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BRAZILIAN AMAZON INDIGENOUS LANDS: ENVIRONMENTAL THREATS, VULNERABILITY, AND PUBLIC POLICIES

Ana Claudia Rorato Vitor

Doctorate Thesis of the Graduate Course in Earth System Science, guided by Drs. Gilberto Câmara, Maria Isabel Sobral Escada, and Judith Anne Verstegen, approved in January 27, 2021.

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"The invaders are angry because of our struggle for land. They are after us Guardians of the Forest and paying gunmen to kill us. They may even kill me, but I will not give up on the fight. When all this is over, we will all be happy. When there are no more invasions and only we indigenous people are here in our land".

Paulo Paulino Guajajara acted as Guardian of the Forest in the Araribóia Indigenous Land. The Guardians are a group of indigenous who patrol and protect the forest against the action of illegal loggers. At least 5 Guardians have already been murdered. On November 1, 2019, Paulo Paulino Guajajara was murdered by the invaders in an ambush. He was not buried. He was not entombed. He was planted, so that new warriors can be born from him.

...for the struggle of Paulo Paulino Guajajara and all Guardians of the Forest.

*A meus pais **José** e **Maria Conceição**, e ao meu companheiro **Pedro***

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ABSTRACT

Amazonian Indigenous Lands (ILs) are currently a worrying case of a vulnerable human-environmental system due to the environmental threats they have been suffering. The focus of this study is on how the different environmental threats affect the Amazonian Indigenous Lands, internally and externally, and how they influence the environmental vulnerability of these territories. In addition, given the strong importance of mining as an environmental threat, we assessed the extent of the potential impact of passing the proposed mining bill (PL 191/2020). Linked to these objectives, we discussed public policies as tools to reduce environmental threats in the ILs and to improve indigenous capacity to deal with them. For this, we explored three different approaches based on indicators as proxies of the threats and adaptive capacities: 1) grouping ILs according to the similarities found in the set of threat indicators within and around their limits through cluster analysis technique; 2) estimating the area of ILs covered by mining requests; 3) developing an environmental vulnerability assessment of Amazonian ILs by adopting the theoretical vulnerability framework of the IPCC. Most of the 383 Amazonian ILs are affected internally by a combination of different environmental threats. The set of threats in the ILs' surroundings are very similar to the set of threats that affect Indigenous Lands internally, but the severity is generally higher. The ILs most affected by multiple and relatively severe threats are located mainly in the arc of deforestation and in the Roraima state. We have identified seven IL clusters with common environmental threats within and around their limits. Regarding the mining threat, we found that the existing mining requests cover 176,000 km^2 of Amazonian ILs, most of them for gold exploration (64%), a factor 3000 more than the area of current illegal mining. In sum, about 15% of the total area of ILs in the region could be potentially affected by mining, if the mentioned bill is approved. The ethnic groups Yudjá, Kayapó, Apalaí, Wayana, and Katuena would even have between 47% and 87% of their lands impacted. Regarding the environmental vulnerability of Amazonian Indigenous Lands, in general, ILs with elevated Vulnerability are most concentrated in the arc of deforestation region and below, but also advancing to the inner of the Pará, Amazonas, and Roraima states. Our results also indicated an increase in Exposure (threats in IL's buffer zones), around 73.9%, and in Sensitivity (threats within IL), around 64.8%, of Amazonian ILs between 2011-2019 compared to 2001-2010, indicating a growing trend of the ILs vulnerability. Based on the results, we suggest four environmental policy priorities to be strengthened and applied in Amazonian ILs: protect ILs' buffer zones; strengthen surveillance actions, and combat illegal deforestation, forest degradation, and mining activities in ILs; prevent and fight fires; and extrude invaders from ILs. In addition, it is essential to not approve predatory activities in ILs, such as mining. The obligation of the State is to enforce existing laws and regulations that put indigenous peoples' rights and livelihoods above economic consideration and not to reduce such protections.

Keywords: Indigenous Peoples. Indigenous Lands. Vulnerability Assessment. Environmental degradation. Public Policies. Amazon.

TERRAS INDÍGENAS DA AMAZÔNIA BRASILEIRA: AMEAÇAS AMBIENTAIS, VULNERABILIDADE E POLÍTICAS PÚBLICAS

RESUMO

As Terras Indígenas (TIs) da Amazônia são atualmente um caso preocupante de sistema humano-ambiental vulnerável devido às ameaças ambientais que vêm sofrendo. O foco deste estudo é como as diferentes ameaças ambientais afetam as Terras Indígenas da Amazônia, interna e externamente, e como influenciam a vulnerabilidade ambiental desses territórios. Além disso, dada a grande importância da mineração como uma ameaça ambiental, avaliamos a extensão do impacto potencial da aprovação do projeto de lei de mineração (PL 191/2020). Vinculado a esses objetivos, discutimos políticas públicas como ferramentas para reduzir as ameaças ambientais nas TIs e melhorar a capacidade de enfrentamento dos povos indígenas à essas ameaças. Para isso, exploramos três abordagens diferentes baseadas em indicadores como proxies das ameaças e capacidades adaptativas: 1) agrupar as TIs de acordo com as semelhanças encontradas no conjunto de indicadores de ameaças, dentro e ao redor de seus limites, por meio da técnica de análise de cluster; 2) estimar a área das TIs sobrepostas pelas solicitações para exploração mineral; 3) desenvolver uma avaliação de vulnerabilidade ambiental das TIs amazônicas, adotando o referencial teórico de vulnerabilidade do IPCC. A maioria das 383 TIs amazônicas é afetada internamente por uma combinação de ameaças ambientais. O conjunto de ameaças no entorno das TIs é muito semelhante ao conjunto de ameaças que afetam as TIs internamente, mas a gravidade geralmente é maior. As TIs mais afetadas por ameaças múltiplas e relativamente graves estão localizadas principalmente no arco do desmatamento e no estado de Roraima. Identificamos sete clusters de TIs com ameaças ambientais comuns dentro e ao redor de seus limites. Em relação à mineração, descobrimos que os pedidos de mineração existentes cobrem 176.000 km ^{2} das TIs amazônicas, a maioria deles para exploração de ouro (64%), um fator 3.000 vezes maior que a área de mineração ilegal atual. Em suma, cerca de 15 % da área total das TIs da região podem ser potencialmente afetadas pela mineração, caso o referido projeto de lei seja aprovado. Os grupos étnicos Yudjá, Kayapó, Apalaí, Wayana e Katuena poderiam ter cerca de 47% e 87% de suas terras impactadas. Em relação à vulnerabilidade ambiental das Terras Indígenas da Amazônia, em geral, TIs com elevada vulnerabilidade estão mais concentradas na região do arco do desmatamento e abaixo, mas também avançando para o interior dos estados do Pará, Amazonas e Roraima. Nossos resultados indicaram um aumento na Exposição (ameaças ao redor das TIs), em torno de 73,9%, e na Sensibilidade (ameaças nas TIs), em torno de 64,8%, das TIs amazônicas entre 2011-2019 em relação a 2001-2010, indicando uma tendência crescente da vulnerabilidade das TIs. Com base nos resultados, sugerimos quatro prioridades da política ambiental a serem fortalecidas para as TIs amazônicas: proteger as zonas de amortecimento das TIs; fortalecer as ações de fiscalização e combate ao desmatamento ilegal, degradação florestal e mineração nas TIs; prevenir e combater incêndios; e expulsar os invasores das TIs. Além disso, é fundamental a não aprovação de atividades predatórias nas TIs, como a mineração. A obrigação do Estado é fazer cumprir as leis e regulamentos existentes que colocam os direitos e meios de subsistência dos povos indígenas acima da consideração econômica e não reduzir essas proteções.

Keywords: Povos Indígenas. Terras Indígenas. Avaliação de Vulnerabilidade. Degradação ambiental. Políticas públicas. Amazônia.

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[2]This chapter is based on the paper: Rorato, A. C., Camara, G., Escada, M. I. S., Picoli, M. C., Moreira, T., Verstegen, J. A. (2020). Brazilian amazon indigenous peoples threatened by mining bill. Environmental Research Letters, 15(10), 1040a3.

1 INTRODUCTION

An important challenge for Earth System Science is to assess the vulnerability of human-environmental systems in a rapidly changing world (STEFFEN et al., 2006). The intense occupation of the Amazon region in the last decades and the advance of environmentally degrading activities constitute a context of vulnerability for this ecosystem, and consequently for indigenous peoples and their lands (VIEIRA et al., 2018; BEGOTTI; PERES, 2019; BEGOTTI; PERES, 2020; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020).

Indigenous Lands are territories demarcated according to Brazil's Federal Constitution to guarantee indigenous peoples the right to their lands, their livelihood, and their social organization (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a). Currently, 383 Indigenous Lands (ILs) in the Legal Amazon region cover more than 1,160,000 km^2, representing 22% of this region (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a). It is estimated that about 355 thousand indigenous people live in Amazonian ILs, divided into more than 150 ethnic groups (INSTITUTO SOCIOAMBIENTAL - ISA, 2019b). Together, the Amazonian Indigenous Lands are home to the largest concentration of indigenous peoples in the world and are currently a worrying case of a vulnerable human-environmental system due to the environmental threats they have been suffering. Hereto, environmental threats are defined as the degrading processes or activities that contribute to environmental degradation and reduce the environmental integrity of a given region.

Among the most important environmental threats to the Amazonian ILs are deforestation, logging, fires (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c), illegal land grabbing, large infrastructure projects (such as hydroelectric plants and long highways) (FERRANTE et al., 2020), mineral exploitation (SONTER et al., 2017; RORATO et al., 2020; SIQUEIRA-GAY et al., 2020a), and the expansion of the agricultural frontier (NEPSTAD et al., 2006; GIBBS et al., 2010; LAURANCE et al., 2014). Although non-indigenous people are prohibited of establishing and developing agricultural or extractive activities in ILs (BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973), several ILs in the Amazon are currently invaded. In general, most of the environmental impacts observed within the ILs are carried out by loggers, miners, farmers, and squatters, who act illegally within these territories (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Besides environmental degradation inside the ILs, the surrounding areas are also drastically affected (NEPSTAD et al., 2006; SOARES-FILHO et al., 2009).

Faced with these multiple environmental threats the context of vulnerability of the Amazonian indigenous Lands is configured. We assume that environmental vulnerability emerges from the existence of a set of threats within and around the ILs, affecting the environmental integrity of the ILs and the security and livelihood of indigenous peoples. In this study, we adopt the vulnerability concept from the IPCC Third and Fourth Assessment Reports (MCCARTHY et al., 2001; PARRY et al., 2007). According to these IPCC reports, the vulnerability of a system is described to be a function of three overlapping components: 1) Exposure (EX), 2) Sensitivity (SE), and 3) Adaptive Capacity (AC). In summary, Exposure defines the nature and amount to which the system is exposed to threats; Sensitivity reflects the system's potential to be affected by changes because of these threats; and Adaptive Capacity characterizes the system's ability to respond to these effects (TURNER et al., 2003b; METZGER et al., 2006; GALLOPÍN, 2006; POLSKY et al., 2007).

Another issue of particular concern about the environmental vulnerability of ILs is the increasing pressure to open these areas for legal mineral exploration (VILLEN-PEREZ et al., 2018; FERREIRA et al., 2014; BEGOTTI; PERES, 2020; COELHO et al., 2017). In February 2020, Brazil's president Jair Bolsonaro sent a bill to Congress (Projeto de Lei - PL 191/2020) that regulates the opening of Indigenous Lands for economic exploration (BRAZILIAN EXECUTIVE POWER, 2020). The proposed legislation sets conditions for private activities in these areas with a particular focus on commercial mining. Mining is widely known for its severe socio-environmental impacts (HOROWITZ et al., 2018; VEGA et al., 2018) and is also responsible for several situations of conflict and violence against indigenous peoples (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; GLOBAL WITNESS, 2020). According to a survey carried out for this study on the perception of different experts on the Amazonian indigenous issues, mining was placed as the main environmental threat to Indigenous Lands. Should this legislation be approved, mining would become an increasingly important threat to indigenous peoples and their territories in the future (VILLEN-PEREZ et al., 2018; HOROWITZ et al., 2018; VILLEN-PEREZ et al., 2020).

Given the importance of the Amazon Indigenous Lands to safeguard human cultural diversity, indigenous rights, and the conservation of extensive areas of tropical forest to know the environmental threats that influence the vulnerability of these territories is extremely important. To identify those most vulnerable ILs in the Amazon is crucial for better allocation of protection measures, the adoption of adequate public policies, to comply with international human rights commitments, and to allow directing adequate safeguards to protect them. In addition, given the imminent threat posed by the proposed mining bill for indigenous peoples in the Amazon and their lands, there is a need to analyze the risks of potential impacts if this law is passed.

In general, most studies carried out for Amazon Indigenous Lands have evaluated these areas combined with other categories of Protected Areas (PAs). Some of these studies focused on the capacity of different categories of PAs to avoiding deforestation advances into their limits, using indicators of the relation between deforestation (DEFRIES et al., 2005; NEPSTAD et al., 2006; JOPPA et al., 2008) or forest fragmentation (CABRAL et al., 2018) inside and outside these areas. However, despite the important contribution of these studies, there is a gap in the knowledge of the current situation of Amazonian ILs regarding the multiple threats involved in the environmental degradation of these territories.

The general objective of this study is to contribute to filling this knowledge gap, providing the first assessment of the multiple environmental threats that affect Amazonian Indigenous Lands and that condition the vulnerability of these areas. The focus of this study is on how the different environmental threats affect the Amazonian Indigenous Lands, internally and externally, and how they influence the environmental vulnerability of these territories. In addition, given the strong importance of mining as an environmental threat, we intended to assess the extent of the potential impact of passing the proposed mining bill (PL 191/2020). Linked to these first objectives, it was intended to discuss the main public policies related to the mitigation of environmental threats in the ILs, as well as policies related to the improvement of the indigenous capacity to deal with these threats. To this end, the present study is structured in three main chapters as scientific articles. A brief description of each chapter is provided below.

Chapter 2, entitled "Environmental threats over Amazonian Indigenous Lands", introduces the theoretical contextualization about the threats involved in the environmental degradation of Amazonian ILs. In this chapter we intend to answer the following questions: *i) Which groups of Amazonian Indigenous Lands with a common set of internal and external environmental threats can be identified? ii) To what extent do the environmental threats inside and around Indigenous Lands differ?* For this, using cluster analysis, we grouped the ILs according to the set of common environmental threats inside and outside their limits (i.e. deforestation, forest degradation, fire, mining, croplands, pastures, and roads). Hereby, we highlight the similarities and differences of the processes responsible for the environmental impacts in ILs and their surroundings. Based on these results, we have identified environmental policy priorities to be strengthened and applied in Amazonian ILs. Finally, we discuss the potential public policy strategies for mitigating environmental threats for each IL cluster.

As mentioned and explored in Chapter 2, one of the most important threats to Amazonian Indigenous Lands is mining. In addition, the current scenario indicates the possibility of opening the ILs for mineral exploration. Thus, Chapter 3, entitled "Brazilian Amazon indigenous peoples threatened by mining bill", addresses this threat in a more specific way. In this chapter we analyzed the risks of the proposed mining bill (PL 191/2020) to Amazonian indigenous peoples and their lands. Hereto, we aimed to answer the following question: *What is the extent of the potential impact of approving the proposed mining bill on Amazonian Indigenous Lands in relation to the mining that currently occurs in these territories?* Although mining is currently forbidden in Indigenous Lands, there is a large number of applications for mineral exploration licenses in ILs registered in Brazil's National Mining Agency (ANM), pending a change in the law. To evaluate the possible impact of the mining bill, we consider all mining license requests registered in ANM that overlap Indigenous Lands as potential mining areas in the future. Following, we compare the extent of potential mining areas with current illegal mining areas in Amazonian ILs. In addition, we also evaluated the risk of each ethnic group to be affected by mining in case the mining bill is approved.

In Chapter 4, entitled "Environmental vulnerability assessment of Brazilian Amazon Indigenous Lands", we developed an environmental vulnerability assessment of Amazonian ILs by adopting the vulnerability theoretical framework of IPCC (MCCARTHY et al., 2001; PARRY et al., 2007). In this study, we intended to answer the following questions about the vulnerability of Amazonian ILs: *i) What is the environmental vulnerability of ILs in the Amazon? and ii) How have the exposure and sensitivity of Amazonian ILs to environmental threats changed in the past ten years?*. In the IPCC's framework, vulnerability is understood as a function of the sensitivity and adaptive capacity of systems (which can be human, environmental, or human-environmental systems) when they are exposed to threats or changes. To make the Vulnerability of ILs operational, we performed an indicator-based approach to describe the main threats involved in the environmental vulnerability of Amazonian ILs and the adaptive capacity of indigenous peoples to deal with these threats.

Finally, in Chapter 5 the general conclusion of the thesis is presented and alternatives for future research are suggested regarding the environmental vulnerability of the Amazon Indigenous Lands.

2 ENVIRONMENTAL THREATS OVER AMAZONIAN INDIGENOUS LANDS[1]

2.1 Introduction

According to Brazil's Federal Constitution, Indigenous Lands (ILs) are territories demarcated to guarantee Indigenous peoples the right to their lands, their livelihood, and their social organization (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a). Under Brazil's law, the Indigenous peoples have the original right to exclusive use of the lands they traditionally occupy (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a; BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1988; BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973). The Brazilian Legal Amazon region[2] shelters the world's largest concentration of Indigenous peoples, divided into several ethnic groups and holding a rich socio-cultural diversity. In this region, approximately 355,000 Indigenous people, divided into 155 ethnic groups, inhabit 383 Indigenous Lands (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a; INSTITUTO SOCIOAMBIENTAL - ISA, 2019b).

The ILs in Brazil are crucial areas for preserving human ethnocultural heritage. Furthermore, they provide myriad ecosystem services, such as regulating the climate and the hydrological cycle (WALKER et al., 2014; RICKETTS et al., 2010; FERNÁNDEZ-LLAMAZARES et al., 2020; BEGOTTI; PERES, 2020). Given that the ILs cover more than 1,160,000 km^2, representing 22% of the BLA (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a), they are crucial for preserving biodiversity. In Brazil, more than half of all ILs retain 90% of pristine vegetation (BEGOTTI; PERES, 2020). Further, Amazonian ILs are considered the most important obstacle to deforestation (NEPSTAD et al., 2006; SOARES-FILHO et al., 2010) and have been shown to contribute far more to reducing emissions from deforestation and forest degradation (REDD) than parks or nature reserves because they cover three times the area and are often in the immediate path of the expanding agricultural frontier (NELSON; CHOMITZ, 2011).

The Amazon region is currently affected by multiple environmental threats (NEPSTAD et al., 2006; NEPSTAD et al., 2008; CARNEIRO FILHO, A. and SOUZA, O. B., 2009; RICARDO et al., 2011; TOURNEAU, 2015; INSTITUTO SOCIOAMBIENTAL - ISA, 2019a), defined

[1]This chapter is based on the paper: Rorato, A. C., Picoli, M. C., Verstegen, J. A., Camara, G., Silva Bezerra, F. G., S Escada, M. I. (2021). Environmental Threats over Amazonian Indigenous Lands. Land, 10(3), 267.

[2]The so-called Brazilian Legal Amazon (BLA) is a political-administrative region covering approximately 5 million km^2. The BLA comprises the states of Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), Roraima (RR), Mato Grosso (MT), Tocantins (TO), and part of Maranhão (MA) (BRAZILIAN EXECUTIVE POWER, 1966).

here as degrading processes or activities that reduce the environmental integrity of a given area. Among the most important environmental threats to the Amazon are deforestation, logging, fires (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c), illegal land grabbing, large infrastructure projects (such as hydroelectric plants and long highways) (FERRANTE et al., 2020), mineral exploitation (SONTER et al., 2017; RORATO et al., 2020; SIQUEIRA-GAY et al., 2020a), and the expansion of the agricultural frontier (NEPSTAD et al., 2006; GIBBS et al., 2010; LAURANCE et al., 2014).

These threats result from an intricate network of social and economic factors that interact with each other. For example, the profitability of the land market encourages people to convert the land to supply the national and international demand for commodities (GIBBS et al., 2010; COSTA, 2012; CAMARA et al., 2015). Regarding deforestation, important drivers of this problem in the Amazon are large-scale mechanized agriculture and extensive livestock farming. Furthermore, the economic gains from mining and logging further increase deforestation and forest degradation. By 2019, the Brazilian Amazon reached about 20% forest loss (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a).

In general, these environmental threats to the Amazonian ecosystem result in loss of forest, loss of habitat for biodiversity, soil erosion, pollution of rivers, and increased susceptibility to fire. Within the ILs, these environmental threats affect people's livelihoods and welfare directly and indirectly, e.g., increasing forest fragmentation, reducing hunting and gathering availability, and drying and polluting rivers (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; TOURNEAU, 2015; CONSTANTINO, 2016). These threats also put the territorial integrity of ILs and Indigenous peoples' safety at risk, as the invasion of ILs can result in land conflicts between Indigenous peoples and the invaders (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; RICARDO et al., 2011; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018). Furthermore, illegal occupation and forced contact with external non-Indigenous peoples are often responsible for the spread of diseases in which Indigenous peoples have no immunity (TOURNEAU, 2015). The environmental threats in the ILs' surroundings also have the potential to affect ILs' environmental integrity (e.g., fire spreading) and people's health and welfare (e.g., contamination by mining pollutants arising from nearby mining activities) (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). In Brazil, the law establishes buffer zones around conservation units (UCs) to protect them against threats, but this regulation does not apply to Indigenous Lands.

In recent years, Brazil has undergone major institutional and environmental policy changes (ABESSA et al., 2019; PEREIRA et al., 2019). The country is under the command of a government that defends the wide economic exploitation of the Amazon, including opening ILs for extractive activities (RORATO et al., 2020; BRAZILIAN EXECUTIVE POWER, 2020). Additionally, a systematic dismantling of environmental policies has been implemented in recent years, reflecting in the suppression and weakening of territorial and environmental surveillance agencies (ARTAXO, 2019; ESCOBAR, 2018; ABESSA et al., 2019; PEREIRA et al., 2019). For example, in recent years the action of the National Indigenous Foundation (FUNAI), the Brazilian agency responsible for implementing the policy to promote and guarantee Indigenous rights, has been undermined and weakened (BEGOTTI; PERES, 2019; HUMAN RIGHTS WATCH, 2019; ABESSA et al., 2019).

With reduced protection, several ILs in the Amazon have been encroached upon by illegal loggers, farmers, squatters, and gold miners, increasing Indigenous peoples' vulnerability (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; BEGOTTI; PERES, 2019). According to the report of the Indigenous Missionary Council (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019), between 2018 and 2019 there was a 134% increase in cases of possessory invasions, illegal exploitation of resources, and damage to property in ILs. In 2018, 109 of these cases were registered in 76 ILs distributed across 13 Brazilian states, while in 2019, 256 cases were registered in 151 ILs across 23 states. In 2019, 277 cases of violence were recorded against Indigenous people in Brazil (113 of which were murders), more than double the 110 cases recorded in 2018 (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). The reduced surveillance and the government's favorable bent toward liberating economic activities in the ILs has been encouraging the invaders and giving them a sense of impunity. In addition, the rise in the value of gold (WORLD GOLD COUNCIL, 2020) and the depletion of wood economically valuable outside the ILs are also responsible for boosting illegal mining and logging in these territories (BEGOTTI; PERES, 2020).

In general, most studies carried out for Amazon Indigenous Lands have evaluated these areas combined with other types of protected areas (PAs). Some of these studies have focused on whether different types of PAs have different capacities for avoiding the advancement of deforestation into their boundaries, using the relation between deforestation (DEFRIES et al., 2005; NEPSTAD et al., 2006; JOPPA et al., 2008) or forest fragmentation (CABRAL et al., 2018) inside and outside these areas. In another approach, other studies have investigated the carbon stocks in Amazonian

PAs, also including ILs (WALKER et al., 2014; NOGUEIRA et al., 2018). For example, Nogueira et al. (2018) estimated the loss of carbon stocks in these areas, while Walker et al. (2014) performed a risk assessment of the carbon stocks by mapping the distribution of multiple current and potential risk factors, e.g., agriculture, grazing, mining, petroleum extraction, timber supply, and transportation. In a recent attempt to investigate the vulnerability of PAs in Brazil to climate change, Lapola et al. (2020) developed indicators of climatic-change hazard and PA resilience (size, native vegetation cover, and the probability of climate-driven vegetation transition). They found that over 80% of Brazil's PAs of high or moderate vulnerability to future climate change are ILs. Despite the important contribution of these studies, the current situation of Amazonian ILs is still murky, as is the complex arrangement of multiple threats that are causing environmental degradation in these areas. In addition, studies are needed to assess the impacts of the recent weakening of environmental legislation with regard to the protection of these territories.

Amazonian Indigenous Lands are widely distributed by regions with different contexts of occupation and environmental degradation. As such, these territories present different environmental impacts within and outside of their limits. While some ILs are located in very deforested regions and with high permeability due to the dense access by highways, other ILs are located in more preserved regions with dense forest cover around them and with less accessibility. Likewise, some ILs have a predominance of different threats, some being more affected by illegal mining, others by logging, and others by the heavy occupation of farmers (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). For the development of appropriate public policies aimed at mitigating environmental impacts on ILs, it is necessary to understand how internal and external threats are distributed over the ILs. Identifying groups of ILs with a common set and severity of threats can lead to the design of policy pathways dedicated to each of these groups.

This study aims to help fill this gap by presenting the first investigation on the main threats (introduced in the next section) involved in environmental degradation of Amazonian ILs. Here we intend to answer the following questions: i) Which groups of Amazonian Indigenous Lands with a common set of internal and external environmental threats can be identified? ii) To what extent do the environmental threats inside and around Indigenous Lands differ? To do this, we use cluster analysis to group the ILs according to the set of common environmental threats inside and outside their limits (i.e., deforestation, forest degradation, fire, mining, croplands, pastures, and roads). Hereby, we highlight the homogeneity and heterogeneity of the processes responsible for the environmental impacts in ILs and their surroundings. Finally, we discuss the potential public policy strategies for mitigating environmental threats for each IL cluster.

2.2 Environmental threats and their impacts on Amazonian Indigenous Lands

2.2.1 Deforestation

Deforestation configures a key environmental threat in the Amazon region, being the most important driver of shifting ecosystem functioning, composition, and balance (WOLTERS et al., 2000; MORRIS, 2010). In general, deforestation leads to the destruction of habitats and depletion of species, causes soil erosion, reduces soil fertility, and leads to silting of water bodies and the drying of the river springs. As consequences of deforestation, Indigenous peoples also face decreased natural resources for subsistence, such as animals, fish, fruits, trees used for construction, and medicinal herbs. In the last years, a significant increase in deforestation rates has been observed in Indigenous Lands (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a). According to the Amazon Deforestation Monitoring Program (PRODES) from INPE, an area of 888.5 km^2 was deforested inside ILs between 2017 and 2019, representing a 117% increase between the two years (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a).

2.2.2 Forest degradation

Unlike deforestation, which is the result of rapid forest clear-cutting, forest degradation is characterized by the gradual and long-term process of reducing forest cover as the result of selective logging and fires (DINIZ et al., 2015; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008). Forest degradation alters the forest structure, ecological composition, and the local climate. Illegal logging has been a major cause of forest degradation within Amazonian ILs and of violent conflicts between Indigenous peoples and loggers (RICARDO et al., 2011). In addition, logged forests are strictly associated with higher fire risks, as microclimatic changes make the forest drier (BARLOW et al., 2020).

2.2.3 Fires

In the Amazon, fires are the result of different drivers (BARLOW et al., 2020). To prevent forest fires in Indigenous Lands, it is important to differentiate between uncontrolled fire provoked by natural, accidental, or criminal causes and controlled burning practices (i.e., controlling fire intensity and limiting it to an area). Indigenous peoples in Brazil use controlled fire in different circumstances, such as hunting, fertilizing the soil with ashes, opening and preparing the land for planting, and removing venomous animals. This practice is most intensive in Amazonian ILs with predominantly savanna vegetation (LACERDA, 2013; BARLOW et al., 2020). Among the several consequences of uncontrolled forest fires are the loss of forest cover and biodiversity, respiratory diseases, imbalance of the local ecosystem, economic loss (ARAGÃO et al., 2018; COCHRANE; SCHULZE, 1999; NEPSTAD et al., 2008), and the loss of Indigenous villages (LACERDA, 2013). Between January and August 2019, there was an 88% increase in fires in Brazil's Indigenous Lands compared to the same period in 2018 (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c). In 2020, the fires in these territories worsened in relation to 2019 (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c) and were mainly due to criminal fires or the spread of fires initiated in the ILs' surroundings (LACERDA, 2013). In 2020, several Indigenous peoples mobilized to fight the fires in their territories, but they lacked government support (RIBEIRO; BARBA, 2020; ANGELO, 2020b).

2.2.4 Agricultural and livestock expansion

The expansion of the agricultural and livestock frontier over tropical forests represents a central environmental issue due to its negative impacts on water availability, soil quality, biodiversity, and local climate (GIBBS et al., 2010; LAMBIN; MEYFROIDT, 2011; TURNER et al., 2007). The advancement of crop and livestock areas over Indigenous Lands threaten the environmental integrity by increasing access to the ILs, increasing the forest's exposure to fire due to agricultural practices, and, in the case of large-scale agriculture, the use of pesticides can cause water contamination (BEGOTTI; PERES, 2020; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Furthermore, land tenure disputes between Indigenous peoples and farmers have historically been marked by situations of intense conflict and violence (RICARDO et al., 2011; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018). Several ILs in the Amazon are immersed in a matrix of agricultural or pasture lands, where the boundary of the IL is often the boundary between forest and monoculture cropland; besides the risk for disputes, this has consequences for the biodiversity in the IL due to the 'edge effect' (HARPER et al., 2005).

2.2.5 Road access

Until the 1950s, Brazilian Amazon occupation was limited to the coastal region and the banks of the main rivers, such that relatively few changes were made in the forest cover at the regional scale (ESCADA; ALVES,). Nowadays, road access is the primary determinant of the spatial distribution of deforestation (ALVES, 2002; LAURANCE et al., 2014; SOARES-FILHO et al., 2004; FERRANTE et al., 2020). That is, forests have been logged, deforested, and converted to other uses mainly where roads provide easy access (FERRANTE et al., 2020). In this way, the road network plays an important role in shaping the patterns of environmental degradation in the Amazon (ALVES, 2002; SOARES-FILHO et al., 2006; NEPSTAD et al., 2008); therefore, ILs closer to regions with a dense road network tend to be more exposed to environmental threats.

2.2.6 Mining

Lastly, mining causes intense socio-environmental impacts in the Amazon region (HILSON, 2002; HOROWITZ et al., 2018). This activity is related to several environmental perturbations, such as contaminating watercourses, soil, and wildlife, and driving deforestation (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; RICARDO et al., 2011; SONTER et al., 2017; BEGOTTI; PERES, 2020; HILSON, 2002; HOROWITZ et al., 2018). In addition, mining is related to severe social impacts, such as contamination by toxic chemical residue (VEGA et al., 2018) and violent situations (OIVEIRA, 2020; PHILLIPS, 2019; GLOBAL WITNESS, 2020). Historically, mining is the precursor to other activities, such that it enables access to other agents and activities such as logging, land market, cattle raising, and even the establishment of larger mining companies, implying more deforestation (FERREIRA et al., 2014; ALVAREZ-BERRIOS; AIDE, 2015). The encroachment of illegal mining in Indigenous territories has been increasing in the last three years (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). According to Rorato2020 551 deforested areas classified as mining were detected in 13 Amazonian ILs between 2017 and 2019, totaling 57.8 km^2.

2.3 Materials and methods

2.3.1 Overview

In this study, we identified the main environmental threats to ILs (i.e., deforestation, forest degradation, fire, mining, croplands, pastures, and road access) and developed a set of indicators to represent them. Based on these indicators, and using cluster analysis, we identified and characterized different clusters of ILs with a set of common environmental threats inside and outside their limits. Finally, we discussed the application of existing environmental policies to combat the advancement of these threats over the Amazonian ILs and how they can be prioritized according to the clusters found. In the next sections, we present the study area [2.3.2], the environmental threat indicators [2.3.3], and the cluster analysis [2.3.4].

2.3.2 Study area

We analyzed 383 Indigenous Lands fully located in the Legal Amazon region (Figure 2.1) for all legal status[3]. The boundaries for all ILs in the Legal Amazon were obtained from the FUNAI website (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019b).

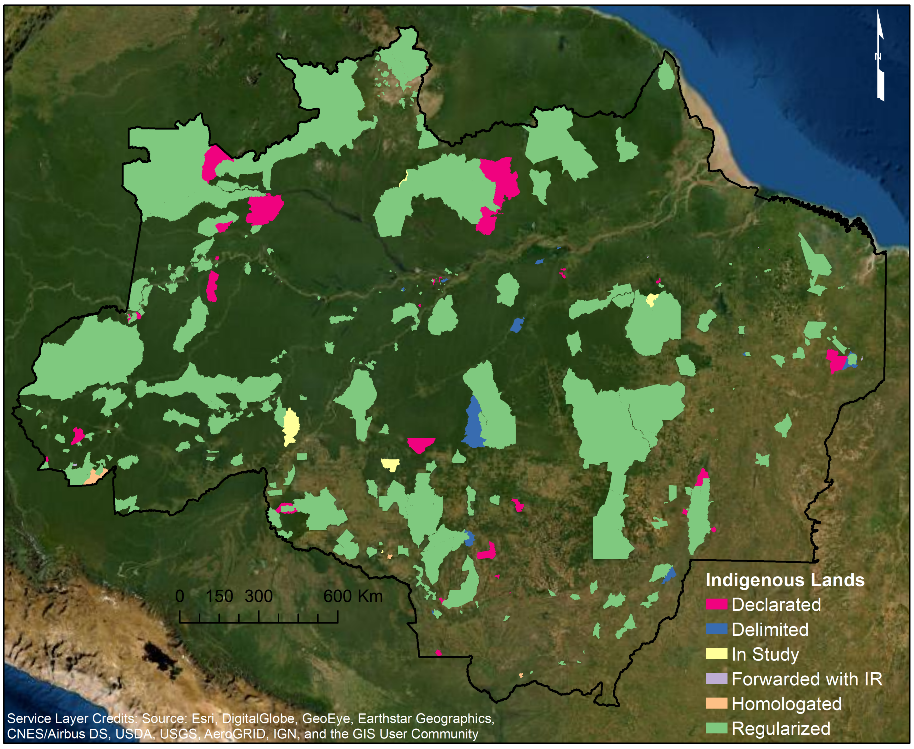
Both the Federal Constitution and the Statute of the Indian (Law 6.001/73) guarantee Indigenous people's permanent possession of the lands they live on, recognizing their right to exclusive usufruct of the natural wealth and all the uses of these existing lands (BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1988; BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973). Any form of land lease or any legal act or business that restricts direct ownership by Indigenous peoples is prohibited on ILs. Further, non-Indigenous people are prohibited from hunting, fishing, settling, or developing agricultural or extractive activities in these territories (BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973).

2.3.3 Environmental threat indicators and data

To explore the environmental integrity of Amazonian ILs, we built a spatial database combining the set of environmental threats described in section 2. Indicators of environmental threat were calculated using maps and data of deforestation, forest degradation, land use, fire, roads, and mining, inside and around the ILs. We considered the boundaries of ILs (inside) and a buffer area of 10 km around each IL (outside). This buffer zone is based on the literature (NEPSTAD et al., 2006; SOARES-FILHO et al., 2010; CABRAL et al., 2018) and on environmental rules. Different environmental policies in Brazil have established a 10-km-radius surrounding protected areas to save its ecosystems against all activities that may affect the biota, such as the repealed CONAMA (National Environmental Council) Environmental Resolution no. 13/1990, the Decree 99.274/1990, and the Interministerial Ordinance No. 60 of 2015, in the

[3]The legal status refers to the recognition status of the Indigenous peoples' rights to land by the State. In the Legal Amazon region 325 ILs are Regularized while the rest are in one of the following recognition stages: In Study (6), Delimited (11), Declared (31), Indigenous reserve forwarded (7), and Homologated (3) (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a; FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a) (Table A.1)

Figure 2.1 - Indigenous Lands in the Legal Amazon region. The Legal Amazon region is delimited by the black line. Colors indicate the legal status of recognition process.



SOURCE: Data from FUNAI (2020).

case of mining exploitation and railway construction (BRASIL. MINISTÉRIO DO MEIO AMBIENTE., 2015). The indicators we used to represent the environmental threats considered in this study are described below and summarized in Table 2.1.

Deforestation was expressed as the accumulated percentage of deforested area relative to the IL area or buffer zone (BF) area. Hereto, we used the accumulated deforestation data through 2019 from INPE's Amazon Deforestation Monitoring Program (PRODES) (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a). The PRODES has carried out satellite monitoring of clear-cutting (complete suppression of the forest) in areas of forest physiognomy in the Legal Amazon since 1988.

Forest degradation was expressed as the accumulated percentage of the area of degraded forests relative to the IL or BF areas. Data were obtained from DEGRAD, an INPE system to detect progressive forest degradation (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008) between 2007 and 2016. Although the

DEGRAD system was discontinued in 2016, the detection of forest degradation is currently provided by the Real-time Deforestation Detection System (DETER) (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b), a system to detect forest perturbations also developed by INPE (DINIZ et al., 2015; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). Data provided by both DEGRAD (2007-2016) and DETER (2016-2019) were combined to generate the forest degradation indicator from 2007 until 2019. In this study, we adopt the definition of forest degradation used by INPE: the process of the gradual loss of forest cover due to the effect of logging and forest fire, of at least 6.25 ha, which does not qualify as clear-cut deforestation by PRODES (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008). We discounted the overlap of areas that have suffered forest degradation more than once.

As an indicator for fires, we computed the accumulated percentage of burned area relative to the IL or BF area. Hereto, data from MODIS' (NASA's Moderate Resolution Imaging Spectroradiometer) Global Burned Area Product (Collection 6) between 2001 and 2019 was used (GIGLIO et al., 2018). The MODIS burned area mapping algorithm detects burned areas daily by locating the occurrence of rapid changes in surface reflectance patterns at a spatial resolution of 500 m. Burned areas are characterized by vegetation loss, accumulation of coal and ash, and changes in the vegetation structure. Based on these characteristics, the burned areas are classified. In this indicator, we also discounted the overlap when the same area was burned in different years.

To estimate the environmental threat resulting from the advance of the agricultural frontier, we calculated the percentage of pasture and cropland areas relative to the IL and BF areas. For this, we used a 2018 map of land use and land cover of the Amazon derived from the MODIS time series (CAMARA et al., 2020).

As an indicator for road access, we calculated the density of roads inside ILs and BFs. For this, we used the road map compiled by the RAISG (Amazon Network of Georeferenced Social and Environmental Information) derived from IBGE (Brazilian Institute of Geography and Statistics) data REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG (2018). The road density was calculated by dividing the sum of road lengths in the IL/BF by the area of the IL/BF (km/km^2).

Finally, for quantifying the threat posed by mining, we calculated the number of occurrences of mining activities within and around the ILs compiled by RAISG in

2018 (REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2018). This dataset aggregates occurrences of mining activities in different cartographic forms of representation, such as polygons that represent areas deforested for mining and detected by remote sensing; points that represent the location records of mining activities; and lines that represent rivers where mining activities have been identified. Given the diversity and richness of this dataset, we grouped all occurrences, of the 3 forms represented into a single indicator.

Table 2.1 - Environmental threats on Amazonian Indigenous Lands, quantification, and data source.

Where	**Threat**	**Quantification**	**Period**	**Source**
	Deforestation	accumulated deforested area (%)	1988-2019	(INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a)
	Forest degradation	accumulated degraded forest area (%)	2007-2019	(INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b)
	Forest fires	accumulated burned area (%)	2001-2019	(GIGLIO et al., 2018)
Indigenous Land	Mining	nº of mining occurrences	2018	RAISG, 2019
	Agriculture	cropland area (%)	2018	(CAMARA et al., 2020)
	Livestock	pasture area (%)	2018	(CAMARA et al., 2020)
	Road access	road density (km/km^2)	2017	RAISG, 2019
	Deforestation	accumulated deforested area (%)	1988-2019	(INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a)
	Forest degradation	accumulated degraded forest area (%)	2007-2019	(INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b)
	Forest fires	accumulated burned area (%)	2001-2019	(GIGLIO et al., 2018)
Buffer Zone	Mining	nº of mining occurrences	2018	RAISG, 2019
	Agriculture	cropland area (%)	2018	(CAMARA et al., 2020)
	Livestock	pasture area (%)	2018	(CAMARA et al., 2020)
	Road access	road density (km/km^2)	2017	RAISG, 2019

2.3.4 Cluster analysis

In this study, we aim to investigate possible patterns in the combination of environmental threats that affect Indigenous Lands in the Legal Amazon region. To this end, we perform cluster analysis of environmental threats in ILs and their surroundings to identify clusters of ILs that share common threats. Cluster analysis is an unsupervised pattern recognition technique that aims to partition a set of data (or objects) into a set of similar groups, often called clusters (JAVADI et al., 2017). In this method, no previous assumptions are made about the clusters, and the areas with similar characteristics, in terms of the values of the variables of interest, are gathered together (FERNANDEZ et al., 2016). The clusters are partitioned according to the distance or similarity between objects in terms of one or more metrics (JAVADI et al., 2017), aiming to maximize both intra-cluster homogeneity and inter-cluster heterogeneity (FERNANDEZ et al., 2016). In our study, the objects are the ILs, while the metrics are the quantified environmental threat indicators for each IL and its corresponding BF.

Before the cluster analysis was performed, the following steps were executed. First, we performed logarithmic transformation of quantified indicators to improve the normality of the distribution[4]. Second, we applied z-score standardization to these logarithmic indicators. The z-score standardization method was chosen to improve the accuracy of the K-means algorithm (MOHAMAD; USMAN, 2013), which is a premise of the cluster analysis since the analysis is based on the Euclidean distance of the observations (MAROCO, 2007). Third, we chose the number of clusters by calculating the coefficient of determination (R^2) from a one-way ANOVA.

We used the partitional K-means clustering algorithm, a commonly used non-hierarchical clustering algorithm. In this algorithm, the number of clusters, k, is determined by the user. Next, k objects are chosen by an iterative procedure as the centers of the k clusters. Then, all objects are divided among the k clusters according to the measure of similarity adopted, so that each object is in the cluster that provides the shortest distance between the object and the center of the cluster. In the K-means algorithm, the average of the objects belonging to each cluster is used to represent the center of the cluster, also called the cluster's center of gravity (HAN et al., 2011). In this study, the square Euclidean distance was used as a measure of similarity.

[4] In order to deal with the fact that the dataset has zero values for numerous observations, we added a constant value of 0.0001 to the original data for all threats before the logarithmic transformation.

The most suitable number of clusters was calculated as follows. Initially, the K-means clustering method was performed with different numbers of clusters (2-9). The results of each partitioning were applied in an one-way ANOVA as the dependent variable and the environmental threat indicators as independent variables. From the ANOVA results, the coefficient of determination (R^2) was calculated by the ratio of the inter-cluster variance (sum of the squares among the groups) and the internal-cluster variance (sum of the total squares for each variable) (MAROCO, 2007; CALINSKI; HARABASZ, 1974). The choice of how many clusters to use was made based on the value of (R^2) in order to optimize the variability gain with the increase in the number of clusters.

All analyses and visualizations were conducted using R (R CORE TEAM, 2014), ArcGIS 10.4 (ESRI, 2016), and Quantum Gis 3.0 (QGIS DEVELOPMENT TEAM, 2009). The clustering analysis was performed using the IBM SPSS Statistics software (SPSS) (IBM CORPORATION, 2015).

2.4 Results and discussion

2.4.1 General view of environmental threats within and around Indigenous Lands

Our results show the heterogeneity of environmental threats affecting Amazonian Indigenous Lands and their surrounding areas (Figures 2.2 and 2.3). Most of the 383 Indigenous Lands are internally affected by a combination of different environmental threats. Although the threatened ILs are scattered across the Amazon, the ILs affected by multiple and relatively severe threats are located mainly in the arc of deforestation region, in the older frontier areas and in the Roraima state. The arc of deforestation is a region where the highest deforestation rates are mainly caused by the agricultural frontier advancing toward the forest. This territory extends from the west of Maranhão and south of Pará toward the west, crossing through Mato Grosso, Rondônia, and Acre states. This region also has roads such as the BR-163, BR-319, and BR-364 (BECKER, 2016) (Figures 2.2H and 2.3H).

The threats related to forest loss (deforestation, forest degradation, and fires) are more intensive in the IL buffer zones than inside the ILs (Figure 2.2) and (Figure 2.3). This result shows, on the one hand, that ILs are effective, in line with other research (NEPSTAD et al., 2006; NOLTE et al., 2013), but that their surroundings are drastically affected by deforestation, forest degradation, and forest fires, mainly in the arc of deforestation region and further north (Figure 2.3). A similar geographical distribution of pasture areas and access by roads can be observed in the buffer zones. Mining occurrences around the ILs can be observed across the Amazon region. Croplands are mainly concentrated around ILs in the arc of deforestation region and Roraima state (Figure 2.3).

In the consolidated areas, there is a more extensive infrastructure network, which increases the possibility of access to ILs, invasion, and exploration of mineral and forest resources (AGUIAR et al., 2007; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020; FERRANTE et al., 2020; SCHIELEIN; BÖRNER, 2018). Just as the predominant presence of agricultural activity in these areas increases the likelihood that such activities will be extended into the ILs. In the innermost areas of the biome, ILs are less threatened internally and externally, a phenomenon that also seems to be influenced by the ease of access. Although some of them, like Yanomami IL, because of mining, are more threatened even in more remote regions.

Figure 2.2 - Environmental threats inside Indigenous Lands. Accumulated deforestation by 2019 (%) (A); Accumulated forest degradation by 2019 (%) (B); Accumulated burned area by 2019 (%) (C); Number of mining occurrences by 2018 (D); Croplands by 2018 (%) (E); Pasture by 2018 (%) (F); Road density (km/km^2) (G); and the Legal Amazon region limits (H). The maps are displayed on a logarithmic scale. Gray indicates 'threat value' = 0. Data sources are provided in Table 1.

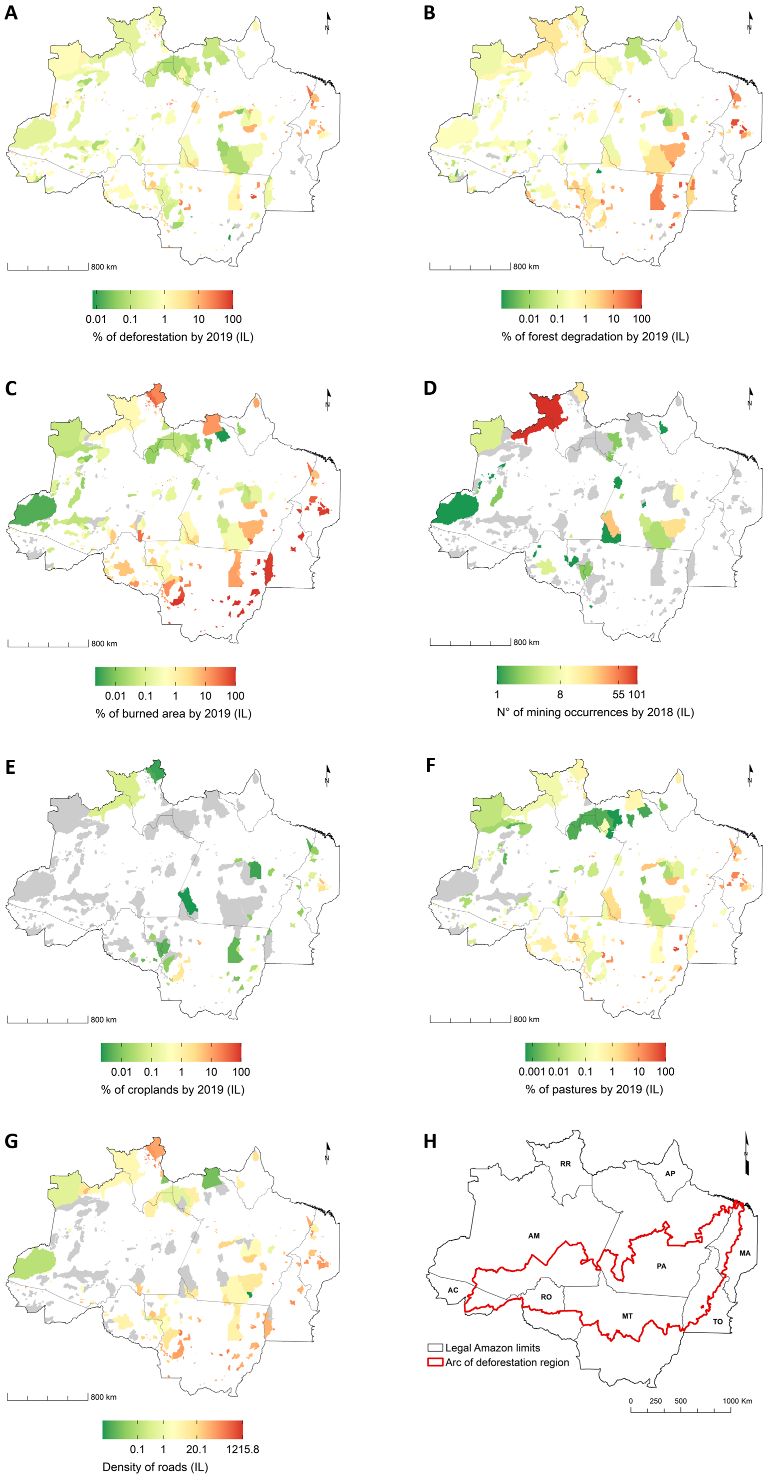
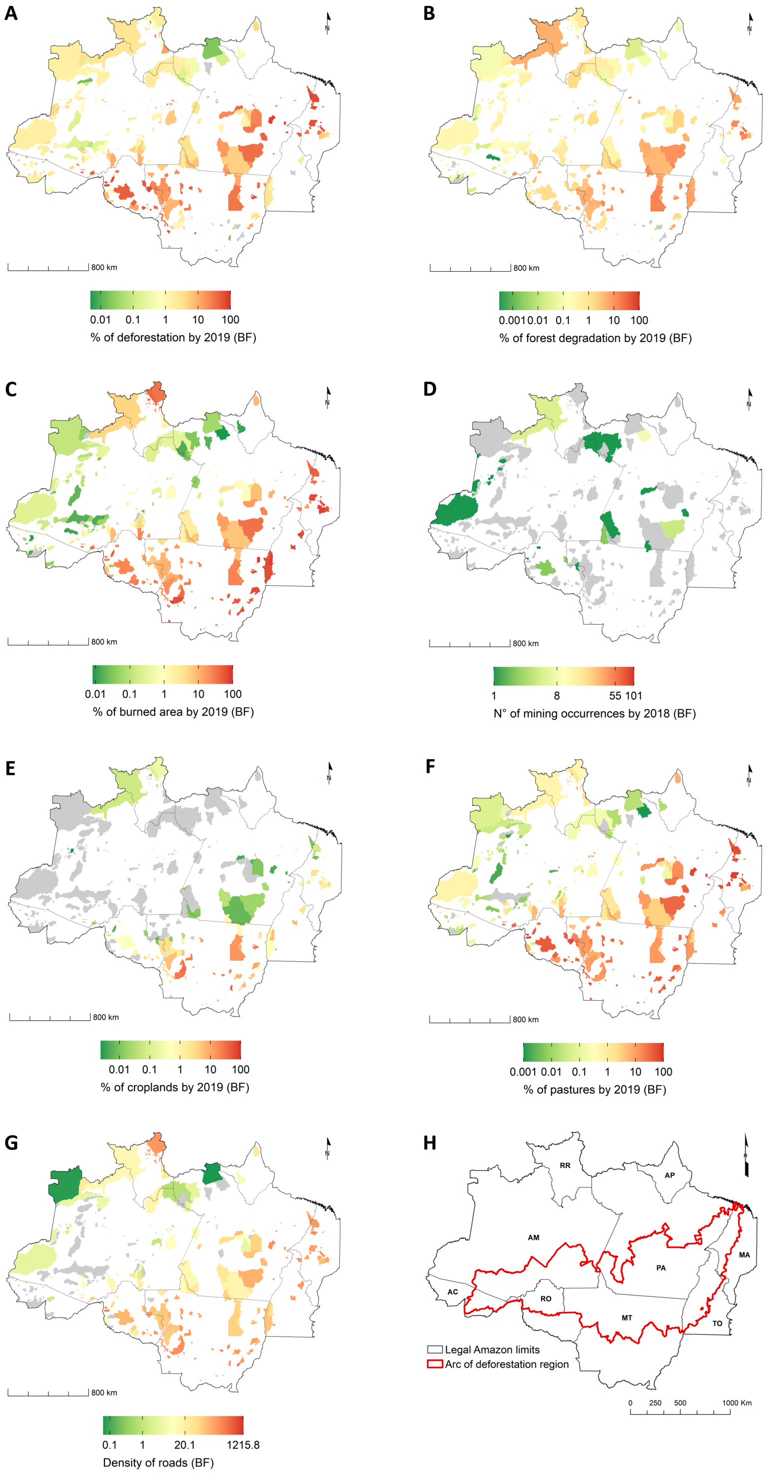


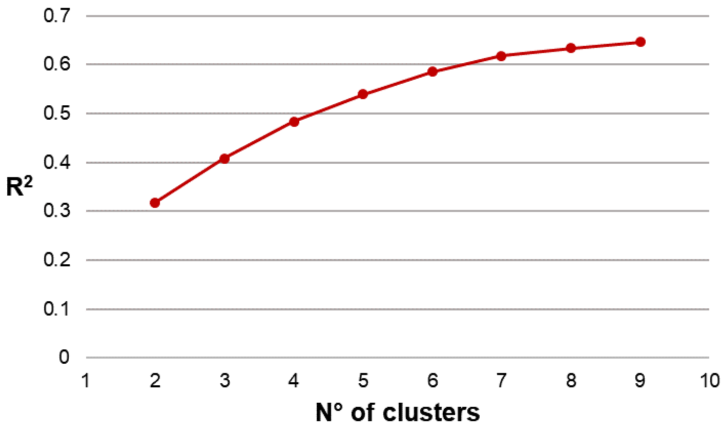
Figure 2.3 - Environmental threats in the buffer zone of Indigenous Lands. Accumulated deforestation by 2019 (%) (A); Accumulated forest degradation by 2019 (%) (B); Accumulated burned area by 2019 (%) (C); Number of mining occurrences by 2018 (D); Croplands by 2018 (%) (E); Pasture by 2018 (%) (F); Road density (km/km^2) (G); and the Legal Amazon region limits (H). The maps are displayed on a logarithmic scale. Gray indicates 'threat value' = 0. Data sources are provided in Table 1.



2.4.2 Clusters of Indigenous Lands

The coefficient of determination (R^2) increased rapidly with the number of clusters until cluster number seven ($R^2 = 0.62$); after this, the gain in R^2 became small (Figure 2.4). Therefore, we applied k=7 clusters in our analysis. The seven clearly separable clusters represent combinations of common environmental threats within and around the ILs (Figure 2.5). The characteristics of each cluster are described below.

Figure 2.4 - Coefficient of determination of the number of clusters.



Cluster 1 stands out for the low intensity of threats inside and around the ILs (Figures 2.6A and A.1; and Table A.2). The predominant threats in this group are deforestation and forest degradation inside and around the ILs. Forest fires, pasture, and roads also appear in this group (inside and outside) with lower severity (Figures 2.6A, 2.7, 2.8, and A.1; and Table A.2). Cluster 1 has 108 ILs, being the largest group, and covering around 247,350 km^2, representing about 21% of the total IL area. The ILs in this cluster are concentrated mainly in the states of Amazonas (AM), Acre (AC), and Pará (PA) (Figure 2.5).

Cluster 2 is characterized by the prevalence of mining as a major threat both inside and outside ILs (Figures 2.6B, 2.7D, 2.8D, and A.1; and Table A.2). In this cluster, the ILs also are affected internally and externally by deforestation, forest degradation, fires, pastures, and roads (Figures 2.6B and A.1; and Table A.2). Cluster 2 has 25 ILs widely distributed in different states in the Amazon region, covering an area of about 525,384 km^2 (44.7%) (Figure 2.5). This cluster consists of Indigenous Lands with large territories, such as Yanomami (RR and AM) with 9665 thousand ha, Vale do Javari (AM) with 8544 thousand ha, Menkragnoti (PA) with 4914 thousand ha, and Mundukuru with 2382 thousand ha. The Yanomami, Mundukuru, and Kayapó ILs are among the most affected by illegal mining activities (RORATO et al., 2020).

The ILs in cluster 3 are mainly characterized by deforestation inside their limits and deforestation and roads in the ILs' buffer zones (Figures 2.6C, 2.7, 2.8, and A.1; and Table A.2). Inside the ILs of cluster 3, forest degradation, fires, and pastures also are present but in lower intensity. This cluster also has a high prevalence of pasture, fires, and forest degradation in the ILs' surroundings. Cluster 3 has 79 ILs scattered throughout the Legal Amazon region (Figure 2.5) covering an area of 127,173 km^2 (10.8%).

Cluster 4 has a greater severity of most threats inside and outside the ILs, with emphasis on the higher prevalence of cultivation areas, pastures, and forest degradation in this group in relation to the others (Figures 2.6D, 2.7, 2.8, and A.1; and Table A.2). Cluster 4 ranks second in terms of the size of burned areas, just behind cluster 5. The other predominant threats in this cluster are roads and deforestation inside and outside ILs. The 28 ILs in this cluster cover an area of 38,380 km^2 (3.3%) and are concentrated mainly in the states of Mato Grosso (MT) and Maranhão (MA)) (Figure 2.5). Mato Grosso is the largest producer of soybeans, maize, and cotton and has the largest cattle herd in Brazil (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE, 2020a; INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE, 2020b), while Maranhão is the second-largest agricultural producer in the Northeast region, producing mainly soybean and corn (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE, 2020a). This means that cluster 4 ILs are under tremendous pressure from agribusiness.

Cluster 5 stands out for presenting the highest amount of burned areas and high density of roads inside and outside the ILs (Figures 2.6E, 2.7, 2.8, and A.1; and Table A.2), in addition to being composed predominantly of small ILs (Figure 2.5). Within and around the ILs, pastures and crops also predominate. Cluster 5 has 24 Indigenous Lands, totaling an area of about 15,223 km^2 (1.3%). Most of these ILs are in the region of the arc of deforestation, in areas of the consolidated agricultural frontier in Mato Grosso (MT) and Tocantins (TO), and some in the Roraima state (RR) (Figure 2.5). This cluster indicates that ILs inserted in consolidated agricultural regions are vulnerable to fire.

Cluster 6 is characterized by high severity for most threats, inside and outside ILs, with minor predominance of crops and mining (Figures 2.6F, 2.7, 2.8, and A.1; and

Table A.2). This cluster faces intense pressure from deforestation, shown by the fact that it has the highest median deforestation value inside and outside ILs (Figures 2.7A and 2.8A). Cluster 6 ranks second in terms of forest degradation and pasture inside IL, just behind cluster 4. Cluster 6 is also the third most threatened by fires (Figures 2.7C and 2.8C). The 103 ILs in cluster 6 are mainly located in the arc of deforestation and in Roraima state (close to the BR-433 road) (Figure 2.5) and cover an area of 155,608 km^2 (13.3%).

Cluster 7 is mainly characterized by the predominance of mining in the ILs' buffer zones (Figures 2.6G and Table A.2). The ILs in this cluster also face deforestation inside and outside their limits, as well as forest degradation, fires, pastures, and roads in the ILs' buffer zones with lower intensity. The 16 ILs in cluster 7 are distributed further north of the Amazon region, in the states of Amazonas (AM) and Pará (PA) and, therefore, further from the arc of deforestation (Figure 2.5). These ILs cover about 65,018 km^2 (5.5%).

Figure 2.5 - Final clusters of Indigenous Lands according to the set of common environmental threats inside and outside these territories.

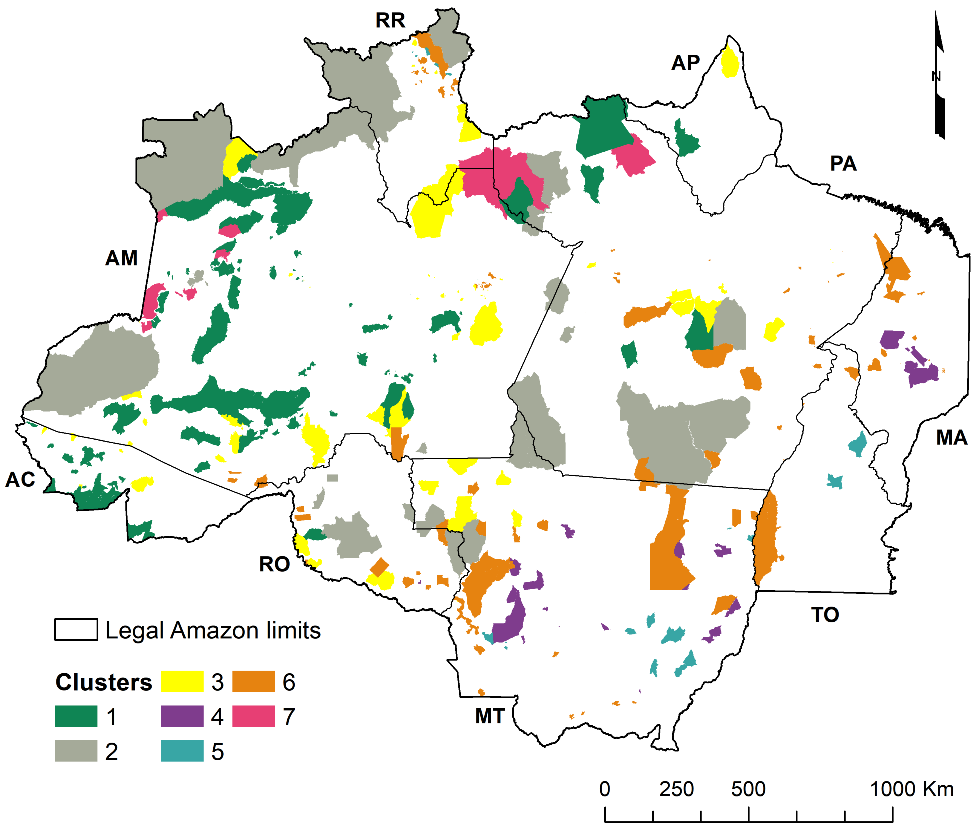


Figure 2.6 - Radar charts of the clusters of Indigenous Lands (A-G). The values are plotted to represent the the mean of each threat for each cluster. To improve the visualization of the results in this graph, we apply the logarithmic transformation followed by scaling between 0-1 (using the min-max method) on the original variables. The central axis delimits the environmental threats in the buffer zone (left) and within the Indigenous Land (right). Threats in the buffer zone are identified by the abbreviation 'bf'. The term 'defor' is an abbreviation for deforestation and 'degrad' for forest degradation.

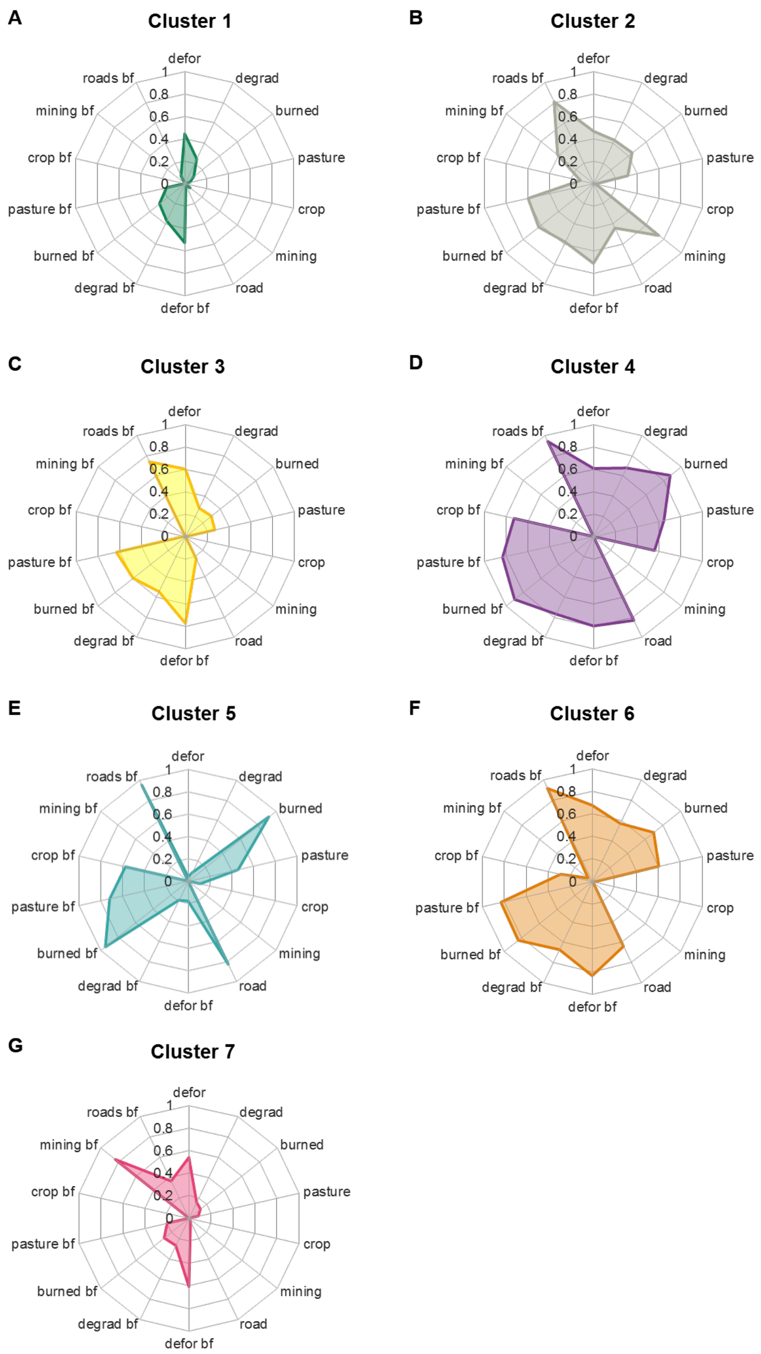


Figure 2.7 - Boxplots of environmental threats within Indigenous Lands (IL). Accumulated deforestation by 2019 (%) (A); Accumulated forest degradation by 2019 (%) (B); Accumulated burned areas by 2019 (C); Number of mining occurrences (D); Croplands by 2018 (%) (E); Pasture by 2018 (%) (F); Roads network density (km/km^2) (G). The axes increase quadratically to improve the visibility of differences. The upper and lower whiskers correspond to the first and third quartiles, and the line inside the box represents the median. Data beyond the end of the whiskers are outliers and plotted as points.

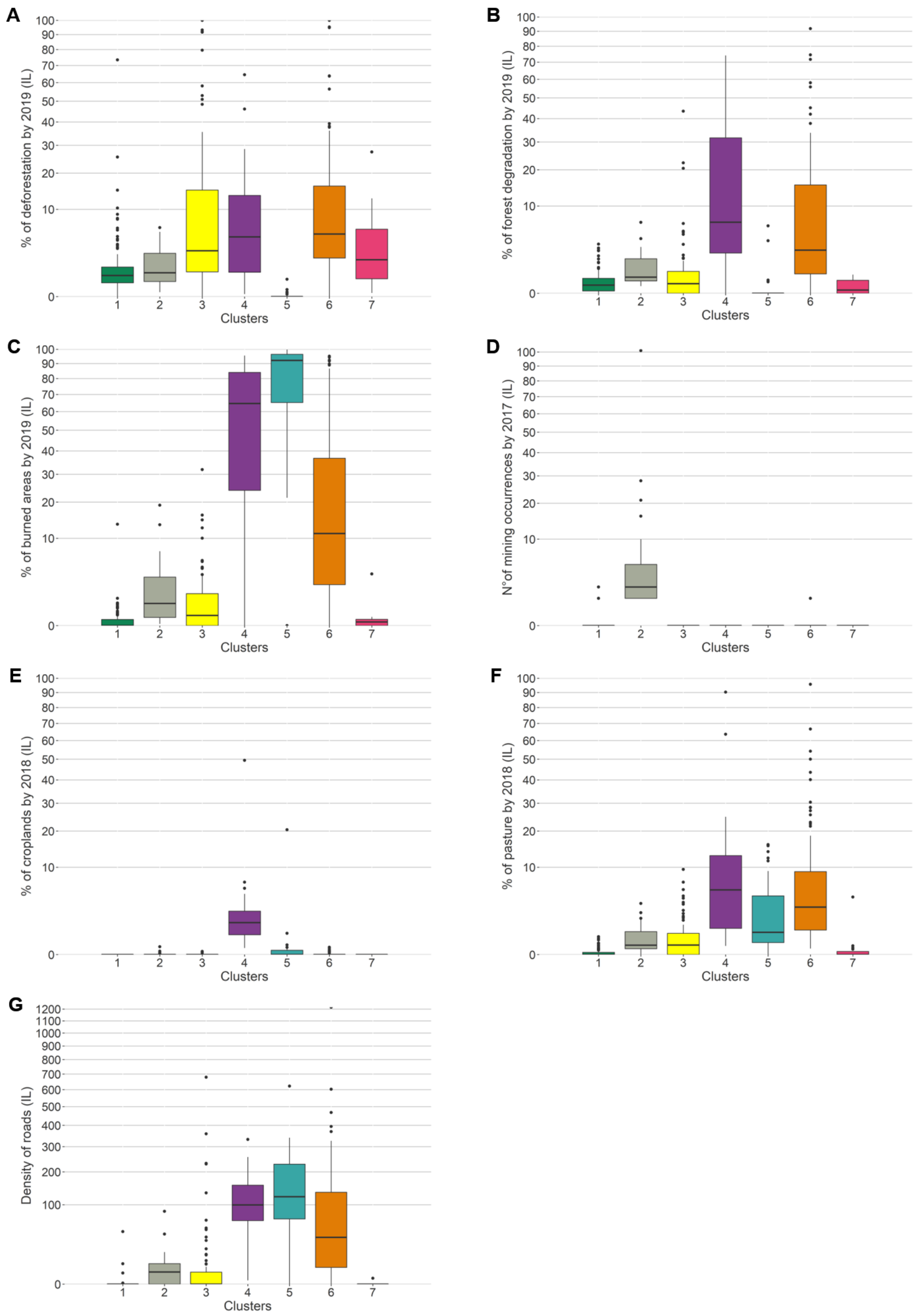
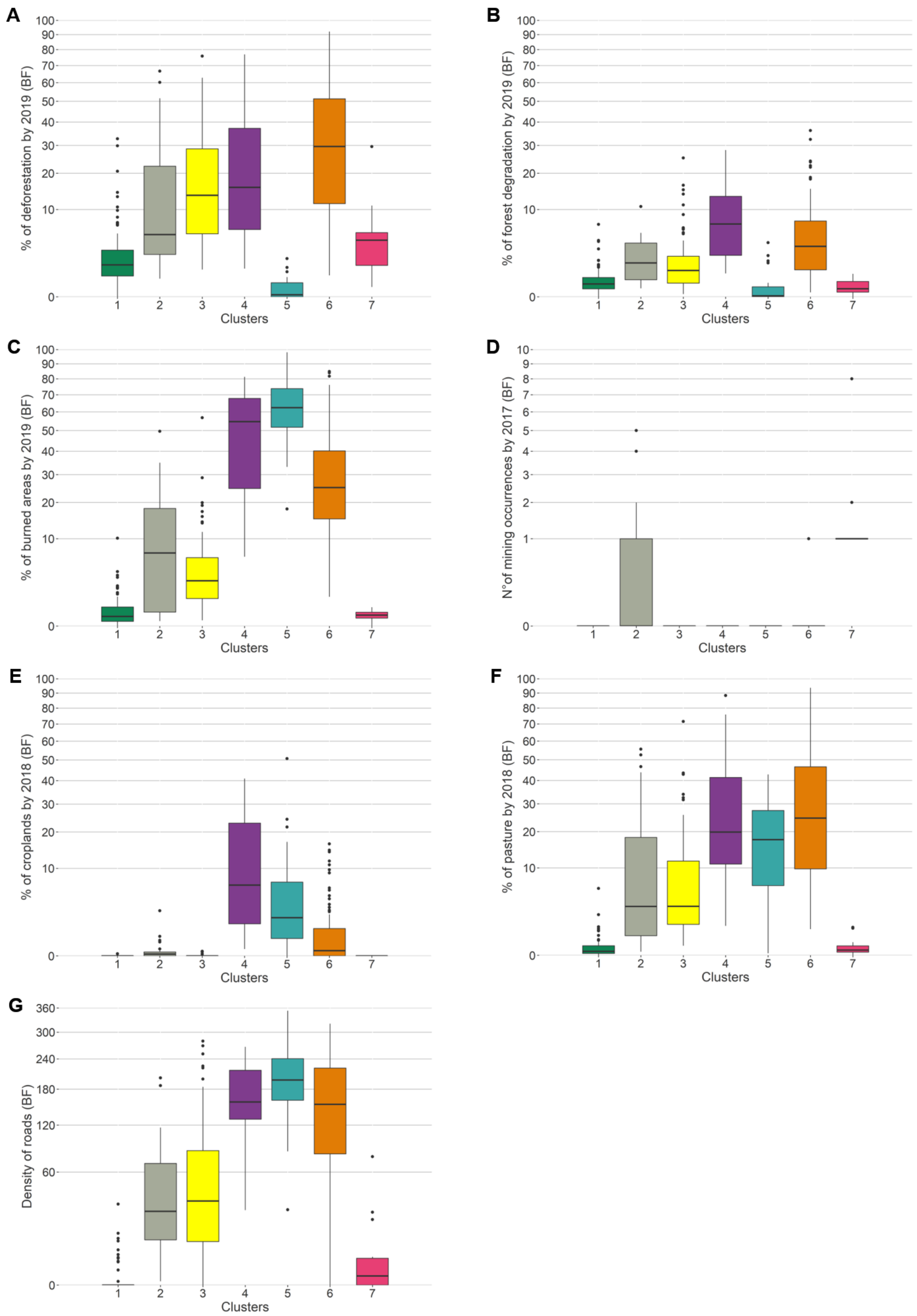


Figure 2.8 - Boxplots of environmental threats in the buffer zone (BF) of Indigenous Lands. Accumulated deforestation by 2019 (%) (A); Accumulated forest degradation by 2019 (%) (B); Accumulated burned areas by 2019 (C); Number of mining occurrences (D); Croplands by 2018 (%) (E); Pasture by 2018 (%) (F); Roads network density (km/km^2) (G). The axes increase quadratically to improve the visibility of differences. The upper and lower whiskers correspond to the first and third quartiles, and the line inside the box represents the median. Data beyond the end of the whiskers are outliers and plotted as points.



2.4.3 Public policies to protect the environmental integrity of Indigenous Lands

Based on our results, we have identified four priorities for environmental policies regarding Amazon ILs:

a) Protecting the ILs' buffer zones throughout the Amazon, as demonstrated by all clusters (Figures 2.3, 2.6, 2.8, and A.1);

b) Combating illegal deforestation, forest degradation, and mining within ILs throughout the Amazon region, as demonstrated by clusters 3, 4 and 6 for deforestation and forest degradation (Figures 2.6, 2.7A, and 2.7B) and by cluster 2 for mining (Figures 2.6B and 2.7D);

c) Preventing and combating fires (within IL and BF) in the arc of deforestation region and the Roraima state, as demonstrated by clusters 4, 6 and mainly 5 (Figures 2.2C, 2.3C, 2.6, 2.7C, 2.8C);

d) Removing invaders of all Amazon ILs, starting with those present intense agricultural activities (crops and pasture) demonstrated by clusters 4, 5 and 6; and intense mining, such as cluster 2 (Figures 2.6, 2.7E, 2.7F and 2.7D).

Brazil has a robust set of environmental legal regulations built over decades because of the struggle of different national society sectors, including Indigenous peoples. The protection and combating of environmental threats in Amazon Indigenous Lands depend on the execution and efficiency of a set of public policies in line. As such, first, it is necessary to identify the main sets of environmental threats that affect each IL. Taking into account the specificities of threats is important to subsidize the development of differentiated public policies to control, prevent, and combat current and future impacts.

From 2003 to 2013, active public policies reduced deforestation in the Amazon region by 80% and also substantially improved indigenous peoples' rights, including the demarcation and creation of protected areas. In the next sections, we discuss the importance and the precariousness of the most important environmental policies to stop the advancing environmental threats to Amazon Indigenous Lands and how these policies need to be restored and strengthened. Herein, we refer to historic policies as these have proven effective. We argue that it is precisely during the dark times, in which government is going in the opposite direction, that we must prepare for change. Despite many imperfections, Brazil is still a working democracy, where regular elections are held. Sooner or later, the current government will be out of office; it is all the more important that a more environmental-friendly government is supported by good and efficient policy.

2.4.3.1 Protecting Indigenous Lands' buffer zones

As evidenced by our results, the environmental threats and their impacts around the Indigenous Lands are substantial (Figures 2.3 and 2.8). The set of threats in the buffer zone are very similar to the set of threats that affect Indigenous Lands internally (Figure 2.6). In this way, there is a need to reinforce the surveillance and control of environmental threats affecting all ILs' buffer zone, mainly those in clusters 4, 5, and 6.

According to the law, the occurrences of illicit environmental acts around ILs and that have the potential to impact them must be monitored by FUNAI and dealt with by competent agencies, such as IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources) (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a). Further, the Interministerial Ordinance No. 60 of 2015 determines the need for environmental licensing for activities that may affect Indigenous Lands, establishing a minimum distance required for different activities (e.g., mining = 10 km) or infrastructure projects (e.g., roads = 40 km). This measure aims to guarantee the integrity of ILs and their ecosystems by protecting their surroundings (BRASIL. MINISTÉRIO DO MEIO AMBIENTE., 2015). However, according to the severity of the environmental impacts observed around the ILs from our results, the combination of these policies appears to be insufficient. We highlight that actions aimed at controlling and combating environmentally illicit activities in ILs' surroundings must be strengthened. We argue that the buffer zones around these territories must be established with stricter environmental rules, potentially protecting ILs against the advancement of degrading activities.

2.4.3.2 Preventing and combating illegal activities in Indigenous Lands

In Brazil, the surveillance and protection of ILs' environmental integrity are obligations of the State and comprise a set of command and control actions to curb illegal activities. FUNAI carries out surveillance actions on ILs in partnership with other government agencies with police power. Among the partner agencies, those that stand out are the Federal Police, in the control of the judicial police; the IBAMA, in actions of environmental competence; the ICMBio (Chico Mendes Institute for Biodiversity Conservation), in the areas overlapping the UCs; the Military Police of the states, in the occurrence of crimes against the individual; the INCRA (Institute for Colonization and Agrarian Reform), for dealing with land tenure and displacement of occupants; the Armed Forces of Brazil (composed of the Army, Navy and Air Force); and the Environmental Military Police (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a).

The main surveillance and combat actions in the ILs are aimed to fight deforestation, selective logging, and illegal mining; repress illegal hunting and fishing; and extrude invaders. Here, we aggregate the combating of deforestation, selective logging, and illegal mining because of the policy similarities employed to address these threats. The latter, namely extruding invaders, will be discussed in a separate section [2.4.3.4].

While these agencies' integrated work helped combat illegal deforestation in the Amazon before 2012 (ARIMA et al., 2014; TREBAT et al., 2019), staff and budget cuts have weakened their ability to enforce environmental laws (ABESSA et al., 2019; PEREIRA et al., 2019; HUMAN RIGHTS WATCH, 2019). The substantial weakening of policies to combat illicit activities and the dismantling of environmental surveillance agencies (IBAMA and ICMBIO) and FUNAI is an issue of concern in Brazil. In general, these agencies are currently without a budget and sufficient personnel to carry out combat and control actions in ILs. These agencies' dismantling can partially explain the observed increase of deforestation, fires, and exploration of natural resources in the Amazon and ILs in recent years (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). While in 2009 IBAMA had around 1,600 agents across Brazil, in 2019 that number dropped to 780 employees (HUMAN RIGHTS WATCH, 2019). Likewise, FUNAI's number of employees has been reduced by about 30% since 2012, from 3,111 to 2,224 in 2019 (HUMAN RIGHTS WATCH, 2019).

According to the Human Rights Watch report, in 2018, IBAMA had only nine field agents to monitor many environmental crimes in the Maranhão state (HUMAN RIGHTS WATCH, 2019). The Indigenous Lands of Maranhão preserve the largest Amazonian forest blocks in the state and are the target of intense environmental degradation (SILVA JÚNIOR et al., 2020), with high levels of accumulated deforestation, fire, and forest degradation, as demonstrated by clusters 4 and 6. The illegal occupation of squatters and loggers is high in these ILs and causes intense conflicts, having resulted in the murders of several Indigenous leaders (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; GLOBAL WITNESS, 2020). This reflects how the State currently neglects vast forest areas in the Amazon and the Indigenous peoples' rights.

Furthermore, these agencies have also lost their operational autonomy. First, career agents with technical experience and those responsible for combating and controlling environmentally illicit activities were removed from their positions and replaced by military personnel with no technical experience. Second, actions to combat environmental illegal acts in the Amazon are now being coordinated by the National Council of the Amazon through intense action by the armed forces, creating a situation of subordination by FUNAI and IBAMA. However, since implementing this new structural arrangement to combat the Amazon's environmental threats, the program has proved inefficient. In the years of 2019 and 2020, the Amazonian ILs saw the highest records of deforestation, forest fires, invasions, and resource exploitation (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). We argue that IBAMA must be reinstated to its full competence to manage environmental policies combating illegal deforestation and other activities in these territories. With budgetary and personnel support, this agency's autonomy has already proved to be efficient for fulfilling its function (ARIMA et al., 2014).

Another point that weakens Brazilian environmental policy and encourages illegal activities is the new regulation created regarding fines against environmentally illicit acts (Decree 9,760). According to the new regulations, environmental fines must be reviewed at conciliation hearings, in which discounts can be offered or fines can even be declared null. Further, the the payment of fines only happens after the conciliation hearing, causing a substantial delay in collecting fines. Given the structural degradation of environmental agencies nowadays, most hearings may not even happen in time, leading to the fine's expiration and cancellation. In 2020, of about 1000 fines imposed by IBAMA for illegal deforestation in the Amazon, only 3 were paid. Thus, instituting fines that, in practice, do not need to be paid cannot help curb environmental crimes (O ESTADO DE SÃO PAULO, 2020; DANTAS, 2020; HUMAN RIGHTS WATCH, 2019).

Illegal mining, deforestation, and illegal logging activities in the Amazon involve a complex logistics chain with high-cost machinery and labor. These activities are orchestrated by organized criminal organizations (HUMAN RIGHTS WATCH, 2019; CAMARGOS, 2019) that are also responsible for the illegal opening of roads in ILs and other federal forests and the organization of export schemes for illegal products, which thus bypass any inspections (HUMAN RIGHTS WATCH, 2019; BRANCALION et al., 2018). We argue that policies to combat these criminal networks must be strengthened both from the bottom up (combating illicit acts in the field, destroying machinery, and punishing the offenders) and from the top down, through punishing the powers behind these organizations. The Public Ministry has a large role in investigating these criminal networks in order to contain threats that degrade the Amazon rainforest.

2.4.3.3 Preventing and combat fires in Indigenous Lands

Policies for preventing and combating fires in Indigenous Lands are established mainly through the program Federal Brigades in Indigenous Lands, a cooperation agreement established in 2013 between FUNAI and the National Center for the Prevention and Fighting of Forest Fires (Prevfogo) from IBAMA (INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS – IBAMA., 2020; LACERDA, 2013). This program aims to select, train, and hire Indigenous brigadiers to monitor and fight fires in their territories. The program also supplies equipment, vehicles, and logistics for work, and the brigades may be dispatched to other Indigenous Lands if necessary. The brigades are formed by Indigenous people, supported by FUNAI's and IBAMA's employees, who combine traditional knowledge with non-Indigenous fire management techniques to reduce the socio-environmental impacts caused by uncontrolled fires (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a; LACERDA, 2013).

The Indigenous brigades have played an important role in preventing and fighting forest fires in the Amazonian ILs. An important part of the brigadiers' activities is focused on preventive actions with prescribed and controlled burning, the opening of firebreaks, and the cleaning of land, together with the recovery of degraded areas (LACERDA, 2013). The firefighters in ILs can count on reinforcement from the Military Fire Brigade and non-Indigenous brigadiers as well.

In the past two years, forest fires in ILs and their surroundings have increased (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c). These fires are mainly caused by the activities carried out around the ILs, which trigger uncontrolled fires toward these territories. Two important causes for the spread of fire in ILs are the practice of surrounding farmers burning their pastures and the practice of burning vegetation in order to open new areas. This points to the need to control and inspect the ILs' surroundings and punish those responsible for fires that affect ILs. In addition, according to reports by Indigenous leaders from different ILs in the Amazon, the uncontrolled fires that affect these territories are often the result of criminal actions inside the ILs, who aim to open certain areas for land exploration. These activities are partly encouraged by government discourse and the lack of vigilance and punishment (FERRANTE; FEARNSIDE, 2020). Although environmental agencies must identify and punish those responsible for spreading fire on ILs, their field combat activities and the effectiveness of fines have been weakened.

Despite the importance of the Indigenous Brigade Program and the excellent results it has produced, currently, its scope and execution have proven to be inefficient. Because of the dismantling of the agencies responsible for implementing this program, FUNAI and IBAMA, and the lack of resources and personnel, this program does cannot strongly support all the brigades in the various ILs. Thus, in many ILs, Indigenous peoples struggle to put out fires on their own without logistics and State support (RIBEIRO; BARBA, 2020; ANGELO, 2020b). As a result, the negative impacts of forest fires in these territories have been increasingly greater.

We argue that support must be provided for the Indigenous Brigades to control and combat forest fires efficiently. Thus, it is necessary to restructure the agencies responsible for this program, namely IBAMA and FUNAI, to re-establish their autonomy and increase the budget and personnel. Additionally, greater attention should be paid to the ILs of clusters 4, 6, and 5 mainly.

Finally, the ILs with a predominance of cerrado vegetation have a history of greater occurrences of uncontrolled fires, due the natural dynamics of this vegetation but also due to traditional fire management practices. For a long time, fire suppression was considered the best strategy in these regions. Over the years it has been realized that an Integrated Fire Management (IFM) policy could be more appropriate (ELOY et al., 2019). In line with the Indigenous Brigades program, several IFM initiatives have been developed in Brazil, to reintroduce fire as a management tool, mainly in Cerrado biome. Such a policy could be strengthened in ILs of clusters 4, 5 and 6 with a predominance of cerrado vegetation and susceptibility to fire.

2.4.3.4 Extrusion of illegal non-indigenous invaders of Indigenous Lands

Extrusion is a legal measure that guarantees Indigenous territorial rights, allowing non-Indigenous occupants to be removed (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a; BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973). This process has been established to remove people who practice illegal activities in Indigenous Lands, such as squatters, gold miners, and loggers, among others; or after the regularization of Indigenous Lands (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a). The law guarantees the extrusion and proves to be a necessary and effective measure to contain the environmental degradation developed by illegal activities within ILs and to guarantee the protection, safety, and the exclusive right of Indigenous peoples to usufruct their lands.

The extrusion of invaders has already been carried out for some Indigenous Lands under intense occupation by non-Indigenous people, such as Awá IL in Maranhão in 2014 and Marãiwatsédé IL in Mato Grosso in 2012 (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a). However, the process of extrusion often takes several years to be concluded, and the lack of inspections has resulted in the return of invaders who act illegally within these territories. For example, recently the Brazilian Justice ordered that the process of extruding invaders from Apyterewa IL must resume, a process that started in 2011 (VERDELIO, 2020). This year, the Federal Supreme Court decreed that non-Indigenous people from Cachoeira Seca IL in Pará and Yanomami IL in Roraima be extruded. In Cachoeira Seca IL, squatters have occupied this IL and have primarily developed agricultural activities. In Yanomami IL, several miners have invaded; currently, about 20,000 illegal gold miners operate in Yanomami IL, resulting in serious socio-environmental impacts, including contaminating the Indigenous population with mercury and spreading COVID-19 (PHILLIPS, 2020; INSTITUTO SOCIOAMBIENTAL - ISA, 2020).

We argue that removing invaders from Indigenous territories is an essential legal measure to combat illegal activities within these lands. Much of the activities that generate environmental degradation and make Indigenous populations vulnerable could be combated with the intense removal and punishment of these illegal invaders. Also, these territories must be constantly monitored after the extrusion process so that invasions do not recur. The extrusion of invaders should be directed toward ILs with large settlements and agricultural activities (cluster 4, 5 and 6), which lead to continuous illegal occupation and deforestation of new areas in order to expand illegal activities, and to ILs that harbor intense illegal mining activity (cluster 2).

2.4.4 Beyond public policies

In addition to the public policies that the State must apply to strengthen the environmental conservation of ILs discussed above, a fundamental role in guaranteeing these territories' integrity lies in the mobilization and self-organization of Indigenous peoples (WALKER et al., 2019). Historically, Indigenous resistance movements have been important drivers of the country's environmental debate, with a powerful presence alongside environmental movements. Due to both parties' claims and struggle, the country's environmental legislation was strengthened and consolidated (TOURNEAU, 2015; FERNÁNDEZ-LLAMAZARES et al., 2020), e.g., via the creation of the Statute of the Indian in 1973 (BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1973) and Article 231 of the 1988 Constitution on the rights of Indigenous peoples (BRASIL. PRESIDÊNCIA DA REPÚBLICA, 1988).

Several Indigenous organizations in Brazil are currently responsible for articulating Indigenous demands and putting pressure on the government (e.g., the Articulation of Indigenous Peoples in Brazil (APIB) and the Coordination of Indigenous organizations in the Brazilian Amazon (COIAB)). Important examples of Indigenous movements are related to the resistance against building large infrastructure projects with the potential to impact their territories, like roads and dams. In the Amazon, the building of dams affecting Indigenous territories is a matter of historical struggle, and Indigenous peoples have had to mobilize to defend their territories against environmental degradation (ATHAYDE, 2014; WALKER; SIMMONS, 2018; WALKER et al., 2019). Currently, several infrastructure projects are planned to be built in the Amazon region, as the planned roads, dams, and ports in the South American Regional Infrastructure Integration program (IIRSA) (WALKER et al., 2019). These projects have a high potential to impact the whole Amazon ecosystem, as well as Indigenous territories throughout the region. In addition, there is a potential risk of worsening mining impacts on Amazonian ILs if bill PL 191/2020, which regulates the opening of these territories to economic activities, were to be approved (RORATO et al., 2020).

Around the world, mineral exploration is generally associated with intense socio-environmental impacts and results in the emergence of conflicts, such as the so-called 'blood diamonds' in Africa and the illegal exploitation that occurs in Amazonian ILs. Measures adopted to inspect and regulate the supply chain of diamonds in Africa, such as an international certification scheme for rough diamonds (the Kimberley Process Certification Scheme) (MACONACHIE, 2009), have shown good results. This experience can be a possible path for the Amazonian gold supply chain so that mining on Indigenous lands is curbed.

The empowerment of Indigenous peoples is recognized worldwide as an important weapon in the fight against climate change, to Amazon conservation (WALKER et al., 2019) and to achieve the Sustainable Development Goals established by the United Nations. Assuring land tenure for Indigenous peoples and supporting their rights have already proved efficient to preserve tropical forests and is considered a positive cost-benefit policy for the country (GARNETT, 2018; FERNÁNDEZ-LLAMAZARES et al., 2020; BARAGWANATH; BAYI, 2020). Further, the involvement of Indigenous peoples in the environmental management of ILs based on their traditional knowledge and supported by the State has great potential to guarantee the survival and maintenance of their ways of life associated with environmental conservation. A good initiative in this area was elaborating the National Policy for Environmental and Territorial Management of Indigenous Lands (PNGATI - Decree No. 7.747 / 2012), with the active participation of Indigenous peoples across the country (BRAZILIAN EXECUTIVE POWER, 2012). The PNGATI provides that the territorial and environmental management of ILs must be carried out by the Indigenous peoples themselves, with autonomy and the State's active support. Within the scope of the PNGATI, each IL must have its own Environmental and Territorial Management Plan elaborated by the resident Indigenous peoples in partnership with governmental and non-governmental entities, aiming to reconcile traditional Indigenous knowledge and the technical support of non-Indigenous knowledge. However, most Amazonian ILs currently lack this plan (SISTEMA DE OBSERVAÇÃO E MONITORAMENTO DA AMAZÔNIA INDÍGENA - SOMAI,). The capacity of Indigenous peoples to cope with environmental threats to their territories is linked with the quantity and quality of resources they have, especially regarding the access to knowledge, the established partnerships, and the accesses to financial resources to carry out IL management. We highlight the urgency of strengthening PNGATI so that Indigenous peoples can be effective actors in the management and environmental protection of Amazonian ILs.

The land tenure regularization of ILs has been an important factor to contain environmental degradation in these territories (BARAGWANATH; BAYI, 2020; INSTITUTO SOCIOAMBIENTAL - ISA, 2019a). However, the new Normative Instruction 9/2020 makes some ILs more vulnerable to environmental threats than others. According to this regulation, areas occupied illegally by non-indigenous squatters can be certified by FUNAI to be in their possession even within Declared and Delimited ILs (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020b). The Delimited and Declared ILs

(Figure 1) that are part of clusters 4, 5, and 6 (Figure 5) suffer intense internal and external environmental threats, and, given this regulation, they are more vulnerable. This measure significantly weakens the guarantee of the right to land to Indigenous peoples who traditionally occupy them and who await land regularization. Such a concern situation is reinforced by the fact that 297 ILs throughout Brazil, under different regularization phases, have part of their legal territory registered with the Rural Environmental Registry (CAR) in the name of private individuals or entities (GUSMÃO; BALDASSA, 2020). In total, 7,739 rural properties included in the CAR overlap with the ILs throughout the country, totaling more than 12,000,000 hectares (GUSMÃO; BALDASSA, 2020).

Finally, several examples of Indigenous mobilization for monitoring and protecting their territories are known in Amazonian ILs, such as the Guardians of the Forest in the Maranhão ILs and the Mundukuru and Kayapó peoples organization to expel invaders (CAMARGOS, 2019). However, we argue that this is not an Indigenous obligation. According to the current context of high exposure to various threats and invaders and the lack of State support in combating the illegal acts in ILs, Indigenous peoples are left under-supported. Several murders and acts of violence against Indigenous peoples have been recorded in recent years, showing these peoples' high vulnerability. The State cannot abandon Indigenous peoples in the fight against invaders. It is not fair that Indigenous peoples have to face criminal actions alone; such illegal activities should be combated and inhibited by the State.

2.4.5 Limitations and future work

We recognize and point out some methodological limitations in our study. First, our approach is limited to the availability of data for different threats. Thus, threats have different time intervals. However, we argue that despite this limitation, the threats considered in this study are represented by the best possible dataset and were compiled in order to establish a correct estimate of these impacts accumulated over the years. Second, the number of k clusters determined in our analysis importantly influences the classification of Indigenous Lands among the clusters. To avoid any biased influence on this result, we have chosen to establish the number of clusters quantitatively, aiming to optimize the variability explained by the variables. In addition, we verified the partitioning of ILs for other k values, and, in all of them, the trend of the clusters formation was maintained.

Third, although the formulation of the mining indicator (absolute number of occurrences of mining activity) is different from other threats, which are based on area, we believe that the number of occurrences better represents the magnitude of this activity in the ILs. We argue that restricting mining occurrences only to occurrences related to polygons of deforested areas does not adequately represent the magnitude of this threat; on the contrary, the magnitude of mining would be underestimated if the other occurrences (points and rivers) were disregarded. The alternative of building a variable from dividing the number of mining occurrences by the IL and BF areas was also evaluated, but this indicator can result in equal values for different threat situations, producing a dubious meaning. In addition, mining is a phenomenon whose threat should not only be measured by the area of the mine itself. Instead, it is a phenomenon whose effect goes beyond the area in which it is observed, as it can cause contamination of rivers and soil, and reduce biodiversity, lead to silting, and cause increased contact between non-Indigenous and Indigenous people (due to a large number of people in these activities) (SONTER et al., 2017; ALVAREZ-BERRIOS; AIDE, 2015; SIQUEIRA-GAY et al., 2020b; SIQUEIRA-GAY et al., 2020a).

Regarding future works on Amazonian ILs, we suggest that it is important to perform temporal analysis of environmental threats, to assess the dynamics of threats and, perhaps, to link the increase in threats to the dynamics of policies. For example, comparing the dynamics of threats to ILs before and after recent political and institutional changes. Further, future studies should perform an environmental vulnerability assessment of these areas, which should include not only exposure to threats but also the adaptive capacity of Indigenous peoples to lead the fight against these threats. In this case, information about the Indigenous people's capacity of organization and articulation is important, which we did not analyze in the present study. Such a study could contribute to the development of special policies to support Indigenous peoples and mitigate environmental impacts in these territories.

2.5 Conclusions

Our results contribute to the effort to understand the specificities of Indigenous Lands in relation to multiple environmental threats and highlight the need for targeted public policies. In this study, we identified and characterized seven distinct IL clusters defined by common environmental threats within and around their boundaries. The environmental threats around Amazonian ILs are substantial, and most ILs are internally affected too. In general, the set of threats in the buffer zones are very similar to the set of threats that affect Indigenous Lands internally. There was a cluster specifically associated with fire, one with mining, some with a high severity for several of the investigated threats, and one cluster that was relatively less threatened.

We point out four environmental policy priorities to be strengthened and applied to Amazonian ILs: protecting ILs' buffer zones; strengthening actions of surveillance and combat in ILs with intense deforestation, forest degradation, and mining; preventing and combating forest fires over ILs; removing invaders from all Amazonian ILs, starting with those intensely occupied by miners and squatters. There is an urgent need to curb illegal activities within these territories. The joint action between FUNAI and IBAMA has previously shown good results in inhibiting environmental infractions in the Amazon and in Indigenous Lands. Strengthening surveillance and combating environmental threats within and around the ILs are essential for the effective protection of these territories and to guarantee the promotion of the Amazonian Indigenous peoples' rights

3 BRAZILIAN AMAZON INDIGENOUS PEOPLES THREATENED BY MINING BILL[5]

3.1 Introduction

The Indigenous Lands (ILs) in the Brazilian Amazon are home to the highest concentration of indigenous peoples in the world, housing close to 355 thousand people divided into more than 150 ethnic groups. Currently, 383 ILs in the Brazilian Legal Amazon[6] region cover more than 1,160,000 km^2, representing 22% of this biome and 98% of the total area of ILs in Brazil. They are territories established by federal jurisdiction to guarantee the land rights of indigenous peoples, their social organization, and the maintenance of their cultural values (TOURNEAU, 2015). Besides, these lands are crucial to preserving tropical forests and the ecosystem services they provide (GARNETT, 2018; WALKER et al., 2014). In recent years, Brazil's political and economic crisis has resulted in the suppression and weakening of territorial and environmental monitoring institutions (ABESSA et al., 2019; PEREIRA et al., 2019). The work of the National Indian Foundation (FUNAI), the federal agency responsible for executing policy and guaranteeing indigenous rights, has been severely hampered by cuts in budgets and staff. Indigenous lands are increasingly under threat from illegal actions (BEGOTTI; PERES, 2019). As the Brazilian government reduced protections in these areas, loggers, farmers, squatters, and gold miners have extensively established illegal occupation in several ILs in the Amazon. Their action has intensified conflicts, environmental degradation, and is placing indigenous peoples in a vulnerable situation (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018). One issue of particular concern is the increasing pressure by the private sector to open ILs for legal mineral exploration (VILLEN-PEREZ et al., 2018; FERREIRA et al., 2014; BEGOTTI; PERES, 2020; COELHO et al., 2017). Intense lobbying action by the mining sector over the Brazilian government is threatening indigenous territories, especially in the Amazon (AGÊNCIA CÂMARA DE NOTÍCIAS, 2020a; ANGELO, 2020a).

Mining is an activity that causes intense socio-environmental impacts (HILSON, 2002; HOROWITZ et al., 2018). The mining infrastructure (digs, roads, railways, tailings dams, and waste piles) causes significant environmental damage (HOROWITZ et

[5]This chapter is based on the paper: Rorato, A. C., Camara, G., Escada, M. I. S., Picoli, M. C., Moreira, T., Verstegen, J. A. (2020). Brazilian amazon indigenous peoples threatened by mining bill. Environmental Research Letters, 15(10), 1040a3.

[6]The so-called Brazilian Legal Amazon (BLA) is a political-administrative region covering approximately 5 million km^2. The BLA comprises the states of Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), Roraima (RR), Mato Grosso (MT), Tocantins (TO), and part of Maranhão (MA) (BRAZILIAN EXECUTIVE POWER, 1966).

al., 2018). Besides, mineral exploration contaminates waterways, soil, and wildlife through toxic waste and heavy metals released into the environment, threatening the health of and food availability to indigenous peoples (VEGA et al., 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; HOROWITZ et al., 2018). In addition, studies show that mining increases deforestation in the Amazon region (ALVAREZ-BERRIOS; AIDE, 2015; SONTER et al., 2017; ASNER; TUPAYACHI, 2017). In mining concession areas, deforestation is three times larger than the average rate of nearby regions and the impacts of mining on deforestation extend up to 70 km beyond the limits of mining concessions (SONTER et al., 2017).

The intended opening of ILs to mining has the potential to increase the vulnerability of indigenous peoples. Recently, attacks and acts of violence against indigenous peoples have increased; particularly those arising in the context of large-scale projects involving extractive industries (UNITED NATIONS, 2018). According to a recent report published by (GLOBAL WITNESS, 2020), mining was the sector linked to the most murders of environmental activists and human rights defenders, with 50 killed in 2019. Brazil has the third highest number of murders of environmental defenders. In 2019, of the 24 defenders killed in the country, 10 were indigenous. Like the cases of the murders of the indigenous leadership Emyra Wajãpi, of the Wajãpi ethnic group, in July last year, and of the two Yanomami indigenous youths, in June this year, murdered by illegal gold miners present in their lands (OIVEIRA, 2020; PHILLIPS, 2019).

Brazil's 1988 Constitution includes a provision that mining rights in indigenous lands could be granted if regulated by law. Until recently, the political consensus in Brazil considered that the social risks of allowing mining in ILs outweighed possible economic benefits; thus, no law regulating such activities has been approved by the Brazilian Congress. However, Brazil's current government has since come out on the side of the mining sector; it is pressuring the Brazilian Congress to pass a law favoring the mining sector's interests (AGÊNCIA CÂMARA DE NOTÍCIAS, 2020a; ANGELO, 2020a).

In February 2020, Brazil's president Jair Bolsonaro sent a bill to Congress (Projeto de Lei - PL 191/2020) that regulates the opening of indigenous lands for economic exploration (BRAZILIAN EXECUTIVE POWER, 2020). The proposed legislation sets conditions for private activities in these areas with a particular focus on commercial mining. The bill does not cover social, cultural, or health matters. It sets conditions for mining of mineral resources in ILs and financial compensation to indigenous peoples.

According to the bill, indigenous populations would be consulted before the start of activities; however, they would have no veto power to extensive mining. Should this legislation be approved, mining would become a significant socio-environmental threat to indigenous peoples and their territories in the future (VILLEN-PEREZ et al., 2018; HOROWITZ et al., 2018; VILLEN-PEREZ et al., 2020).

The mining bill contradicts the Declaration on Rights of Indigenous Peoples of the United Nations (UN), which Brazil has signed (UNITED NATIONS GENERAL ASSEMBLY., 2007). Under this Declaration, indigenous peoples have the right to Free, Prior, and Informed Consent, which allows them to agree or reject a project that affects their livelihoods. Such rights are also enshrined in the Indigenous and Tribal Peoples Convention No.169 of the International Labour Organization (INTERNATIONAL LABOUR ORGANIZATION – ILO, 1989), which was ratified by Brazil in 2004. Despite these violations of international treaties to which Brazil is a part of and the rejection of the vast majority of the indigenous peoples to open their lands for mining, there is intense pressure for the bill to be approved by the Brazilian Congress. Given this imminent threat, this work evaluates the risks to the Amazonian indigenous peoples of the proposed mining expansion in their territories and compares it with current illegal mining in these areas.

3.2 Methods

3.2.1 Data

3.2.1.1 Indigenous Lands

The polygon data set with limits for all ILs in Brazil was obtained from the FUNAI website (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a). This layer also contains information about the ethnic groups living in each IL.

In this study, we considered all ILs entirely within the Legal Amazon with any legal status. The legal status refers to the recognition status of the indigenous peoples' rights to land by the State. The recognition process of indigenous territories comprises several steps and generally takes several years. Currently, in the Legal Amazon, 325 ILs are Regularized while the rest is in one of the following recognition stages, listed from the earliest step: In Study (6), Delimited (11), Declared (31), Forwarded with Indigenous Reserve (7), and Homologated (3) (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a). A detailed description of the stages of the indigenous lands recognition process is presented in Table A.1 in Appendix.

3.2.1.2 Illegal mining and deforestation in ILs

Data on current mining areas in the Legal Amazon were obtained from the Real-time Deforestation Detection System (DETER) from the Brazilian National Institute for Space Research (INPE) (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). These data refer to evidence warnings of forest cover change between August 2016 to April 2020. Deforested areas are mapped when satellites detect the withdrawal of native forests, then these areas are classified into the following classes: selective cut (geometrical and disordered), degradation (burning scar and degradation), clear-cut deforestation, deforestation with vegetation, and mining (DINIZ et al., 2015). The DETER system operates with a spatial resolution of around 60 m. This resolution allows monitoring with a minimum area of 3 ha mapping. In the present study, we considered only the deforested areas classified as mining in the years fully available (2017, 2018, 2019) to explore the number and area of mining polygons inside ILs. Since mining is prohibited within ILs, all mining polygons are considered to be illegal mining areas. Data on increments of deforestation in the same region and time frame were obtained from Amazon Deforestation Monitoring Program (PRODES) also from INPE (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a). The mapping scale of the deforested data from PRODES and DETER, as well as the boundaries of indigenous lands from FUNAI, is 1:250000.

3.2.1.3 Potential mining exploitation areas

The mining activity in Brazil is regulated by a process of licensing mediated by Brazil's National Mining Agency (ANM) (AGÊNCIA NACIONAL DE MINERAÇÃO – ANM., 2020). This process encompasses several phases, from mineral research authorization until the final step that configures the approval of licensing to exploitation. A mining request consists of an administrative process applied to ANM, in which an area, geographically delimited by a polygon defined by the applicant, is requested for mineral exploration.

The georeferenced mining requests were obtained from the ANM database on February 17, 2020 (AGÊNCIA NACIONAL DE MINERAÇÃO – ANM., 2020). The polygon data file, publicly available from the ANM, contains all mining processes, approved or under consideration, with their respective information, such as the applicant's name, the mineral to be exploited, and the licensing-process phase it is in. We separated the mining requests processes by this "phase" attribute, only selecting the polygons in one of the following phases: research requirement, research authorization, availability, mining requirement, gold digger mining requirement, licensing requirement, extraction registration requirement, and right to request mining. Our final selection thus contains all pending mining licensing applications that have not yet been approved.

Although mining is currently forbidden in indigenous lands, there is a large number of applications for mineral exploration licenses in ILs registered in ANM, pending a change in the law. The first mining requests overlapping indigenous lands date back to 1971 (Figure A.2 Appendix). It is noteworthy that many of these indigenous lands had not yet been regularized when part of these requests was made. However, even after the regularization of these areas as indigenous lands, requests for mineral exploration remain on the ANM registry and can be approved if the legislation permits.

For comparison of the requested minerals, information on current mineral exports and tax collection were obtained in the Mineral Sector Report - First Quarter 2020, of the Brazilian Mining Institute (INSTITUTO BRASILEIRO DE MINERAÇÃO - IBRAM., 2020).

3.2.2 Estimating indigenous lands and ethnic groups at risk by the potential mining exploitation

To evaluate the possible impact of the new mining bill, we included mining requests that have an overlap of 5% or more with an IL. We consider this minimal overlap between the mining areas and ILs to avoid inconsistencies in georeferencing of the IL and mining requests layers. The two layers, ILs and mining requests were clipped with the boundary of the Legal Amazon region, obtained from the Ministry of the Environment database (BRASIL. MINISTÉRIO DO MEIO AMBIENTE, 2020). For the ILs with an affected area of more than 30%, the area covered by mining requests is presented in (Table 3.1).

In addition, we evaluated the risk of each ethnic group to be affected by mining. In the Legal Amazon region, 155 ethnic groups are divided over 383 ILs. Different ethnic groups can inhabit a single IL and a single ethnic group can be present in more than one IL. First, we calculated the total territory occupied by each ethnic group considering the sum of the area of ILs inhabited by each group. Thereafter, we calculated the respective area of each group territory covered by mining requests.

In the same way, we also computed the relative contribution of each mineral to be exploited to the total mining requests in the territories of the ethnic groups. For visualization purposes, we only list the 9 minerals with the largest relative area separately while all others are grouped into the 'other' category. To avoid overestimation due to overlapping mining requests, we converted the potential mining polygon data to raster, using the ArcGIS "polygon-to-raster" tool. In this conversion, the choice of features overlapping the same cell was based on the smallest feature identification (FID) number (i.e. the identification code for all georeferenced mining requests). Since FIDs are given out in order, the lowest FID number refers to the first request of mining in that area. The mining requests registered with ANM can be considered as a kind of "waiting list" and, once the law is authorized, the list will dictate the priority of the mining companies' requests. Therefore, our approach obtains the mining request most likely to be granted. Next, we applied the "tabulate area" function in ArcGIS using the raster with the values of the minerals and the vector data of the ILs. Thus, the resulting table provided the area of each mineral in each IL, without overlap. All analyzes and maps were conducted using R (R CORE TEAM, 2014) and ArcGIS 10.4 (ESRI, 2016).

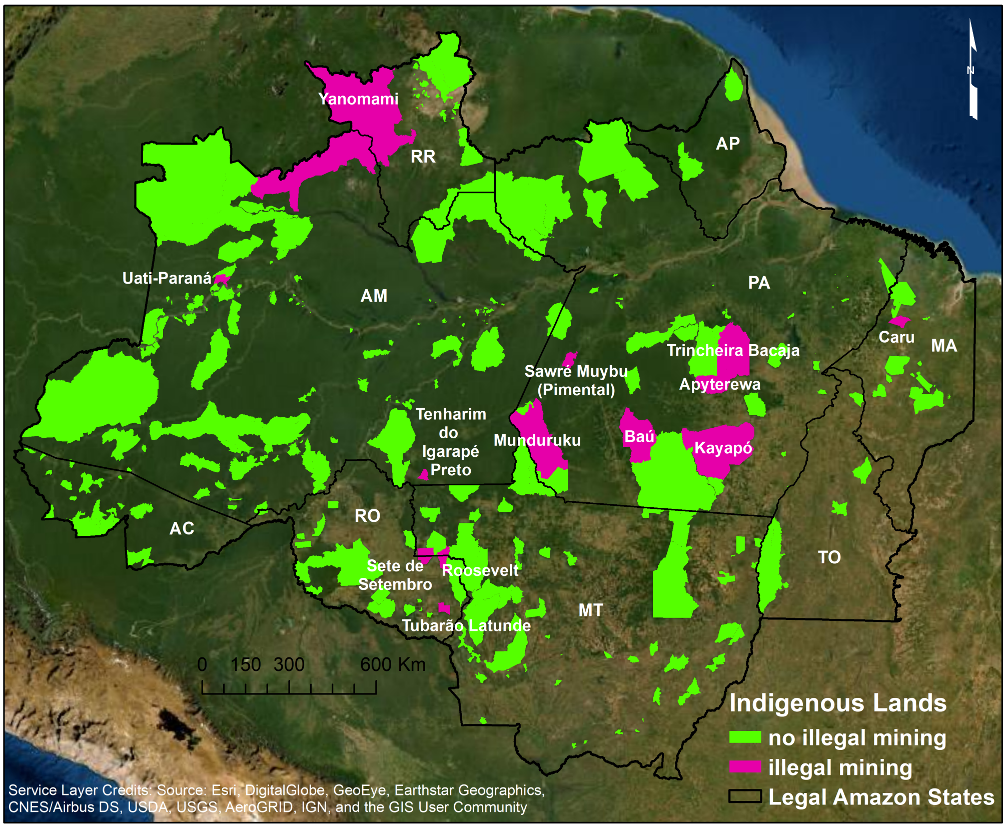
3.3 Results and discussion

3.3.1 Current illegal mining in indigenous lands

Currently, mining inside ILs is prohibited. Yet, the encroachment of illegal mining in indigenous territories has been increasing in the last three years (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). This activity has been encouraged by the current rise in the value of gold (WORLD GOLD COUNCIL, 2020), the favorable signs from the government, and reduced surveillance of the ILs. According to our analysis of data from the Real-time Deforestation Detection System (DETER), 551 deforested areas classified as mining were detected in 13 Amazonian ILs between 2017 and 2019 (2017 = 92; 2018 = 155; and 2019 = 304) totaling 57.8 km^2 (Figure 3.1 and 3.2A). These ILs are mainly concentrated in the state of Pará (Figure 3.1). The illegal mining that occurs in these ILs is mainly related to artisanal gold-mining (COELHO et al., 2017; CAMARGOS, 2019).

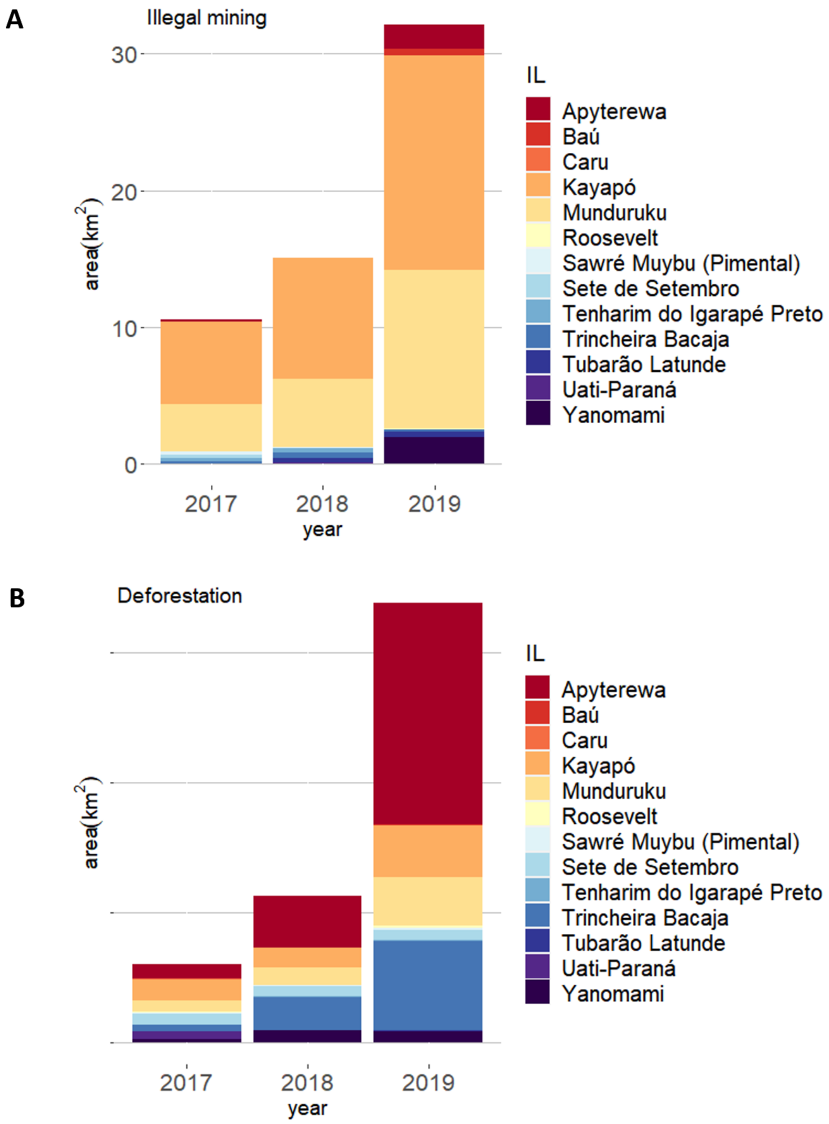
The Amazon Deforestation Monitoring Program (PRODES) detected that yearly deforestation increased by 458% between 2017 and 2019 in these ILs, from 30.3 km^2 in the first year to 169.1 km^2 in the latter, totaling 255.6 km^2 in this period (Figure 3.2B). Part of these deforested areas represent the direct and short-term impacts of mineral exploration. For example, in Apyterewa IL, deforestation is mainly related to land-use change for agricultural activities by illegal non-indigenous squatters, while, in Kayapó and Munduruku ILs, a large part of deforestation is associated with illegal mining activity. Besides the direct effect of deforestation, the indirect effects of mining have the potential to cause several long-lasting environmental impacts (HOROWITZ et al., 2018), such as forest fragmentation and degradation in relatively undisturbed regions with negative impacts on biodiversity (SIQUEIRA-GAY et al., 2020b). The total areas detected by DETER and PRODES for the three years are detailed in Tables A.3 and A.4 in the Appendix.

Figure 3.1 - Indigenous lands with illegal mining detected by DETER between 2017–2019. In white are indicate the names of the indigenous lands with illegal mining and the abbreviations of the states of the Legal Amazon region.



SOURCE: Data from Fundação Nacional do Índio - FUNAI (2019a); Instituto Nacional de Pesquisas Espaciais - INPE (2020b).

Figure 3.2 - Illegal mining and deforestation within indigenous lands in the Legal Amazon between 2017–2019. Illegal mining areas detected by DETER (A), deforested areas detected by PRODES (B).



SOURCE: Data from Instituto Nacional de Pesquisas Espaciais - INPE (2020a, 2020b); Fundação Nacional do Índio - FUNAI (2019a).

3.3.2 Indigenous lands potentially affected by mining bill

Given that mining in ILs is prohibited, currently only mining requests outside of ILs are approved (Figure 3.3A). To evaluate the possible impact of the new mining bill, we consider all mining license requests (registered in ANM) that overlap ILs as potential mining areas in the future. Until February 2020, no less than 2760 mining requests overlap ILs in the Brazilian Amazon, covering a total area of $\approx$ 176.9 thousand km^2 (Figure 3.3B). Mining requests in ILs represent 6.7% of the total of 41,413 existing requests for the entire Legal Amazon and 17% of the total requested area (Figure 3.3B). Considering only these existing requests, about 15% of the total area of ILs in the region could be directly affected by mining if the bill is approved. When compared the total illegal mining area in ILs verified between 2017 and 2019, the proposed new law has the potential to increase the mining area within ILs by 305,728%. In total, 66 ILs have more than 1 % of their total area overlaid with requested mining areas. Herein, 16 ILs have more than 80% of their area covered by potential mining areas, 7 ILs have between 60 and 80%, 7 ILs have between 40 and 60%, 12 ILs have between 20 and 40%, and 24 ILs have between 1 and 20%. The Pará (PA) and Roraima (RR) states have the largest area at risk (Figure 3.3C).

Four ILs – Cajueiro (RR), Araça (RR), Boqueirão (RR), and Aningal (RR) – have over 98% of their area covered by mining requests (Figure 3.3C; Table 3.1). Other ILs with substantial potential impact are Truaru (RR), Barata Livramento (RR), Sucuba (RR), Pium (RR), Xikrin do Rio Catete (PA), Anta (RR), Baú (PA) and Mangueira (RR); mining requests overlap 90% or more of these lands. In terms of size (absolute area), the ILs with the highest areas of incidence of mining requests are Yanomami (RR), Menkragnoti (PA/MT), Baú (PA), Parque do Tumucumaque (PA), and Kayapó (PA) (Figure 3.3C; Table 3.1).

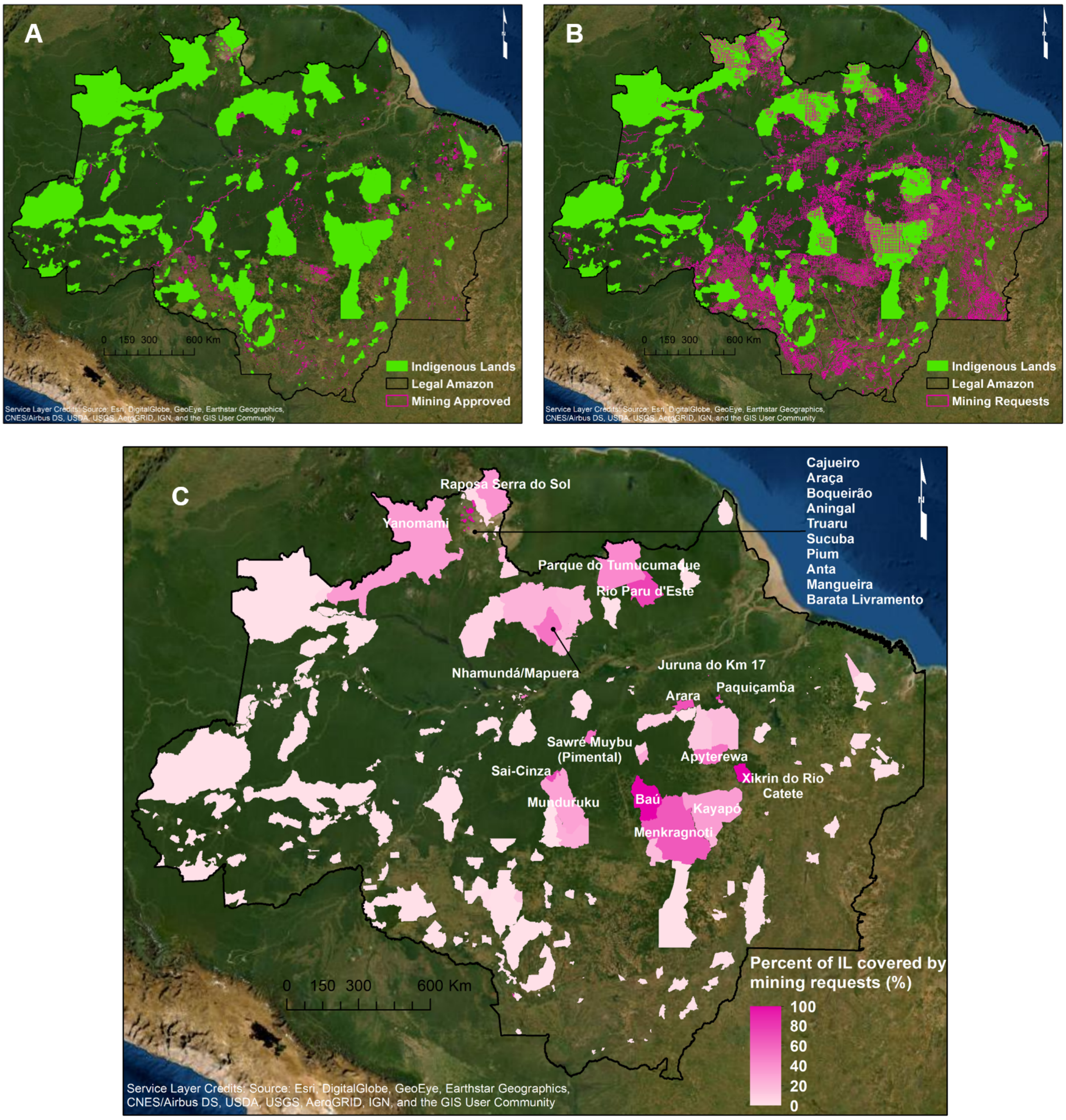
Most indigenous lands where illegal mining was detected by DETER (Figure 3.1) have mining requests inside their limits. Among them, the most affected are Apyterewa IL with 54.5% of its area requested to mining, Baú with 92.4%, Kayapó 33.4%, Munduruku 31.4%, Sawré Muybu (Pimental) 56.8%, and Yanomami 34.4%. The main minerals requested for exploration in these ILs, in terms of relative area and in decreasing order, are gold, iron, copper, silver, and tin. The other ILs with detected illegal mining – Caru, Tenharim do Igarapé Preto, Tubarão Latunde, and Uati-Paraná – do not have mining requests.

Table 3.1 - Area and percentage of Indigenous lands covered by mining requests. Only Indigenous lands with an affected area of more than 30% are listed.

Indigenous Lands	**Ethnic group**	**Legal status**	**Area (km^2)**	**Requested mining area (km^2)**	**Requested mining area (%)**	**Illegal mining area (km^2)**
Cajueiro	Makuxí	R	43.04	42.72	99.26	
Araça	Wapixana	R	500.18	494.30	98.82	
Boqueirão	Makuxí, Wapixana	R	163.54	160.89	98.38	
Aningal	Makuxí	R	76.27	74.89	98.19	
Truaru	Makuxí, Wapixana	R	56.53	54.73	96.82	
Barata Livramento	Makuxí, Wapixana	R	128.83	124.48	96.62	
Sucuba	Makuxí	R	59.83	57.37	95.89	
Pium	Wapixana	R	46.08	43.67	94.77	
Xikrin do Rio Catete	Kayapó	R	4391.51	4066.06	92.59	
Anta	Wapixana	R	31.74	29.37	92.55	
Baú	Kayapó	R	15409.30	14241.10	92.42	0.50
Mangueira	Makuxí	R	40.64	36.85	90.68	
Paquiçamba	Yudjá	DC	157.33	135.14	85.90	
Anaro	Wapixana	R	304.74	258.67	84.88	
Paquiçamba	Yudjá	R	43.84	35.85	81.76	
Raimundão	Makuxí, Wapixana	R	42.77	34.78	81.33	
Juruna do Km 17	Yudjá	FI	23.82	18.51	77.69	
Paukalirajausu	Nambikwára	DL	84.00	64.72	77.05	
Rio Paru d'Este	Wayana, Apalaí	R	11957.86	9026.03	75.48	
Sai-Cinza	Mundurukú	R	1255.52	916.23	72.98	
Arara	Arara do Pará	R	2740.10	1915.22	69.90	
Praia do Índio	Mundurukú	FI	0.32	0.21	66.76	
Menkragnoti	Kayapó	R	49142.55	32301.12	65.73	
Sawré Muybu (Pimental)	Mundurukú	DL	1781.73	1012.14	56.81	0.40
Apyterewa	Parakanã	R	7734.70	4218.97	54.55	1.99
Nhamundá/Mapuera	Hixkaryána, Wai Wai	R	10495.20	5700.82	54.32	
Karajá Santana do Araguaia	Karajá	R	14.86	7.88	53.03	
Arara da Volta Grande do Xingu	Arara do Pará	R	255.25	128.87	50.49	
Jauary	Múra	DL	248.31	124.02	49.95	
Parque do Tumucumaque	Wayana, Apalaí	R	30710.68	13304.22	43.32	
Raposa Serra do Sol	Taulipáng, Makuxí, Ingarikó, Wapixana	R	17474.65	6850.00	39.20	
Yanomami	Yanomámi	R	96649.75	33262.77	34.42	1.95
Kayapó	Kayapó	R	32840.05	10962.70	33.38	30.48
Munduruku	Mundurukú	R	23817.96	7475.00	31.38	20.01

R = Regularized, **DL** = Delimited, **DC** = Declared, and **FI** = Forwarded with IR.

Figure 3.3 - Mining areas in the Legal Amazon region as of February 2020. Approved mining areas (A), requested mining areas (B), and percentage of ILs covered by mining requests (C).



SOURCE: Data from Fundação Nacional do Índio - FUNAI (2019a); Agência Nacional de Mineração - ANM (2020).

3.3.3 Ethnic groups at risk

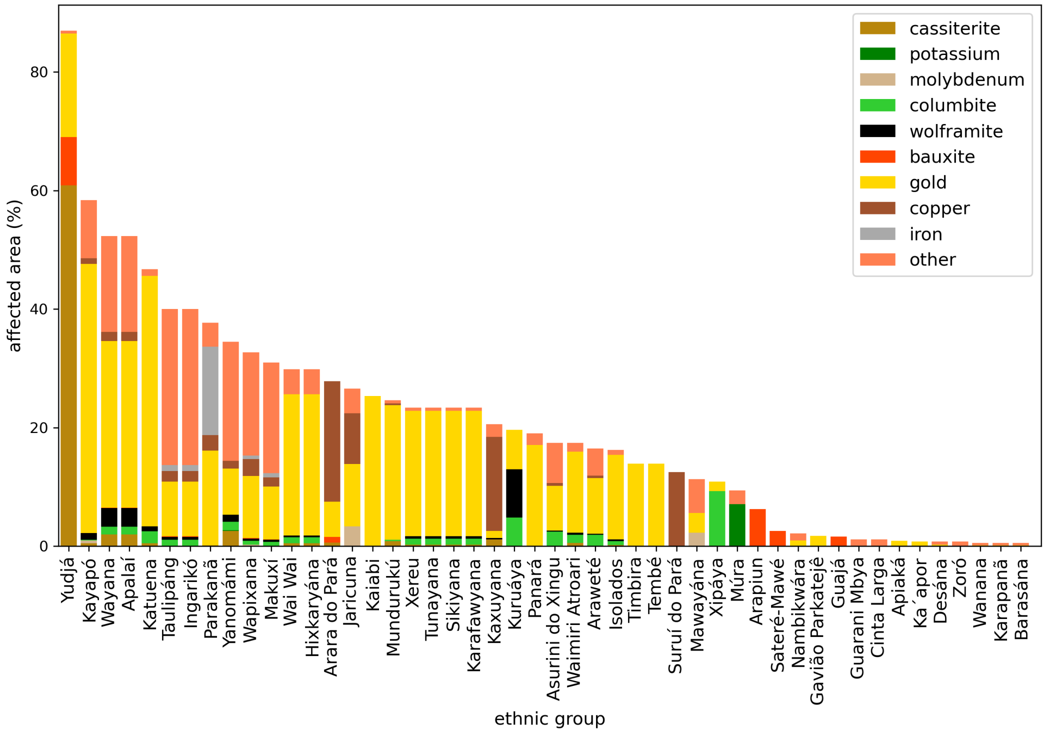
Our results indicate that the Yudjá ethnic group is the potentially most affected by mining, with around 87% of territory overlapped by requested mining areas (Figure 3.4). Other important concerned ethic groups are the Kayapó, Apalaí, Wayana and Katuena indigenous peoples with 58%, 52%, 52%, and 47% of their territories to be affected. In terms of territorial size, the ethnic groups with the highest area of mining requests in their territories are Kayapó with $\approx$ 62.3 thousand km^2, Yanomami with $\approx$ 33.3 thousand km^2, Apalaí and Wayana with $\approx$ 22.3 thousand km^2, and Katuena with $\approx$ 18.6 thousand km^2.

In total, the mining requests cover 75 different minerals. Around 64% of the total mining area requested within ILs is for gold exploitation, followed by copper (3.7%), columbite (3%), wolframite (2.4%), and cassiterite (2.2%) (Figure 3.4). Iron ore, which dominated around 66% of Brazil's mineral exports and 77% of tax collection in the first quarter of 2020, according to the (INSTITUTO BRASILEIRO DE MINERAÇÃO - IBRAM., 2020), accounted for only 0.76% of the requested mining areas in ILs. In contrast, gold represented 14% of exports and only 6% of total tax collection in the same period.

Up to now, in particular the Munduruku and Kayapó peoples have suffered intensely from illegal mining in their territories (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018). Among 551 illegal mining areas detected in indigenous territories between 2017 and 2019, 497 occurred only in the Munduruku and Kayapó ILs in Pará. In the Munduruku IL, there was a 239% increase in the illegal mining area in this period, totaling 20 km^2 (Figure 3.2A), spread over 211 different mining areas (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). While in the Kayapó IL, the increase of illegal mining was 161%, totaling an area of 30.5 km^2 distributed over 286 mining areas. Together, Kayapó (35.9 km^2) and Munduruku ILs (29.2 km^2) accounted for 25% of total deforestation in ILs occupied by mining activity in this period (figure 3.2B). Due to the invasions of their territories, without alternatives and in the absence of government protection, the Kayapó and Munduruku peoples are organizing themselves to monitor and expel the illegal miners from their lands. They created groups responsible for patrolling their territories, destroying bridges, and removing machinery used by the invaders, risking their own lives (CAMARGOS, 2019).

For the legal mining that may be allowed under the new bill, the Yanomami people are facing 448 mining license requests, the largest number among all ILs. For these

Figure 3.4 - Percentage of ethnic group territories covered by mining requests. Colour indicates the mineral. Only ethnic groups with an affected area of more than 0.5% are shown.



SOURCE: Data from Fundação Nacional do Índio - FUNAI (2019a); Agência Nacional de Mineração - ANM (2020).

people, the strong pressure on their territory through the invasions by gold miners and the negative impacts on the population is an old reality. In the 80 and 90s, high mortality rates among the Yanomami people were registered due to the transmission of diseases by illegal miners (TOURNEAU, 2015; HILSON, 2002). Also, recent research has found that some Yanomami groups are contaminated by mercury, a toxic chemical residue from illegal gold mining in their territory (VEGA et al., 2018). According to DETER, 13 new deforested areas to illegal mining were detected in 2019 and 4 until April 2020. This may be an underestimation, because illegal mining in this IL takes place mainly through ferries and dredges floating in rivers, making detection by remote monitoring systems difficult. As reported in recent months, there are records that around 20,000 gold miners are working illegally in Yanomami IL, increasing the tension of the conflict, the impacts of mining, and the risk of spreading diseases to the indigenous population (PHILLIPS, 2020; INSTITUTO SOCIOAMBIENTAL - ISA, 2020).

3.3.4 The road ahead

In countries where mining in indigenous territories has been legalized, such as the United States, Australia, and Canada, several negative impacts have affected indigenous peoples (HOROWITZ et al., 2018; MILANEZ, 2020), such as the demographic changes caused by the migration of foreign workers (HILSON, 2002), the increased exposure of indigenous peoples to diseases (HILSON, 2002; TOURNEAU, 2015), a displacement from their territories, the establishment of new frontiers for urban development, and the fact that indigenous people are co-opted to work in mining, resulting in a break in the social dynamics of these peoples (HILSON, 2002; HOROWITZ et al., 2018; MILANEZ, 2020).

To try to avoid similar problems from what is happening in Brazil, indigenous organizations are articulating themselves to resist. One month after the federal government proposed the mining bill, indigenous leader Davi Kopenawa Yanomami filed a complaint against government violations of the rights of indigenous peoples at the United Nations Human Rights Council (CHADE, 2020). The complaint aimed to alert the international community about the vulnerable situation of indigenous peoples in Brazil and about the recent threat of the proposed mining bill. Likewise, some indigenous leaders have already met with the president of the National Congress requesting that the mining bill not be voted on (AGÊNCIA CÂMARA DE NOTÍCIAS, 2020b).

However it's not enough, institutions such as FUNAI and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) must be strengthened and their actions must be strongly supported by the government. Joint inspection operations, punishment, and expulsion of those responsible for illegal mining in indigenous lands must be carried out in an exemplary manner, showing that such activity cannot be admitted in these areas. Complementary, we believe that organized actions by civil society are also important, adopting the values of a market-based society (NEPSTAD et al., 2014). For this, it's important to put pressure on large mining companies and other companies that are part of the mineral production chain to join this initiative. The international public opinion combined with civil society is crucial helping to pressure the Brazilian government to avoid legal mining in indigenous lands. The combination of public actions based on a command and control strategy and private supply chain arrangements proved to be highly effective in reducing deforestation rates in the Amazon from 2004 to 2012.

3.4 Conclusion

Preserving the indigenous lands of the Brazilian Amazon is essential to safeguard the rights of close to 355 thousand indigenous people and their 155 ethnic groups. Their livelihoods and culture have their rights guaranteed in the Brazilian Constitution and various international treaties that Brazil has signed. Still, requested mining areas cover around 176,000 km^2 of indigenous lands. If turned into law, the mining bill proposed by the current Brazilian government is likely to cause major social and environmental degradation in these areas. There is a high risk of land conflicts involving indigenous territories, further exposing indigenous peoples to rural violence, contamination by toxic pollutants, and contagious diseases. Furthermore, substantial environmental impacts in these territories can be expected, such as extensive deforestation, loss of local biodiversity, and contamination of rivers and soil. Financial compensation cannot compensate for the loss of welfare, livelihoods, and the violation of rights of indigenous peoples. Brazil has sound strong environmental legislation. The obligation of the government is to enforce existing laws and regulations that put indigenous rights and livelihoods above economic consideration and not to reduce such protections.

4 ENVIRONMENTAL VULNERABILITY ASSESSMENT OF BRAZILIAN AMAZON INDIGENOUS LANDS

4.1 Introduction

In recent decades, the vulnerability of socio-ecological systems has become a prominent theme in the fields of science related to sustainability and global environmental and climate change. (TURNER et al., 2003a; FÜSSEL, 2007; HINKEL, 2011; MCCARTHY et al., 2001; PARRY et al., 2007; NGUYEN et al., 2016; LAPOLA et al., 2020). Diverse research areas in natural and social science have used vulnerability approaches in different contexts, resulting in a wide range of vulnerability definitions and methods found (ADGER, 2006; TURNER et al., 2003a; GALLOPÍN, 2006; NGUYEN et al., 2016; JURGILEVICH et al., 2017). Despite the challenges that exist in estimating the vulnerability of human and environmental systems, because it is not an observable phenomenon, vulnerability assessments have the potential to identify vulnerable regions or population groups, provide information to monitoring strategies, and have an important role in guiding the formulation of adaptation plans to climate and environmental change (NGUYEN et al., 2016).

The theoretical framework on vulnerability to climate change from the Intergovernmental Panel on Climate Change (IPCC) (MCCARTHY et al., 2001; PARRY et al., 2007) provides a starting point to guide the development of vulnerability assessments. In the IPCC Third and Fourth Assessment Reports, the Vulnerability was defined as the degree to which a system is susceptible to suffer damage or the lack of capacity to cope with adverse effects when exposed to change. In this conception, Vulnerability is understood as a function of the Sensitivity and Adaptive Capacity of systems (which can be human, environmental, or human-environmental systems) when they are exposed to threats or changes.

Adopting the IPCC vulnerability framework (MCCARTHY et al., 2001; PARRY et al., 2007), a growing number of vulnerability assessments has been developed in a wide range of scales, from local, regional, national, and global extent, and approaching different social and environmental contexts. Such studies arise to estimate the vulnerability of populations living in extreme poverty (LEICHENKO; SILVA, 2014); the vulnerability of ecosystem services (METZGER et al., 2006); the rural livelihood vulnerability (EAKIN; BOJÓRQUEZ-TAPIA, 2008); the vulnerable situation of populations in the face of environmental and climate change (CUTTER et al., 2003; O'BRIEN et al., 2004; PANDEY et al., 2017; BANKOFF et al., 2004); as well as the vulnerability of economic sectors (ALLISON et al., 2009) and agricultural production (VELÁZQUEZ-

ANGULO, G.; RODRÍGUEZ-GALLEGOS, H. B.; FLORES-TAVIZÓN, E.; FÉLIX-GASTÉLUM, R.; ROMERO-GONZÁLEZ, J.; GRANADO-OLIVAS, A., 2017) to climate change.

The Indigenous Lands (ILs) in the Brazilian Legal Amazon (BLA) region[7] are home the largest concentration of indigenous peoples in the world and are currently a worrying case of a vulnerable human-environmental system due to the environmental threats they have been suffering (REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020; CARNEIRO FILHO, A. and SOUZA, O. B., 2009; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). The ILs in the BLA (hereafter, referred to as Amazonian ILs) cover over 1,160,000 km^2, representing 22% of this region (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2020a; INSTITUTO SOCIOAMBIENTAL - ISA, 2019b) and play a fundamental role in guaranteeing indigenous peoples the right to land that they traditionally occupy and its rich cultural diversity (BEGOTTI; PERES, 2020). At the same time, Amazonian ILs are crucial for an effective global strategy to preserve tropical forests, with the potential to contribute to climate change mitigation and conservation of biodiversity (WALKER et al., 2014; GARNETT, 2018; BARAGWANATH; BAYI, 2020; FERNÁNDEZ-LLAMAZARES et al., 2020).

Historically, Amazonian ILs face internal and external pressure from multiple environmental threats and varying severity (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Hereto, environmental threats are defined as the degrading processes or activities that contribute to environmental degradation and reduce the environmental integrity of ILs, as adopted earlier in Chapter 2. Among the most important environmental threats affecting ILs are those related to forest cover reduction, such as deforestation, forest degradation, and fires, as well as the facility of access provided by roads, and the advancing of economic activities such as logging, mining, agriculture and livestock (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; RORATO et al., 2020). The combination of threats that advances on each Amazonian IL is the result of the historical context in which the IL is inserted, such as the historical process of occupation of the region and the IL itself. In this way, different

[7]The so-called Brazilian Legal Amazon (BLA) is a political-administrative region covering approximately 5 million km^2. The BLA comprises the states of Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), Roraima (RR), Mato Grosso (MT), Tocantins (TO), and part of Maranhão (MA) (BRAZILIAN EXECUTIVE POWER, 1966).

exposure and sensitivity histories for heterogeneous sets of environmental threats at different degrees of severity, added to the response capacity of indigenous populations, influence the level of environmental vulnerability in Amazonian ILs.

In the past, Amazonian ILs have shown to be important barriers to deforestation, containing deforestation even in places with high deforestation pressure (NOLTE et al., 2013). However, in recent years, there has been a substantial increase in fires and deforestation rates across these territories (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020c; ALENCAR et al., 2019). According to INPE's Amazon Deforestation Monitoring Program (PRODES), around 260.6 km^2 were deforested within the Amazonian ILs in 2018, while in 2019, deforestation in these territories reached around 497.4 km^2; showing an increase of 90.9 % between these two years. Following this trend, the invasions for land speculation and illegal exploitation of natural resources have also increased (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Amazonian ILs have been encroached by illegal loggers, farmers, squatters, and gold miners, placing indigenous peoples at greater vulnerability and aggravating environmental degradation in these areas (CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019; BEGOTTI; PERES, 2019).

To date, two studies have attempted to investigate the risk (WALKER et al., 2014) or the vulnerability situation (LAPOLA et al., 2020) of Amazonian Indigenous Lands combined with other categories of protected areas (PAs). Walker et al. (2014) performed a spatially explicit risk assessment to investigate the risk situation of carbon stocks in different categories of PAs and ILs in the Amazon Basin. They mapped the distribution of current and potential risk factors (i.e., agriculture, grazing, mining, petroleum, timber, and transportation) in these areas and surroundings. However, the study did not quantify the importance of each risk factor nor estimate the PAs' and ILs' degree of vulnerability. To investigate the vulnerability of PAs and ILs in Brazil to climate change, Lapola et al. (2020) developed a vulnerability assessment combining climatic-change hazard indicators with indicators of PAs and ILs resilience (size, native vegetation cover, and the probability of climate-driven vegetation transition). According to the results, 80% of the areas of high or moderate vulnerability to changes induced by climate change are ILs.

Despite the important contribution of these studies, there is a gap in the knowledge of the current vulnerability situation of Amazonian ILs regarding the multiple threats involved in the environmental vulnerability of these territories, not only for climate change. Given the worsening threats over Amazonian ILs, Brazil requires scientific studies of indigenous territories' environmental vulnerability to support the current and future application of public policy strategies. In addition, to identify those most vulnerable ILs in the Amazon is crucial for better allocation of conservation measures, to the compliance with international human rights commitments, and so allows directing adequate safeguards to protect them. This study aims to contribute to filling this knowledge gap by providing the first assessment of the environmental vulnerability of Amazonian ILs.

Hereto, we adopted the vulnerability theoretical framework of IPCC (MCCARTHY et al., 2001; PARRY et al., 2007) in an indicator-based approach to describe the main threats involved in the environmental vulnerability of Amazonian ILs and the adaptive capacity of indigenous peoples to deal with these threats. The threat indicators were quantified using maps and data of deforestation, forest degradation, land-use, fire, roads, and mining, inside and around the ILs. These indicators were compiled for three periods (2001-2019, 2001-2010 and 2011-2019) to assess ILs' Vulnerability and temporal changes in Exposure and Sensitivity patterns. Adaptive Capacity, or capacity of response, was estimated through proxies indicators that represent indigenous self-organization, level of education, access to knowledge, land ownership, external income, and institutional arrangement. In this study, we intend to answer the following questions about the vulnerability of Amazonian ILs: *i) What is the environmental vulnerability of ILs in the Amazon? and ii) How have the exposure and sensitivity of Amazonian ILs to environmental threats changed in the past ten years?*

4.2 Methods

4.2.1 Theoretical framework and scope

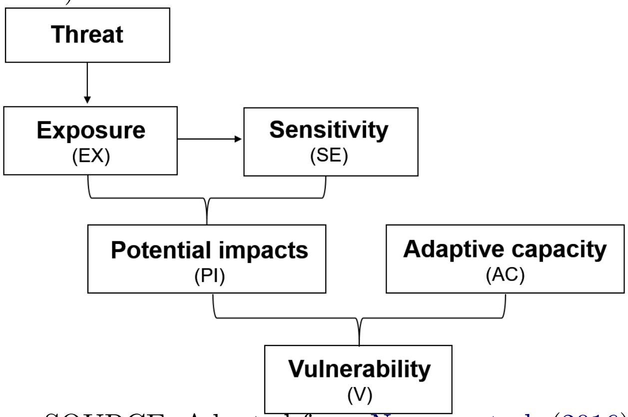
The concept of vulnerability in the environmental and climate change context arises from the approach used in the natural hazards research field (ADGER, 2006; NGUYEN et al., 2016). Studies about the risk of hazards or natural disasters tend to focus on the concept of risk and the likelihood of a specific threat; those from the social sciences and climate change field often prefer to use the term vulnerability of systems (NGUYEN et al., 2016; JURGILEVICH et al., 2017). Conceptually, the vulnerability of a system depends on the nature of the threat to which the system in question is exposed and the system's sensitivity that will make it more vulnerable to certain types of threats than to others (GALLOPÍN, 2006).

In the IPCC Third and Fourth Assessment Reports (MCCARTHY et al., 2001; PARRY et al., 2007), the vulnerability of a system is described to be a function of three overlapping components: 1) Exposure (EX), 2) Sensitivity (SE), and 3) Adaptive Capacity (AC). In summary, Exposure defines the nature and amount to which the system is exposed to threats; Sensitivity reflects the system's potential to be affected by changes because of these threats; and Adaptive Capacity characterizes the system's ability to respond to these effects (TURNER et al., 2003b; METZGER et al., 2006; GALLOPÍN, 2006; POLSKY et al., 2007). Following this conceptual approach, Potential Impacts on the system are defined as a function of Exposure and Sensitivity. In its turn, the system's Vulnerability is a function of Potential Impacts and its Adaptive Capacity (METZGER et al., 2006; NGUYEN et al., 2016) (Figure 4.1). Thus, a system is expected to be more vulnerable if it is exposed to threats, if it is sensitive to those threats and their consequent impacts, and if it has a low Adaptive Capacity to cope with those impacts (MCCARTHY et al., 2001; PARRY et al., 2007).

The challenge of vulnerability assessments is making the theoretical framework operational (TATE, 2013). The selection of what should be included depends on the system at risk, the context (O'BRIEN et al., 2007), and the intention of the assessment. One of the three approaches is generally used in vulnerability assessments: a participatory, a simulation-model-based, or an indicator-based approach (NGUYEN et al., 2016). The latter approach, the one applied in this study, is the most used method, which considers a set of indicators to explain the three vulnerability components - EX, SE, and AC (LUERS et al., 2003; LUERS, 2005; GALLOPÍN, 2006; SCHRÖTER et al., 2005). In the indicator-based approach, indicators are variables that represent attributes, such as quality and/or characteristics of the system relevant for its condition (HINKEL, 2011). Usually, after selecting indicators, they are scaled, weighted, and combined to form a final index for each vulnerability component, which can be aggregated in a final system's Vulnerability index (SCHRÖTER et al., 2005).

In this study, we adopted the theoretical vulnerability framework by IPCC (MCCARTHY et al., 2001; PARRY et al., 2007) and followed the steps described by (SCHRÖTER et al., 2005) to make this concept operational and to assesses the environmental vulnerability of Amazonian ILs: (1) To hypothesize who is vulnerable to what; (2) To find indicators for the elements that comprise the vulnerability, i.e., to develop a place-based set of indicators relating to EX, SE and AC of the system; (3) To weight and combine the indicators of EX, SE, and AC to produce measures of the contribution of each component to the system's Vulnerability. The three-step operationalization is described in the following subsections, after the description of the study area.

Figure 4.1 - IPCC's conceptual vulnerability framework (MCCARTHY et al., 2001; PARRY et al., 2007).

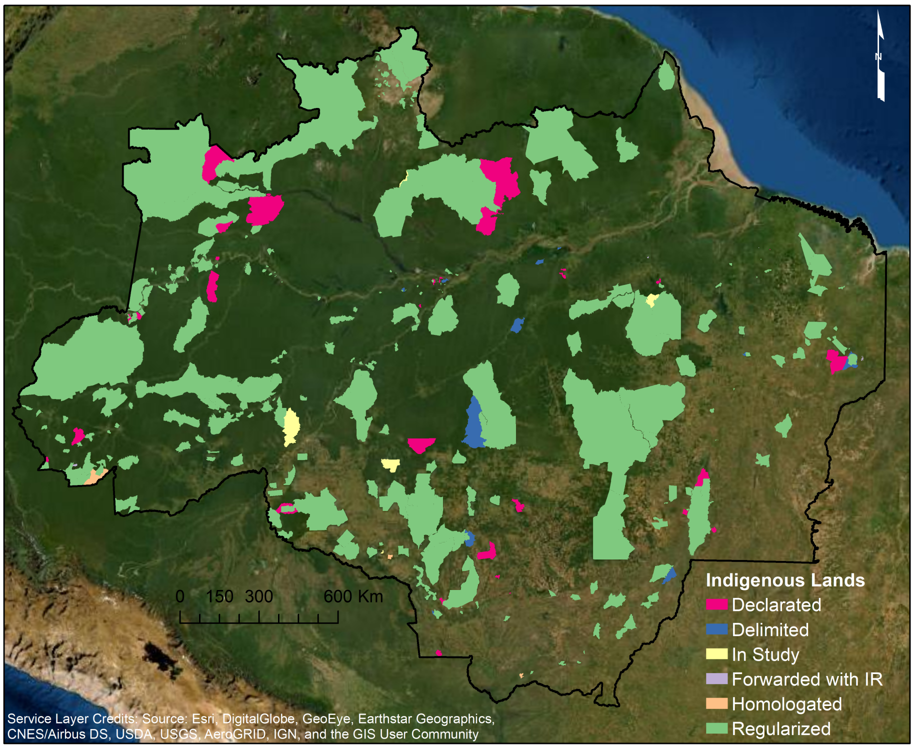


SOURCE: Adapted from Nguyen et al. (2016).

4.2.2 Study area

Under Brazil's current Federal Constitution and international indigenous rights treaties that Brazil is a party of, indigenous peoples have the original right to exclusive usufruct of the lands they traditionally occupy (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a; INTERNATIONAL LABOUR ORGANIZATION – ILO, 1989; UNITED NATIONS GENERAL ASSEMBLY., 2007). Hereto, we considered the ILs located entirely within the Legal Amazon region for all legal phases of land regularization derived from FUNAI (National Indigenous Foundation) website (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019b) (Figure 4.2). In Brazil, the process of regularizing indigenous lands comprises different stages and usually takes years to complete. Currently, of the 383 ILs in the Legal Amazon, 325 ILs are Regularized, while the others are in one of the following phases of regularization, listed since the initial phase: In Study (6), Delimited (11), Declared (31), Forwarded with Indigenous Reserve (7), and Homologated (3) (FUNDAÇÃO NACIONAL DO ÍNDIO - FUNAI, 2019a). The explanation of each phase of the process of land regularization of ILs by the State is presented in Table A.1 of the Appendix.

Figure 4.2 - Indigenous Lands in the Legal Amazon region. Colors indicate the legal status of recognition process.



SOURCE: Data from FUNAI (2020).

4.2.3 Hypothesizing who is vulnerable to what

In this study, we focus on the environmental vulnerability of Amazonian ILs and the environmental threats that make them vulnerable. We suppose the environmental vulnerability emerges because of the existence of a set of threats inside and surrounding the ILs, affecting the ILs' environmental integrity and the indigenous peoples' safety and livelihood (CARNEIRO FILHO, A. and SOUZA, O. B., 2009; RICARDO et al., 2011; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018).

According to the literature and several reports consulted, the main threats associated with the environmental vulnerability of Amazonian ILs (i.e., for its potential to induce environmental degradation) are deforestation, forest degradation, fires, the agricultural frontier advance, mining, and the access provided by roads (NEPSTAD et al., 2006; NEPSTAD et al., 2008; CARNEIRO FILHO, A. and SOUZA, O. B., 2009; RICARDO et al., 2011; TOURNEAU, 2015; INSTITUTO SOCIOAMBIENTAL - ISA, 2019a; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020). Thus, this set of environmental threats was grouped into three dimensions: Forest cover, Economic activities, and Access.

The first dimension, Forest cover, is related to the threats causing direct disturbances and negative impacts on the forest cover, such as deforestation, forest degradation, and fires. In particular, deforestation (i.e., the forest's clear-cutting) causes loss of habitat and biodiversity, soil erosion, silting and drought of rivers. Forest degradation, in turn, is characterized by the gradual long-term process of forest cover loss, mainly because of selective logging and fires (DINIZ et al., 2015; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008). Forest degradation results in negative damages, such as changes in the forest's structure and its associated ecological processes, besides altering the local climate making the forest drier and more susceptible to fire (BARLOW et al., 2020). Last, the spreading of uncontrolled fires on Amazonian ILs also causes the loss of forest cover and biodiversity, besides aggravating respiratory diseases, unbalancing the local ecosystem (ARAGÃO et al., 2018; COCHRANE; SCHULZE, 1999; NEPSTAD et al., 2008), destroying subsistence crops, and leading to the loss of indigenous villages (LACERDA, 2013). The combination of these threats over the ILs' forest can impact indigenous peoples by reducing natural resources for subsistence, such as hunting, fish, fruits, trees used for construction, and medicinal herbs. Also, illegal logging is responsible for many violent conflicts involving indigenous people and the invaders (RICARDO et al., 2011).

The Economic activities dimension is expressed by the development of economic activities also responsible for negative impacts on indigenous peoples and their territories, such as agriculture, livestock, and mining. Currently, several ILs are occupied by illegal squatters who carry out agricultural activities. Besides, the surrounding areas of some ILs are predominantly dominated by croplands or pastures. In the Amazon, the expansion of livestock and croplands represents a key driver of environmental degradation (GIBBS et al., 2010; CAMARA et al., 2015), with negative impacts on water availability, soil quality, biodiversity, and local climate (GIBBS et al., 2010; LAMBIN; MEYFROIDT, 2011; TURNER et al., 2007). The advancement of agricultural activities threatens the environmental integrity of ILs by driving deforestation, increasing the forest's exposure to fires, and contaminating soil and water with pesticides (BEGOTTI; PERES, 2020; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Furthermore, the presence of squatters and farmers in these territories has resulted in many situations of conflict and violence against indigenous peoples (RICARDO et al., 2011; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2018).

Another economic activity that intensely threatens Amazonian ILs is exploiting mineral resources in and around these territories. Mining is widely known for its severe socio-environmental impacts, such as removing vegetation, the contamination of soil and water bodies by toxic waste, and consequently the contamination of the local fauna and flora and the indigenous populations living there (SONTER et al., 2017; HOROWITZ et al., 2018; VEGA et al., 2018). In addition, like the other economic activities described above, mining is also responsible for several situations of conflict and violence against indigenous peoples (HOROWITZ et al., 2018; CONSELHO INDIGENISTA MISSIONÁRIO – CIMI, 2019). Currently, several Amazonian ILs are invaded by illegal gold miners (RORATO et al., 2020).

Finally, the third dimension, Access, is expressed by the facility of access provided by roads and its role to increase the environmental vulnerability of Amazonian ILs. Historically, in the Amazon region, the opening of roads is directly linked with the process of clearing forest, typically to establish new areas of settlement and land acquisition. In general, deforestation, forest degradation, and fires are most intense in areas of a consolidated and expanding agricultural frontier (AGUIAR et al., 2007; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2015) and associated with roads network (ALVES et al., 2002; SOARES-FILHO et al., 2006; AGUIAR et al., 2007). The set of threats described here was considered for creating the EX and SE components in our vulnerability assessment.

4.2.4 Indicators of the exposure, sensitivity, and adaptive capacity components

In this study, we developed an indicator-based approach, expressing the system's Vulnerability by a set of indicators. The aim of indicators selection is to choose relevant proxy variables to explain theoretical components of the system's vulnerability, such as biophysical, social, and economic characteristics (TATE, 2013). To make the Vulnerability of ILs operational, a set of indicators was formulated considering the potential factors that explain the components of EX, SE, and AC. The indicators of Exposure and Sensitivity representing the environmental threats over Amazonian ILs were developed based on Chapter 2.

The indicators of EX and SE were extracted considering the boundaries of ILs (inside) and a buffer area of 10 Km around each IL (outside). The buffer delimitation range was based on previous studies (NEPSTAD et al., 2006; SOARES-FILHO et al., 2010; CABRAL et al., 2018) and on environmental regulations which establishe a 10-km-radius surrounding protected areas to preserve its ecosystems of all activities that may cause negative damages [8]. The indicators for the AC component were compiled per IL.

The vulnerability components definition and their respective indicators are detailed in next sections and summarized in Table 4.1. Both the EX and SE indicators were calculated to represent three different periods: 1) 2001 to 2019, from which the ILs Vulnerability was calculated; 2) 2001 to 2010 (*t1*); and 3) 2011 to 2019 (*t2*). The indicators calculated for periods *t1* and *t2* were used for the temporal comparison of EX and SE only. From this, we investigated the changes that occurred in the Exposure and Sensitivity of ILs between the two periods and answering the second scientific question of the present study.

4.2.4.1 Exposure (EX)

The first component of vulnerability, the Exposure, is defined as nature and degree to which systems are exposed to threats (MCCARTHY et al., 2001; PARRY et al., 2007). More specifically, it is described as the magnitude, duration, and/or extent to which the system is in contact with, or subject to, the threat (LUERS, 2005; ADGER, 2006). In this component, we have chosen indicators to represent the magnitude of ILs'

[8] The repealed CONAMA (National Environmental Council) Environmental Resolution no. 13/1990, the Decree 99.274/1990, 208 and the Interministerial Ordinance No. 60 of 2015, in case of mining exploitation and built of railways.

exposure to external threats being deforestation, forest degradation, fires, livestock, agriculture, road access, and mining, calculated in the ILs' buffer zone (BF).

The indicator of ILs' exposure to deforestation was calculated as the accumulated percentage of deforested areas relative to the BF area for each period. The accumulated deforestation (total suppression of the forest) data, since 1988, were provided by INPE's Amazon Deforestation Monitoring Program (PRODES) (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020a).

The ILs' exposure to forest degradation was calculated by the accumulated percentage of the area of degraded forest relative to the BF area for each period. We used forest degradation [9] data from DEGRAD, a system from INPE (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008) between 2007-2016. The DEGRAD monitoring system was interrupted in 2016, but the detection of forest degradation start to be provided by Real-time Deforestation Detection System (DETER) (DINIZ et al., 2015; INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2020b). Both data provided by DEGRAD (2007-2016) and DETER (2016-2019) were combined to generate the forest degradation indicator. The overlapping of areas that have suffered a process of forest degradation more than once has been discounted. As there are no forest degradation data prior to 2007, for *t1* we used data from 2007-2010, that is, only 4 years, which may have caused an underestimation of the degraded area. However, as there is a lot of recurrence of degraded areas among the years, in the database used, this underestimation is partially compensated (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE, 2008; RODRIGUES et al., 2019).

The indicator of ILs exposure to fires was calculated as the accumulated percentage of burned area relative to the BF area for each period. For this indicator, we used data from MODIS' (NASA's Moderate Resolution Imaging Spectroradiometer) Global Burned Area Product (Collection 6) (GIGLIO et al., 2018). This product results from the daily detection of burned areas at a spatial resolution of 500 m. To generate this indicator, the overlapping of areas that burned more than once has been discounted.

The indicators of ILs' exposure to agriculture and livestock were estimated by annual (2010 and 2019) percentage of pastures and cropland areas relative to the BF area. Hereto, we used the annual maps of land-use and land-cover (LULC) of the Brazilian Amazon (2001-2019) developed from MODIS time series by (CAMARA et al., 2020).

[9] In this study, we adopt the definition of forest degradation used by INPE: the process of the gradual loss of forest cover due to the effect of logging and forest fire, of at least 6.25 ha, which does not qualify as clear cut deforestation by PRODES.

The exposure of ILs to road access was expressed by the density of roads in BF by 2010 and 2017. The road density was calculated by dividing the sum of the lengths of the roads in the BF by the area of the BF (km/km^2). The 2010 road network data was obtained from the LAPIG's map platform (Laboratory of Image Processing and Geoprocessing at the Federal University of Goiás) and derived from several institutional sources, such as Brazilian Institute of Geography and Statistics (IBGE), DNIT (National Infrastructure and Transport Department), and ANTT (National Land Transportation Agency) (UNIVERSIDADE FEDERAL DE GOIÁS. LABORATÓRIO DE PROCESSAMENTO DE IMAGENS E GEOPROCESSAMENTO - UFG. LAPIG., 2019). The 2017 road network data was obtained from the roads map compiled by the Amazon Network of Georeferenced Social and Environmental Information (RAISG) (REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2018) derived from IBGE data.

Lastly, to express the exposure of ILs to mining, we calculated the count of occurrences of mining activities in BF by 2018. The data used in this indicator were compiled by RAISG (REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2018).

4.2.4.2 Sensitivity (SE)

The second vulnerability component, Sensitivity, is described as the degree to which a system is affected, either adversely or beneficially, by stimuli (MCCARTHY et al., 2001; PARRY et al., 2007). In this conception, the Sensitivity can be measured in terms of the quantity of transformation experienced by the system (LUERS, 2005; GALLOPÍN, 2006). Since some characteristics of the system determine its sensitivity to the set of exposures (TURNER et al., 2003a), we considered Sensitivity indicators correspondent to each Exposure threat in our vulnerability assessment.

To make the Sensitivity of ILs operational, we estimated the environmental threats inside the ILs (Table 4.1) to measure the degree to which the system (the IL) is affected. All Sensitivity indicators were formulated in the same way as the indicators of Exposure were described above (deforestation, forest degradation, fires, livestock, croplands, roads, and mining); however, for the sensitivity component, the same set of variables was measured within the IL instead of in the BF.

4.2.4.3 Adaptive Capacity (AC)

The Adaptive Capacity component is defined as the ability of the system to adjust to changes or threats to moderate potential damages, take advantage of opportunities, or cope with the consequences (METZGER et al., 2006; GALLOPÍN, 2006; MCCARTHY et al., 2001; PARRY et al., 2007). The AC can be understood as the extent to which a system can react and change its circumstances to move to a less vulnerable condition and depends on the quantity and quality of resources that the system has (TURNER et al., 2003a; LUERS, 2005). To create this vulnerability component, we selected a set of variables from different data sources. Since the Adaptive Capacity depends on the quantity and quality of the system's resources, we divided this component into four dimensions based on literature: 1) Natural Resources, 2) Human Resources, 3) Law Resources, and 4) Economic Resources (MOSS et al., ; O'BRIEN et al., 2004; METZGER et al., 2006; PANDEY et al., 2017). These dimensions are an attempt to represent indigenous peoples' capacity to deal with environmental degradation and illegal occupation on their territories. In the present study, our Adaptive Capacity component is mainly composed of indicators related to local development projects in ILs. This set of variables describes the socio-political context in which the indigenous peoples of the Amazon articulate their demands and their social and economic development projects in the last decades (ALBERT, 2019). For each dimension, we selected one or more indicators. Our rationale for using these indicators in this component is explained below. The indicators are summarized in Table 4.1.

First, the Natural Resources dimension refers to the level of the environmental integrity of ILs, represented by a landscape metric of forest cover integrity. To represent this indicator, we extracted the Largest Patch Index (LPI) metric from the annual LULC maps already described above (CAMARA et al., 2020). The LPI quantifies the percentage of total landscape area (IL + BF) covered by the largest forest patch. Hereto, the LPI was used as a measure of ILs' forest integrity, since the higher the LPI greater the integrity of the original ILs' forest area and the lower the fragmentation (MCGARIGAL,). Fragmented forests tend to be more susceptible to fires, to present reduced provision of ecosystem services, and lower quality of habitat for various species; reducing the availability of food (hunting, fruits, vegetables) and, consequently, decreasing the livelihood and Adaptive Capacity of the indigenous peoples (BROADBENT et al., 2008; LAURANCE et al., 2011; CONSTANTINO, 2016).

The second dimension, Human Resources, aims to capture indigenous peoples' access to formal education, knowledge and information in various contexts, as well as the autonomy of indigenous peoples to self-organize. As an indicator of the level of formal education, we considered the percentage of literate indigenous people of at least ten years old in each IL in 2010. This data was obtained from the IBGE Demographic Census (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA – IBGE, 2010). For the indicator of the indigenous peoples' access to knowledge and information in different contexts, we considered the number of thematic projects developed in each IL. The information on thematic projects developed in Amazonian ILs was made available by the *Instituto Socioambiental* (ISA), from its database of the Protected Areas Information System (SisArp), collected on August 7, 2019. This data set comprises information compiled systematically along the last decades about every thematic projects developed in the ILs of Legal Amazon. Altogether, around 2,200 projects were developed or started between 1988-2019, and are considered in this study. The thematic projects are developed for different purposes, such as training, social mobilization, encouraging culture and sustainable practices. The projects are divided into eight main themes: territory, environment, culture, health, infrastructure, school education, income generation and citizenship, and political representation.

Still in the Human Resources dimension, the indicator of self-organization was expressed by the number of indigenous organizations involved in developing projects per IL. Finally, the institutional arrangement indicator was calculated by counting the number of institutions and organizations that executed, financed, proposed, and acted as partners in the development of projects per IL in the period considered. Each institution and organization was counted only once by IL.

In turn, the Economic Resources dimension refers to the financial capacity of indigenous peoples derived from external incomes. Here, we used the total amount of funds raised for projects development per IL during 1988-2019. This indicator also was obtained from the SisArp data set from ISA and was computed in Real.

Finally, to represent the Law Resources dimension, we consider the legal status of ILs as an indicator. Hereto, we assume that the land regularization of ILs by the State is an important factor in increasing the Adaptive Capacity of indigenous peoples since it is a key factor in brake environmental degradation and illegal occupation in Amazonian ILs. In an exploratory analysis, we compared the yearly rates of deforestation before and after the regularization of Regularized ILs between 1997-2018. We found a significant difference between the yearly rates of deforestation that occurred in these two periods (Wilcoxon test: $V = 880$, $p < 0.00001$), indicating that deforestation rates before the regularization is larger than deforestation rates that occur after the regularization of these lands. This trend also was verified by a recent territorial consolidation assessment on Amazonian ILs (INSTITUTO SOCIOAMBIENTAL - ISA, 2019a) and in the recent study developed by (BARAGWANATH; BAYI, 2020). In this way, the legal status of ILs was classified (between 0-1) according to the sequence of steps followed until the conclusion of the IL recognition process. The values assigned to ILs status were: In Study = 0.2, Delimited = 0.4, Declared and Forwarded IR = 0.6, Homologated = 0.8 and Regularized = 1.0.

In sum, we considered that the set of indicators presented above can represent cues of different ways that indigenous peoples are prepared to face or deal with the environmental threats and illegal occupation in their territories. Our premises are: 1. the involvement with different thematic projects; 2. the presence of self-governance in terms of indigenous organizations; 3. the access of investments from various sources to subsidize projects; 4. a major level of population's literacy and incomes; 5. lower forest fragmentation; 6. and the legal recognition of land tenure for indigenous peoples; are directly related to indigenous peoples' Adaptive Capacity. We argue that these combined indicators can act as a proxy for the level of empowerment of these populations to self-organize, dialogue, and exchange knowledge with other sectors of society, and of their ability to deal with the environmental threats to which they are exposed.

Table 4.1 - Vulnerability components, its dimensions, indicators, weights, and data source.

Component	Dimension	Indicator	Quantification	Weight	Period	Source
	Forest Cover	Deforestation	accumulated deforested area in BF (%)	0.166	2001-2019, 2001-2010, 2011-2019	Prodes (INPE)
	Forest Cover	Forest degradation	accumulated degraded forest area in BF (%)	0.154	2001-2019, 2001-2010, 2011-2019	Degrad/Deter (INPE)
	Forest Cover	Fires	accumulated burned area in BF (%)	0.098	2001-2019, 2001-2010, 2011-2019	Burned Area Product (MODIS)
EX	Economic activity	Agriculture	cropland area in BF (%)	0.118	2010 and 2018	(CAMARA et al., 2020)
	Economic activity	Livestock	pasture area in BF (%)	0.156	2010 and 2018	(CAMARA et al., 2020)
	Economic activity	Mining	nº of mining occurrences in BF	0.171	2018	RAISG
	Access	Roads	road density in BF (km/km^2)	0.137	2010 and 2017	LAPIG and RAISG
	Forest Cover	Deforestation	accumulated deforested area in IL (%)	0.166	2001-2019, 2001-2010, 2011-2019	Prodes(INPE)
	Forest Cover	Forest degradation	accumulated degraded forest area in IL (%)	0.154	2001-2019, 2001-2010, 2011-2019	Degrad/Deter (INPE)
	Forest Cover	Fires	accumulated burned area in IL (%)	0.098	2001-2019, 2001-2010, 2011-2019	Burned Area Product (MODIS)
SE	Economic activity	Agriculture	cropland area in IL (%)	0.118	2010 and 2018	(CAMARA et al., 2020)
	Economic activity	Livestock	pasture area in IL (%)	0.156	2010 and 2018	(CAMARA et al., 2020)
	Economic activity	Mining	nº of illegal mining occurrences in IL	0.171	2018	RAISG
	Access	Roads	road density in the IL (km/km^2)	0.137	2010 and 2017	LAPIG and RAISG
	Natural Resources	Forest cover integrity	largest forest patch index IL+BF (%)	0.101	2018	(CAMARA et al., 2020)
	Human Resources	Education level	literated indigenous people over 10 years (%)	0.087	2010	Census IBGE
AC	Human Resources	Access to knowledge	nº of thematic projects	0.154	1988-2019	SisArp (ISA)
	Human Resources	Self-organization	nº of indigenous organizations	0.199	1988-2019	SisArp (ISA)
	Human Resources	Institutional Arrangement	nº of partner and funding organizations	0.123	1988-2019	SisArp (ISA)
	Economic Resources	External incomes	total funds raised for projects (R$)	0.149	1988-2019	SisArp (ISA)
	Law Resources	Land ownership	status of IL regularization	0.188	2019	FUNAI

4.2.5 Vulnerability index

All indicators calculated as percentages were converted in fractions ranging between 0-1. To turn the set of indicators compatible, the other indicators were scaled between 0-1 using the Minimum-Maximum method. The scaling of indicators to a comparable scale is generally used to overcome the incompatibilities to combine different measurement units (TATE, 2013; NGUYEN et al., 2016).

Given that the indicators represent different characteristics that constitute the Vulnerability of the system under analysis, we consider the influence of the indicators on the Vulnerability of the system is not equal. In this way, a weighting method was applied to express the relative importance of individual indicators to their respective component. In vulnerability assessments, a weight-based approach helps to include empirical knowledge about the system in the analyzes. Different methods to determine the weight values in the multi-criteria analysis are found in the literature, such as based on expert opinions or the involvement of stakeholders (TATE, 2013; NGUYEN et al., 2016). Here, we used 10 experts' knowledge on Indigenous issues in the Amazon to establish the indicators' weights of the three vulnerability components.

The weights were assigned according to the experts' perception of the importance of each indicator. For this, experts were asked to classify the indicators according to the degree of environmental threat they represent to ILs (EX and SE components); and to classify the indicators according to their importance for the capacity of indigenous peoples to deal with environmental threats in their territories (AC component). According to the experts' perception, the importance of indicators related to the EX and SE of the Amazonian ILs were classified in the following decreasing order (that is, from the most important to the least important): mining, deforestation, livestock, forest degradation, road access, agriculture, and fires (see Weight in Table 4.1). Concerning the AC component, the indicators were classified in the following decreasing order according to their importance: self-organization, land ownership, access to knowledge, external incomes, institutional arrangement, forest cover integrity, and education level (see Weight in Table 4.1).

Using the Weighted Linear Combination (VOOGD, 1983), the indicators and their respective weights were combined into a final value to each vulnerability component (EX, SE, and AC) per IL, according to the followings Equations 4.1, 4.2, and 4.3:

$$EX = \sum_{i=m}^{n} (Vex_i * Wex_i) \tag{4.1}$$

$$SE = \sum_{i=m}^{n} (Vse_i * Wse_i) \tag{4.2}$$

$$AC = \sum_{i=m}^{n} (Vac_i * Wac_i) \tag{4.3}$$

where:

Vex_i = the calculated value for the EX indicator i
Wex_i = the assigned weight by experts for the EX indicator i
Vse_i = the calculated value for the SE indicator i
Wse_i = the assigned weight by experts for the SE indicator i
Vac_i = the calculated value for the AC indicator i
Wac_i = the assigned weight by experts for the AC indicator i

Finally, the three vulnerability components can be combined in a final Vulnerability index per IL. Since vulnerability is the interrelation of the Exposure and the Sensitivity of the system to multiple threats with the Adaptive Capacity as the potential of the system to decrease the Potential Impact; the following conceptual framework of vulnerability can be used to the components aggregation (METZGER et al., 2006; TAUBENBOCK et al., 2008) (Equations 4.4 and 4.5):

$$PI = EX + SE \tag{4.4}$$

where:

PI = Potential Impact index
EX = Exposure index
SE = Sensitivity index

$$V = \frac{PI + (1 - AC)}{3} \tag{4.5}$$

where:

V = Vulnerability index
PI = Potential Impact index
AC = Adaptive Capacity index

Using these Equations to combine the values of vulnerability components, we quantified the Vulnerability of all Amazonian ILs by 2019 and assess changes over time in Exposure and Sensitivity between *t1* (2001-2010) and *t2* (2011-2019). Due to the lack of data for mining in the *t1* period, the temporal comparison was made without considering mining indicator for both components of EX and SE.

4.2.6 Sensitivity analysis

Sensitivity analysis has been widely recommended to improve the understanding of the uncertainties raised by multi-criteria analysis and the adoption of weight-based approaches (TATE, 2013; CHEN et al., 2010; XU; ZHANG, 2013). Since the assignment of the indicators' weights occurred through the experts' perception, we decided to check the relative influence of these weights in the final results of Vulnerability. For this, we carried out a sensitivity analysis to investigates the robustness of the final Vulnerability index against slight changes in the weights of the indicators (CHEN et al., 2010; BRITO et al., 2019; TATE, 2013). In our sensitivity analysis, we adapted and performed the local One-At-a-Time (OAT) method. The OAT method analyzes the relative influence of one parameter on the function at a time, keeping the other parameters fixed. In this way, the OAT method does not provide insight into how the interactions among parameters influence the function result (XU; ZHANG, 2013).

The OAT sensitivity analysis was performed by changing each indicator's weight value in turn for each simulation performed and evaluating the model's response. The weights of the indicators were multiplied by 0.5, 1, 1.5 and 2, and the weight difference compared to the default value was redistributed over the other weights so that in each simulation the sum of the weights was 1 (XU; ZHANG, 2013). Finally, we calculated the sensitivity of the Vulnerability index, that is, its median, minimum and maximum values over all ILs, to changes in all indicators' weights.

4.3 Results and discussion

In the next sections, we present the results and discussion of Vulnerability indexes and their components (EX, SE, PI, and AC) for the total period investigated (2001-2019). Subsequently, the result of the sensitivity analysis on Vulnerability results is presented. Further, we present the EX and SE indexes' changes over the two periods analyzed (2001-2010 and 2011-2019) without the mining threat. Finally, we point out some limitations of our study and future work directions regarding the vulnerability of Amazonian Indigenous Lands.

4.3.1 Exposure, sensitivity, and potential impact

According to our results, the Exposure index (EX) varied from 0.00018 to 0.44. The ILs in the 4th quantile of the EX index (the most exposed ILs) varied from 0.18 to 0.44. The ILs in the 1st quantile of the EX index (the less exposed ILs) varied from 0.00018 to 0.011. In general, the Amazonian ILs most exposed to environmental threats are concentrated in the region of the arc of deforestation and below; and in the north of Roraima state (Figure 4.3A and 4.3F). Regarding the high Exposure, the ILs of the states of Maranhão, east of Pará, and Rondônia stand out. The fifteen ILs more exposed in descending order are Lago Aiapua, Geralda Toco Preto, Rio Pindaré, Umutina, Urucu/Juruá, Igarapé Ribeirão, Sororó, Arariboia, Las Casas, Igarapé Lage, Cana Brava/Guajajara, Morro Branco, Tuwa Apekuokawera, Rio Omerê, and Pequizal (Table 4.2).

The Sensitivity index (SE) varied from 0 to 0.38. The ILs in the 4th quantile of the SE index (the most sensitive ILs) varied from 0.087 to 0.38. The ILs in the 1st quantile of the SE index (the less sensitive ILs) varied from 0 to 0.0028. Similar to the Exposure, the ILs most sensitive to the threats studied are concentrated in the arc of deforestation region and in the state of Roraima (Figure 4.3B). The fifteen most sensitive ILs in descending order are Praia do Índio, Maraiwatsede, Tuwa Apekuokawera, Apipica, Tadarimana, Cana Brava/Guajajara, Jarudore, Recreio/São Félix, Urucu/Juruá, Governador, Urubu Branco, Las Casas, Bacurizinho, Rodeador, and Lago Aiapua (Table 4.2).

The sum of the threats inside (SE) and around (EX) ILs generated the Potential Impact index (PI), varing from 0.00077 to 0.69. The ILs in the 4th quantile of the PI index (the more impacted ILs) varied from 0.27 to 0.69. The ILs in the 1st quantile of the PI index (the less impacted ILs) varied from 0.00077 to 0.018. As to EX and SE, the PI index is higher in ILs in the region of the arc of deforestation and in the state of Roraima (Figure 4.3C). The fifteen ILs that presented higher PI index in descending order are: Tuwa Apekuokawera, Maraiwatsede, Lago Aiapua, Praia do Índio, Urucu/Juruá, Rio Pindaré, Cana Brava/Guajajara, Las Casas, Jarudore, Governador, Arariboia, Geralda Toco Preto, Bacurizinho, Umutina, and Tadarimana (Table 4.2).

Figure 4.3 - Final indexes of Exposure (A), Sensitivity (B), Potential Impact (C), Adaptive Capacity (D), and Vulnerability (E) by 2019 of the Amazonian Indigenous Lands. Limits of the regions of the Legal Amazon and the arc of deforestation (F). The maps are displayed on a quadratic scale.

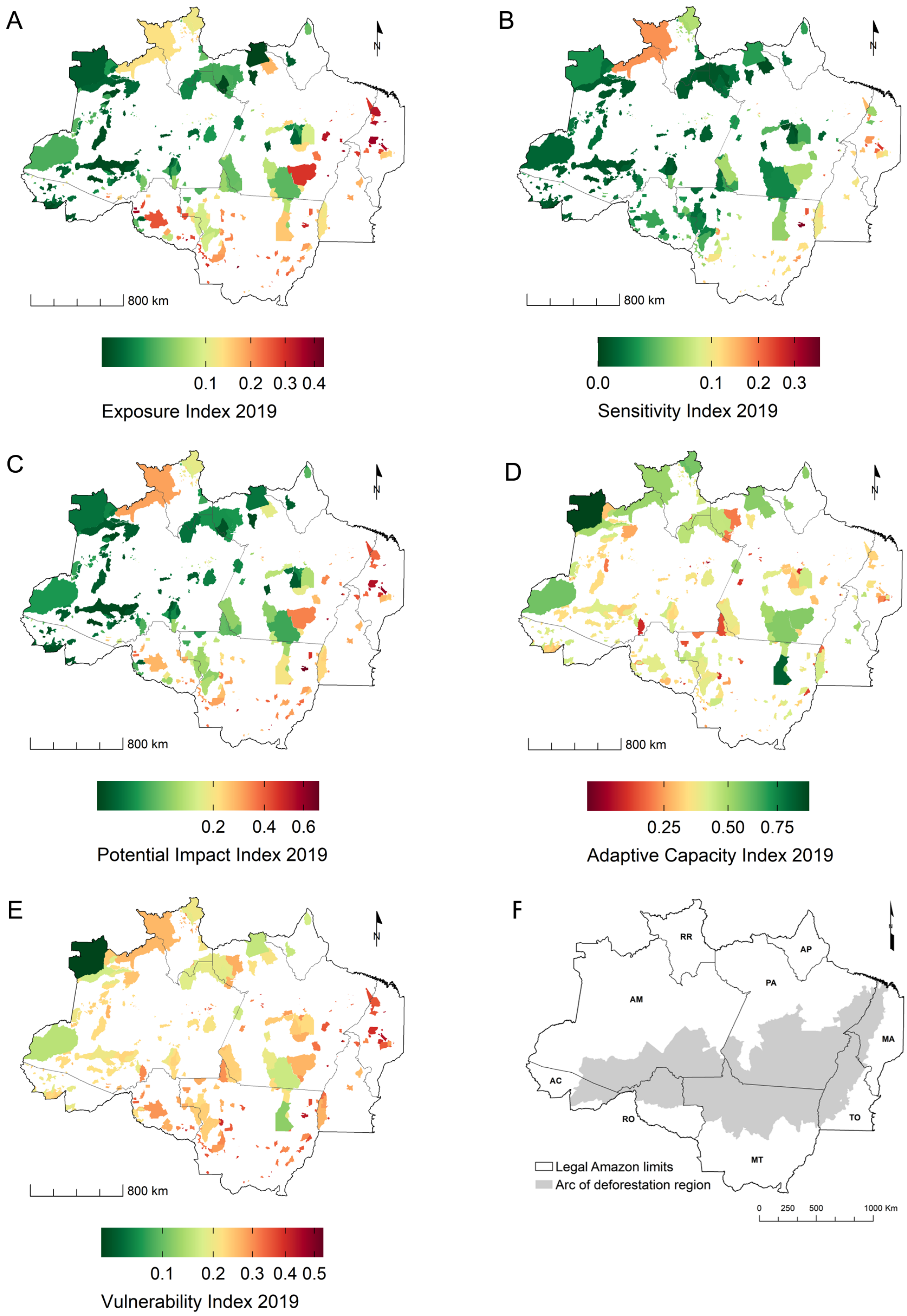


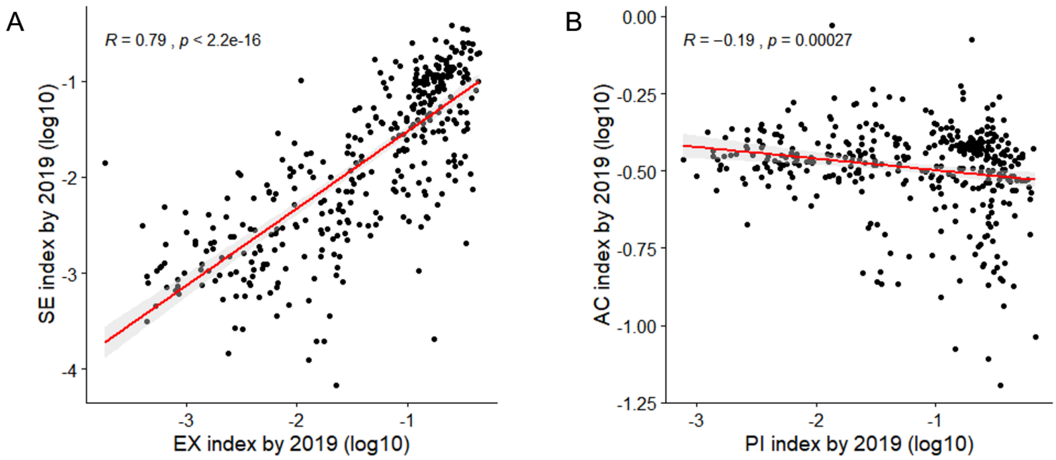
Table 4.2 - Final values of Exposure, Sensitivity, Potential Impact, Adaptive Capacity, and Vulnerability indexes of Indigenous Lands in the Amazon.

	Exposure		Sensitivity		Potential Impact		Adaptive Capacity		Vulnerability	
Rank	**IL name**	**Value**	**IL name**	**Value**	**IL name**	**Value**	**IL name**	**Value**	**IL name**	**Value**
1	Lago Aiapua	0.435	Praia do Índio	0.381	Tuwa Apekuokawera	0.688	Tanaru	0.064	Tuwa Apekuokawera	0.532
2	Geralda Toco Preto	0.430	Maraiwatsede	0.352	Maraiwatsede	0.665	Cobra Grande	0.078	Praia do Índio	0.478
3	Rio Pindaré	0.418	Tuwa Apekuokawera	0.343	Lago Aiapua	0.633	Jauary	0.084	Lago Aiapua	0.455
4	Umutina	0.410	Apipica	0.269	Praia do Índio	0.630	Tuwa Apekuokawera	0.092	Urucu/Juruá	0.454
5	Urucu/Juruá	0.380	Tadarimana	0.258	Urucu/Juruá	0.619	Praia do Mangue	0.116	Rio Pindaré	0.443
6	Igarapé Ribeirão	0.379	Cana Brava/Guajajara	0.251	Rio Pindaré	0.610	Vista Alegre	0.123	Maracaxi	0.441
7	Sororó	0.371	Jarudore	0.246	Cana Brava/Guajajara	0.603	Maracaxi	0.134	Cana Brava/Guajajara	0.435
8	Arariboia	0.369	Recreio/São Félix	0.246	Las Casas	0.575	Estação Parecis	0.135	Maraiwatsede	0.431
9	Las Casas	0.369	Urucu/Juruá	0.239	Jarudore	0.560	Jacareúba/Katauixi	0.136	Tanaru	0.429
10	Igarapé Lage	0.362	Governador	0.221	Governador	0.543	Igarapé Taboca do Alto Tarauacá	0.136	Las Casas	0.427
11	Cana Brava/Guajajara	0.351	Urubu Branco	0.221	Arariboia	0.541	Ituna/Itatá	0.138	Jarudore	0.422
12	Morro Branco	0.347	Las Casas	0.206	Geralda Toco Preto	0.529	Menkü	0.139	Praia do Mangue	0.420
13	Tuwa Apekuokawera	0.345	Bacurizinho	0.204	Bacurizinho	0.501	Murutinga/Tracaja	0.139	Pequizal	0.412
14	Rio Omerê	0.345	Rodeador	0.203	Umutina	0.491	Paukalirajausu	0.142	Geralda Toco Preto	0.412
15	Pequizal	0.344	Lago Aiapua	0.199	Tadarimana	0.481	Pirititi	0.148	Menkü	0.409

For the EX, SE, PI, and V indexes, the 15 ILs with the highest values are presented. For the AC index, the 15 ILs with the lowest values are presented.

Overall, our results demonstrate the strong relationship between the environmental threats affecting Amazonian ILs internally and externally, that is, SE and EX (Spearman $r = 0.79$, $p < 0.0001$) 4.4A). This result is in line with the result presented in Chapter 2 of this manuscript. It highlights the need for policy strategies to combat and control environmental threats within and around ILs in the Amazon. We argue that, without the effective control of the environmental agencies over the activities developed around the ILs, it is difficult to contain the progress of environmental degradation over these territories.

Figure 4.4 - Scatter plot of the final indexes of Exposure and Sensitivity (A), and Potential Impact and Adaptive Capacity (B). The indexes are displayed on a logarithmic scale. Indigenous lands are represented as points.



Regarding Exposure and Sensitivity, both the most exposed and the most sensitive ILs are located in areas of consolidated settlement (arc of deforestation or older frontier areas). Although the magnitude is different, the Sensitivity is less intensive in ILs than the Exposure, which would be expected, as they are areas that still have some protection. The surrounding areas are much more environmentally degraded than the interior of the ILs. In the consolidated areas, there is a more extensive infrastructure network, which increases the possibility of access to ILs, invasion, and exploration of mineral and forest resources (AGUIAR et al., 2007; REDE AMAZÔNICA DE INFORMAÇÃO SOCIOAMBIENTAL GEORREFERENCIADA – RAISG, 2020; FERRANTE et al., 2020; SCHIELEIN; BÖRNER, 2018). In the innermost areas of the biome are ILs with less sensitivity and less exposure, a phenomenon that also seems to be influenced by ease of access. Although some of them, like Yanomami IL, because of mining, are more sensitive and exposed even in more remote regions. In turn, the

Potential Impact, which is a synthetic indicator, expresses the accumulation of these threats inside and outside ILs (SE and EX) and reinforces that the ILs located in the arc of deforestation and that have smaller dimensions are inserted in historically more degraded environmental contexts.

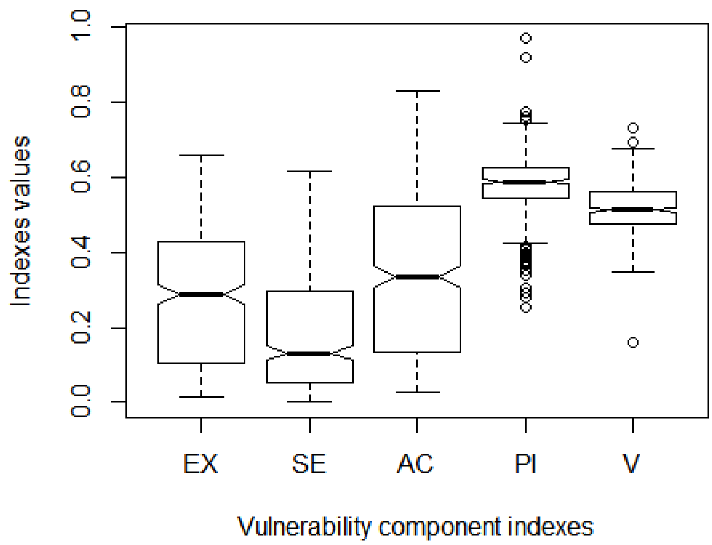
4.3.2 Adaptive capacity

The Adaptive Capacity index (AC) varied from 0.064 to 0.94. The ILs in the 1st quantile of the AC index (the ILs with lower AC) varied from 0.064 to 0.30. The ILs in the 4th quantile of the AC index (the ILs with higher AC) varied from 0.39 to 0.94. According to the results, the AC index varies widely across the ILs in the Amazon region (Figure 4.3D). The fifteen ILs with lower AC index in ascending order are Tanaru, Cobra Grande, Jauary, Tuwa Apekuokawera, Praia do Mangue, Vista Alegre, Maracaxi, Estação Parecis, Jacareúba/Katauixi, Igarapé Taboca do Alto Tarauacá, Ituna/Itatá, Menkü, Murutinga/Tracaja, Paukalirajausu, and Pirititi (Table 2). Two ILs stand out in relation to the high Adaptive Capacity they have: Alto Rio Negro IL (AM) with AC = 0.94 and Parque do Xingu (MT) with AC = 0.84. Following are the ILs São Marcos - RR, Vale do Javari, Raposa Serra do Sol, Menkragnoti, Kayapó, Parque do Tumucumaque, Uaçá, Rio Paru DEste, Waiãpi, Jumina, Yanomami, Andirá-Marau, Galibi, and Kraolandia ranging between AC = 0.50 and AC = 0.59.

Our results also demonstrated a significant, although weak, relationship between AC and PI indexes (Spearman $r = -0.19$, $p < 0.00027$) 4.4B). The negative relationship indicates that ILs with a high PI (i.e., the sum of SE and EX) are likely to have low AC, in line with our assumptions. However, we highlight that some ILs classified with high AC values also showed high SE index values. Such as the ILs Yanomami, Kraolandia, Krikati, Xerente, Pareci, Parque do Araguaia, Funil, São Marcos - MT, Bakairi, Porquinhos, Merure, Parabubure, Pimentel Barbosa, and Kanela. Indicating that even ILs that have a strong articulation with the majority society, a high capacity to self-organize and to raise funds, and have their lands regularized, face constant environmental threats within their territories, exceeding their resistence capacity, requiring State and intitutional support through enforcement actions, punishments and policies to control and combat these threats.

The Adaptive Capacity component showed greater variability among the others (Figure 4.5), indicating that the Indigenous Lands of the Amazon are highly heterogeneous in relation to their organization and socioeconomic conditions. This is because, for some ILs, the people have greater power of organization and articulation, which allows them to have access to different types of local projects on various topics. Part of the indigenous organizations in the Amazon has access to sources of external resources as local development projects, aiming at different purposes: health and education programs, environmental and territorial management, organization of assemblies and meetings, self-support and marketing of their products, cultural reaffirmation, and sustainable management and production practices (RICARDO et al., 1998). We highlight here the fundamental role of indigenous organizations in this articulation. It was from the creation of indigenous organizations, from the late 1980s, that the indigenous peoples of the Amazon came to have greater autonomy to deal with the different spheres of the majority society (public, private, national, and international) and started to articulate their territories, health, education demands (RICARDO et al., 1998).

Figure 4.5 - Boxplots of the final indexes of Exposure, Sensitivity, Adaptive Capacity, Potential Impact, and Vulnerability. The axes increase quadratically to improve the visibility of differences.



We also draw attention to the importance of partnerships established between indigenous organizations with different partner institutions, whether private, governmental, or non-governmental, to develop local projects. Through this articulation, the conditions and potential for environmental preservation and sustainable development of indigenous lands in the Amazon have emerged in recent decades (ALBERT, 2019). We highlight the need to strengthen indigenous organizations and direct partnerships to develop local projects in the ILs with a low Adaptive Capacity index.

Regarding the improvement in the Adaptive Capacity and reduction of Vulnerability, indigenous peoples must be supported by public policies that aim to increase these peoples' autonomy and capacity for the environmental management of their territories. In this regard, a good strategy would be to strengthen the National Policy for Environmental and Territorial Management of Indigenous Lands (BRAZILIAN EXECUTIVE POWER, 2012), expanding its reach power throughout the ILs in the Amazon. PNGATI was developed to promote indigenous peoples' empowerment in relation to the environmental and territorial management of their territories, with autonomy, but with active support from the State. Besides, PNGATI provides for the strengthening of indigenous organizations, guaranteeing indigenous participation in PNGATI governance; valuing and developing environmental management as an instrument for protecting territories; training of indigenous populations regarding the environmental and territorial management of ILs and the recovery of degraded areas; and supporting for sustainable and economic indigenous initiatives that generate alternative livelihoods for these peoples.

4.3.3 Vulnerability

In our assessment, the ILs most vulnerable to environmental threats are those that present a high Potential Impact and a low Adaptive Capacity. The Vulnerability index (V) of Amazonian ILs varied widely from 0.025 (Alto Rio Negro IL) to 0.53 (Tuwa Apekuokawera IL). The ILs in the 4th quantile of the V index (the most vulnerable ILs) varied from 0.31 to 0.53. The ILs in the 1st quantile of the V index (the less vulnerable ILs) varied from 0.025 to 0.22. In general, ILs with elevated vulnerability index are most concentrated in the arc of deforestation region and below, but also advancing to the inner of the states of Pará, Amazonas, and Roraima (Figure 4.3E). The fifteen Amazonian ILs most vulnerable to environmental threats in descending order are Tuwa Apekuokawera, Praia do Índio, Lago Aiapua, Urucu/Juruá, Rio Pindaré, Maracaxi, Cana Brava/Guajajara, Maraiwatsede, Tanaru, Las Casas, Jarudore, Praia do Mangue, Pequizal, Geralda Toco Preto, and Menkü (Table 4.2).

The ILs Las Casas, Lago Aiapua, Cana Brava/Guajajara, and Urucu/Juruá are among the fifteen first ILs with higher EX and SE indexes. The Tuwa Apekuokawera IL, the most vulnerable, is among the fifteen first ILs with higher EX and SE, and lower AC; and its land regularization process has not yet been concluded, being only Delimited. In addition, the Tuwa Apekuokawera IL is among the ILs considered highly vulnerable to changes induced by climate change (LAPOLA et al., 2020). The other two Amazonian ILs with high vulnerability to undergo changes related to climate change are Uru-Eu-Wau-Wau and Paraná do Arauató, which in our evaluation present moderate Vulnerability (V = 0.29 (3rd quantile) and V = 0.26 (2nd quantile), respectively).

In general, we argue that the results of our adaptation of the IPCC's vulnerability framework are in line with what we might expect for some ILs that are well known for their history of environmental degradation, as is the case for the ILs in the state of Maranhão. Among 19 ILs in the state of Maranhão (in the Legal Amazon region), 16 are classified with a high Vulnerability index (4th quantile).

Among them are ILs that shelter isolated indigenous peoples and of recent contact, such as the ILs Caru, Arariboia, Awá, Cana Brava/Guajajara, and Alto Turiaçu. Isolated indigenous peoples refer to the indigenous groups in isolation, that were not officially contacted by FUNAI and keep refusing contact with non-indigenous peoples and other indigenous groups. These groups live in constant movement and, because of their isolation, population aspects such as demographic composition, language, and customs are yet unknown. It is believed that the isolated position of these peoples can be a consequence of negative experiences suffered by them in the past (VAZ, 2013; BRACKELAIRE, ; AMORIM, 2016). The indigenous peoples of recent contact, in turn, are the peoples who were contacted by FUNAI not so long ago (a few years) and are now in regular contact with other indigenous groups and FUNAI servants mainly. Nowadays, the vulnerability of isolated indigenous peoples and of recent contact configure under different ways, among them: epidemiological vulnerability because of the lack of immunity against diseases; demographic vulnerability due to the fragility of the population, mainly because of the high mortality rates as a result of the conflicts; and the territorial vulnerability due to high pressure over their territories, such as deforestation, logging and mining (VAZ, 2013; AMORIM, 2016). The isolated indigenous people of the IL Awa (V = 0.37), belonging to the Awá Guajá ethnic group, are considered the most vulnerable indigenous people in the world by the Survival International Foundation. Besides, the ILs Xikrin do Rio Catete (PA) and Urubu Branco (MT) also present references for isolated indigenous peoples and are classified as highly vulnerable to environmental threats.

Concerning to the vulnerability framework design, the most recent IPCC report (FIELD et al.,) presents some changes in relation to the previous reports, which were adopted in this study (MCCARTHY et al., 2001; PARRY et al., 2007). The most important change is Vulnerability's conceptualization, defined as an intrinsic property of the system and being composed only by Sensitivity and Adaptive Capacity components (SHARMA; RAVINDRANATH, 2019). In this way, the Exposure is treated as an external component and would not enter into the Vulnerability calculation. In the present study, we argue the importance of maintaining Exposure as a component of Vulnerability in certain cases. For example, for the Amazonian Indigenous Lands, external exposure to threats seems to have a great influence on the threats that advance on these territories. We assume that by not considering the processes around these territories, we would neglect an important component in the emergence of the Vulnerability of Amazonian ILs.

Another important point about the framework is related to the use of synthetic indexes, such as PI and V itself. We understand the need for indexes that synthesize the other components, but we highlight the importance of evaluating the components separately, as is the case of SE, EX, and AC. Looking at these components (SE, EX, and AC) can be more informative and more appropriate to guide the design of appropriate public policies since they are more understandable and the variation of information for the synthetic components is reduced (PI and V) (Figure 4.5).

Our results also indicated an important influence of the AC component in the final result of the V index. Hereto, we observe that the AC component acts reducing the variability of the Vulnerability values index compensating the high and low values of Sensitivity and Exposure, as conceived in the formulation of this synthetic index (Figure 4.5).

4.3.4 Sensitivity analysis

In general, the sensitivity analysis results show that our vulnerability assessment is robust in relation to the weights assigned to the PI (EX and SE) and AC indicators. As seen in the Figures 4.6 and 4.7, very small changes in the Vulnerability index result are reported for substantial changes in the indicators' weights (i.e., -50%, +50%, and +100%) of PI and AC components, respectively. Among the indicators related to the PI component, the Vulnerability index seems to be more sensitive to changes in the weights of the mining, deforestation, and livestock indicators, which have the highest values attributed by the experts. For indicators of the AC component, the Vulnerability index seems to be more sensitive to variations in the weights of the indicators of the regularization status of ILs (land ownership) and self-organization, also the indicators with the highest weights.

Figure 4.6 - The OAT sensitivity analysis results for the weights of the Potential Impact indicators (i.e. EX and SE indexes). The graphs show the influence of changes in the weights of the indicators on the median, the maximum and minimum value of the Vulnerability index.

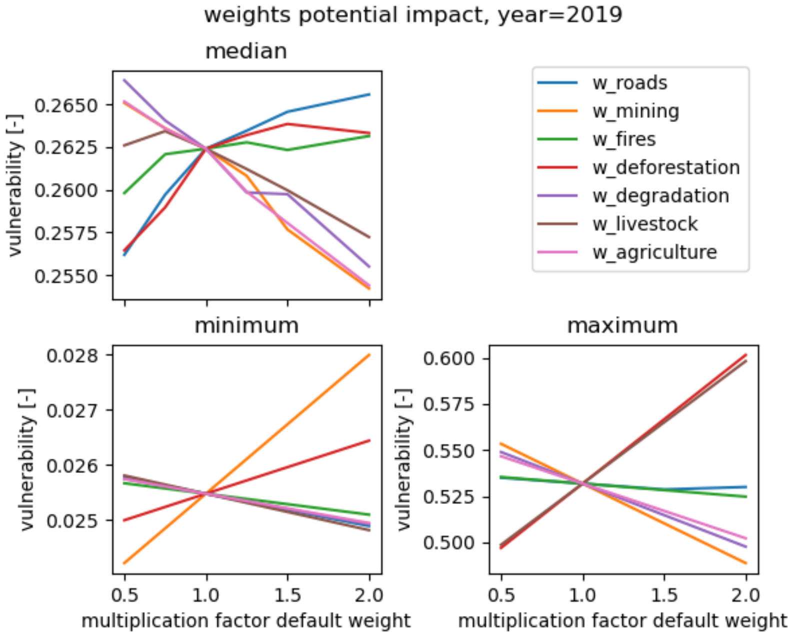
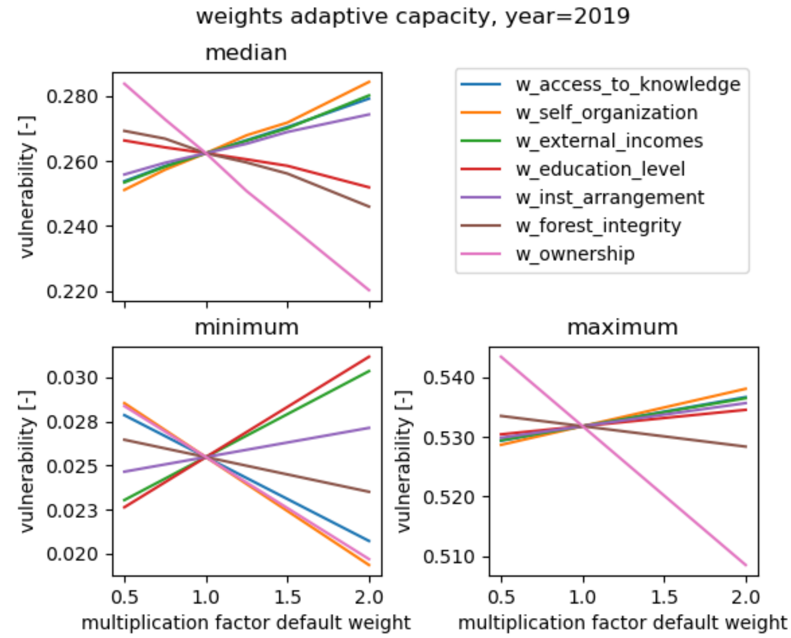


Figure 4.7 - The OAT sensitivity analysis results for the weights of the Adaptive Capacity indicators. The graphs show the influence of changes in the weights of the indicators on the median, the maximum and minimum value of the Vulnerability index.



4.3.5 Changes in exposure and sensitivity of ILs between the periods 2001-2010 and 2011-2019

The temporal comparison of the ILs' components of EX, SE, and PI over the two periods investigated (*t1* = 2001-2010 and *t2* = 2011-2019) highlights the different sets of ILs most threatened in the periods from 2000 to 2010 and 2011 to 2019 (Figures 4.8A, B and C). Most Amazonian ILs had greater Exposure, Sensitivity, and consequently Potential Impact in period *t2* when compared with period *t1* (Figures 4.8A, B, C, 4.9; Table 4.3). Both the EX and SE indexes for the period 2001-2010 differ significantly from EX (Wilcox v = 17367, $p < 0.0001$) and SE (Wilcox v = 22857, $p < 0.0001$) indexes for the period 2011-2019. In total, 283 ILs (73.9% of the total ILs) showed to be more exposed to environmental threats in period *t2* than in period *t1* (Figure 4.9). Regarding the SE, 248 ILs (64.8% of the total ILs) showed to be more sensitive in period *t2* (Figure 4.9). While, 205 ILs (53.5%) presented higher Exposure and Sensitivity in period *t2* than in period *t1* (Figure 4.9).

Table 4.3 - Mean, median, and standard deviation of the Exposure and Sensitivity indexes for periods *t1* (2001-2010) and *t2* (2011-2019).

	Exposure		**Sensitivity**		**Potential Impact**	
	t1	***t2***	***t1***	***t2***	***t1***	***t2***
mean	0.086	0.098	0.039	0.044	0.125	0.142
median	0.061	0.075	0.012	0.013	0.079	0.103
sd	0.089	0.101	0.057	0.061	0.131	0.147

The most ILs in the states of Maranhão, Roraima, Pará, Tocantins, and Mato Grosso presented an increasing of Exposure in period *t2* in relation to the period *t1* (Figure 4.8A). While some ILs in the northwest of Pará, Mato Grosso, Amazonas and Amapá states, and all ILs in the state of Acre, presented higher exposure in *t1* than in *t2* period. The fifteen ILs that showed the greatest increase in PI for the period *t2* are: Urucu/Juruá, Bragança-Marituba, Lago Aiapua, Rodeador, Krahô-Kanela, Maracaxi, Cana Brava/Guajajara, Terena Gleba Iriri, Alto Rio Guamá, Karipuna, Las Casas, Rio Jumas, Awa, Muduruku-Taquara, Boqueirão.

Our results suggest a trend of increasing Exposure and Sensitivity to environmental threats for most Amazonian ILs between 2011-2019. The recent worsening of environmental threats over ILs can be explained in part by changes related to socio-environmental governance in the Amazon region (CAPOBIANCO et al., 2019). In an analysis of environmental governance in the Amazon from 1950 to the present day, Capobianco et al. (2019) highlights that the period from 2003 to 2009 was characterized by the resumption of the role of the Federal Government with strong integrated action to combat environmental degradation in the Amazon. On the other hand, the period from the beginning of 2010 to the present day is characterized mainly by reducing the protagonism and abandonment of the socio-environmental agenda by the Federal Government. Besides, in last years there has been a dismantling of the country's environmental policy (ABESSA et al., 2019; PEREIRA et al., 2019). Profound structural and regulatory changes, coupled with a severe shortage of financial resources and personnel, have drastically reduced environmental agencies' operational capacity in the country (ARTAXO, 2019; ESCOBAR, 2018; ABESSA et al., 2019; PEREIRA et al., 2019). As a result, there was a weakening of territorial and environmental surveillance of ILs and actions to combat illegal activities. Should this trend continue, a vulnerable future might await the indigenous peoples and their territories.

Because of the recent worsening of Amazonian ILs' Exposure and Sensitivity to environmental threats, only the mechanisms and internal mobilizations of indigenous peoples, in partnership with other institutions, despite being very important, seem to be insufficient to prevent environmental degradation in these territories. In this sense, government action is of paramount importance so that the Exposure and Sensitivity of ILs are reduced, and consequently, their Vulnerability. The strengthening of the FUNAI and IBAMA (Brazilian Institute of the Environment and Renewable Natural Resources) agencies and the resumption of policies to control and combat illegal activities are fundamental to reduce the environmental vulnerability of ILs and safeguard the rights of indigenous peoples.

Figure 4.8 - The difference between the Exposure (A), Sensitivity (B), and Potential Impact (C) indexes between the periods 2001-2010 (*t1*) and 2011-2019 (*t2*) (i.e. difference = index *t2* - index *t1*). Because of the lack of mining data available for the first period, mining was not considered in the calculation of these indexes. Negative values mean that the index is higher in period *t1*, while positive values represent that the index is higher in period *t2*.

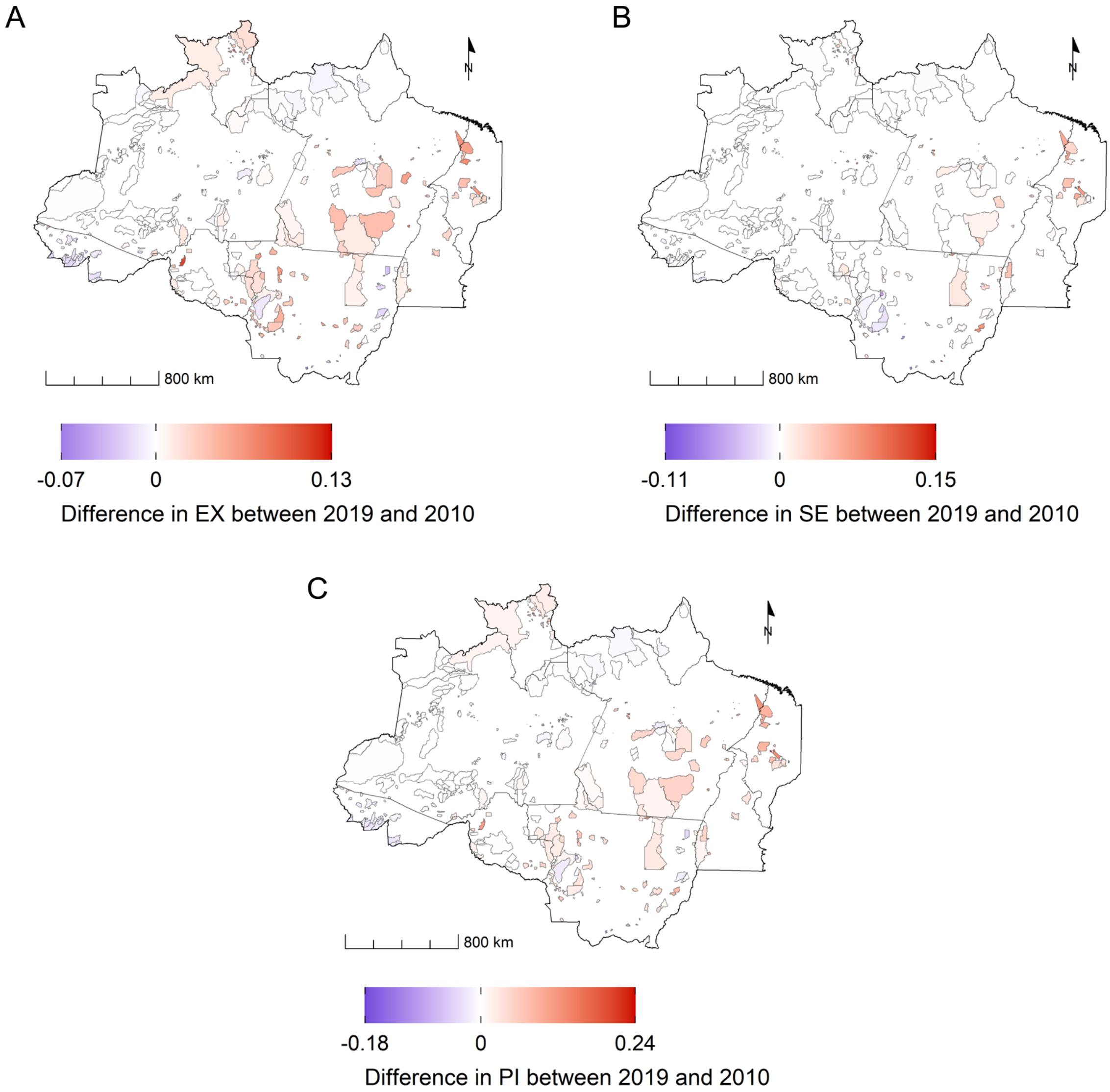
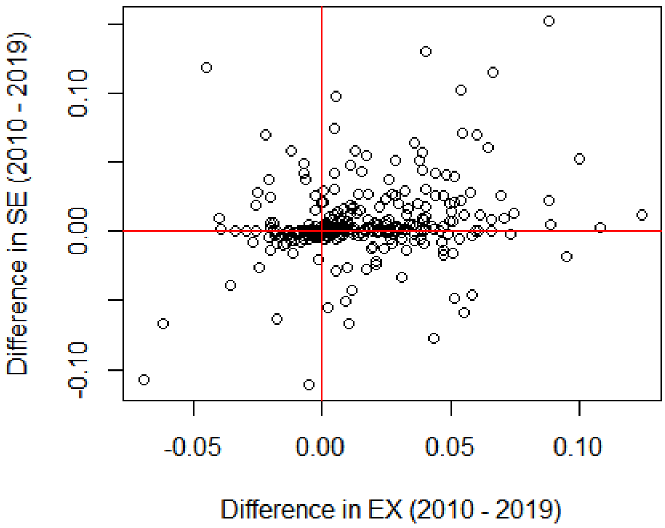


Figure 4.9 - Scatter plot of the difference of Exposure indexes between periods t1 and *t2* and of Sensitivity indexes between periods t1 and *t2* (i.e. difference = index *t2* - index *t1*). Negative values mean that the index is higher in period *t1*, while positive values represent that the index is higher in period *t2*. Indigenous lands are represented as points.



4.4 Limitations and future works

First, we highlight the limitations and difficulties in creating a component of the Adaptive Capacity of Brazilian indigenous peoples. One limitation is that we analyze indigenous lands instead of indigenous people, and this is because of the lack of data related to indigenous populations. The most complete compilation of socio-demographic data of the Brazilian indigenous population was carried out in 2010, during the last Demographic Census in the country. These data do not exist for all analyzed ILs. Thus, we chose not to include the size of the indigenous population and other variables related to socioeconomic dimensions in the AC component, despite their importance. We emphasize the need for a systematic compilation of the Brazilian indigenous population's socio-demographic data to enable coherent assessments of the vulnerabilities of these peoples and to guide the adoption of appropriate public policies to safeguard them.

Second, we recognize the limitation because of the lack of data for the occurrence of mining activities in the first period *t1* (2001-2010); making time comparison with this indicator unfeasible. Third, in any indicator-based approach, the selection of indicators is arbitrary, but it is based on knowledge. In this sense, to assess the vulnerability of the Amazon Indigenous Lands, other researchers could have chosen other threats and other ways of representing the indicators. Generally, the choice of variables is strongly related to data availability.

Concerning future works, modeling the adoption of public policies to reduce the environmental vulnerability of the Amazon region and ILs can be an excellent tool to explore the potential of different strategies. Future research should explore alternative scenarios of policies to control and combat environmental threats, as well as the issue of loosening of legislation that allows the exploitation of natural resources in the ILs. From modeling approaches, it's possible to project the effects of such measures on the future vulnerability of Amazonian Indigenous Lands.

4.5 Conclusion

The environmental vulnerability of Amazonian Indigenous Lands varies widely across the region. In general, ILs with elevated Vulnerability indexes are most concentrated in the arc of deforestation region and below, but they are advancing to the inner of the Pará, Amazonas, and Roraima states. The state that presents most of its ILs with high Vulnerability values is Maranhão state where among the 19 IL existent, 16 (84%) are classified with a high Vulnerability.

We found a strong relationship between the environmental threats that affect Amazonian ILs internally and in their surroundings, indicating most of the time, the great pressure exerted on ILs by external processes and the need for policies aimed at greater control and inspection of the activities carried out in the vicinity of these areas. Our results also indicated a substantial increase in Exposure and Sensitivity of Amazonian ILs between 2011-2019 compared to 2001-2010. In sum, around 73.9% ILs were more exposed to environmental threats in the most recent period, while 64.8% ILs showed to be more sensitive.

International treaties aimed at environmental conservation, reducing human populations' vulnerability, and targeting sustainable development recognizing the importance of joint social and environmental agendas to face global sustainability challenges. In this way, the indigenous peoples of the Amazon and its territories represent a key socio-environmental system of global relevance to achieve these sustainability goals. First, because this system encompasses the largest concentration of indigenous peoples in the world, possessing invaluable ethnic and cultural diversity, and which today is vulnerable to different threats. Furthermore, because together, the ILs represent about 22% of the Legal Amazon region, being strategic areas for the conservation of this ecosystem. There is a very promising potential behind the empowerment of indigenous peoples and the improvement of their adaptive capacity: reconciling the sustainable environmental management of their territories with viable alternative livelihoods for these peoples. The adoption of appropriate public policies by the State, such as combating and controlling illegal activities within and around ILs, and strengthening PNGATI play a fundamental role in achieving this goal and reducing the environmental vulnerability of Amazonian Indigenous Lands.

5 CONCLUSION

5.1 Data and methodological approaches

In this section, we present some final considerations about the data and methodological approaches used in the present study.

Regarding the data:

a) There is no official unified database on the population of Brazilian ILs. The best database on Indigenous Lands, their population, projects, and economic activities is from the Instituto Socioambiental (ISA), a non-governmental organization. Thanks to this database, it was possible to build the Adaptive Capacity indicators for the indigenous populations of Amazonian ILs.

b) Data on environmental threats are still missing. Mining data was not available for the first period. In addition, forest degradation data were incomplete and may have affected the results.

Regarding methodological approaches:

a) The construction phase of the indicators plays a very important role in the success of the assessment, since the threat indicators need to be consistent and, in fact, be proxies to environmental threats. The way in which threats were represented by means of the indicators developed was fundamental for obtaining consistent and coherent results such as those obtained in the cluster analysis in Chapter 2 and with the Vulnerability index and its components in Chapter 4.

b) The development of the vulnerability framework is based on knowledge about the evaluated system, therefore, the greater the knowledge, the better the results obtained. The sensitivity analysis showed robustness in relation to the indicators and weights that make up the Potential Impact and Adaptive Capacity indexes.

c) In addition to analyzing the Vulnerability Index, a synthetic index, it is important to separately analyze its Exposure and Sensitivity components, as they are easier to interpret and can guide the adoption of public policies more clearly.

5.2 Final considerations on the results of the study

The present study contributes to the effort to understand the specificities of Indigenous Lands in relation to multiple environmental threats and highlight the need for targeted public policies. In general, the results of Chapter 2 show that the most 383 Amazonian ILs are affected internally and externally by a combination of different environmental threats. However, the environmental threats are more intense in the ILs' buffer zone than within. The ILs most affected by multiple and relatively severe threats are located mainly in the arc of deforestation and the in Roraima state.

In general, the set of threats in the buffer zone are very similar to the set of threats that affect Indigenous Lands internally. This results also is reinforced by the results of Chapter 4, that demonstrated the strong relationship between the Sensitivity and Exposure of Indigenous Lands to environmental threats. It highlights the need for policy strategies to combat and control environmental threats within and around ILs in the Amazon. We argue that, without the effective control of the environmental agencies over the activities developed around the ILs, it is difficult to contain the progress of environmental degradation over these territories. In Chapter 2, we identified and characterized seven distinct IL clusters defined by common environmental threats within and around their boundaries. Some clusters present a preponderant threat, such as mining, fire, or deforestation. While other clusters present multiple threats in greater or lesser severity. This information is important in the formulation of differentiated strategies for the protection of Indigenous lands, as well as in the articulation of the agencies that must act, together with FUNAI, in the actions of surveillance and combating illegal activities in these territories, such as IBAMA and the Federal Police.

One of the groupings found in the analysis performed in Chapter 2, has mining as one of the main threats. This result is in line with what was raised in consultation with the experts, in which mining was identified as the most important threat currently to the environmental integrity of ILs. In addition, there is a pending bill (PL 191/2020) that seeks to legalize mining as a legal activity in these territories. So we analyzed the potential impact of the mining bill in Chapter 3. We found that the existing mining requests cover 176,000 km^2 of Amazonian Indigenous Lands, a factor 3000 more than the area of current illegal mining. Considering only these existing requests, about 15% of the total area of ILs in the region could be potentially affected by mining if the bill is approved. The ethnic groups Yudjá, Kayapó, Apalaí, Wayana, and Katuena would even have between 47% and 87% of their lands impacted. Gold mining, which has previously shown to have several socio-environmental impacts, accounts for 64% of the requested areas. We conclude that the proposed bill is a significant threat to Amazonian indigenous peoples, further exposing indigenous peoples to rural violence, contamination by toxic pollutants, and contagious diseases.

Indigenous peoples have their rights guaranteed in the Brazilian Constitution and in several international treaties signed by Brazil. The proposed mining bill contradicts what is established in the Constitution and in those treaties since it provides that indigenous peoples would not have veto power to extensive mining in their territories. The Brazilian majority society must support the indigenous cause against the approval of predatory activities in the ILs, which favor only the economic interests of a minority to the detriment of the indigenous peoples' rights. The obligation of the government is to enforce existing laws and regulations that put indigenous rights and livelihoods above economic consideration and not to reduce such protections.

The environmental vulnerability of Amazonian Indigenous Lands varies widely across the region. In general, ILs with high vulnerability are most concentrated in the arc of deforestation region and below, but also advancing to the inner of the Pará, Amazonas, and Roraima states. This result is in line with the results of Chapter 2 and it is a warning. As the occupation frontier expands into the interior of the states of the Amazon, the vulnerability of ILs may increase, as the surrounding environmental context changes (i.e. less forest, more fires and forest degradation, more fragmentation)(SCHIELEIN; BÖRNER, 2018). This scenario is probable since, in our temporal analysis, a substantial increase in Exposure and Sensitivity of Amazonian ILs to environmental threats was found in 2011-2019 compared to 2001-2010. In sum, around 73.9% ILs were more exposed to environmental threats in the most recent period, while 64.8% ILs were more sensitive. Considering the strong relationship found between external and internal threats, efficient strategies for the whole Amazon region to control and combat deforestation, fires, illegal mining, and logging, are crucial to protect the ILs.

Based on the results of the study, we have identified four environmental policy priorities to be strengthened and applied in Amazonian ILs: protect ILs' buffer zones; strengthen surveillance actions, and combat illegal deforestation, forest degradation, and mining activities in ILs; prevent and fight fires; and expel invaders from all ILs in the Amazon. However, the substantial weakening of policies to combat illegal activities in the Amazon and the dismantling of inspection agencies such as IBAMA and FUNAI is a matter of concern in Brazil. We argue that there is a need to reinstate

IBAMA's and FUNAI's full competence and autonomy to manage environmental policies to combat illegal deforestation and other activities in Amazonian Indigenous Lands. With budgetary and personnel support, the combined work of these agencies has already proved to be efficient for fulfilling its function. FUNAI and IBAMA must be strengthened and their actions must be strongly supported by the government. Joint inspection operations, punishment, and expulsion of those responsible for illegal illegal activities in ILs must be carried out in an exemplary manner, showing that such activity cannot be admitted in these areas.

Finally, this thesis contributes to the field of Earth System Sciences by presenting the first investigation on the influence of multiple threats on the environmental vulnerability of the Amazon Indigenous Lands. In addition, the present study brings reflections on public policies with the potential to decrease the environmental vulnerability of ILs. Preserving the Indigenous Lands of the Brazilian Amazon is essential to safeguard the rights of close to 355 thousand indigenous people and their 155 ethnic groups. In this study, we warn about the growing vulnerability of indigenous peoples in the Amazon because of the threats presented. We alert the urgent need to contain illegal actions in these territories and the surroundings to guarantee the indigenous peoples' rights.

5.3 Future works

Based on the results of this thesis and the knowledge gaps that still remain about the environmental vulnerability of the Amazon Indigenous Lands, two suggestions for future researches are pointed out. First, we highlight the importance of performing temporal analysis of environmental threats on ILs, to assess the dynamics of threats and, perhaps, link the increase in threats to the dynamics of adopted policies. Second, future research should explore alternative scenarios of policies to control and combat environmental threats, as well as the issue of loosening of legislation that allows the exploitation of natural resources in the ILs. With modeling approaches it is possible to project the effects of such measures on the future vulnerability of Amazonian Indigenous Lands.

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APPENDIX - A

This appendix presents supplementary Figures and Tables:

Table A.1 - Stages of the recognition process of Indigenous Lands in Brazil. Source: FUNAI.

Stage	Description
In study	Conducting anthropological, historical, land, cartographic and environmental studies, which support the identification and delimitation of indigenous land.
Delimited	Lands that had their studies approved by the Funai Presidency, with their conclusion published in the Official Gazette of the Union and the State, and that are in the administrative contradictory phase or under analysis by the Ministry of Justice, for a decision on the issuing of a Declaratory Ordinance traditional indigenous possession.
Declarated	Lands that obtained the expedition of the Declaratory Ordinance by the Minister of Justice and are authorized to be physically demarcated, with the materialization of the landmarks and georeferencing.
Homologated	Lands that have their materialized and georeferenced limits, whose administrative demarcation was approved by Presidential decree.
Regularized	Land that, after the homologation decree, was registered in a Notary's Office in the name of the Union and in the Federal Heritage Secretariat.
Forwarded with Indigenous Reserve	The Indigenous Reserve constitutes a differentiated category of Indigenous Land, mainly due to the way it is acquired by the State and intended for the indigenous population. In this way, this category is out of the stages of the recognition process cited above. The Indigenous Reserves are areas that are in the administrative process of acquisition by the Union (direct purchase, expropriation or donation) intended for the possession and occupation of indigenous peoples; where they can live and obtain means of subsistence, with the right to enjoy and use natural resources, guaranteeing the conditions for their physical and cultural reproduction.

Table A.2 - Final center of clusters.

Where	**Threat**	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**	**Cluster 7**
	deforestation	-0.35	-0.26	0.29	0.31	-1.98	0.58	0.03
	degradation	-0.43	0.20	-0.30	1.06	-0.99	0.69	-0.73
	burned	-0.88	0.02	-0.37	1.19	1.31	0.71	-0.82
Indigenous Land	pasture	-0.96	-0.06	-0.22	1.06	0.43	0.93	-0.83
	crop	-0.34	-0.21	-0.32	3.11	0.35	-0.23	-0.34
	mining	-0.02	3.17	-0.32	-0.32	-0.32	-0.29	-0.32
	roads	-0.86	0.19	-0.36	1.16	1.15	0.68	-0.83
	deforestation	-0.63	0.16	0.43	0.53	-2.15	0.70	-0.30
	degradation	-0.59	0.27	0.12	1.04	-1.33	0.64	-1.01
	burned	-1.12	0.06	-0.04	1.03	1.18	0.81	-1.15
Buffer Zone	pasture	-1.21	0.14	0.24	0.87	0.52	0.87	-1.12
	crop	-0.61	-0.20	-0.58	1.91	1.38	0.39	-0.61
	mining	-0.31	1.40	-0.31	-0.31	-0.31	-0.11	3.18
	roads	-1.30	0.46	0.29	0.78	0.81	0.72	-0.61

Figure A.1 - Bar charts of the clusters of Indigenous Lands. The values were plotted to represent the final cluster centers for each threat. Environmental threats within the Indigenous Land are plotted on the left, while threats in the Buffer Zone are plotted on the right with the dashed border. Threats in the buffer zone are identified by the abbreviation 'bf'. 'Defor' is an abbreviation for deforestation and 'degrad' for forest degradation. The central axis delimits the mean.

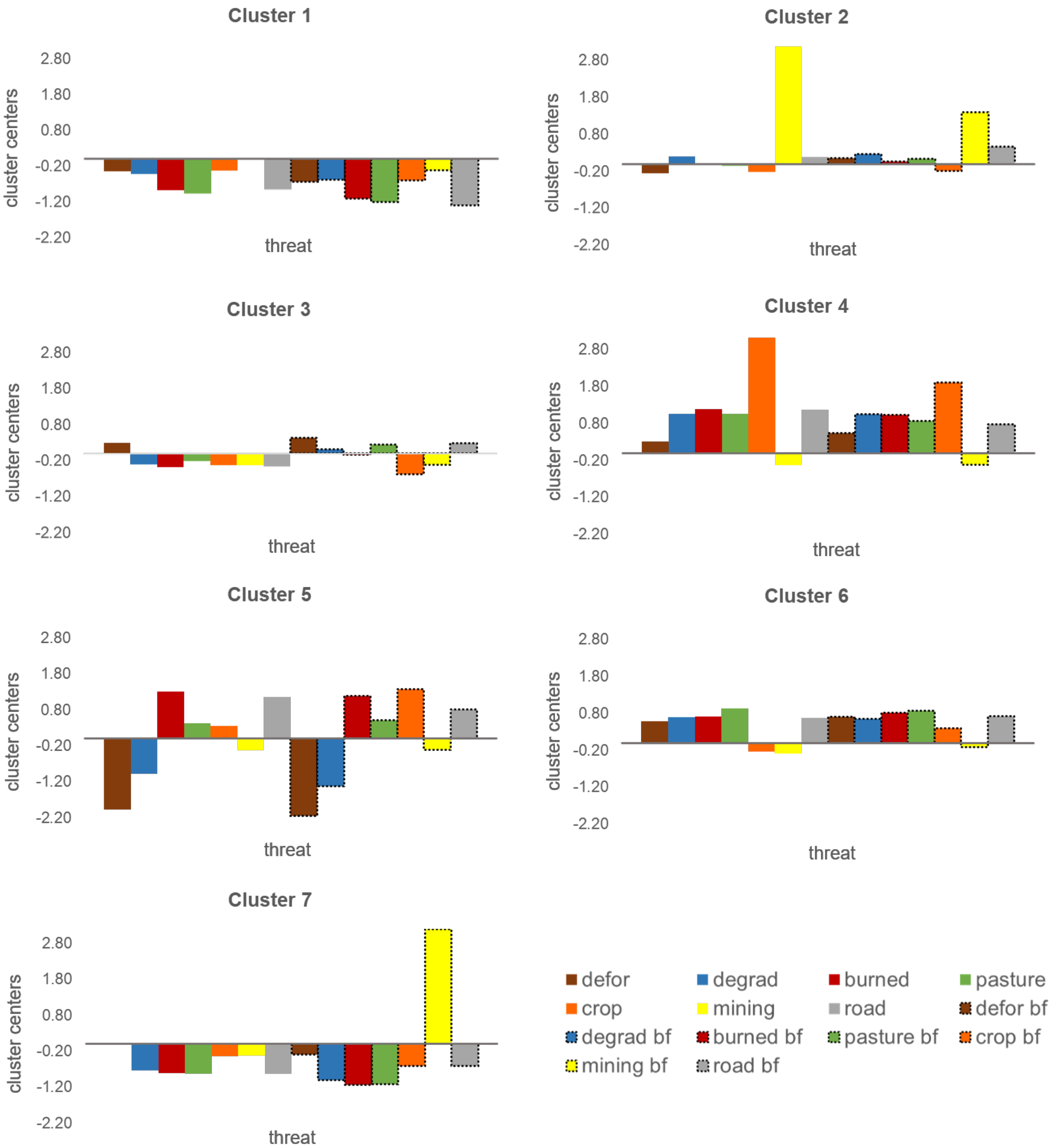
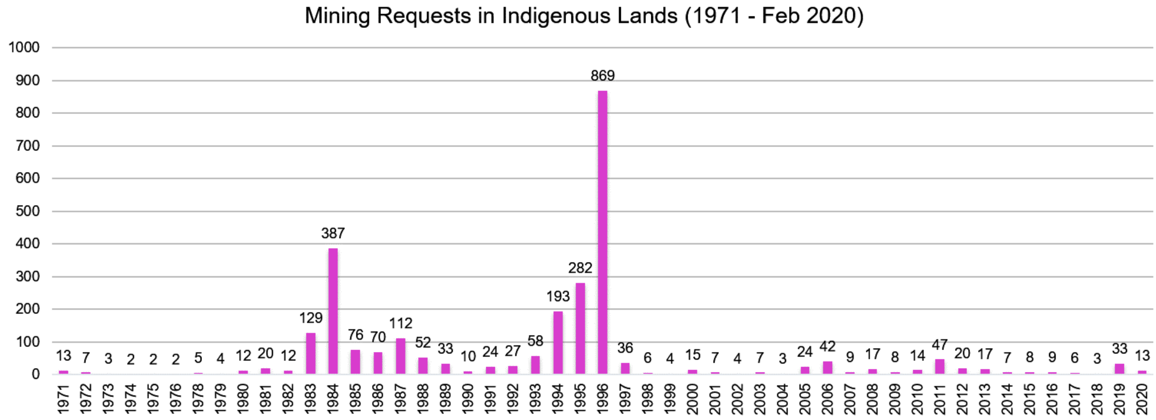


Figure A.2 - Mining requests in Indigenous Lands in the Amazon between 1971–Feb 2020.



SOURCE: Fundação Nacional do Índio - FUNAI (2019a); Agência Nacional de Mineração - ANM (2020).

Table A.3 - The total area of mining polygons (km^2) detected by DETER monitoring in the Legal Amazon region and Indigenous Lands.

Year	**Legal Amazon**	**Total ILs with mining***	**Kayapó***	**Munduruku***	**Other ILS***
2017	52.4	10.6	6.0	3.4	1.2
2018	85.6	15.1	8.8	5.0	1.3
2019	105.6	32.2	15.7	11.6	4.9
total	243.6	57.8	30.5	20.0	7.3

*Indigenous lands in which illegal mining was detected.

Table A.4 - The total area of deforestation increments (km^2) detected by PRODES monitoring in the Legal Amazon region and Indigenous Lands.

Year	**Legal Amazon**	**Total ILS**	**Total ILS with mining***	**Kayapó***	**Munduruku***	**Other ILs***
2017	7000	198.1	30.3	8.2	4.3	17.8
2018	7200	260.6	56.2	7.7	6.6	42.0
2019	10300	429.9	169.1	20.0	18.3	130.7
total	24500.0	888.5	255.6	35.9	29.2	190.5

*Indigenous lands in which illegal mining was detected.

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