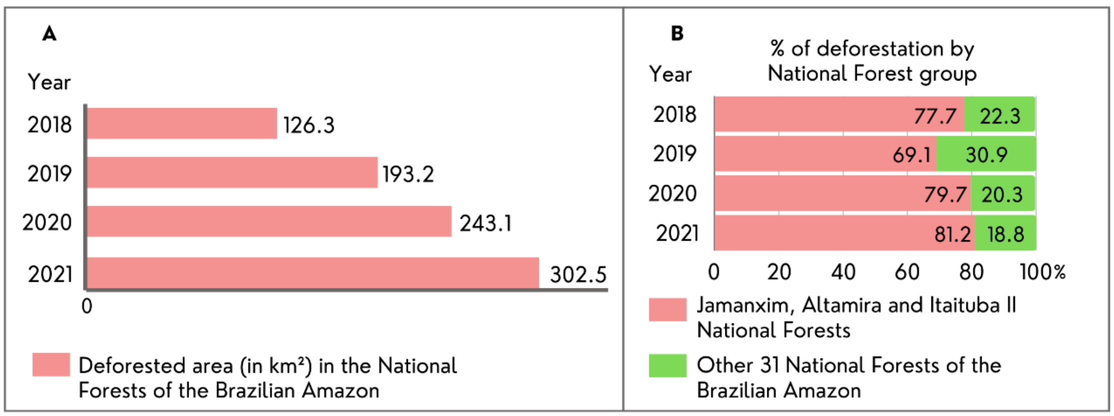

Figure 2 – (A) Deforestation in km² that occurred in all National Forests (FLONAs) in the Amazon biome; (B) Percentage deforested by group of FLONAs in the Amazon biome (2018-2021). (Source: Authors' elaboration based on MAPBIOMAS, 2024b).

Figure 3 highlights the contrast in accumulated forest cover loss within FLONAs relative to their total area up to 2021. Most FLONAs lost up to 2% of their total forested area. The highest deforestation rates are concentrated in northern Rondônia and southwestern Pará, ranging from 3.7% to 18.4% forest loss. Conversely, Amazonas, Acre, Roraima, and Amapá states show the lowest deforestation rates, below 1.8%. The largest proportions of deforestation occurred in Bom Futuro (18.4%), Jamanxim (16.3%), and Itacaiúnas (15.2%). Three FLONAs (Jamanxim, Altamira, and Itaituba II) accounted for 81.2% of total deforestation, particularly in 2021. This means that for every 100 km² deforested in Amazon biome FLONAs, approximately 81.2 km² occurred in these three PAs.

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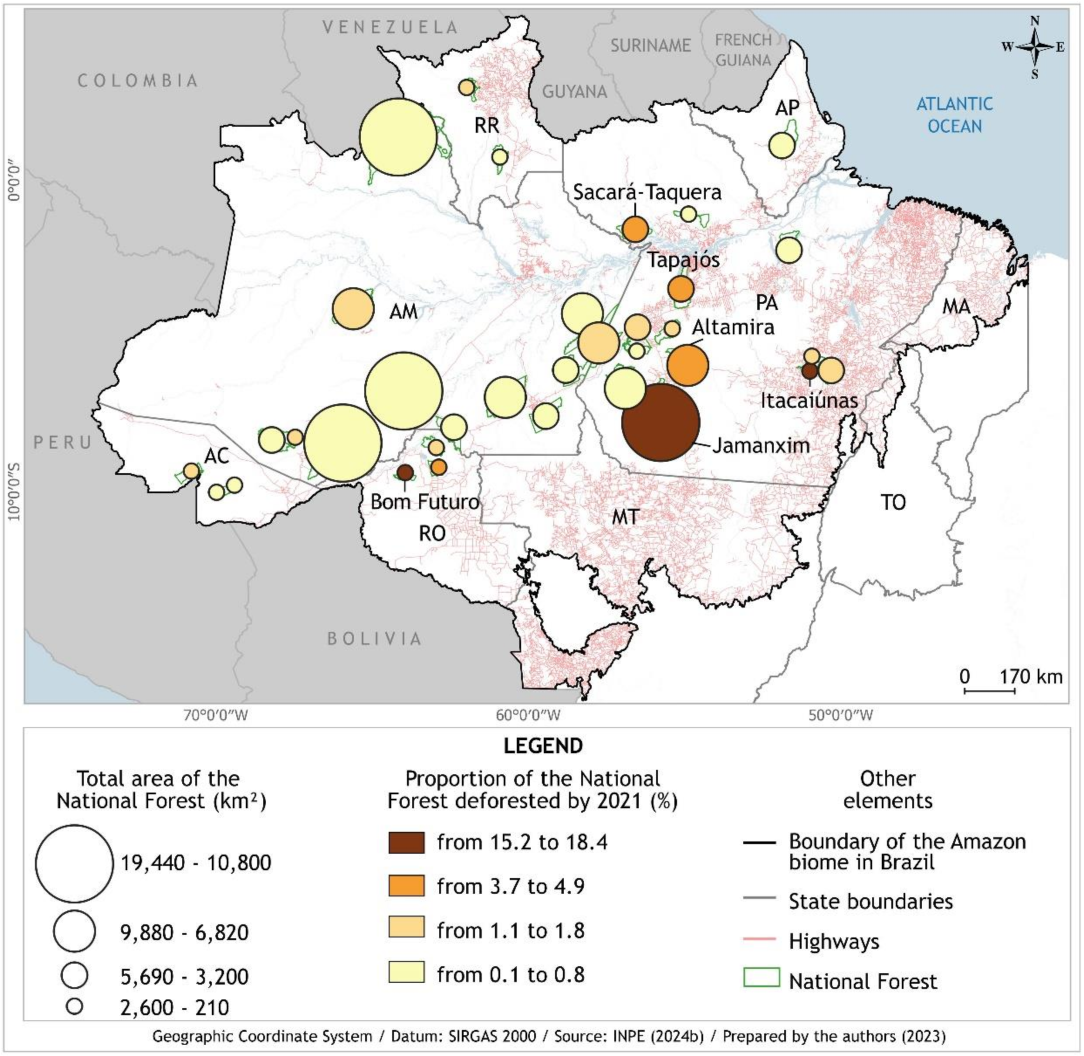

Figure 3 - Total area of the National Forest and proportion of accumulated deforestation up to 2021. (Source: Authors' elaboration based on MAPBIOMAS, 2024b).

In Bom Futuro National Forest in Rondônia, deforestation has increased due to the fertile soils attracting small farmers, ranchers, miners, and loggers, which exacerbates the issue due to weak institutional oversight of sustainable use PAs (PEDLOWSKI et al., 2005; RIBEIRO; VERÍSSIMO, 2007). Additionally, hydroelectric dams on the Madeira River contribute to deforestation and land speculation (COSTA et al., 2015). As a response to these pressures, part of the FLONA was downsized to allow agricultural activities and land regularization, leading to the establishment of two new conservation areas (an Environmental Protection Area and a State Forest) to mitigate impacts (COSTA et al., 2015).

The Itacaiúnas National Forest, located in eastern Pará, is amidst a region heavily impacted by expanding agricultural frontiers (POCCARD-CHAPUIS et al., 2020). It spans between São Félix do Xingu and Marabá, ranking among the top three municipalities for deforestation in Pará. Parauapebas, its administrative center, ranks 69th

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in the state for deforestation (INPE, 2024a). This area is a key mining hub and an established frontier for agricultural expansion, primarily cattle ranching, with an increasing presence of soybean cultivation (NEVES et al., 2014; SOUZA-FILHO et al., 2016; MENDES; GOMES JÚNIOR, 2021).

The Jamanxim, Altamira, and Itaituba II National Forests, located in southwestern Pará, are in a region that saw the highest increase in deforestation, as shown in Figure 4. These three PAs are situated in municipalities (Novo Progresso, Altamira, and Itaituba, respectively) ranked among the top 10 for deforestation in Pará (INPE, 2024a). BR-163 highway, running through this area, was a focal point for deforestation in 2021, follwed by northern Rondônia (Bom Futuro National Forest). The road's paving since the 1970s has eased access, driving migration and intensive land use. This accelerated agricultural expansion and illegal logging, leading to widespread forest conversion to farming and pasturelands, heightening land disputes and illegal land grabbing (CASTRO, 2007; FEARNSIDE, 2007; BRITO; CASTRO, 2018). Additionally, BR-163 has become a critical corridor for soybean exports from Brazil's Midwest, driving further agricultural expansion into previously pristine Amazon areas (GARRETT et al., 2013; GOLLNOW et al., 2017). Consequently, PAs and TIs in the BR-163 zone face intense pressures from land speculation, mining, and illegal logging (DOBLAS, 2015).

The Jamanxim National Forest, known for high carbon emissions from deforestation (COLLINS; MITCHARD, 2017), is targeted for cattle ranching expansion. Half of its deforestation occurred after its establishment in 2006 (KLINGLER; MACK, 2020). The Rural Environmental Registry (CAR) is used to secure land ownership, leading to political pressure to reduce the FLONA's area (MARQUES; PERES, 2015; KLINGLER; MACK, 2020). Gama et al. (2023) projected a 1.52% increase (198.79 km^2) in primary forest loss in Jamanxim FLONA by 2030. Nascimento et al. (2011), analyzing historical PRODES data up to 2009 for Altamira FLONA, found ineffective environmental policies in controlling deforestation, influenced by agricultural expansion along BR-163. Due to internal and external pressures on the units, both Itaituba II and Itaituba I FLONAs are under pressure to downsize for regularization of illegally occupied land for agriculture and mining (MARQUES; PERES, 2015).

The region known as the "Arc of Consolidated Settlement," previously called the "Arc of Deforestation" (BECKER, 2009), faces the highest human pressure on FLONAs. This belt covers eastern, southeastern, southern, and southwestern Amazonia, the most deforested area in the biome (OVIEDO et al., 2019; MESSIAS et al., 2021). Figure 4 shows varied spatial deforestation patterns: 18 FLONAs (53% of total) experienced deforestation rates mostly exceeding 90%, concentrated in southwestern Pará, northern Rondônia, and southern Amazonas. In six FLONAs (17.7% of total), deforestation decreased, notably in southwestern and northern Amazonas and

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southeastern Pará near Carajás mining areas. Six FLONAs (17.7% of total) had no deforestation in 2021, and four FLONAs (11.6% of total) resumed deforestation in 2021 after a period without records. Overall, deforestation in Amazonian FLONAs varied significantly, ranging from -66.9% to 2,785%.

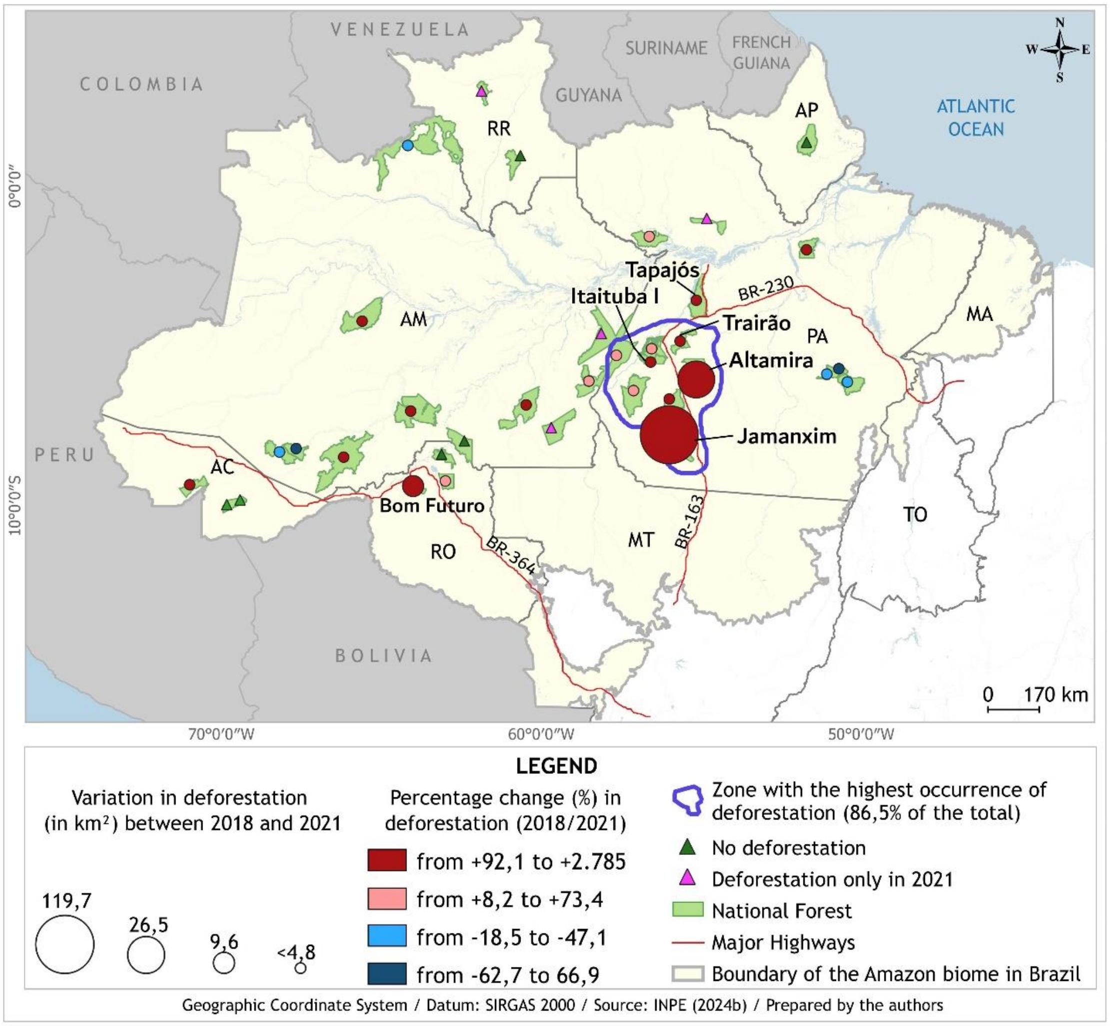

Figure 4 - Absolute and relative variation in deforestation across all FLONAs in the Amazon biome between 2018 and 2021. (Source: Authors' elaboration based on data from INPE, 2024b).

The variation in the deforestation can be explained by external pressures on FLONAs within their regional context. Pellin et al. (2022) have shown that deforestation in Amazonian protected areas is driven more by accessibility and agricultural expansion than by effective management. Figure 4 also indicates that FLONAs face varied anthropogenic pressures depending on their proximity to highways. For example, roads contribute significantly to anthropogenic pressure on the Jamari FLONA, covering up to 60% of its area (NUNES et al., 2012). In FLONAs Ariupanã and Urupadi in southern Amazonas, deforestation is linked to their proximity to the Trans-Amazonian highway and its branches, as well as navigable rivers, which facilitate illegal logging (BARBER et al., 2014; DUARTE et al., 2019). Similarly, the most deforested areas in Jamanxim FLONA are near roads,

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settlements, and rivers (GAMA et al., 2023), allowing deforestation to penetrate deep into the unit, over 35 km from BR-163 (see Figure 7). This accessibility effect of roads and highways in the Amazon on PAs has been observed across other protection categories, including Indigenous Territories (BARBER et al., 2014; PFAFF et al., 2014; SILVA-JUNIOR et al., 2023). Effective planning and control of roads and highways by the State and society are crucial for FLONAs and other PAs. Opening roads and highways should be carefully evaluated due to its inevitable impact on land use change and deforestation pressures.

Figure 5 describes the relationship between the 34 FLONAs and three land uses (pasture, agriculture, and mining) using Principal Component Analysis (PCA). The first axis (PC1) effectively separates FLONAs dominated by pasture (left) and mining (right), explaining 65% of the land use variation. The second axis (PC2) primarily distinguishes FLONAs with higher agricultural areas, explaining 34% of the variation. Pasture is present in deforested areas across all 34 FLONAs, agriculture in 15, and mining in 12 of them.

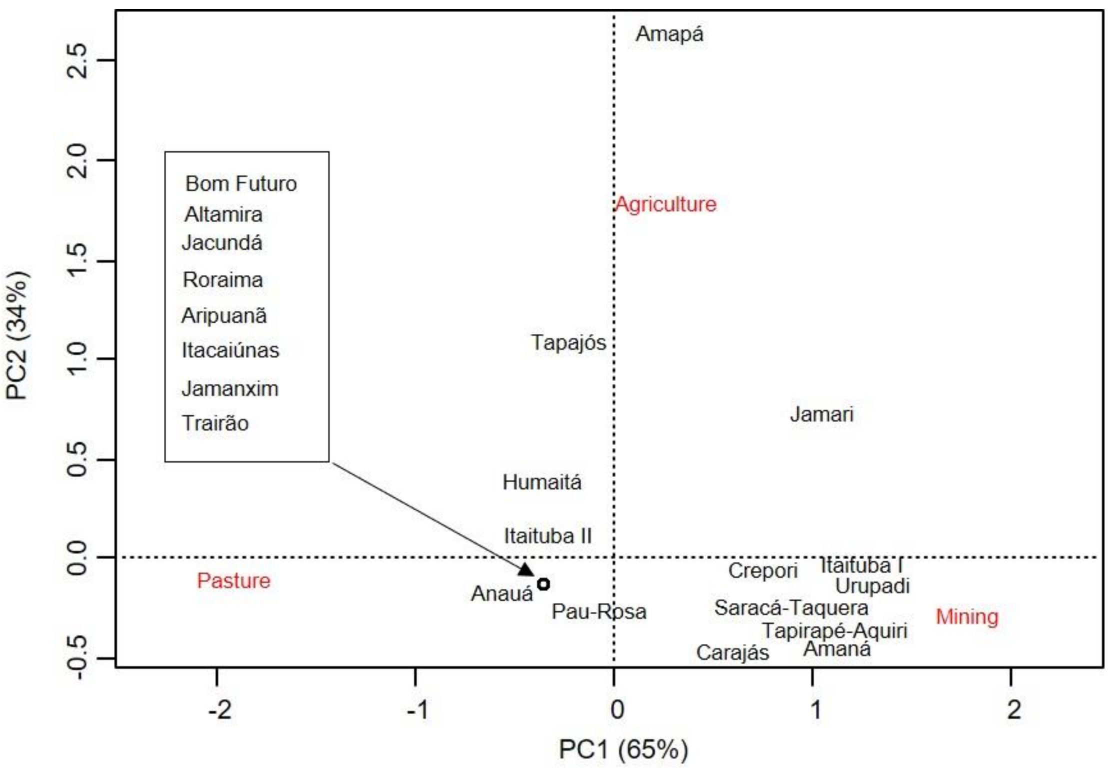

Figure 5 - Principal Component Analysis showing the relationship between the 34 FLONAs and the three land uses (agriculture, pasture, and mining). (Source: Authors' elaboration based on MAPBIOMAS, 2023).

Pastures within the FLONAs covered 2,900.97 km², followed by mining (363.87 km²) and agriculture (16.50 km²). This reflects the general trend in the Amazon biome (Figure 6), where pastures occupy 54.4 million hectares, far exceeding agriculture (7 million hectares) and mining (272.000 hectares) (MAPBIOMAS, 2023). The

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main driver of deforestation is the extensive cattle ranching on pastures, due to minimal soil preparation, low capital investment, and few restrictions imposed by the terrain and newly deforested areas (WOOD; PORRO, 2002; ALVES, 2009; RIVERO et al., 2009).

In the three FLONAs with the most deforestation, pastures made up 99% of land use in Jamanxim, 97% in Altamira and Itaituba II (Figure 7). In absolute terms, Jamanxim had the largest pasture area with 1,795 km², followed by Altamira (250.60 km²), Itacaiúnas (163.05 km²), and Bom Futuro (134.21 km²). The others had less than 100 km². Marcuartú et al. (2017) showed persistent deforestation in Jamanxim between 2000 and 2014, with forests mainly converted to pastures due to land grabbing facilitated by the state's absence or complicity. By 2021, the pasture area in Jamanxim was twenty times larger than in 2000, when it was just 86.89 km² (MAPBIOMAS, 2023). In Jamanxim and Altamira, both located along the BR-163, this trend dates back to the occupation of the Amazon by agricultural frontiers from northern Mato Grosso (SILVA, 2021).

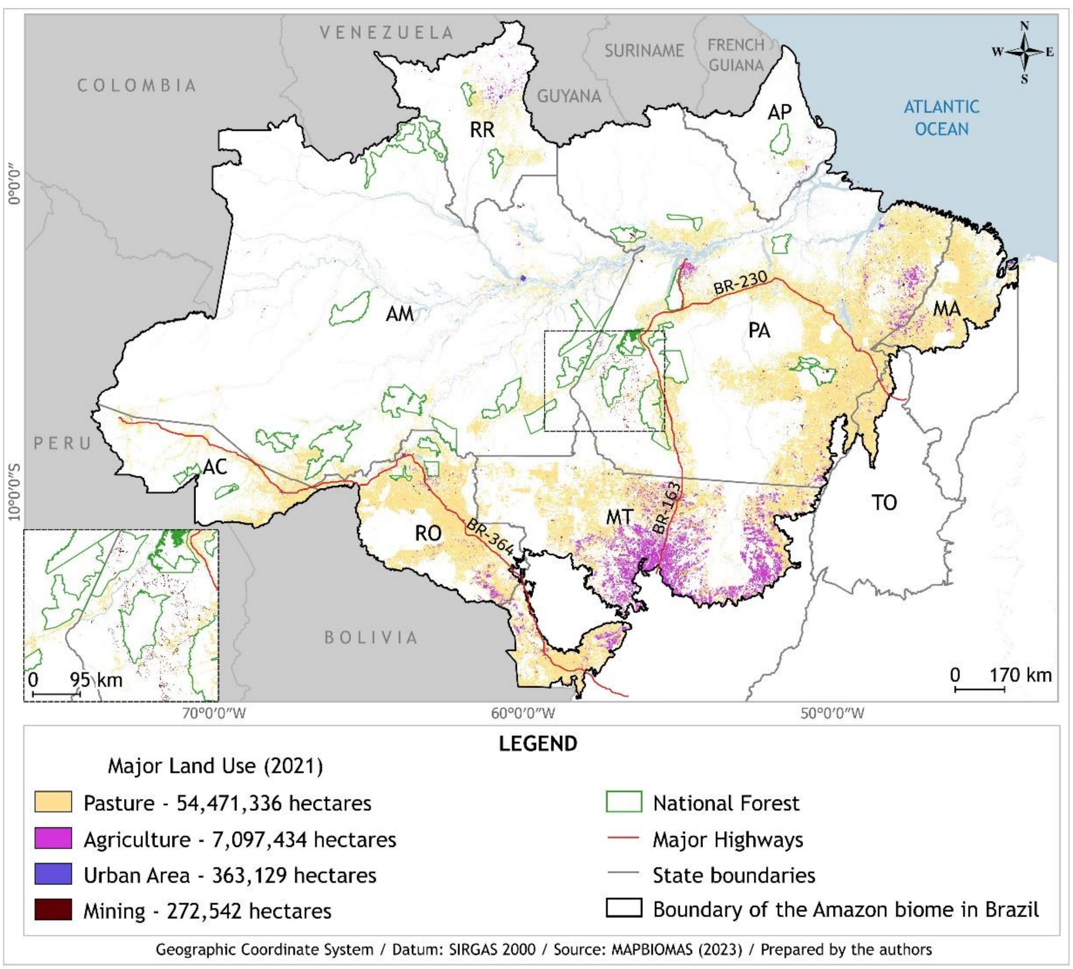

Figure 6 - National Forests and the most representative land uses in the Amazon biome in 2021. The inset highlights areas with the largest mining areas, mainly artisanal mining. (Source: Authors' elaboration based on MAPBIOMAS, 2023).

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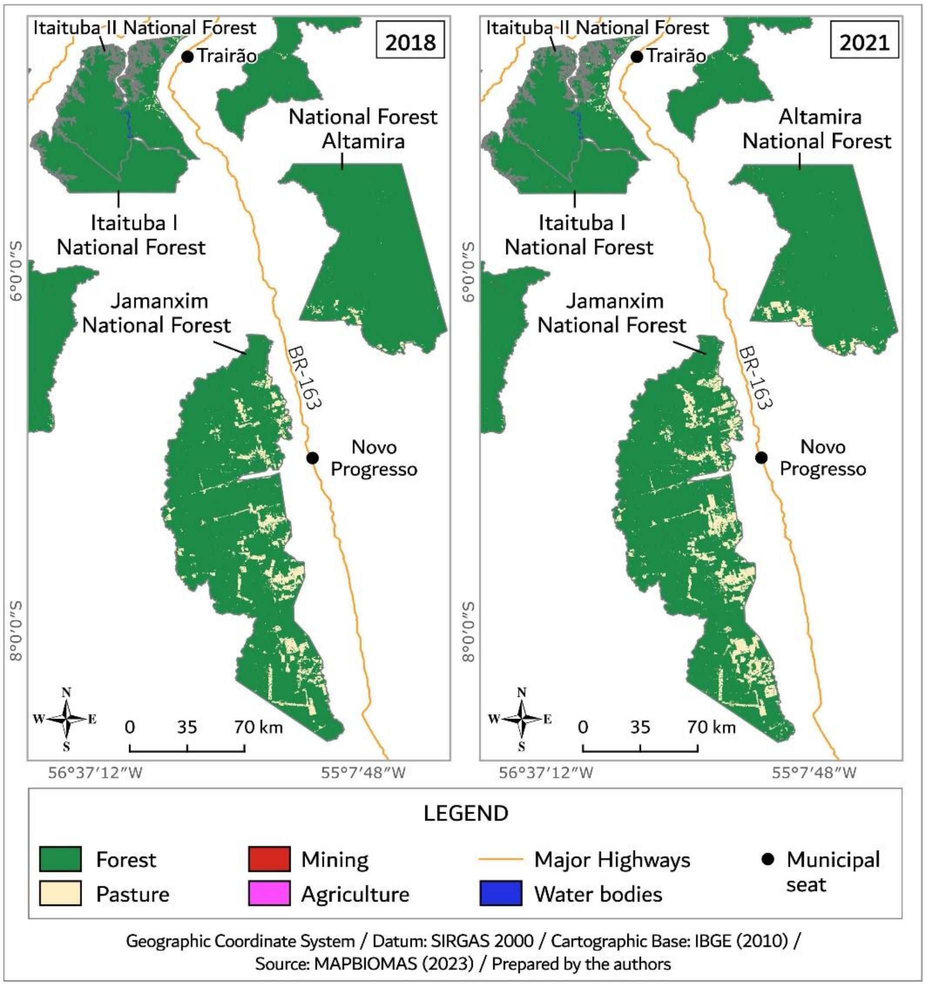

Figure 7 - Forest, pasture, mining, and agriculture in National Forests with the most deforestation in the Amazon biome in 2018 and 2021. (Source: Authors' elaboration based on MAPBIOMAS, 2023).

Agricultural use within the FLONAs was most significant in Tapajós (PA) (11.77 km²), Jamari (RO) (2.16 km²), and Jamanxim (PA) (1.21 km²). Only in the Amapá National Forest was agricultural use greater, covering 0.45 km². The other 11 FLONAs with agricultural use in deforested areas each had less than 1 km². Figure 5 shows the association of these FLONAs with agricultural use, linked positively to the vertical axis (PC2) of the PCA. In the Tapajós region, influenced by BR-163 and port infrastructure, soybean cultivation has grown in municipalities along the highway (FEARNSIDE, 2007; OLIVEIRA et al., 2013).

Data from MAPBIOMAS (2023) also identified soybean cultivation near the Jamari and Bom Futuro National Forest in Rondônia (Figure 8). In the Tapajós National Forest, despite the management plan allowing up to three hectares of deforestation (two in secondary vegetation and one in primary vegetation) by traditional residents, Cohenca (2007) noted larger areas being cleared, driven by agricultural product prices.

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Like Bom Futuro and Jamari National Forests, the Tapajós faces pressure from increasing cultivation around it (Figure 8). In Jamari, agricultural pressure is in the south and west, near Itapuã do Oeste, Cujubim, and Rio Crespo. In Bom Futuro, the pressure is in the north and northeast, near the BR-364 highway. These FLONAs are in strategic Amazon logistics corridors for exporting grains like soy and corn, with the Tapajós and Madeira rivers crucial for transport (MTPA, 2017). Studies show a correlation between soybean expansion and supporting infrastructure (waterways, ports, warehouses, and roads) with deforestation in many Amazon municipalities (FEARNSIDE, 2007; GARRETT et al., 2013). However, this link might be indirect, as cultivation often takes over previously cleared pasture areas, potentially the case within the FLONAs, displacing cattle ranching to new forest areas (RIVERO et al., 2009; DOMINGUES; BERMANN, 2012; COHN et al., 2016).

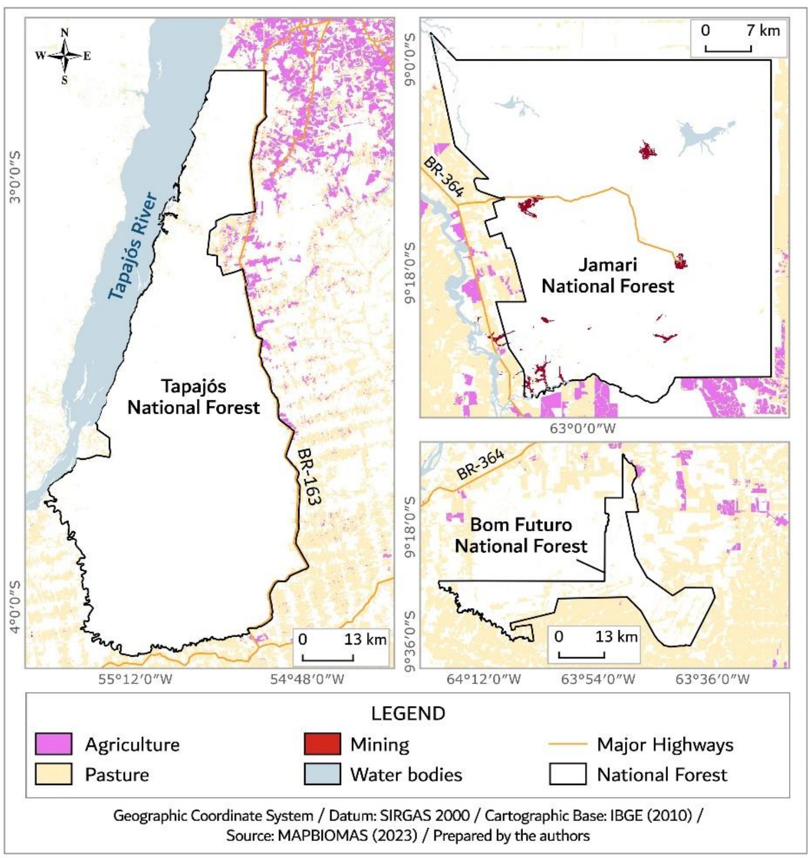

Figure 8 - National Forests in the Amazon biome with the highest presence or threat from agriculture (2021). (Source: Authors' elaboration based on MAPBIOMAS, 2023).

Mining, though less prevalent than other land uses, was also observed within FLONAs. In the PCA analysis, the first axis (PC1) showed that FLONAs such as Saracá-Taquera, Carajás, Amaná, Tapirapé-Aquiri, Crepori, Jamari, Urupadi, and Itaituba I had predominant mining in deforested areas. While mining is prohibited in federal fully protected PAs, its legality within sustainable use units, such as FLONAs, is somewhat controversial

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(for details, see Lima, 2006). Industrial exploitation by large companies has led to the creation of several PAs, including Saracá-Taquera, Carajás, Tapirapéaquiri, and Jamari National Forests (WANDERLEY, 2008). Industrial mining is focused in the Serra do Carajás in southeastern Pará, known for deposits of iron, copper, gold, and other minerals. Artisanal mining is more prevalent in southwestern Pará (MAPBIOMAS, 2023), impacting Itaituba I, Itaituba II, Crepori, Amaná, and Jamanxim National Forests (Figure 9), increasing their vulnerability to deforestation. Nunes et al. (2012) found that artisanal mining in Jamari National Forest (RO) affected 1% of the area (2,242.6 hectares), while Ariupanã and Urupadi National Forests in southern Amazonas have mineral deposits awaiting exploration (DUARTE et al., 2019). Both mining types exert pressure on these forests, potentially leading to further deforestation and diverse ecosystem impacts, such as observed in Amaná National Forest, where artisanal mining has degraded riverbanks and compromised water quality, threatening undiscovered species (BELTRÃO et al., 2016).

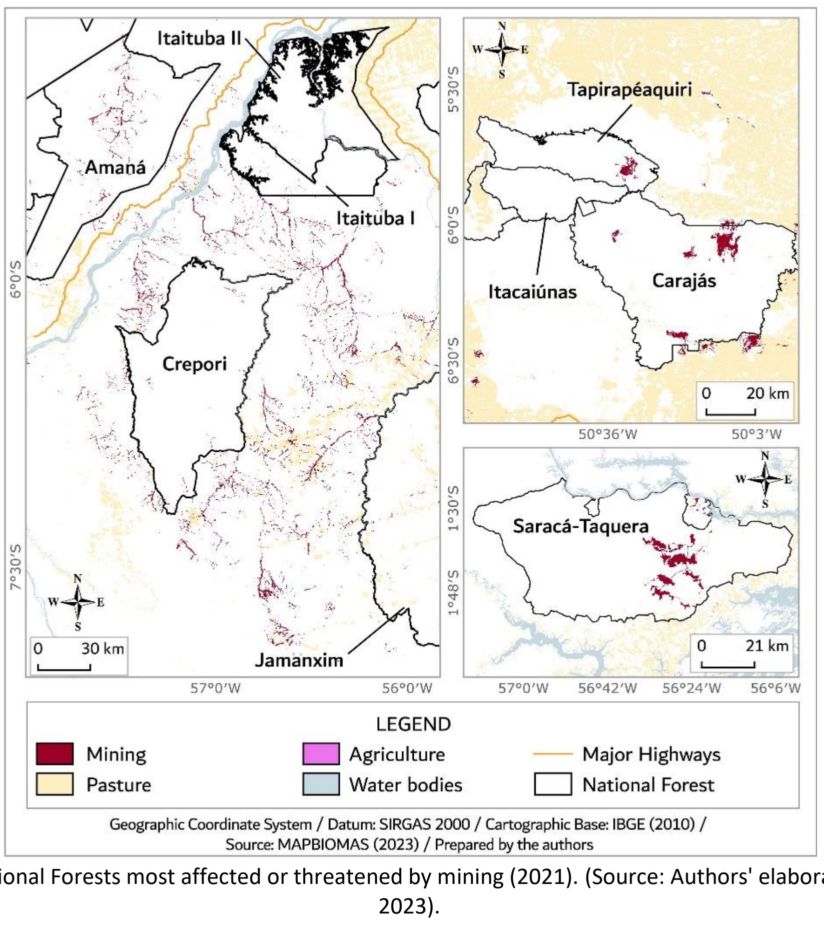

Figure 9 - Amazon biome National Forests most affected or threatened by mining (2021). (Source: Authors' elaboration based on MAPBIOMAS, 2023).

This study's findings show a rising trend of deforestation within FLONAs, consistent with broader patterns in Amazonian conservation areas. FLONAs were originally established to conserve forest resources sustainably. Currently, six FLONAs have active timber concessions (four in Pará – Saracá-Taquera, Crepori,

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Altamira, Caxiuanã – and two in Rondônia – Jacundá and Jamari) for selective logging (SFB, 2023). Areas identified as deforested in this study, using PRODES' minimum mapping area (6.25 hectares), likely do not result from sustainable forest management as per Monteiro et al.'s analysis (2013) for Jamari National Forest. According to the authors, concession areas within the unit adhere to established standards, with major impacts observed outside these areas.

Forest concessions in the Brazilian Amazon are a strategy aimed at replacing predatory exploitation of forest resources with sustainable management, primarily to prevent illegal deforestation and unplanned occupation of public forests (VERÍSSIMO; BARRETO, 2004; RODRIGUES et al., 2020). Studies have highlighted benefits of concessions such as reducing vulnerability of forests under concession, creating direct employment opportunities benefiting local populations, and contributing to forest cover maintenance and associated ecosystem services (MONTEIRO et al., 2011; ESPADA et al., 2018; NATIVIDADE et al., 2018). Forest concessions are recommended as a strategy, including for undesignated lands, to strengthen management of these units, prevent destructive use of their territories, and generate economic benefits through timber and non-timber forest products extraction (VERÍSSIMO et al., 2002a; VERÍSSIMO et al., 2002b; ANSOLIN et al., 2020; GUERRERO et al., 2020). Given the results of this study, it is clear there is a need for effective natural resource management strategies within FLONAs, with forest concessions as a potential pathway, albeit requiring further research to assess their actual social, economic, and environmental effectiveness. Strengthening monitoring and enforcement activities is crucial to ensure sustainability of these areas.

IV. Conclusion

Data analysis revealed a consistent rise in deforestation within Amazon biome FLONAs from 2018 to 2021. However, the deforestation was concentrated in just three FLONAs (Jamanxim, Altamira, and Itaituba II), all located near each other along the BR-163 highway in southwestern Pará, less than 100 kilometers apart. This distribution pattern underscores the environmental vulnerability of these PAs along this highway. Regarding deforestation trends, the study found that most FLONAs saw an increase, six had a decrease, and six showed no change in 2021, highlighting the varied anthropogenic pressures on these PAs.

Pasturelands, agriculture, and both artisanal and industrial mining have been identified as threats to deforestation in FLONAs. However, pastureland was identified as the primary land use associated with deforestation in most FLONAs, particularly due to its link with cattle ranching and beef production in the Amazon

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region. This finding underscores the need for public policies to mitigate deforestation caused by the expansion of livestock farming in these PAs.

In summary, the results suggest that the intensity and dynamics of deforestation in FLONAs are influenced by their proximity to highways and agricultural frontiers. The study's limitation lies in the challenge of fully explaining all political and socioeconomic factors that influenced varied deforestation rates in each FLONA, given the lack of studies on some units and their relationship with permitted logging areas. Despite these limitations, the methods and data used enabled a comprehensive analysis of FLONAs within the biome, identifying spatial patterns in deforestation and land use. This analysis contributes to understanding the spatial processes influencing deforestation in these PAs and may aid in defining more effective strategies for their protection.

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